United States Department of Agriculture
Natural Resource Conservation Service **Chester, PA 19013**

Subject: Geophysical Investigations in Monroe and Union Counties, Illinois; 27 - 30 March 1995

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Purpose:
To conduct geophysical assessments of various sites using ground-penetrating radar (GPR) and electromagnetic induction (EM) techniques. At the request of Southern Illinois University, an archaeological site assessment was conducted on Dillow's Ridge in Union County with GPR. The study conducted in Monroe County was to produce a model suitable for delivery to customers which will help to explain how soils and hydrologic processes are interconnected within a selected landscape.

Participants:
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Activities:
On March 27, a study was conducted at a site of a prehistoric village on Dillow's Ridge in southern Union County. The purpose of this study was to assess the feasibility of using GPR techniques for archaeological site assessments. On March 28 and 29, an EM survey was conducted on a site near Ames in southern Monroe County. On March 30, GPR surveys were conducted on splay deposits on the Mississippi River flood plain.

MATERIALS AND METHODS

Equipment

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 digital control unit (DC-2) with keypad, VGA video screen, and connector panel. The system was powered by a 12-volt battery. The model 3105 (300 mHz) and 3102 (500 mHz) antennas were used in this investigation.

The electromagnetic induction meters were the EM38 and EM31, 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.[1] 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 and 6 m in the horizontal and vertical dipole orientations, respectively.[2] Measurements of conductivity are expressed as milliSiemens per meter (mS/m).

DISCUSSION:

GPR Survey at Dillow's Ridge

The 1.4 hectare archaeological site on Dillow's Ridge contains remains of a prehistoric village that dates to the Mississippian Period. Previous field studies at this site have documented the presence of thirty depressions. Most of these depressions represent prehistoric house basins. Excavations within the site have revealed additional, often superposed and overlapping structures. The use of GPR to detect additional house basins and other cultural features within the site was explored.

The site was located on the summit of a ridge in an area of Goss-Alford complex, 30 to 70 percent slopes. Goss is a member of the clayey-skeletal, mixed, mesic Typic Paleudalfs family. Alford is a member of the fine-silty, mixed, mesic Typic Hapludalfs family. It was anticipated that the relatively high clay content and base saturation of these soils would dissipate the radar signals and limit the observation depth of the radar. In similar soils, depths of observation were restricted to the upper part of the argillic horizon.

Four GPR traverses were conducted across portions of the site. A scanning time of 70 nanoseconds was used. Based on tabled values for wet, medium-textured soils (dielectric constant of 19 and velocity of propagation 0.23 feet/nanoseconds), this scanning time provided a maximum profiling depth of about 8 feet. However, relatively high rates of signal attenuation appeared to limit profiling to depths of less than 3 feet.

Because of its more restricted profiling depths in relatively high-loss soils, the 500 mHz antenna proved inappropriate for use on Dillow's Ridge. In addition, radar profiles collected with this antenna were cluttered with high levels of unwanted, background noise. Parallel bands of noise masked the detection of many relatively shallow, subsurface interfaces.

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1. 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.

2. McNeill, J. D. 1979. EM31 operating manual for EM31 noncontacting terrain conductivity meter. Geonics Ltd., Mississauga, Ontario. p. 35.

The 300 mHz antenna provided the best balance of profiling depth and resolution. It is believed that this antenna, even under moist soil conditions, would provide sufficient depths (3 feet) of observation to detect most buried cultural features. Unfortunately, dielectric gradients existing between soil and cultural layers were relatively weak and, as a consequence, most buried artifacts were poorly expressed on radar profiles. Buried layers having high concentration of flint fragments were fairly well expressed and observable on radar profiles.

In general, GPR techniques can be used with limited success on Dillow's Ridge for archaeological investigations. However, results will be highly interpretative. Subsurface layers having high concentrations of flint fragments were detectable with GPR. Because of weak reflective coefficients, many buried cultural features (floors or other structures) will not be detected, or will be overlooked or miss identified by the interpreter.

EM survey of the Ames study site in Monroe County

The study site was located near Ames in southern Monroe County. The grid was established in a cultivated field in the southeast 1/4 of Section 36, T. 4 S., R. 9 W. The site was located on an upland area. The northwest portion of the site was on the floodplain of Paint Creek. The grid was located in areas of Blair silty clay loam, 5 to 10 percent slopes (5C3); and Muren silt loam, 2 to 5 percent slopes (453B); Blair and Muren soils are members of the fine-silty, mixed, mesic Aquic Hapludalfs family.

Field Methods

A 600 by 550 foot grid (7.58 acres) was established across the site. The grid interval was 50 feet. This interval provided 156 grid intersections or observation sites. The coordinates of the grid were 38^{o} 08' 34 N Lat., 90^{o} 02' 34 W Long. ;38^{o} 08' 27 N Lat., 90^{o} 02' 34 W Long.; 38^{o} 08' 27 N Lat., 90^{o} 02' 42 W Long.; 38^{o} 08' 34 N Lat., 90^{o} 02' 42 W Long.

A transit and stadia rod were used to determine the relative elevation of the surface at each grid intersection. Elevations were not tied to an elevation benchmark; the lowest recorded grid intersection was recorded as the 0.0 foot datum. At each grid intersection, measurements were taken with an EM38 and an EM31 meter. Measurements were taken with each meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At 20 grid intersections, soils were classified, and soil textures and depths to paleosols were determined with hydraulic probes. The recorded depths to these features and EM data collected at each grid intersection were compared and used to develop regression equations to predict the depths to paleosol from values of apparent conductivity. To help summarize the results of this survey, the software program SURFER for Windows was used to construct two- and three- dimensional simulations.

Figures 1 represent a two-dimensional contour plot of the study site. Figure 2 represents a three-dimensional surface net diagram of the study site. In each simulation, measurements are in feet. In figures 1 and 2, the contour intervals are 1 and 2 feet, respectively.

Within the site, relief was about 32 feet. The site resembles a broad amphitheater. Higher-lying areas bound the study site on its northeast, east, south, and west sides. The lowest-lying and presumably wettest areas were located in the north-northwest portion of the site. Most points within the site slope towards this portion of the site. This low-lying area extends beyond the study site onto the flood plain of Paint Creek. Within the study site, two, fairly well defined intermittent drainageways descend into this low-lying area from the adjoining uplands.

Interpretations of the EM data are based on the identification of spatial patterns within the data set. Figures 3 and 4 are two-dimensional plots of the EM data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 5 and 6 are two-dimensional plots of the EM data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the interval is 2 mS/m.

Comparing figures 3, 4, 5, and 6, values of apparent conductivity, as a rule, increase and become slightly more variable with increasing observation depth (responses of the EM38 meter were less those of the EM31 meter, and, for each meter, responses in the horizontal dipole orientation were typically less than those in vertical dipole orientation).

The site was characterized as consisting of a relatively thin (29 to 140 inches) mantle of medium and moderately-fine textured Peoria loess and Roxana silts overlying fine-textured Illinoian till. Higher EM responses with increasing observation depths were attributed to the higher clay contents of the underlying argillic horizon and till. The observed texture of the surface layers were silt loam, the argillic horizon was heavy silt loam or silty clay loam, and the till was silty clay or heavy silty clay loam. Depths to the argillic horizon were observed to range from 3 to 38 inches. However, a few observation sites (10 percent) lacked argillic horizons. Depths to till were observed to range from 29 to 140 inches. A paleosol, formed in the upper part of the Illinoian till, had a redder (7.5YR to 5YR) color than the overlying loess (10YR). Within drainageways, areas of silty Cahokia alluvium were observed.

Table 1
Ames Study Site in Monroe County, Illinois
(all values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	14	38	18	23	27	23
EM38	Vertical	20	41	24	28	30	29
EM31	Horizontal	28	60	32	35	41	39
EM31	Vertical	40	85	45	50	61	55

EM responses became more variable with increasing observation depth. This relationship was believed to represent variations in the texture, thickness, moisture, and chemistry of soil and geologic layers. These relationship were presumed to be related to the higher clay content of the fine-textured Illinoian till which underlies the medium textured Peoria loess and Roxana silts.

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

Variations in EM measurements with depth conformed with the basic conceptual model of the site. For the purpose of this investigation, the site was assumed to consist of two principal layers: loess and till. The medium and moderately-fine textured loess has a lower clay content and was presumed to have lower apparent conductivity values than the underlying fine-textured till.

Thickness of loess varied across the site because of erosion, deposition, and landscape position. Because of differences in clay content between the surface layers and the argillic horizons, and the loess and the underlying Illinoian drift, vertical contrasts in electrical conductivity were assumed to exist. It was assumed that variations in the magnitude of the EM response could provide estimates of the thickness of the loess or the depth to Illinoian drift.

Based on twenty observation points, the average depth to till was 84 inches with a range of 29 to 140 inches. A comparison of soil probe and EM data collected at the twenty observation points revealed no significant correlation between the observed depths to till and the EM data (see Table 2).

Table 2

Relationship Among EM Measurements and Depth to Illinoian Till
(20 observations)

Meter and Orientation	r^2
EM38 Meter (Horizontal Dipole Orientation)	0.118298
EM38 Meter (Vertical Dipole Orientation)	0.000314
EM31 Meter (Horizontal Dipole Orientation)	0.006752
EM31 Meter (Vertical Dipole Orientation)	0.004168

Within the study site, measurements taken with the EM meters varied from 14 to 85 mS/m (see Table 1). In a study conducted in south-central Illinois with the EM38 meter, responses greater than 30 mS/m most often indicated a sodium-affected soil, responses greater than 55 mS/m indicated a soil with a natric horizon.[3] These authors described areas of sodium-affected soils as being irregular in shape, small in size, and spotty in occurrence. It was inferred from the high EM responses within the Ames site that sodium-affected soils were present.

3. Nettleton, W. D., L. Bushue, J. A. Doolittle, T. J. Endres, and S. J. Indorante. 1994. Sodium-affected soil identification in south-central Illinois by electromagnetic induction. Soil Sci. Soc. Am. J. 58:1190-1193.

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. [4] In such areas, information is gathered on the dominant factor, and assumptions are made concerning the behavior of the other factors. [5] Within the Ames site, two factors (clay and salt contents) varied making it difficult to attribute variation in the EM response to the depth to clay alone.

Data collected at each of the observation points were group according to EM response. As the observation depths of the EM38 meter in the vertical dipole orientation and the EM31 meter in either the horizontal or vertical dipole orientation most closely brackets the range in observed depths to the Illinoian till, their responses were used to group the data. Those observation points (7) having EM38 responses less than 30 mS/m and EM31 responses less than 40 mS/m in the horizontal dipole orientation and less than 45 mS/m in the vertical dipole orientation were not considered to be sodium-affected. Those observation points (13) having EM38 responses greater than 30 and/or EM31 responses greater than 40 mS/m in the horizontal dipole orientation and greater than 45 mS/m in the vertical dipole orientation were considered sodium-affected.

Tables 3 and 4 shows the relationship that existed for the grouped data between the observed depths to Illinoian till and the responses measured with the EM38 and EM31 meters. For each group, the highest correlations were found between the depths to till and the responses of the EM31 meter in the vertical dipole orientation.

Table 3

Relationship Among EM Measurements and Depth to Illinoian Till
(7 observations where EM31H <40 mS/m and EM31V < 44 mS/m)

Meter and Orientation	r^2
EM38 Meter (Horizontal Dipole Orientation)	0.677245
EM38 Meter (Vertical Dipole Orientation)	0.554045
EM31 Meter (Horizontal Dipole Orientation)	0.106115
EM31 Meter (Vertical Dipole Orientation)	0.705770

4. Cook, P. G., M. W. Hughes, G. R. Walker, and G. B. Allison. 1989. The calibration of frequency-domain electromagnetic induction meters and their possible use in recharge studies. Journal of Hydrology 107:251-265.

5. Cook, P. G. and G. R. Walker. 1992. Depth profiles of electrical conductivity from linear combinations of electromagnetic induction measurements. Soil Sci. Soc. Am. J. 56:1015-1022.

Table 4

Relationship Among EM Measurements and Depth to Illinoian Till
(13 observations where EM31H > 40 mS/m and EM31V > 45 mS/m)

Meter and Orientation	r^2
EM38 Meter (Horizontal Dipole Orientation)	0.563797
EM38 Meter (Vertical Dipole Orientation)	0.358154
EM31 Meter (Horizontal Dipole Orientation)	0.584609
EM31 Meter (Vertical Dipole Orientation)	0.887634

Data collected with the EM31 meter in the vertical dipole orientations were used to develop two predictive regression equation:

$$D = 717.0806 + (-15.306 * EM31V) \qquad [1]$$

$$D = -164.7328 + (3.733 * EM31V) \qquad [2]$$

where "D" is depth to paleosol (inches) and "EM31V" is the apparent conductivity (mS/m) measured by the EM31 meter in the vertical dipole orientation.

Equation 1 was used to estimate the depth to paleosol at grid intersections where values of apparent conductivity measured with the EM31 meter in the vertical dipole orientation were less than 45 mS/m. Equation 2 was used to estimate the depth to paleosol at grid intersections where values of apparent conductivity measured with the EM31 meter in the vertical dipole orientation were greater than 45 mS/m.

The large coefficients used in these equations [1 and 2] attest to the variability of soil and geologic properties within the site, increase the likelihood of measurement errors, and reduce the accuracy of the resulting simulations and models. To verify their accuracy, depths to paleosol were estimated using these predicative equations and compared with the depths measured at the twenty "probed" observation sites. Fifty-five percent of the estimated depths were within 0 to 20 inches of the actual depth to paleosol and twenty-five percent were within 20 to 40 inches.

Based on 156 EM31 measurements and the predictive equations [1 and 2], the average depth to paleosol was estimated to be 86 inches with a range of 0 to 166 inches. One-half of the observations had depths to paleosol between 22 and 86 inches. The paleosol was shallow (<20 in) at 21 percent, moderately deep (20 to 40 in) at 16 percent, deep (40 to 60 in) at 23 percent, and very deep (>60 in) at 40 percent of the observation points.

Figure 7 is a two-dimensional plot showing the depths to the paleosol within the study site. Figure 8 is a three-dimensional representation of the study site showing the distribution of depths to the paleosol across the study site. These spatial patterns indicate that the depths to paleosol are variable over relatively short distances. The greatest depths to paleosols occur on summits, lower sideslopes, and some along drainageways. The shallowest depths to paleosols principally occur on higher-lying convex sideslopes and shoulders.

Figure 9 is a three dimensional surface net diagram of the soil and the underlying paleosol surfaces. The topography of the buried paleosol surface resembles the topography of the soil surface, but it is more irregular and has greater relief. The loess appears to have blanketed and subdued the expression of the buried, dissected till surface. The locations of the present drainageways appear to coincide with earlier, more incised drainageways.

RESULTS:

1. Results from the archaeological investigation at Dillow's Ridge were inconclusive. At this site, GPR techniques can be used with limited success. While the use of GPR at this site is not discouraged, because of attenuating soil conditions, results will be depth restricted and highly interpretative.

2. Field work in Monroe County indicates that EM techniques can be used to extend the depths of interpretation and to estimate the depths to the finer-textured Illinoian till. Values of apparent conductivity can be used to develop regression equations to predict the depth to Illinoian till or the thickness of loess. The techniques used in this study can be used to help understand and model the three-dimensional flow of water through the soil system. As the depth to the Illinoian till influences water movement through this landscape, the techniques used in this study can be used to create a conceptual model of how and where water moves through the landscape.

3. This study documented the presence of sodium-affected soils, Peorian loess, Roxana silts, and Illinoian till in areas predominant considered free of sodium-affected materials.

It has been my pleasure to assist in this project.

With kind regards

James A. Doolittle
Research Soil Scientist

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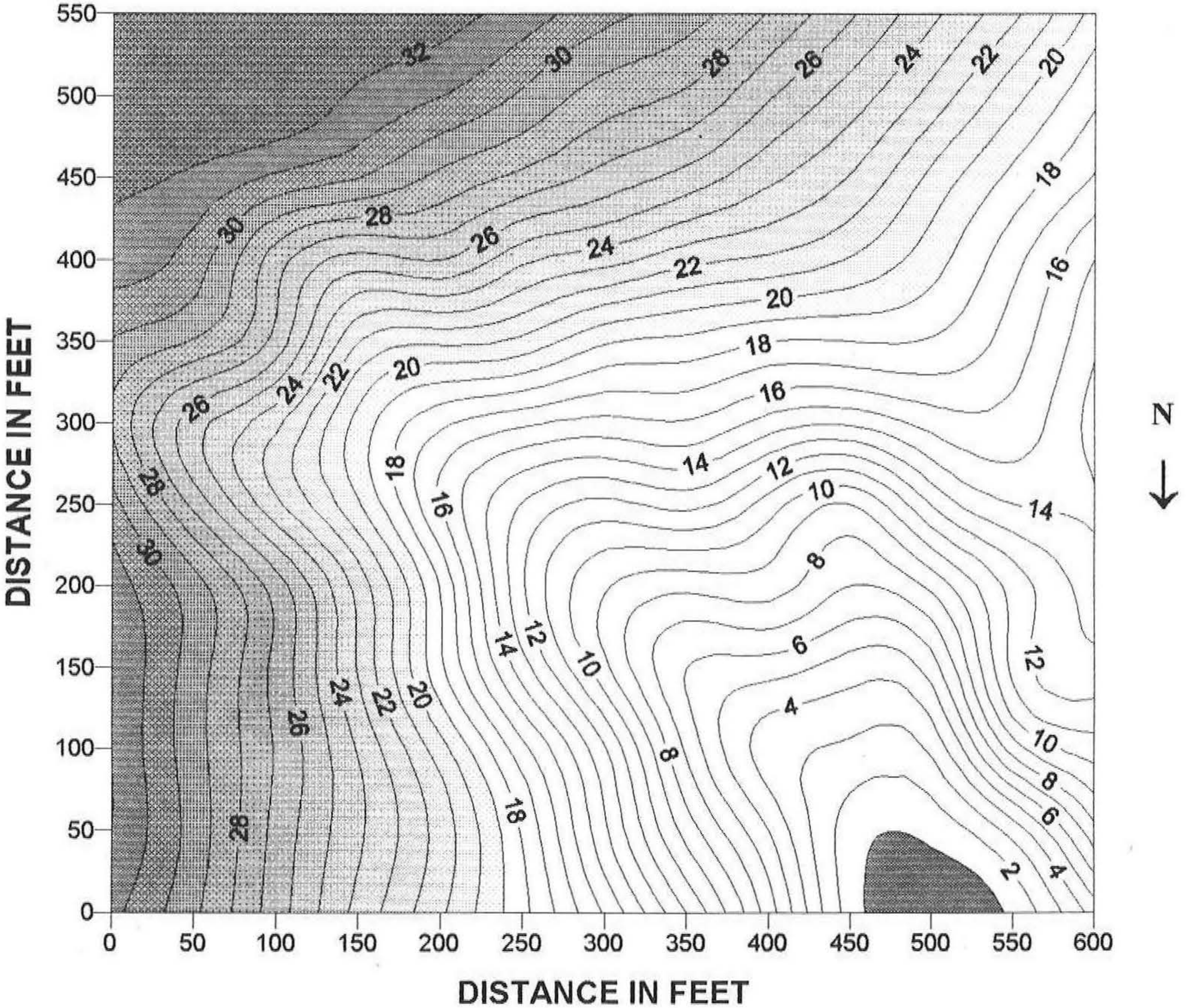
MONROE COUNTY, ILLINOIS
AMES STUDY SITE
RELATIVE TOPOGRAPHY



MONROE COUNTY, ILLINOIS
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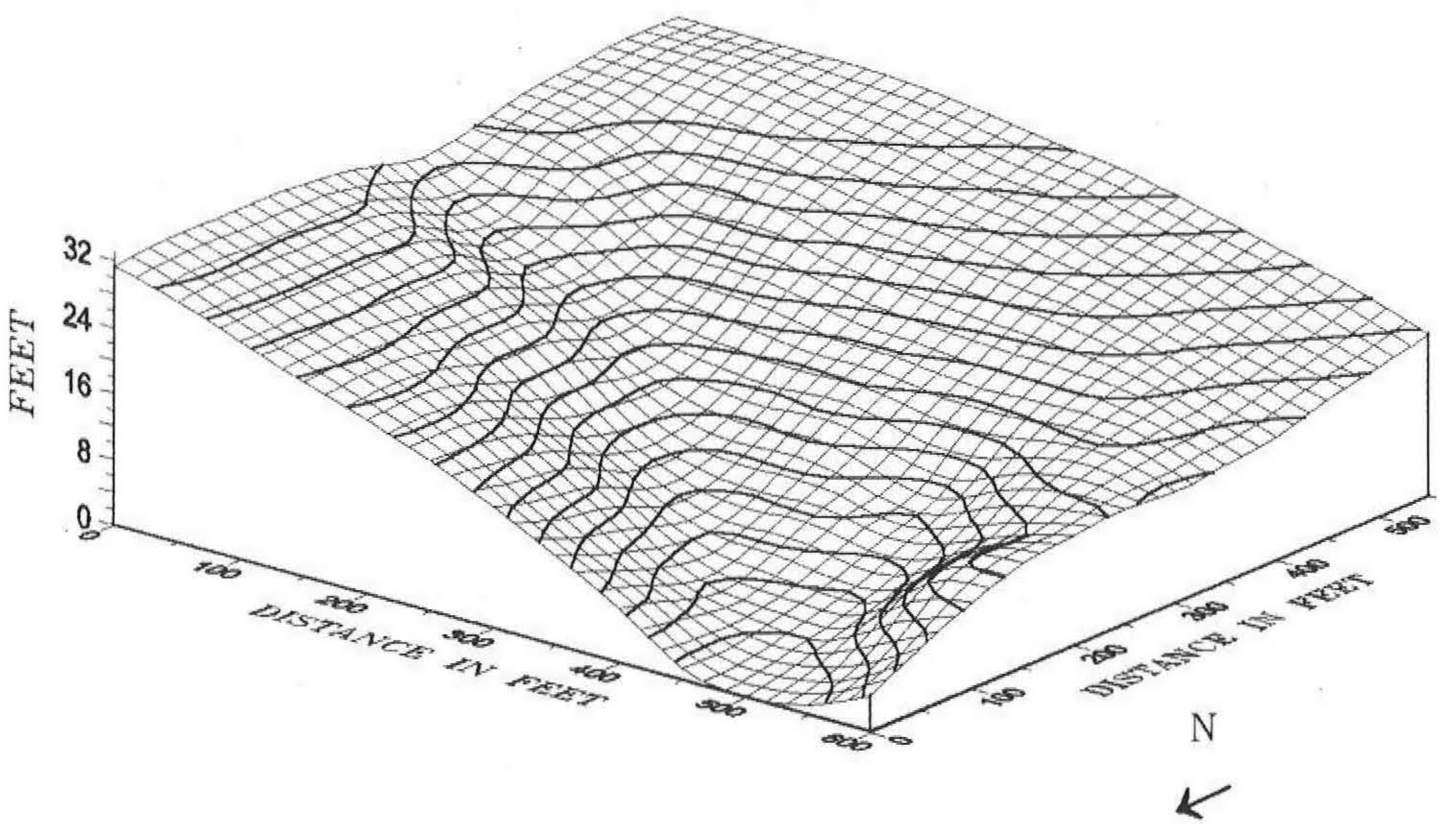
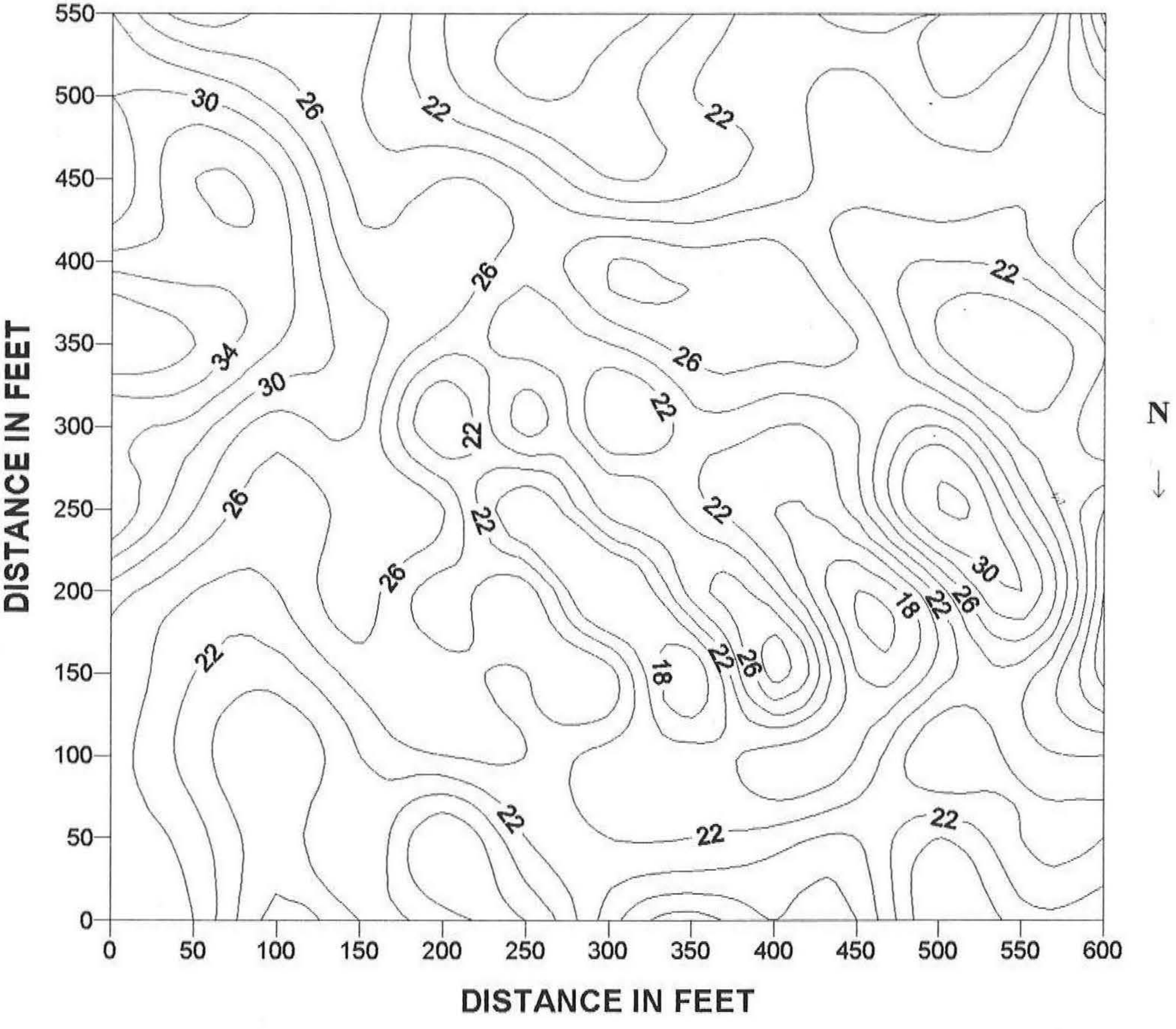
RELATIVE TOPOGRAPHY



MONROE COUNTY, ILLINOIS
AMES STUDY SITE
EM38 SURVEY
HORIZONTAL DIPOLE ORIENTATION



MONROE COUNTY, ILLINOIS
AMES STUDY SITE
EM38 SURVEY
VERTICAL DIPOLE ORIENTATION

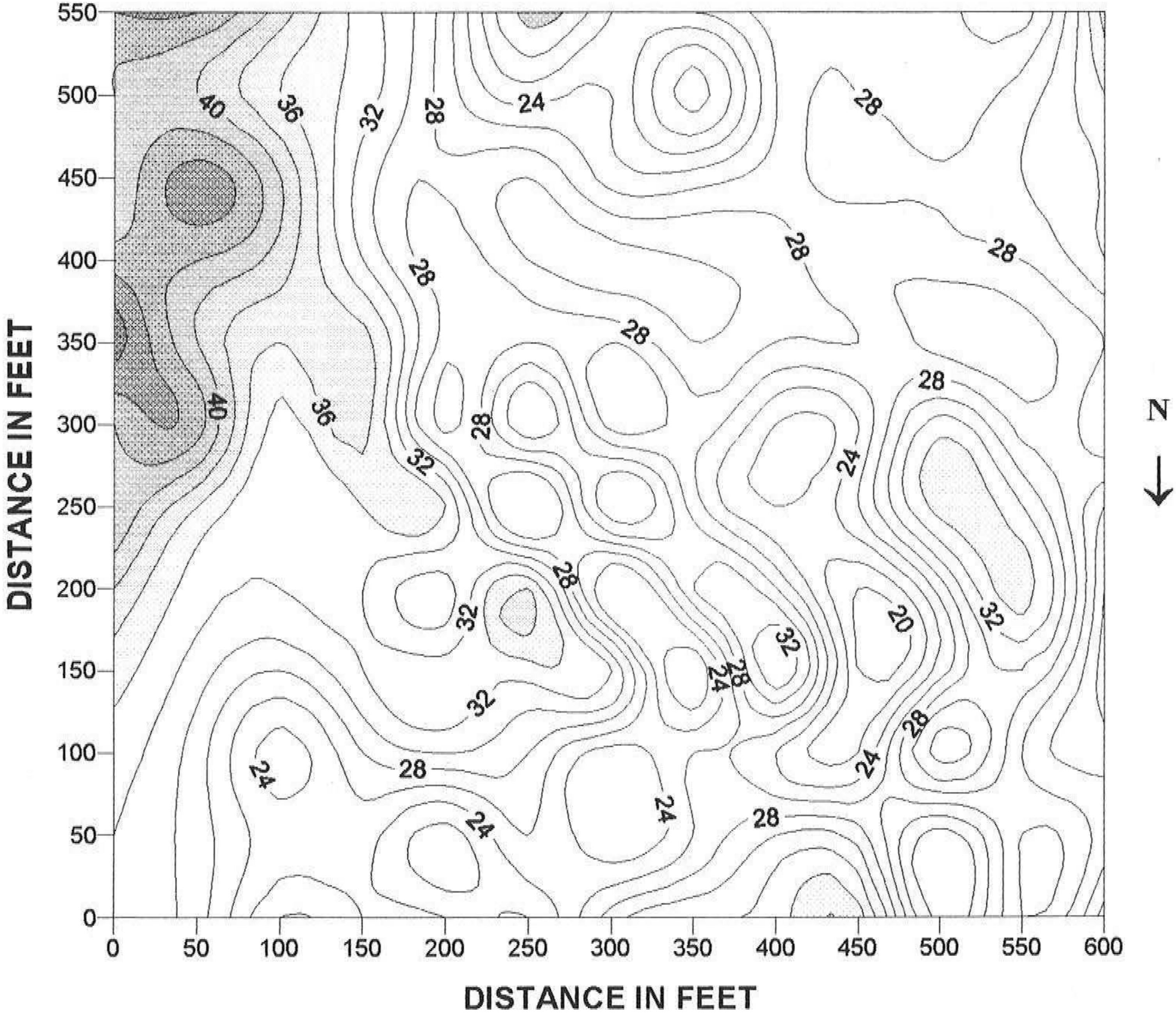
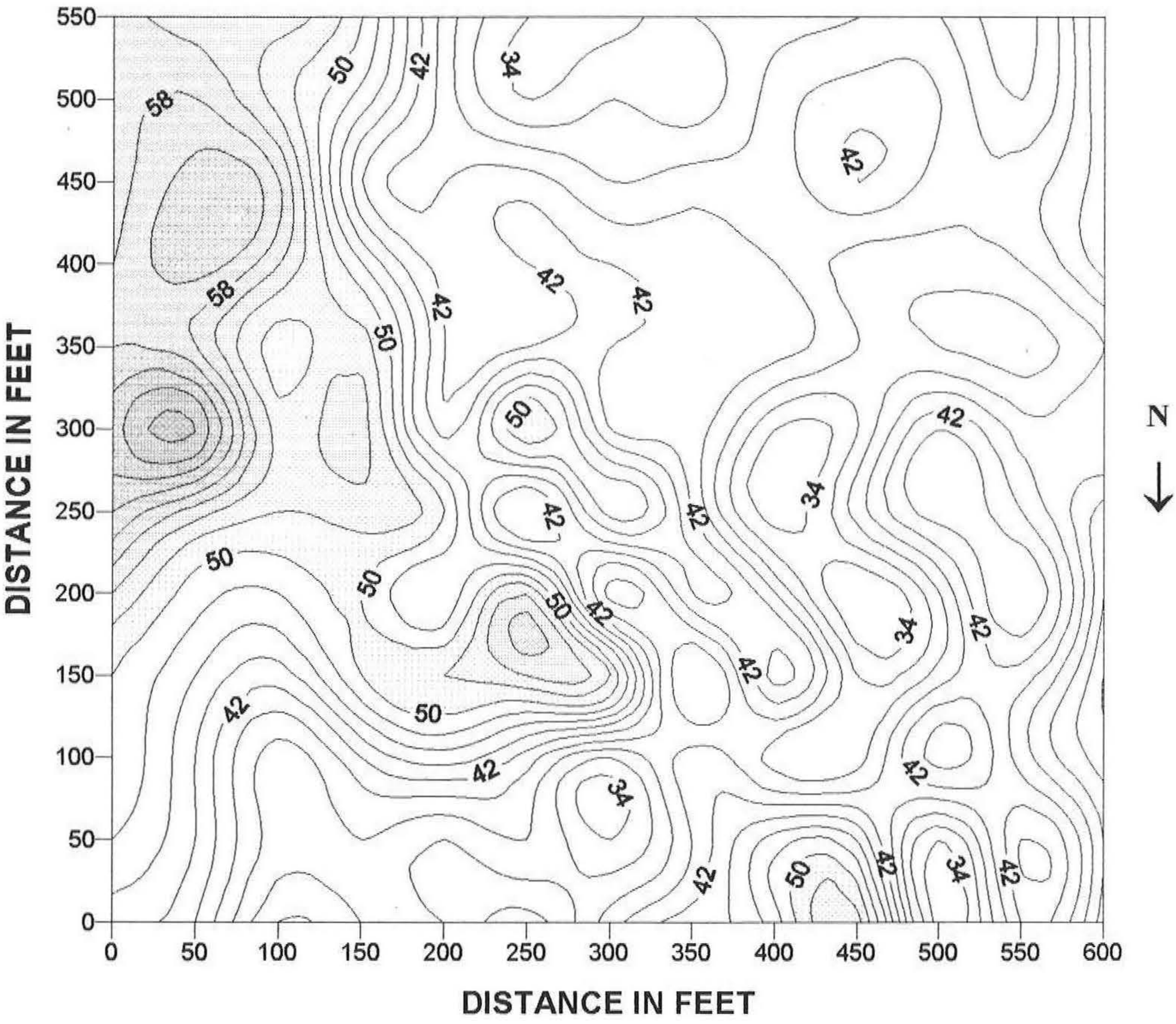
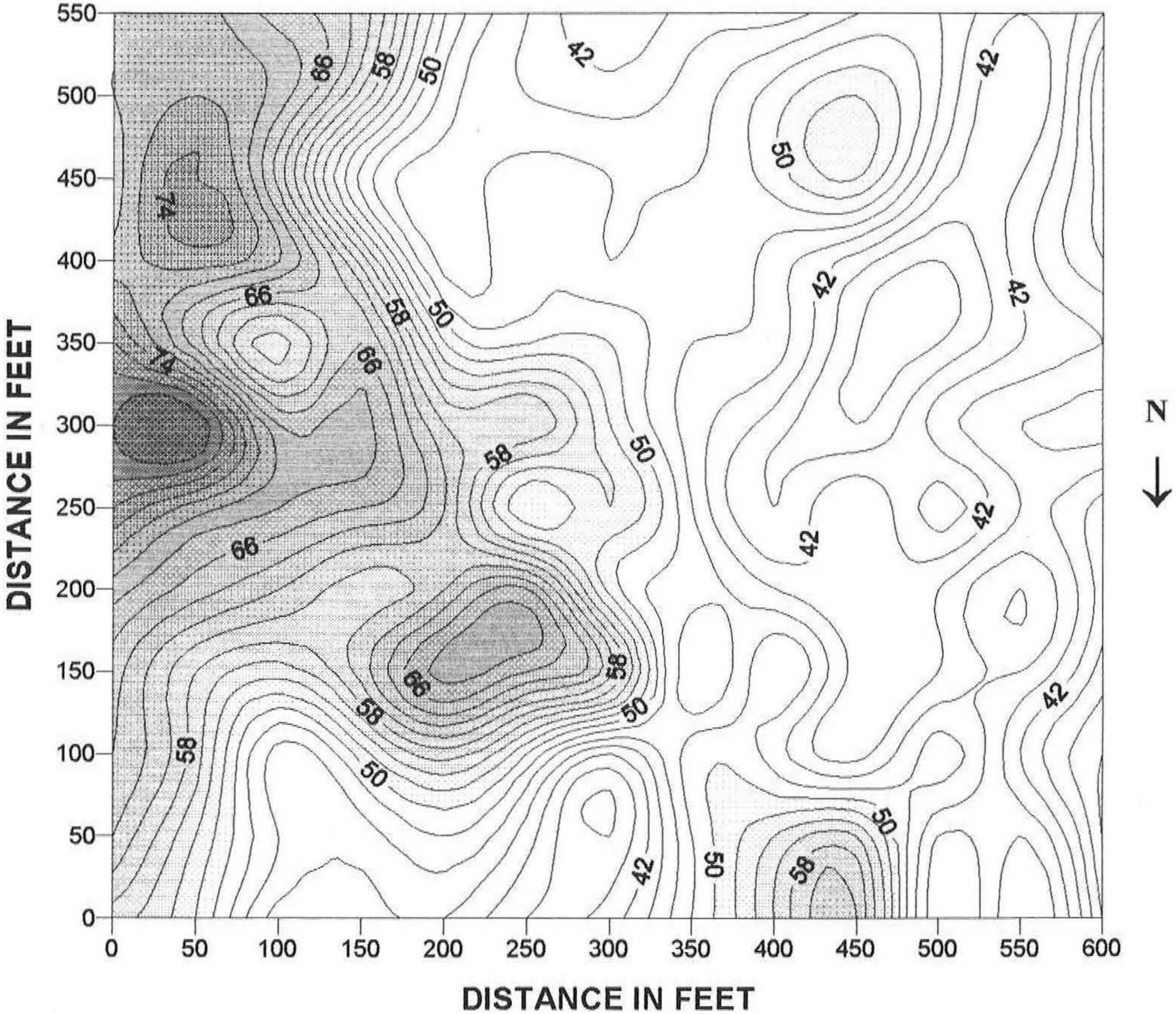


Figure 5

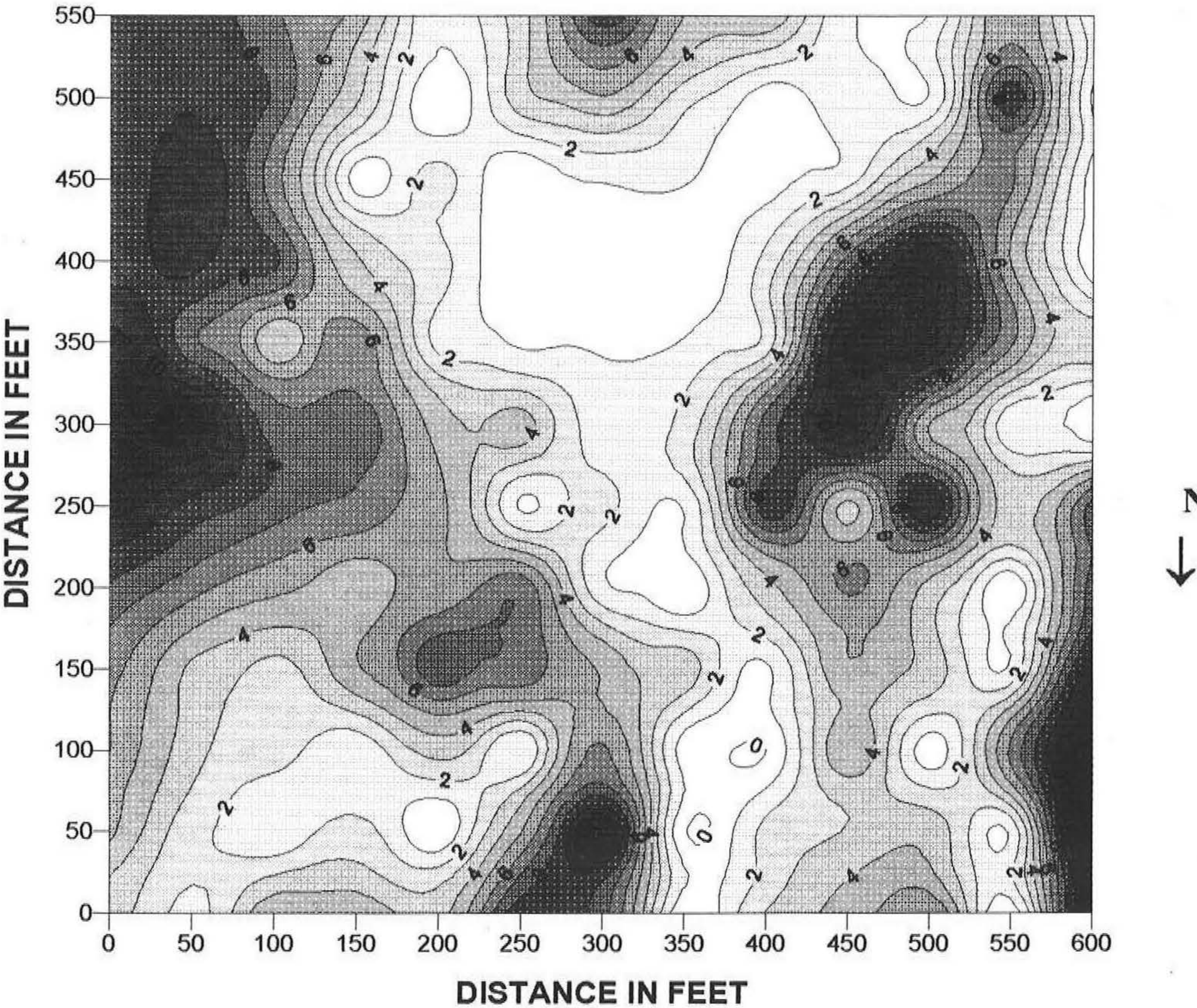
MONROE COUNTY, ILLINOIS
AMES STUDY SITE
EM31 SURVEY
HORIZONTAL DIPOLE ORIENTATION



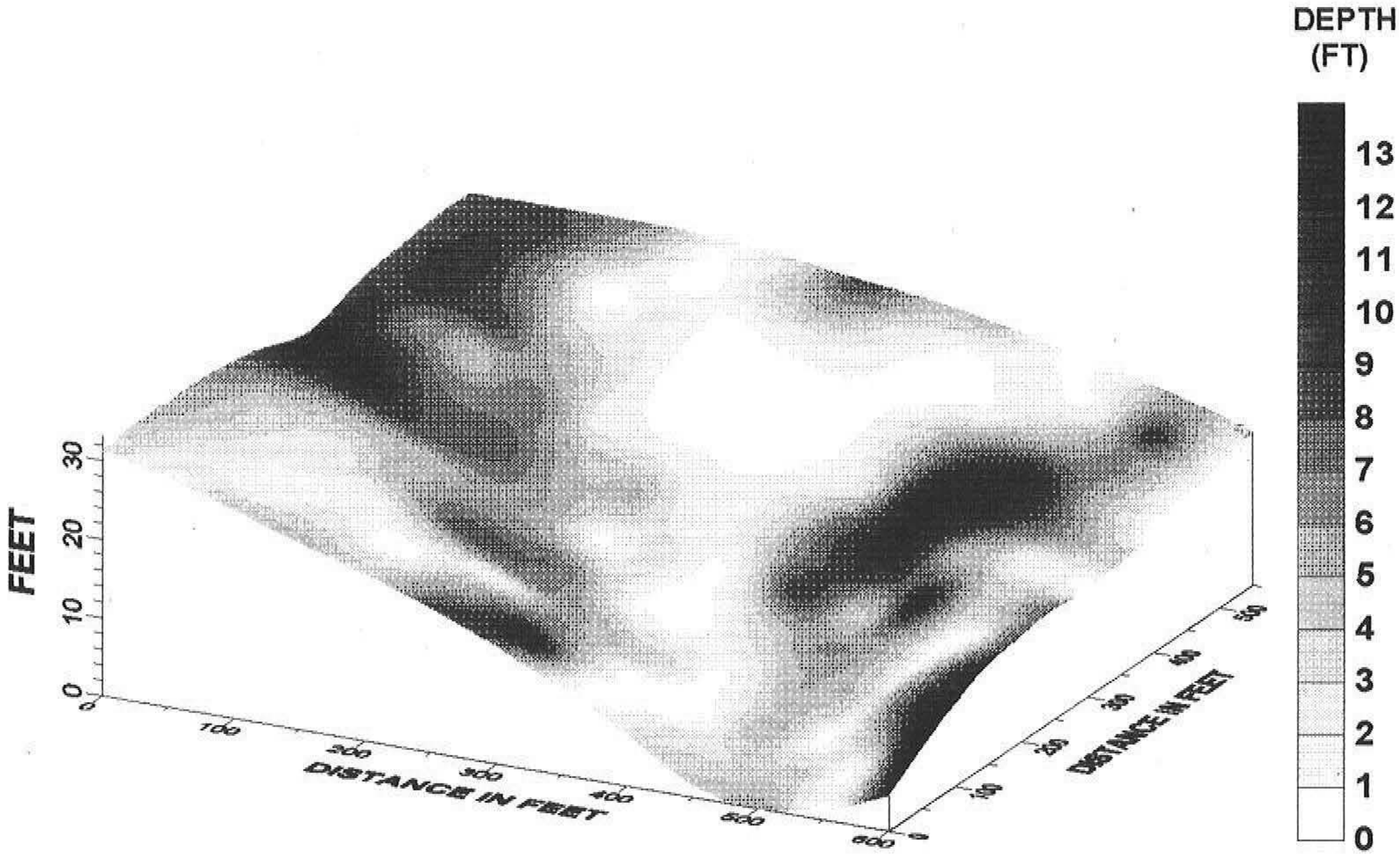
MONROE COUNTY, ILLINOIS
AMES STUDY SITE
EM31 SURVEY
VERTICAL DIPOLE ORIENTATION



AMES STUDY SITE
MONROE COUNTY, ILLINOIS
DEPTH TO PALEOSOL



DEPTHS TO PALEOSOL
AMES STUDY SITE
MONROE COUNTY, ILLINOIS



RELATIVE TOPOGRAPHY OF SOIL SURFACE AND PALEOSOL AMES SITE, MONROE COUNTY, ILLINOIS