United States Department of Agriculture	Chester, PA 19013
Soil Conservation Service	610-490-6042

Subject: Geophysical Workshop	**Date:** 17 October 1994

To: Dean Fisher
State Conservationist
USDA - Soil Conservation Service
Federal Building
200 Fourth Street SW
Huron, South Dakota 57350-2475

Purpose:
To conduct a training workshop on the uses of electromagnetic induction (EM) techniques for engineering and soil investigations.

Participants:
Pete Anderson, Ag. Engineer, SCS, Brookings, SD
Wayne Bachman, Asst. State Soil Scientist, SCS, Huron, SD
Kim Benthin, Ag. Waste Team Tech., SDACD, Brookings, SD
Kailash Bhatt, SDDENR, Pierre, SD
Scott Bickler, SDDENR, Sioux Falls, SD
Roy Boschee, Area Engineer, SCS, Brookings, SD
David Bronson, CET, SCS, Watertown, SD
Rick Carnduff, SDDENR, Pierre, SD
Kevin Christensen, SDDENR, Rapid City, SD
Jay Cofer, Office Manager, SDDENR, Vermillion, SD
Jim Doolittle, Professor, SDSU, Brookings, SD
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Tony Hagen, Technician, Lake Pelican Water Project District, Watertown, SD
Patricia Hammond, Hydrogeologist, SD Geological Survey, Vermillion, SD
Richard Hammond, Geologist, SD Geological Survey, Vermillion, SD
Curt Hanssen, Director, BSLP, Sisseton, SD
Arlan Jerke, SCT, SCS, Aberdeen, SD
Joe Jipp, SCT, SCS, Watertown, SD
Jim Kearney, Eng. Geologist, MNTC, SCS, Lincoln, NE
Kim Kempton, Soil Scientist, SCS, Webster, SD
Gary Kirschman, SCT, SCS, Madison, SD
Carlene Larson, SCT, SCS, Webster, SD
Ken Madison, Nat. Resource Scientist, SDDENR, Watertown, SD
Doug Malo, Professor, SDSU, Brookings, SD
Kalumbu Malekani, Graduate Student, SDSU, Brookings, SD
Mokgwakgwe Mashatola, Graduate Student, SDSU, Brookings, SD
Danny Merchen, SCT, SCS, Parker, SD
Jim Millar, Soil Scientist, SCS, Redfield, SD
Craig Olson, SCT, SCS, Brookings, SD
Eugene Preston, Soil Scientist, SCS, Sioux Falls, SD
Stacy Quail, Technician, Lake Pelican Water Project District, Watertown, SD
Ken Read, Ag. Waste Team Project Leader, SCS, Brookings, SD
Carol Reed, Geologist, SCS, Bismarck, ND
Diane Rickerl, Professor, SDSU, Brookings, SD
Steven Scholtes, SDDENR, Pierre, SD
Layne Schulz, Geologist, SD Geological Survey, Vermillion, SD
Loren Schultz, Soil Scientist, SCS, Aberdeen, SD
Cris Skonard, SDDENR, Sioux Falls, SD

Cindy Steele, Env. Engineer, SCS, Huron, SD
Cheryl Stohr, SCT, SCS, Clear Lake, SD
Mark Vomacka, SDDENR, Pierre, SD
Mary Lou Woolf, District Conservationist, SCS, Redfield, SD
Steve Winter, Soil Scientist, SCS, Redfield, SD

Activities:
Workshop adhered to the schedule outlined in Rodney Baumberger's letter of 2 September 1994. Field demonstration sites were located near Sisseton, Watertown, Redfield, and Sioux Falls, South Dakota.

Equipment:
The electromagnetic induction meters used were the EM38, EM31, and EM34-3 manufactured by Geonics Limited+. For each meter, the depth of observation is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter integrates values of apparent conductivity over the upper 0.75 m in the horizontal dipole orientation, and over the upper 1.5 m in the vertical dipole orientation. The EM31 meter integrates values of apparent conductivity over the upper 2.75 m in the horizontal dipole orientation, and over the upper 6.0 m in the vertical dipole orientation.

The EM34-3 meter has intercoil spacings of 10, 20, or 40 m. A 10-m intercoil spacing was used in the investigations reported in this paper. With a 10-m intercoil spacing, the EM34-3 meter has observation depths of about 7.5 m and 15 m in the horizontal and vertical dipole orientations, respectively.

Discussion:

<u>Agricultural Waste Facilities:</u>

The purpose of this survey was to familiarize participants with the operations of the various meters, and to demonstrate the use of EM techniques to chart the extent of seepage and surface runoff from animal-waste holding facilities.

<u>Site 1 - Roberts County</u>
The survey area was located in an area of Heimdal-Svea loams, 0 to 2 percent slopes. Heimdal is a member of the coarse-loamy, mixed Udic Haploborolls and Svea is a member of the fine-loamy, mixed Pachic Udic Haploborolls families.

An irregularly shaped, rectangular grid was established in an open field on the eastern side of the Serocki waste-holding facility. The survey area covered about 2.0 acres with maximum dimensions of 500 and 250 feet. The grid interval was 50 feet. Survey flags were inserted in the ground at each 50 foot grid intersection. At each of the 44

+ Trade names have been used to provide specific information. Their mention does not constitute endorsement.

grid intersections, measurements were obtained with an EM31 meter in both the horizontal and vertical dipole orientations.

Figures 1 and 2 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. The interval is 5 mS/m. In each simulation, noticeable zones of relatively high apparent conductivity values (> 85 mS/m) appear to emanate from the east and northeast portions of the waste-holding facility. Within each zone, values of apparent conductivities decrease both horizontally (in an outward and downslope direction) and vertically (with increasing soil depth (horizontal > vertical dipole measurements)). The zones of higher conductivity values are restricted to a radius of about 50 to 100 feet from the facility. These patterns suggest the possible concentration of animal wastes in the upper part of soil profiles and its likely dissemination from the waste-holding facility. However, these patterns could also reflect the concentration of animal wastes in the soil from previous land use or management practices, or variations in soil type, till, or earthen materials related to the construction of the facility.

Several anomalous areas having high apparent conductivity values are evident in the southeast and northeast portions of the survey areas. These areas do not appear to be connected or associated with the animal waste-holding facility. They may represent differences in soils, till, or previous land uses.

Several fingers of low conductivity values extend from eastern (lower) border of the survey area toward the waste-holding facility. These fingers may delineate the locations of underlying lenses of coarser-textured materials within the till.

Site 2 - Roberts County

The selected site (Fischer) was located in an area of Forman-Buse loams, 9 to 15 percent slopes, and Buse-Forman loams, 21 to 40 percent slopes. Buse is a member of the fine-loamy, mixed Udorthentic Haploborolls and Forman is a member of the fine-loamy, mixed Udic Argiborolls families. However, as a large portion of the survey area was located on the embankment, most earthen materials profiled were borrowed.

The investigated waste-management system (Fischer) was designed to control lot runoff and collect waste from a 75 beef-cow operation. The pond does not hold water. In an attempt to detect seepage, a 350 by 60 foot, rectangular grid was established across a portion of the pond's embankment. The grid intervals were 20 and 50 feet. The survey area covered about a 0.5 acre area.

Survey flags were inserted in the ground at 20 by 50 foot intervals. At each of the 32 grid intersections, measurements were obtained with an EM31 meter in both the horizontal and vertical dipole orientations. A transit was used to establish grid lines and determine the surface elevation of each grid intersection. Elevations were not tied to a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

Figure 3 is a topographic map of the survey area. The contour interval is 2 feet. Relief along the embankment face was about 24 feet. The pond was located to the immediate south of the survey area. The borrow materials were located in the central portion of the survey area. Two prominent bends in the contour lines occur near the interface separating the borrow and natural materials.

Figures 4 and 5 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. The interval is 5 mS/m. In both plot, a fairly noticeable zone of relatively high apparent conductivity values appears in the north-central portion of the survey area along the base of the embankment. As water was observed on the soil surface within this zone, the higher apparent conductivity values were believed to reflect increased moisture contents of the borrowed materials.

In both figures, on the top of the embankment adjacent to the pond (south border of survey area), apparent conductivity increase in the eastern portion of the borrow materials. This pattern could indicate differences in the composition of the borrowed materials or seepage. In addition, values were conspicuously higher in measurements obtained in the vertical dipole orientation suggesting the possibility of either deep seepage or higher clay contents in this portion of the embankment.

A comparison of the patterns in figures 4 and 5 suggests a lateral flow of seepage near the base of the embankment. With the EM31 meter in the deeper-sensing (6 m) vertical dipole orientation, the zone of higher conductivities appears further up-slope (see Figure 5) than in measurements obtained in the shallower-sensing (2.75 m) horizontal dipole orientation. This zone appears to have been displaced further down the embankment in the data collected with the EM31 meter in the horizontal dipole orientation. If this zone does in fact represents seepage, it was detected at deeper depths within the borrow materials on higher-lying sections of the embankment and at shallower depths along the base of the embankment.

<u>Site 3 - Codington County</u>
The waste-management system was designed to control runoff and collect waste from a dairy operation. The pond appears to hold water but a nearby wells have become contaminated. An irregularly shaped, 950 by 500 foot, rectangular grid was established around the east, south, and west sides of the waste-holding structure. The grid intervals was 50 feet. The survey area covered about a 4.2 acre area. Farm buildings, fence lines, and hay bales obstructed survey operations and limited the size of the survey area. In addition, crews operating different meters (EM38, EM31, and EM34-3) surveyed different portions of the grid.

Survey flags were inserted in the ground at 50 foot intervals. At each incorporated grid intersections, measurements were obtained with the EM38 (60), EM31 (82) and EM34-3 (76) meters in both the horizontal and vertical dipole orientations. A transit was used to establish grid lines and determine the surface elevation at 69 grid intersections. Elevations were not tied to a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

Figure 6 is a topographic map of the survey area. The contour interval is 1 foot. Within the survey area, relief was about 12 feet. The surface slopes towards the southeast. A drainage channel was located to the southeast and east of the survey area.

Figures 7 and 8 are two-dimensional plots of the data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. The interval is 5 mS/m. In both plot, values of apparent conductivity increase towards the south and away from the waste-holding structure. In both orientations, values of apparent conductivity were highest in the southwest portion and bordering a drainage channel in the southeast portion of the study area. Though these elevated values were associated with increase moisture contents and variations in soil types, values in excess of 70 mS/m are generally believed to indicate high concentration of soluble salts within the soil profiles.

In figures 7 and 8, a zone of higher conductivity values extends towards the waste-holding structure between grid lines 250 and 400 (near lower border of plots). As values within this zone are highest at a slight distance away from the waste-holding facility, no direct linkage is possible without other supporting information.

Figures 9 and 10 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. The interval is 5 mS/m. In both plot, values of apparent conductivity increase towards the south and away from the waste-holding structure. In both orientations, values of apparent conductivity were highest in the south-central and in the southwest portion of the study area.

As with measurements taken with the EM38 meter (see figures 7 and 8), a zone of higher conductivity values extends towards the waste-holding structure between grid lines 250 and 400. As values within this zone are highest at a slight distance away from the waste-holding facility and increase towards the drainage channel, no direct association is possible without other information.

In Figure 9, a zone of higher conductivity values extends away from the farm structures in the extreme northeast portion of the study area. This feature represents either a near-surface phenomenon or signal interference from nearby farm buildings. Values within this zone were highest (>90 mS/m) near the structures and decrease towards the east. This zone is considered significant because of its proximity to the existing well system. Further investigations should be made in this area.

In Figure 10, a zone of higher conductivity values appears to extend away from the farm structures in the northeast portion of the study area. This feature may represent interference caused by the farm buildings or possible seepage. Values within this zone are highest (>60 mS/m) near the structures and dissipate in a plume-like fashion towards the south. This zone is considered significant because of its proximity to the existing well system. Further investigations should be made in this area.

Figures 11 and 12 are two-dimensional plots of the data collected with the EM34-3 meter in the horizontal and vertical dipole orientations, respectively. The interval is 5 mS/m. In general, compared with other plots of apparent conductivity within the study area (see figures 7 to 10), these values are lower and less variable. It is therefore presumed that the earthen materials become less conductive and more homogeneous with increasing observation depths.

In Figure 12, a conspicuous, anomalous pattern appears in the southwest portion of the study area. This pattern is believed to have been produce from "cultural noise" or signal interference from a fence-line.

Soils Investigation with EM techniques

Electromagnetic induction techniques can be used to map spatial variations and assess the rate and magnitude of change in soils and soil properties. Values of apparent conductivity are seldom diagnostic in themselves. However, lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Electromagnetic responses are dependent on soil properties. Variations in electromagnetic responses are produced by changes in soil moisture, salt content, texture, and mineralogy. Each of these factors will affect the apparent conductivity of soils.

Soils and soil map units have been differentiated by their unique and characteristic ranges of EM responses. As EM measurements integrate several soil properties, responses can be correlated within a given geographic areas to a particular soil or soils.

Each soil will have a characteristic EM response. For a particular soil, the EM response will constitute a range of values which will be influenced by temporal variations in soil moisture and temperature. Furthermore, cultural and terrain features can be expected to influence these ranges. Within a given geographic area, the conductivities of some soils will overlap. Similar soils will share a similar range in EM responses. However, some soil properties and types can be inferred with EM techniques provided one is cognizant of changes in parent materials, drainage, topography, and vegetation.

Site 4 - Area of Beotia-Rondell silt loam, Spinks County

The study site consisted of about 0.9 acre of cropland in central Spinks County. Relief was about 1.4 feet. Beotia is a member of the fine-silty, mixed Pachic Udic Haploborolls family. The Rondell soil is a member of the fine-silty, mixed, Typic Calciborolls family.

A 200 by 200 foot rectangular grid was established across the study site. Survey flags were inserted in the ground at 50 foot intervals. At each of the 25 grid intersections, measurements were obtained with an EM38 and EM31 meters in both the horizontal and vertical dipole orientations.

A transit was used to establish grid lines and determine surface elevations at each grid intersection. Elevations were not tied to a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

The topography of study site has been simulated in Figure 13. The contour interval is 0.25 foot. In general, the surface slopes towards the north and northeast.

Figures 14 and 15 represent two-dimensional plots of apparent conductivity values collected with an EM38 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the interval is 10 mS/m. In both plots, responses appear to increase laterally towards the north and northwest. This pattern followed a general decline in surface elevations and an observed change in soil type from Beotia to Rendoll. Higher values of apparent conductivity in areas of Rendoll soil were attributed to higher concentration of calcium carbonate and other more soluble salts in the profile. However, values in excess of 100 mS/m were associated with saline soil conditions.

Figures 16 and 17 represent two-dimensional plots of apparent conductivity values collected with an EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the interval is 10 mS/m. Similar patterns can be observed between the data collected with both the EM38 and EM31 meters and in both orientations. Both meters can be used to map variations in soils and soil properties.

In both figures 16 and 17, EM responses appear to increase laterally towards the north and northwest. Spatial patterns were similar to those collected with the EM38 meter (Figures 14 and 15). However, EM responses measured with the EM31 meter were generally lower and less variable than response measured with the EM38 meter across the site. With the EM31 meter, at all observation sites, responses decreased with increasing depths of observation (vertical < horizontal dipole orientation). This trend implies the occurrence of more conductive materials (i.e. higher clay, soluble salts, or moisture contents) near the surface and more resistive materials at greater soil depths.

<u>Site 5 - Area of Great Bend-Beotia silt loams, till substratum, 0 to 2 percent slopes, Spinks County</u>

The study site consisted of about 0.7 acre, partly in cropland and partly idle land in south-central Spinks County. Relief was about 3.3 feet. Great Bend and Beotia soils are members of the fine-silty, mixed Udic Haploborolls and the fine-silty, mixed Pachic Udic Haploborolls family, respectively.

A 200 by 150 foot rectangular grid was established across the study site. Survey flags were inserted in the ground at 50 foot intervals. At each of the 20 grid intersections, measurements were obtained with an EM31 meter in both the horizontal and vertical dipole orientations.

A transit was used to establish grid lines and determine surface elevations at each grid intersection. Elevations were not tied to a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

The topography of study site has been simulated in Figure 18. The contour interval is 0.5 foot. In general, the surface slopes towards the west and the James River (immediately to the west of survey area).

Figures 19 and 20 represent two-dimensional plots of apparent conductivity values collected with an EM31 meter in the horizontal and vertical dipole orientations, respectively. In each figure, the interval is 5 mS/m. In both plots, responses appear to increase laterally towards the east. This pattern was related to changes in surface elevations, distance from the James River, and followed a predicted increase in the thickness of lacustrine deposits over till. Higher values of apparent conductivity were associated with thicker deposits of lacustrine sediments over till. Lower values of apparent conductivity were observed along the bluffs and over coarser textured (sand and gravel deposits) soil materials.

The affects of differences in management practices existing between the idle land to the west of the fence line and cultivated cropland to the east of the fence line on EM responses were not evident in the plots.

Site 6 - Area of Great Bend-Beotia silt loams, 0 to 2 percent slopes, Spinks County

In portions of Spinks County, irrigation waters have deposited excessive amounts of sodium salts on the soil surface. Through this process, some areas of Great Bend and Beotia have become sodium-affected.

Three sites having differing lengths (long, short, none) of irrigation were selected within a delineation of Great Bend and Beotia silt loam, 0 to 2 percent slopes. The purpose of this investigation was to evaluate the performance of the EM38 meter in areas of sodium-affected soils.

Results from a brief study conducted on adjoining fields of the same delineation of Great Bend and Beotia silt loam, 0 to 2 percent slopes, appeared favorable. However, additional studies are needed with a greatly expanded sample population and some chemical analysis to confirm the seeming relationship. Table 1 summarizes the results of the cursory study.

Table 1
EM Response in irrigated areas of Great Bend and Beotia soils under differing lengths of irrigation

Length of Irrigation	Number of Observations	EM38(H) Average	Standard Deviation
Long	4	45.25 mS/m	6.40
Short	5	34.60 mS/m	4.56
None	6	24.83 mS/m	2.93

The measurements obtained with an EM38 meter in the horizontal dipole orientation on the three sites were analyzed by means of an analysis of variance. The results indicate a significant difference in EM responses collected in the horizontal dipole orientation (observation depth 0 to 75 cm) among the three sites (see Table 2).

Table 2
Analysis of Variance for EM38 (horizontal) Measurements among Three Irrigation Sites

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-value	Probability
Between	2	1008.95	504.48	24.33	.0001
Within	12	248.78	20.73		

Results:
1. Results from EM surveys conducted in South Dakota have been condensed into the accompanying two-dimensional plots. Results from EM survey are interpretative and should be verified with field observations. The enclosed plots provide understanding into the subsurface conditions existing within each study area. These plots can be used to guide the selection of monitoring or sampling sites.

2. All participants had the opportunity to operate and become familiar with the various EM meters. At each study site, the performance of the various meters to chart the extent of seepage and surface runoff from animal-waste holding facilities was evaluated by the participants. General response among the participants appeared to be very favorable. Based on this response, an EM34-3 meter was loaned to South Dakota by Jim Kearney of the MNTC.

3. The results of soil investigations with EM31 and EM38 meters in Spinks County were perceived as favorable. Electromagnetic induction techniques may provide a rapid and accurate method to describe variations in soils, soil properties, and stratigraphies in South Dakota. Geophysical field assistance is available to South Dakota through the National Soil Survey Center (See part 631.04b of the National Soil Handbook (NSH)). Limited field investigation assistance or loan of EM meters can be requested through the NSSC (see NSH 631.06b).

4. I wish to applaud Cindy Steele for her excellent preparation and organization of this workshop. Cindy deserved credit for her assistance in introducing this technology to the people and various agencies represented at this workshop.

With kind regards,

James A. Doolittle
Soil Specialist

cc:
Bill Broderson, Team Leader LRR 4, NSSC, MNTC, SCS, Lincoln, NE
James Culver, Assistant Director, NSSC, MNTC, SCS, Lincoln, NE
Steve Holzhey, Assistant Director, NSSC, MNTC, SCS, Lincoln, NE
Jim Kearney, Eng. Geologist, MNTC, SCS, Lincoln, NE
Jerome Schaar, State Soil Scientist, SCS, Huron, SD
Cindy Steele, Env. Engineer, SCS, Huron, SD

EM Survey at Serocki Farm

EM31 Meter
Horizontal Dipole Orientation

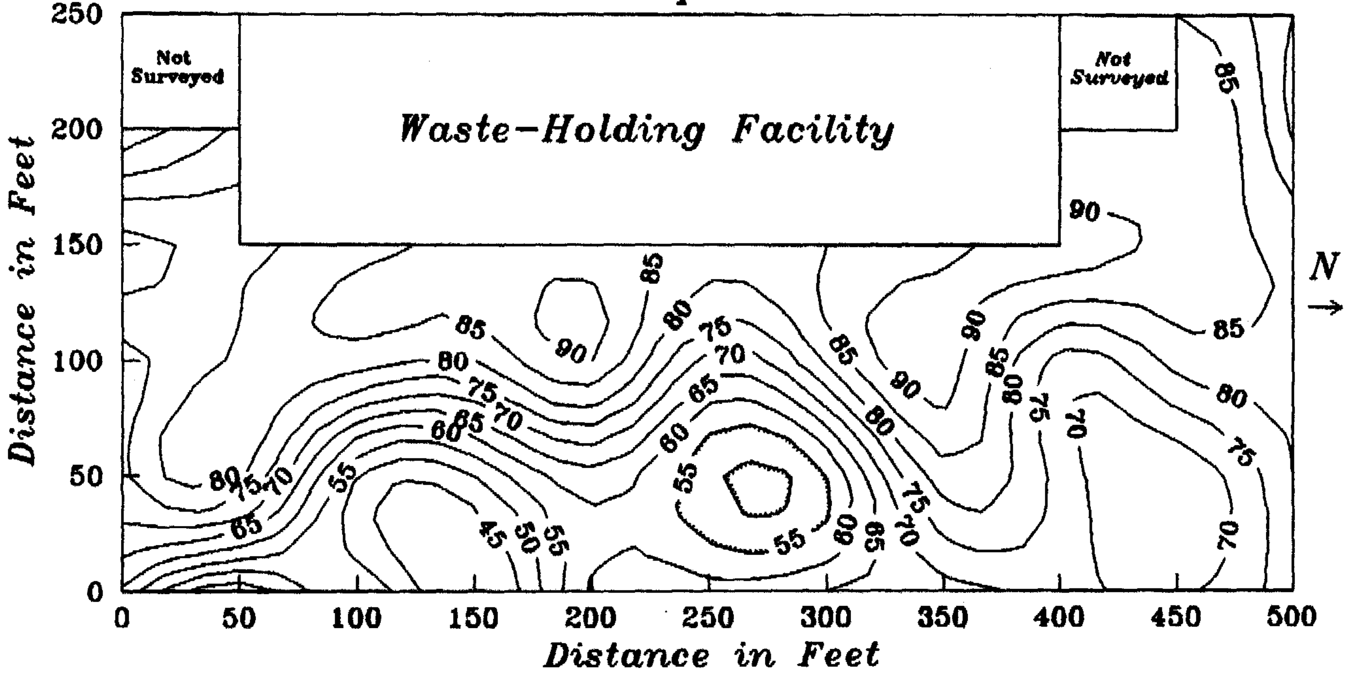
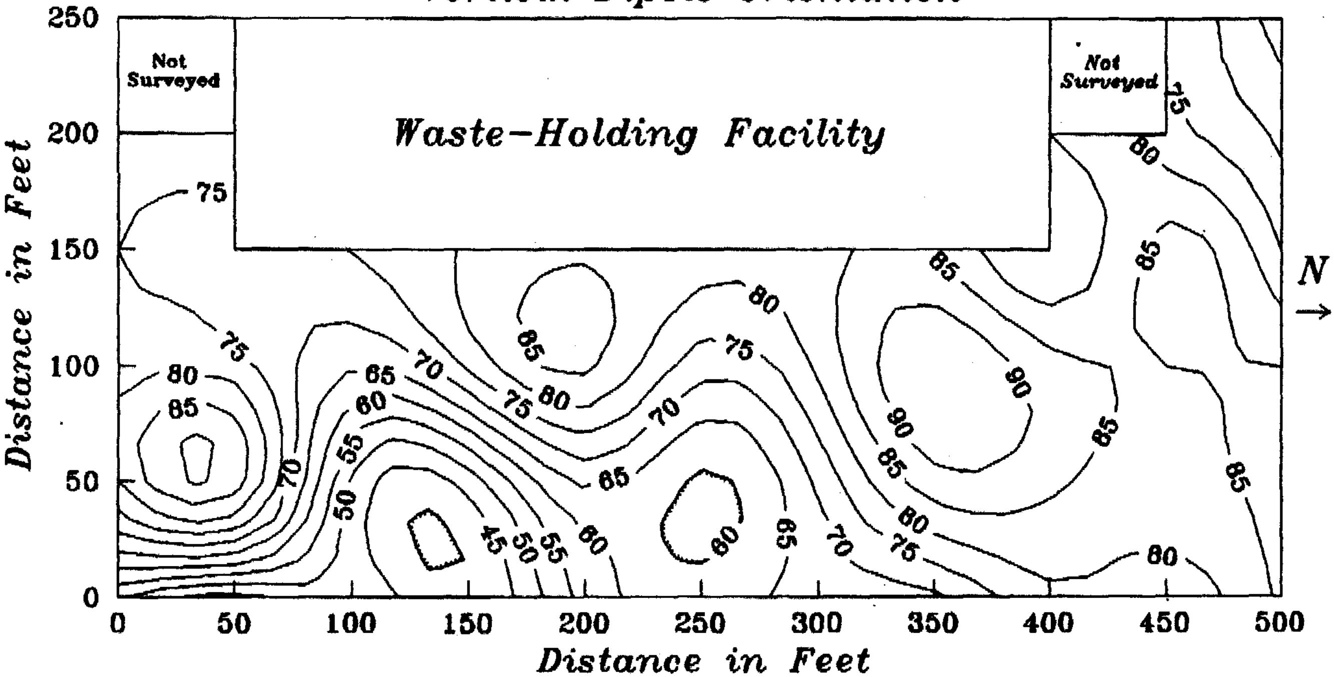


Figure 2

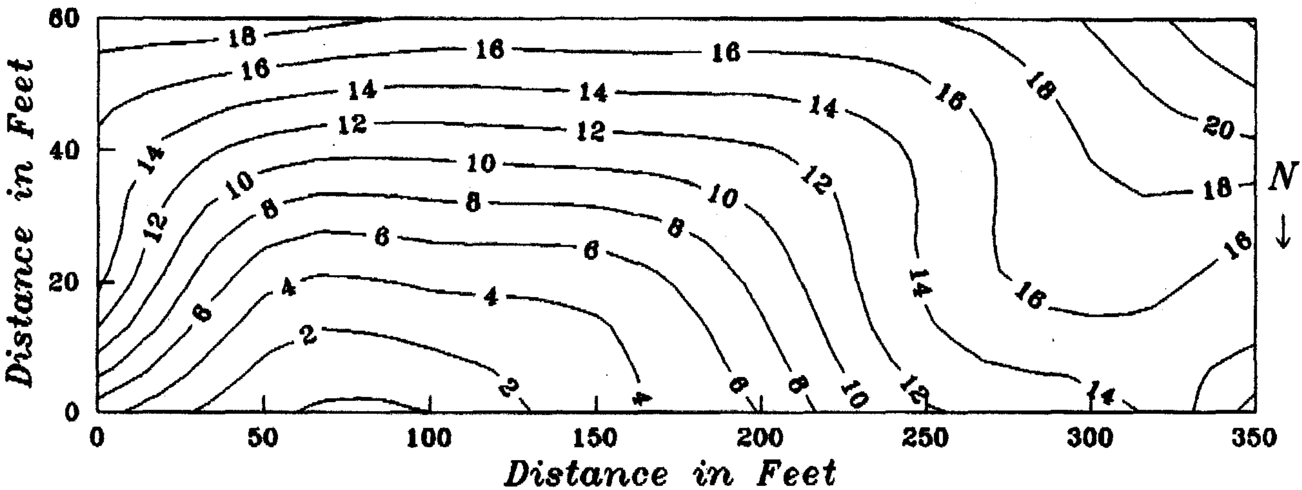
EM Survey at Serocki Farm

EM31 Meter
Vertical Dipole Orientation



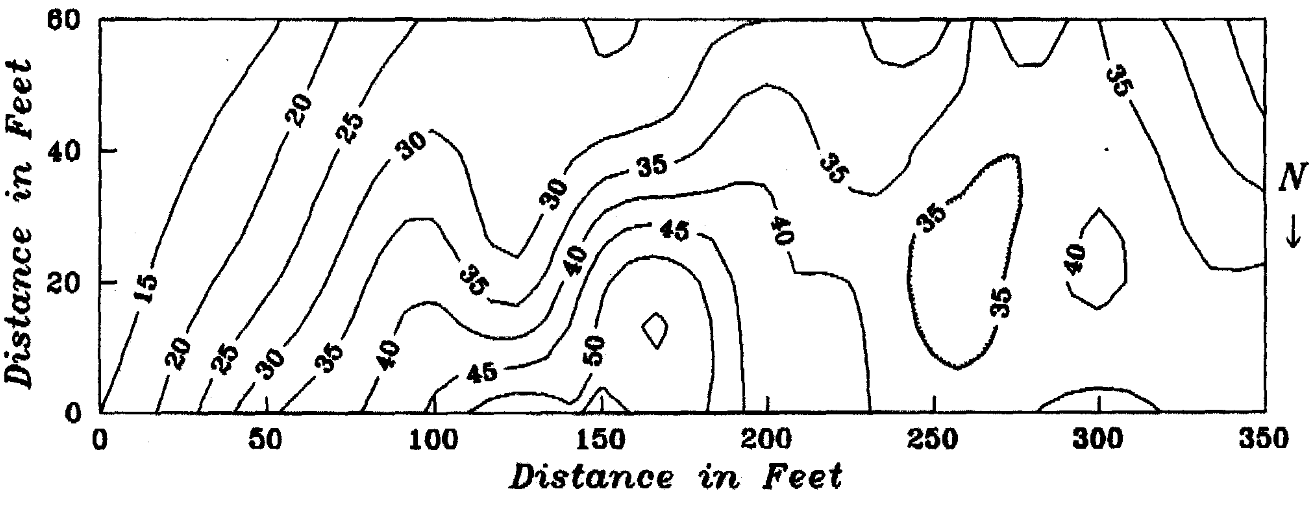
Relative Topography at Fischer Site

Contour Interval = 2.0 Feet



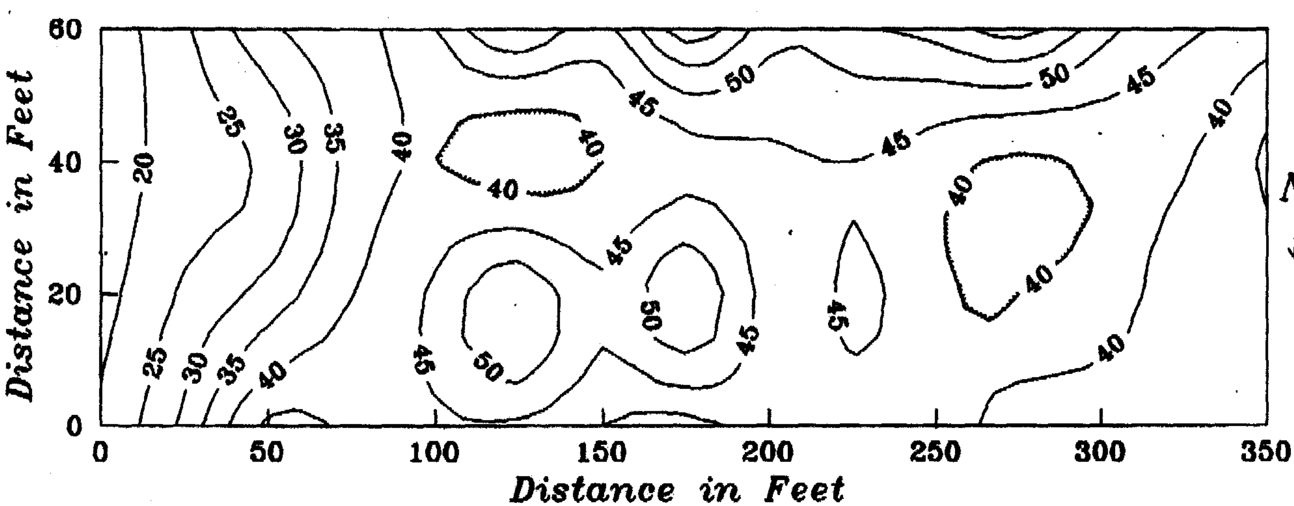
EM Survey at Fischer Farm

EM31 Meter
Horizontal Dipole Orientation



EM Survey at Fischer Farm

EM31 Meter
Vertical Dipole Orientation



Relative Topography of the Site in Codington County

Contour Interval = 1.0 foot

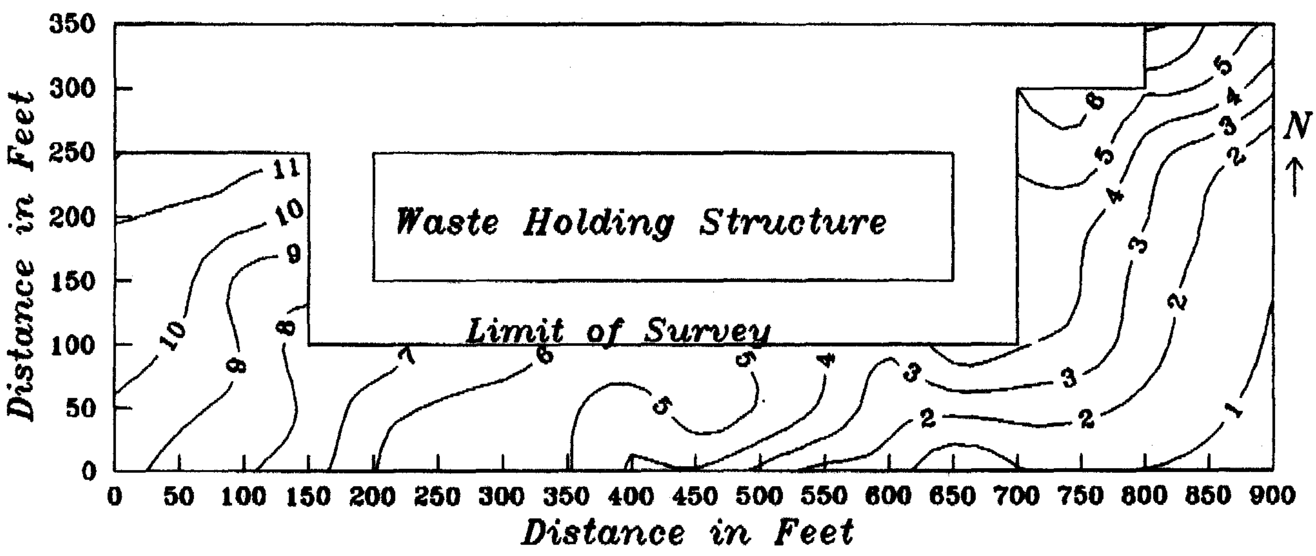
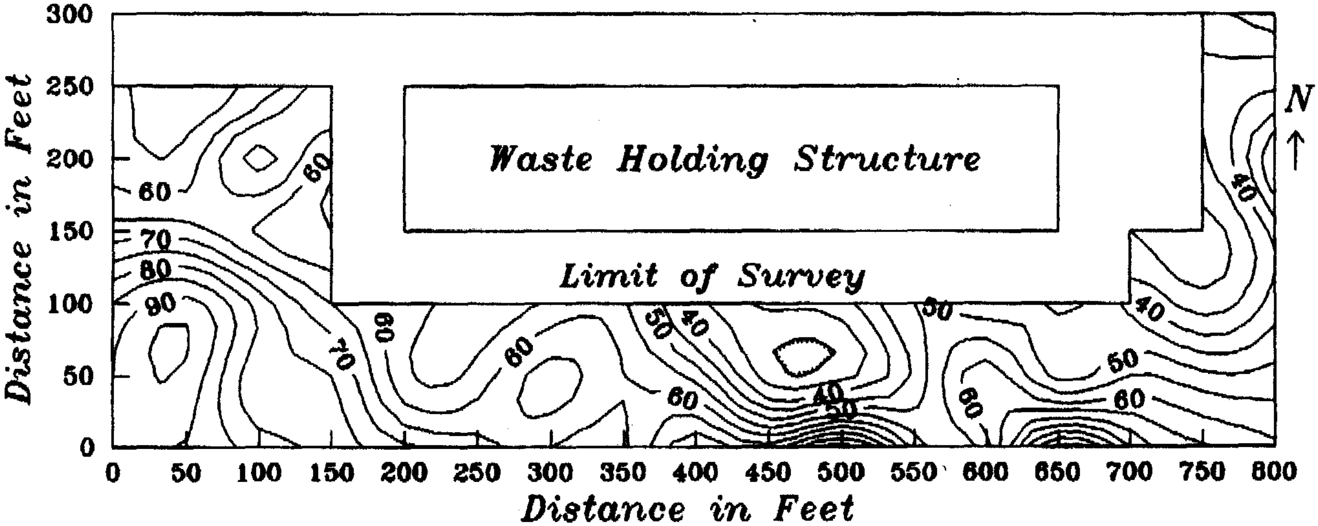


Figure 7

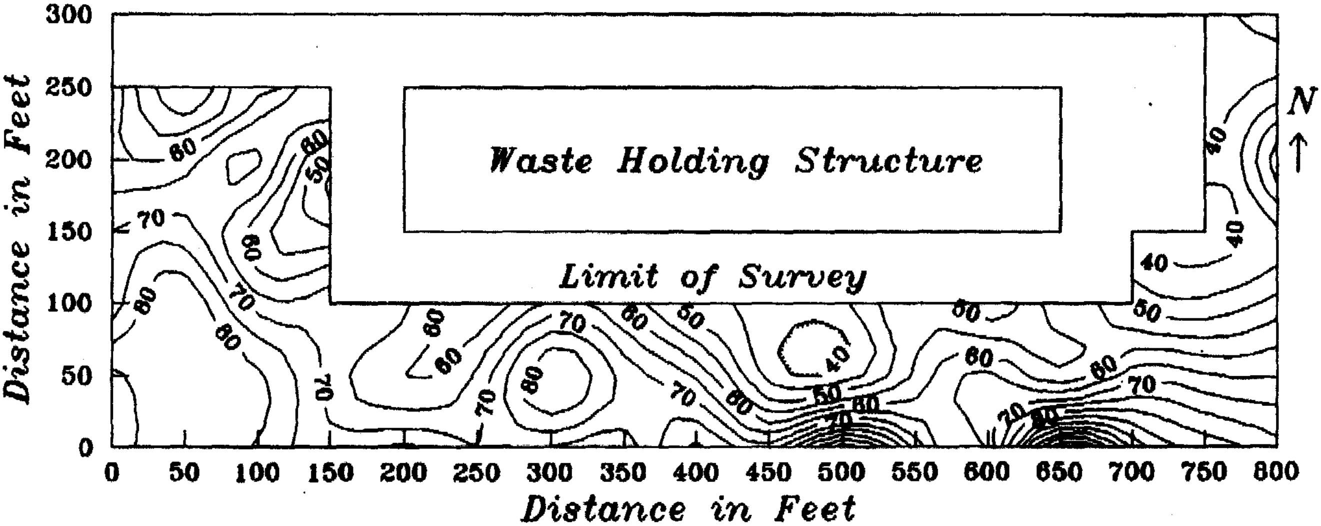
EM38 Survey of Site in Codington County

Horizontal Dipole Orientation



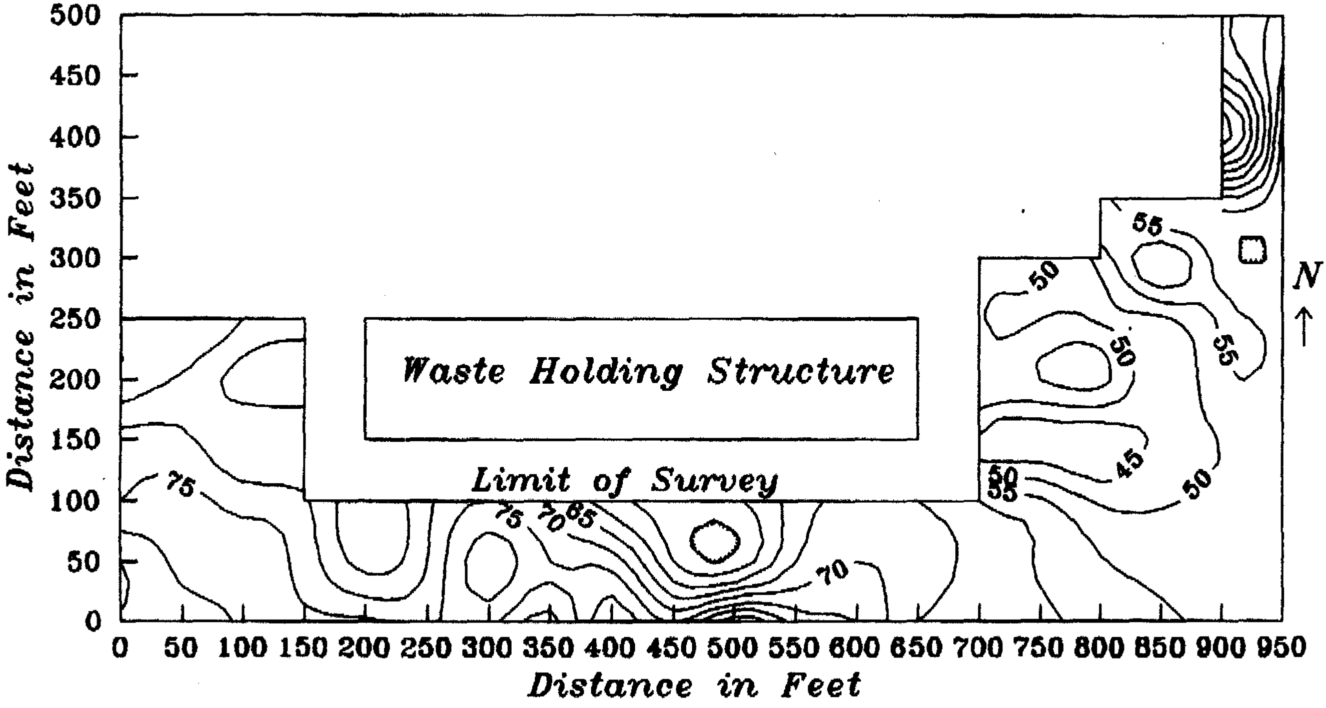
EM38 Survey of Site in Codington County

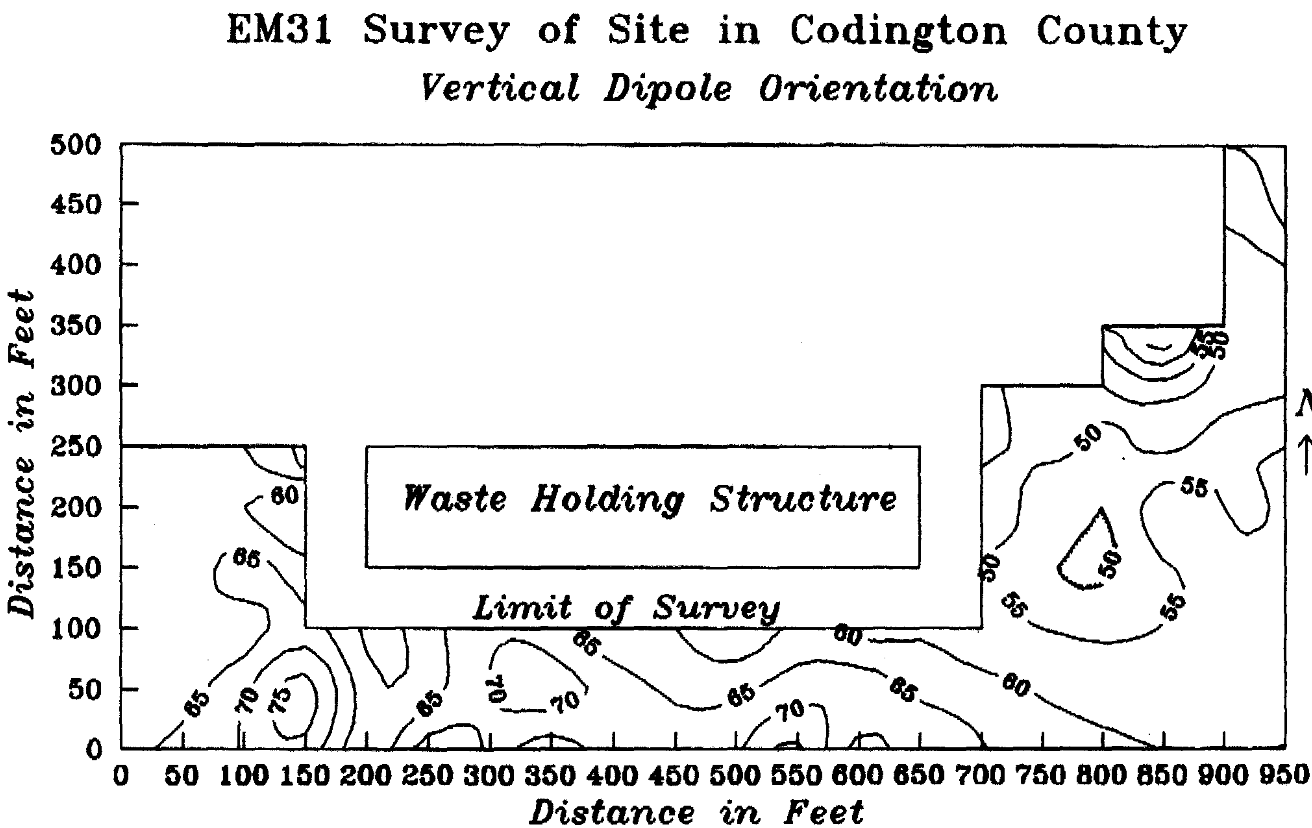
Vertical Dipole Orientation



EM31 Survey of Site in Codington County

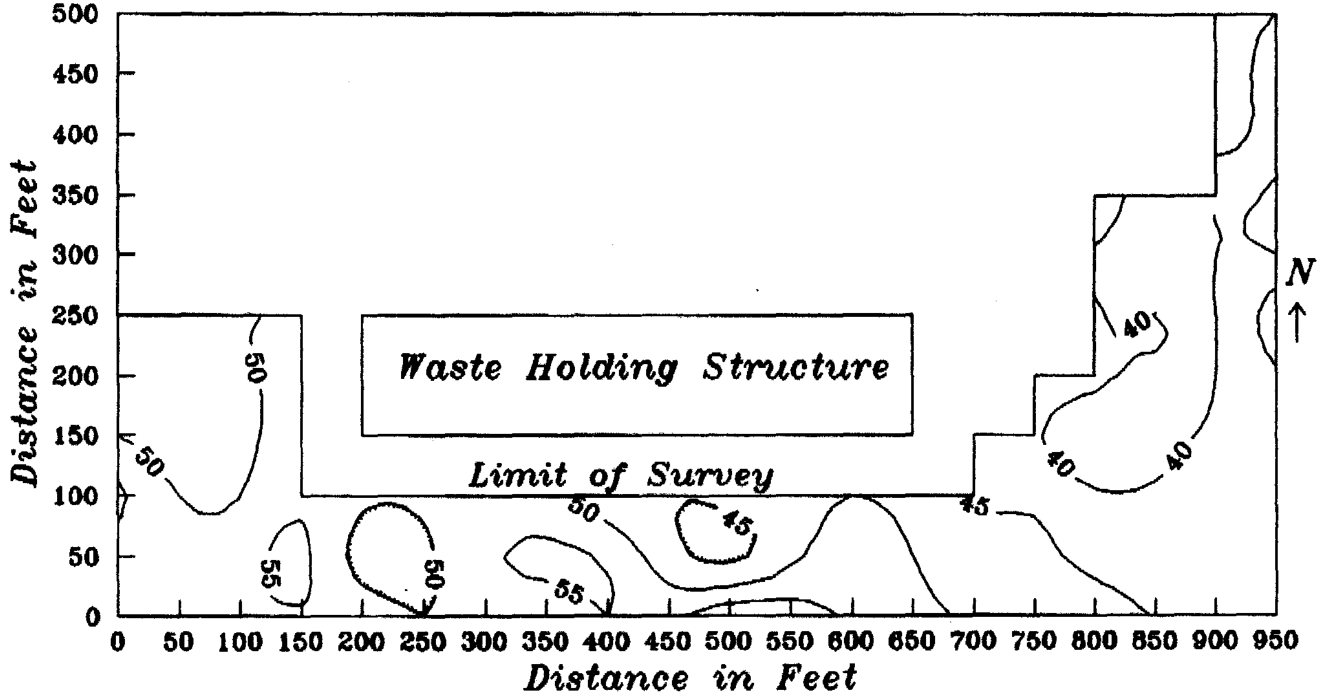
Horizontal Dipole Orientation




EM31 Survey of Site in Codington County
Vertical Dipole Orientation
Waste Holding Structure
Limit of Survey
Distance in Feet
Distance in Feet
N
500
450
400
350
300
250
200
150
100
50
0
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950
60
65
65
70
75
65
70
70
65
65
70
60
65
60
50
55
50
50
55
55
55
50

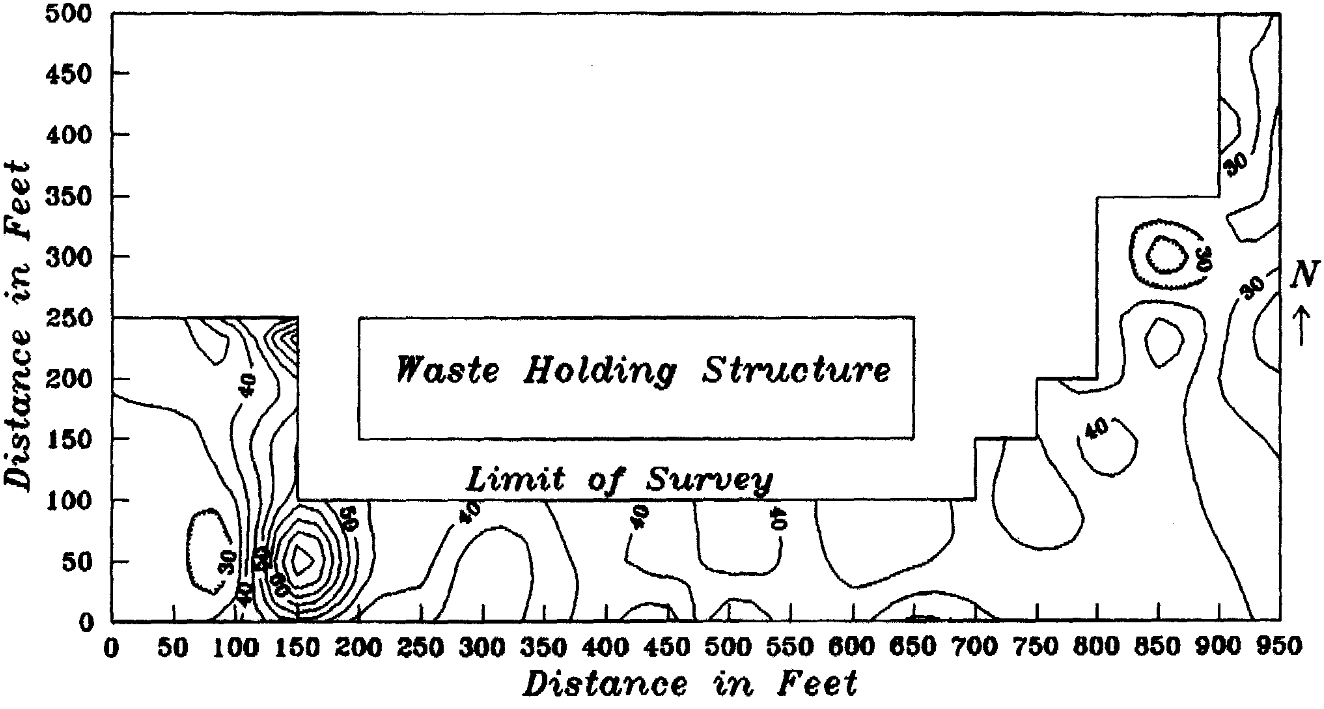
EM34 Survey of Site in Codington County

Horizontal Dipole Orientation



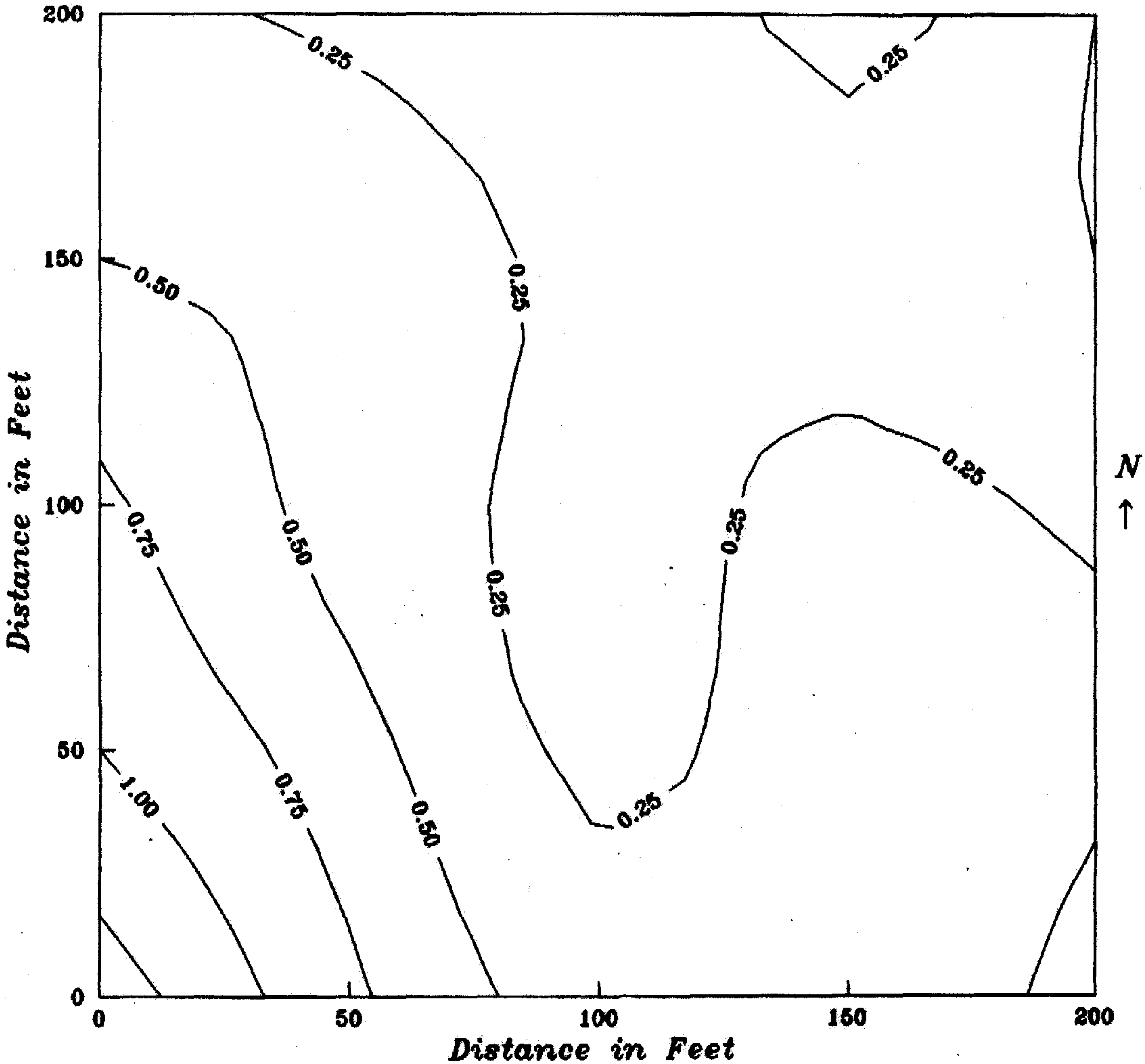
EM34 Survey of Site in Codington County

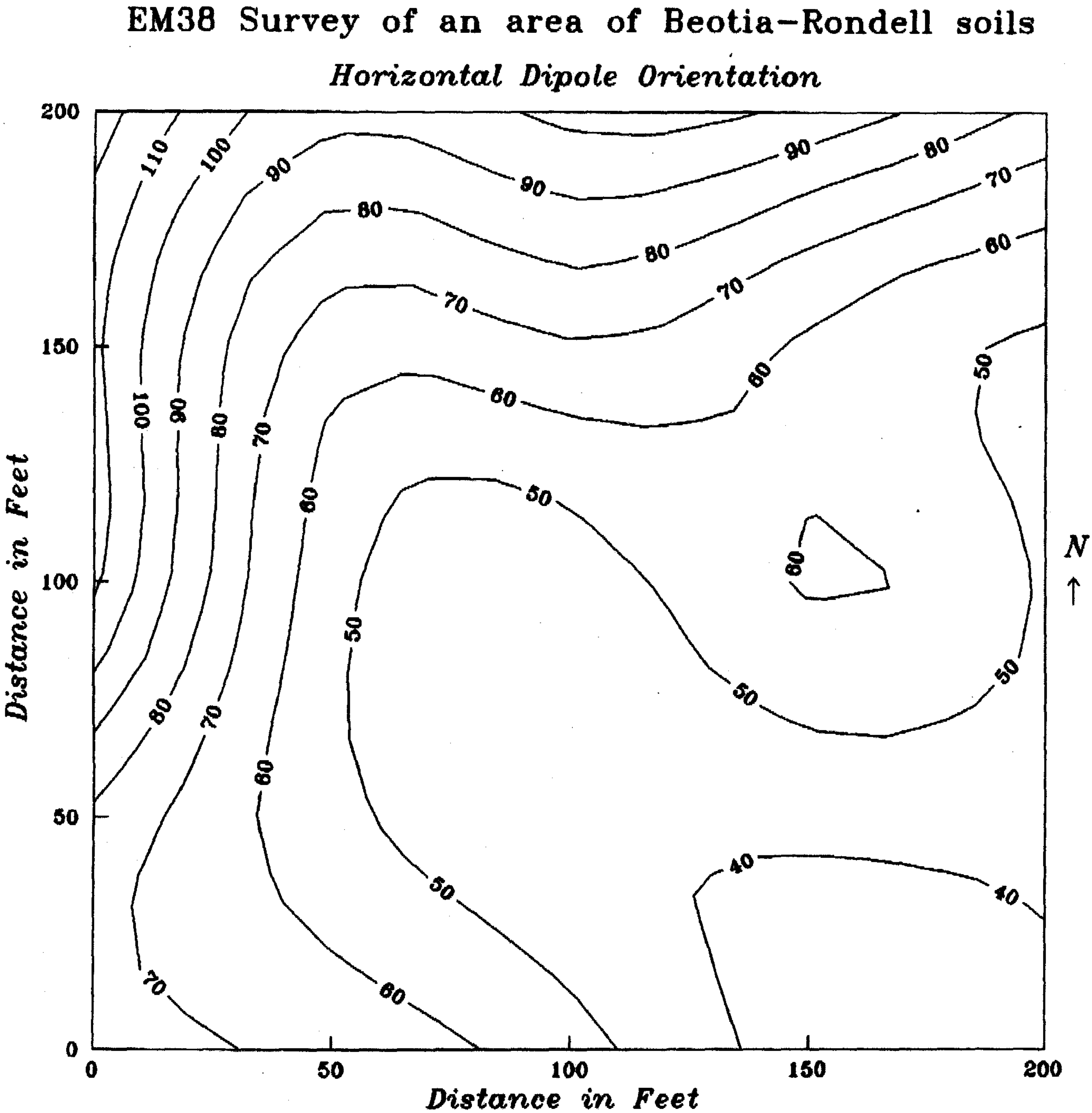
Vertical Dipole Orientation

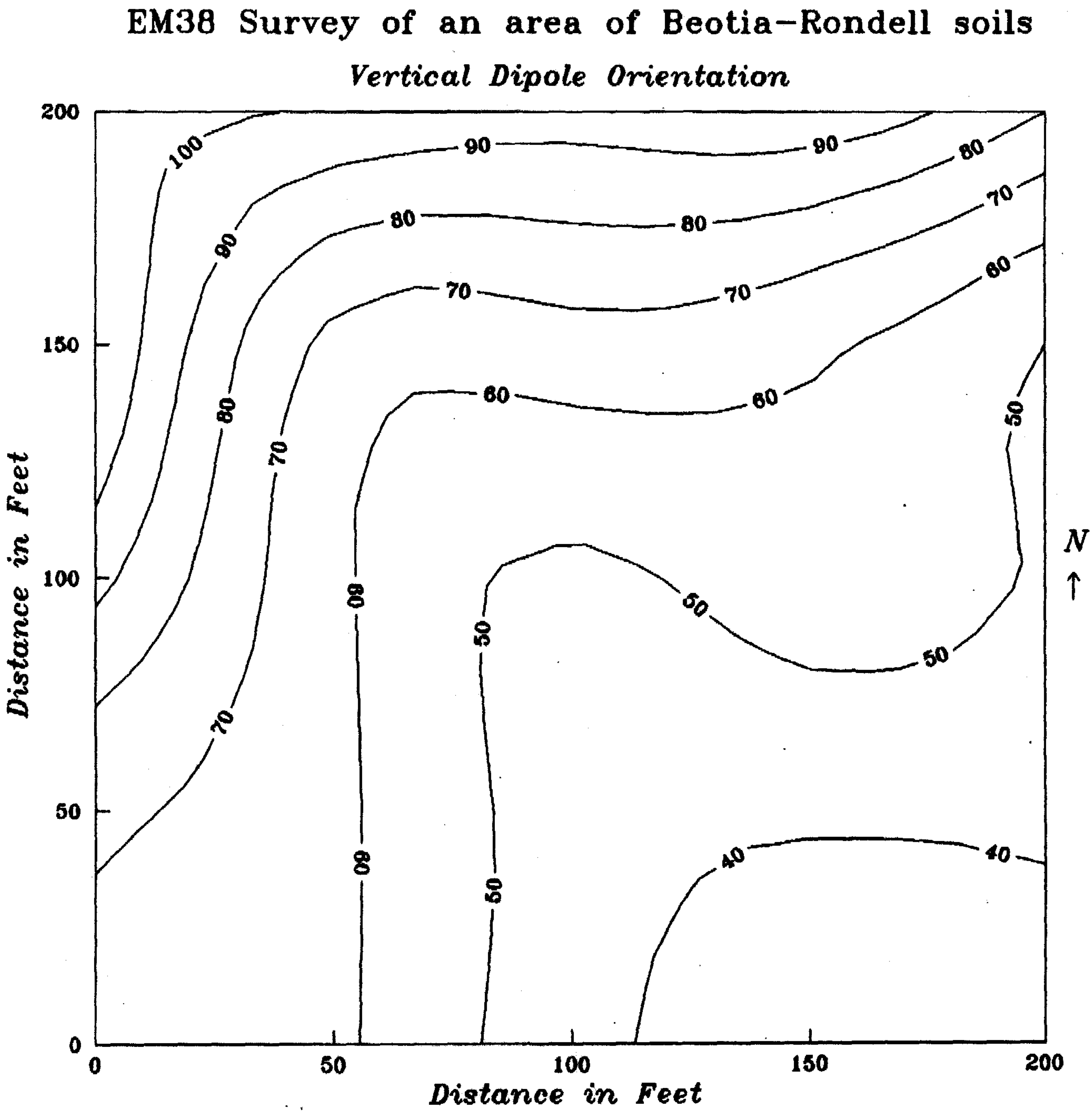


Topography of an area of Beotia-Rondell soils

Contour Interval = 0.25 Foot

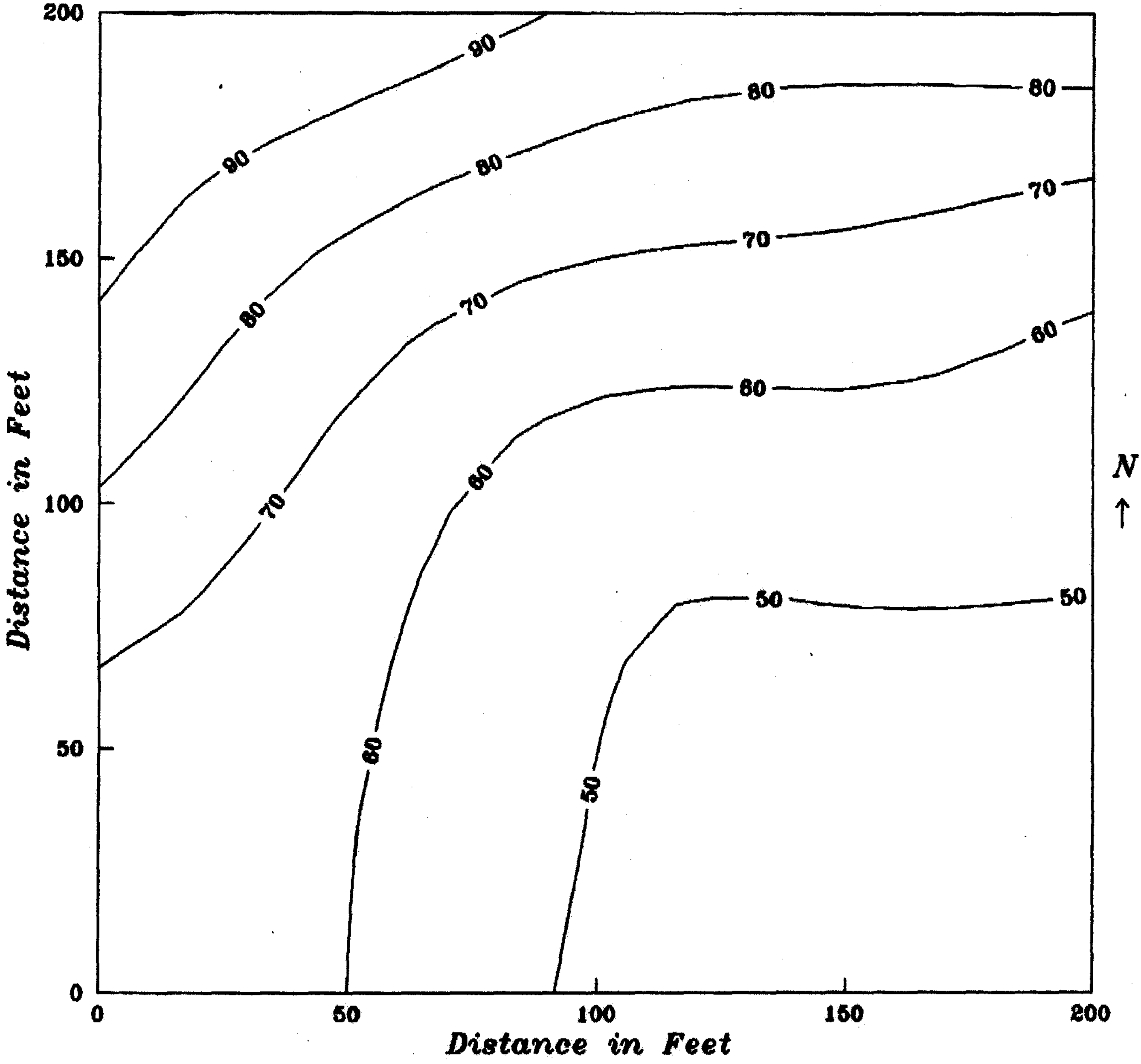


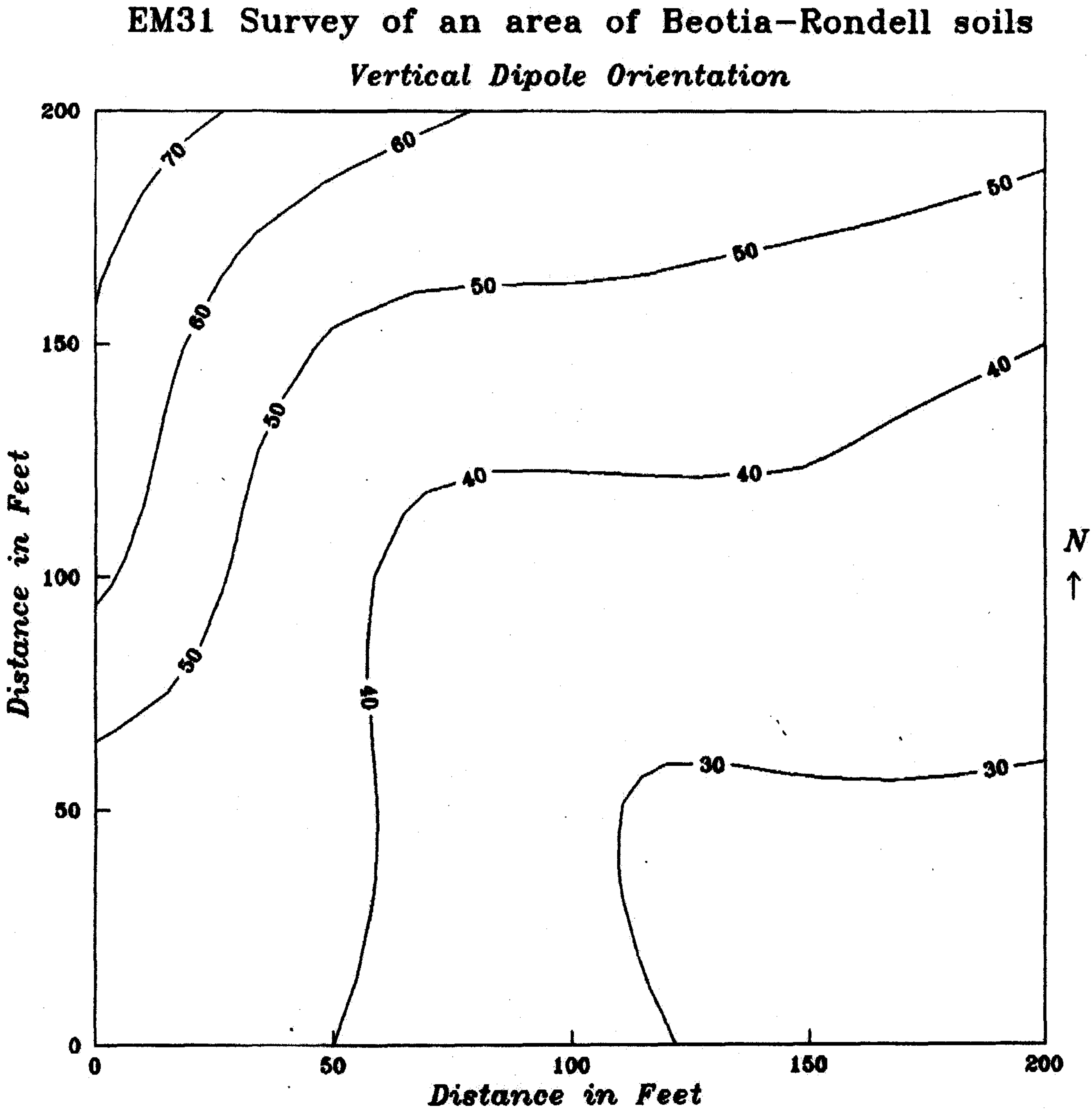

EM38 Survey of an area of Beotia-Rondell soils
Horizontal Dipole Orientation
Distance in Feet
Distance in Feet
0
50
100
150
200
N
110
100
90
80
70
60
50
40


EM38 Survey of an area of Beotia-Rondell soils
Vertical Dipole Orientation
Distance in Feet
Distance in Feet
N
0
50
100
150
200
100
90
80
70
60
50
40

EM31 Survey of an area of Beotia-Rondell soils

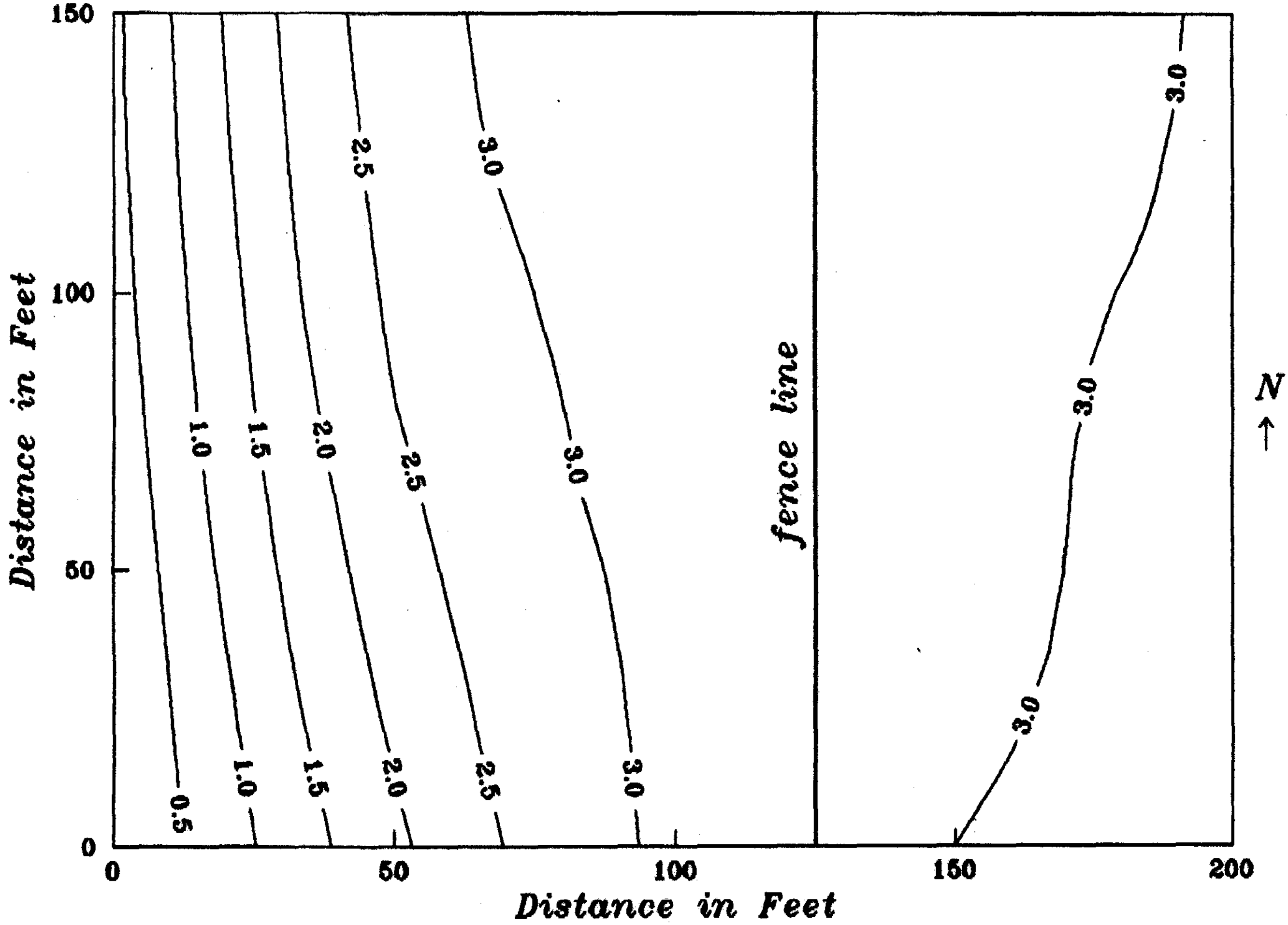
Horizontal Dipole Orientation




EM31 Survey of an area of Beotia-Rondell soils
Vertical Dipole Orientation
200
150
100
50
0
0
50
100
150
200
70
60
60
50
50
50
50
50
40
40
40
40
30
30
Distance in Feet
Distance in Feet
N
↑

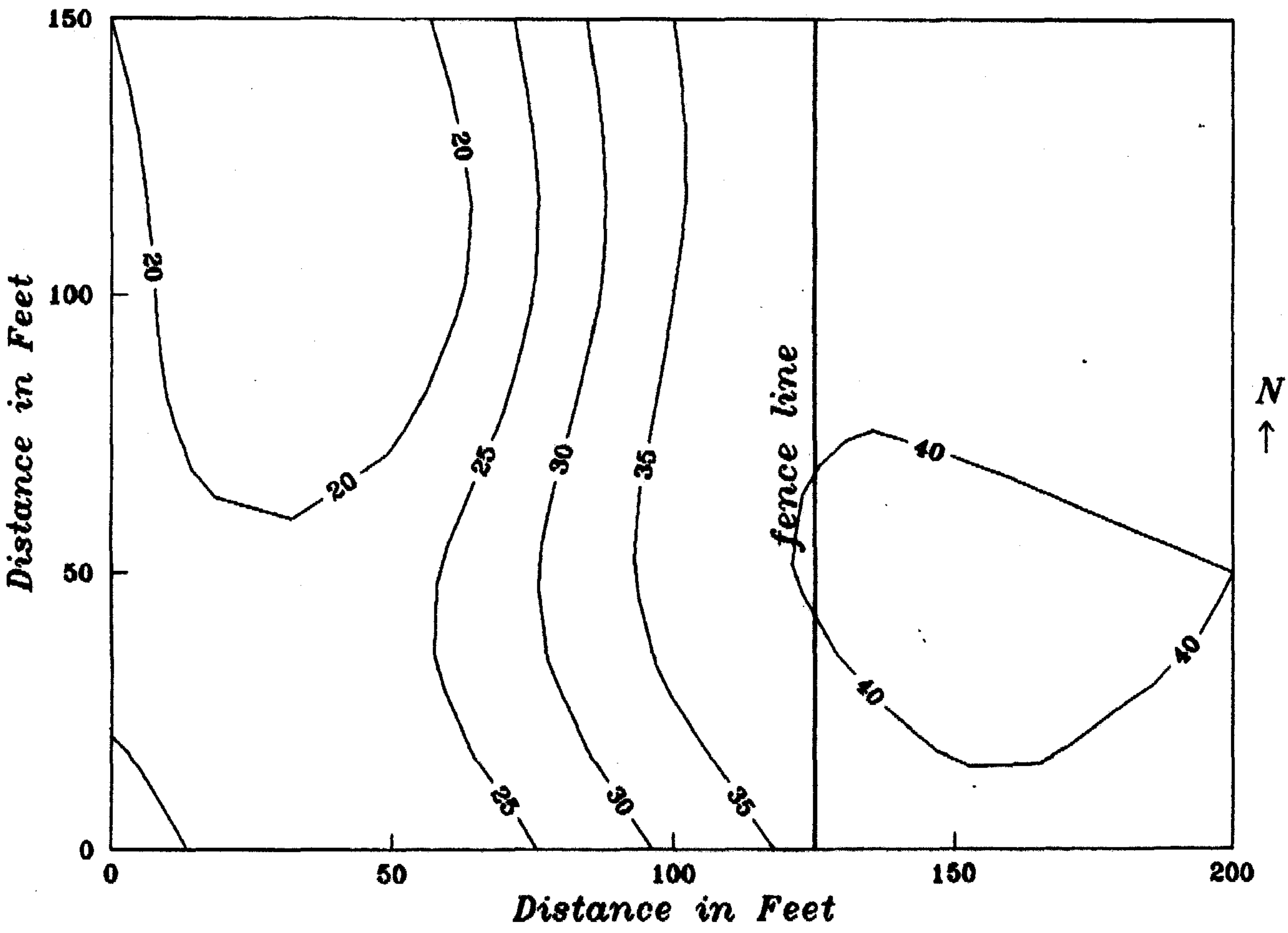
Topography of an area of Great Bend till substratum

Contour Interval = 0.5 Foot



EM31 Survey of an area of Great Bend till substratum

Horizontal Dipole Orientation



EM31 Survey of an area of Great Bend till substratum

Vertical Dipole Orientation