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

Subject: Electromagnetic Induction Surveys of Proposed Site for Valmeyer, Illinois; 14 - 18 March 1994. **Date:** 18 April 1994

To: Charles Whitmore
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Purpose:
To conduct a geophysical assessment of the proposed relocation site for the town of Valmeyer, Illinois, using electromagnetic induction (EM) techniques. The purpose of this survey is to provide interpretative maps which can be used to assist planners and developers assess and avoid potential geologic hazards.

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Background:
The town of Valmeyer was devastated by the 1993 floods of the Mississippi River. The people of Valmeyer have decided to relocate the town to an upland area about 1.8 miles east of the former town site. The proposed relocation site (550 acres) is located in an area of karst.

While the relocation site is considered suitable for community development, karst features represent a potential geologic hazard. Fourteen sinkholes have been identified within the proposed relocation site by the Illinois State Geological Survey (ISGS). The ISGS considers that these hazards can be minimized or circumvented through appropriate construction practices. Most of the identified sinkholes are clustered in the northeast part of the relocation site in an area known as the "northern arm." The greater occurrence of sinkholes in the "northern arm" is presumed to be a consequence of thinner surficial deposits overlying the limestone bedrock (Erdmann and Bauer, 1993). The identified sinkholes are distributed in a linear pattern which suggest a probable fracture line in the bedrock (see Figure 1, from Erdmann and Bauer, 1993). It is also probable that other solution features exist within the relocation site, but lack surface expression.

On 16 November 1993, the Soil Conservation Service conducted an electromagnetic induction (EM) survey on a portion of the proposed relocation site (Doolittle, 1993). The purpose of this investigation was to assess the feasibility and appropriateness of using this technique in areas of karst. Electromagnetic induction methods have been used in areas of karst (Canace and Dalton, 1984; Pazuniak, 1989; Robinson-Poteet, 1989; Rumbens, 1990) to define anomalous subsurface patterns which indicate the presence of solution features. The results of the survey conducted by SCS were favorable. In February 1994, the agency was requested by the Village of Valmeyer to continue the EM survey across a larger portion of the proposed site (Knobloch and Andres, 1994). It was proposed that the EM survey and further testing should be concentrated in the area surrounding the karst features identified by ISGS.

MATERIALS AND METHODS

Equipment
The electromagnetic induction meter used was the EM34-3 manufactured by Geonics Limited.** General theory on the operation and use of this meter have been described in detail by McNeill (1983). In this report, values of apparent conductivity are expressed as millisiemens per meter (mS/m).

The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM34-3 meter has intercoil spacings of 10, 20, or 40 m. Because the depth to bedrock within the relocation site was characterized as being generally greater than 60 feet (two earth resistivity soundings near the site of the EM survey had predicted the depth to the bedrock surface as being 75 and 67 feet), a 20-m intercoil spacing was used in this investigation. With a 20-m intercoil spacing, the EM34-3 meter has effective observation depths of about 15 m (about 50 feet) and 30 m (about 98 feet) in the horizontal and vertical dipole orientations, respectively (McNeill, 1983).

ISGS Review of Previous Field Investigations using EM Techniques
We were fortunate to have had the results of the earlier research study (Doolittle, 1993) reviewed by the staff of the Illinois State Geological Survey. The ISGS recognized the EM34-3 meter as a "reasonable tool for mapping karst features" (Bauer and Erdmann,

** Trade name has been used to provide specific information and does not constitute endorsement by the authors.

1994). Furthermore, the ISGS noted that results from the research study indicated general trends in the bedrock surface. However, the agency recommended the use of the EM34-3 meter with a 40-m intercoil spacing and a smaller grid interval (Bauer and Erdmann, 1994). The ISGS concluded that because of these deficiencies, the "EM34 was not appropriately tested in the study."

A 100 foot grid interval rather than the recommended 15 to 25 foot intervals was used in the present study. Constraints imposed by time and available resources restricted the use of a smaller grid interval. However, the use of the 100 foot grid interval was not considered inappropriate for the expressed intentions of this survey. The purpose of this reconnaissance survey was to attempt to capture broad subsurface patterns and trends rather than to identify and resolve all karst features. Undoubtedly, most smaller and some larger dissolution features were overlooked in the present survey because of the relatively coarse sampling interval used and the limited sensitivity and resolution of the EM34-3 meter with either a 20- or 40-m intercoil spacing. However, as noted earlier, the ISGS review acknowledged that results obtained with the EM34-3 meter and a 100 foot interval did "indicated general trends in the bedrock surface" and suggested several anomalies "which could be karst features."

Generally, larger intercoil spacing are used to increase observation depths. With the 40-m intercoil spacing, the EM34-3 meter has effective observation depths of about 30 m (about 98 feet) and 60 m (about 197 feet) in the horizontal and vertical dipole orientations, respectively (McNeill, 1980 and 1983). However, with increased observation depths, the resolution of subsurface features is reduced. Larger intercoil spacings integrate values of apparent conductivity across larger areas. Electromagnetic induction techniques will smooth, suppress, or omit the expression of most naturally occurring subsurface features that have widths smaller than a meters intercoil spacing.

Depths to limestone bedrock within the relocation site were assumed to be greater than 60 feet, but within the observation depths of the EM34-3 meter with a 20-m intercoil spacing. It was felt that the 20-m intercoil spacing would provide not only the desired observation depth, but, when compared with the 40-m intercoil spacing, superior resolution of some subsurface features.

In a follow-up to the recommendations of the ISGS, a comparative study was conducted across a portion of the relocation site with the EM34-3 meter using both 20- and 40-m intercoil spacings. Measurements were collected at 176 observation sites with the 20-m intercoil spacing in both the horizontal and vertical dipole orientations and with the 40-m intercoil spacing in the horizontal dipole orientation. Though depths of maximum sensitivity are different for each orientation of the EM34-3 meter, observation depths are purportedly the same (30 m) with the 20-m intercoil spacing in the vertical dipole orientation as with the 40-m intercoil spacing in the horizontal dipole orientation (McNeill, 1980).

Figure 2 contains simulated contour plots from this experiment. Though patterns are remarkably similar, values of apparent conductivity are highest for the horizontal dipole orientation with a 20-m intercoil spacing. This orientation and intercoil spacing provided the shallowest observation depth and are believed to be more greatly influenced by the relatively conductive, drift deposits than by the underlying, more resistive bedrock.

Generally, patterns (see Figure 2) are remarkably similar for measurements taken in the vertical dipole orientation with a 20-m intercoil spacing and measurements taken in the horizontal dipole orientation with a 40-m intercoil spacing. However, the patterns appear more intricate and variable with the 20-m intercoil spacing. It was presumed that the larger intercoil spacing has smoothed, suppressed, and omitted the expression of some of subsurface features resolved with the smaller intercoil spacing.

Based on the results of this experiment and because of time constraints, the survey was completed with only the 20-m intercoil spacing.

Study Area

The proposed relocation site is on an upland area about 1.8 m east of the former site of the town of Valmeyer, Illinois. The site is located in areas of Alford soils (Higgins, 1987). Alford is a member of the fine-silty, mixed, mesic Typic Hapludalfs family. This well drained, moderately permeable soil formed in loess. Slopes are frequently less than 5 percent but range from 2 to 30 percent.

The relocation site is located in an area with karst. Fourteen sinkholes have been identified by the ISGS within the proposed site (see Figure 1). According to ISGS, the surficial deposits of loess and till are generally greater than 50 feet thick. The thickness of these deposits is presumed to be greatest beneath the highest parts of the landscape and least on the more steeply sloping areas (Erdmann and Bauer, 1993).

Field Methods

The relocation site consists of 550 acres located in sections 35 and 36, T2S, R11W; and sections 1 and 2, T3S, R11W. Because of time constraints, only a portion of the proposed relocation site (NE 1/4 section 2, T3S, R11W, and SE 1/4 section 35, T2S, R11W) was surveyed. The survey was restricted to non-wooded areas. Generally, the wooded areas are more steeply sloping and less likely to be developed.

An irregularly shaped, 2600 by 4000 foot grid (approximately 108 acres) was established across the survey area. The grid interval was 100 feet. Survey flags were inserted in the ground at each grid intersection. This provided 541 observation sites. At each grid intersection, measurements were taken with the EM34-3 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At each grid intersection, the elevation of the surface was determined. A total station level was used to determine surface elevations.

RESULTS

Figures 3 thru 6 are two-dimensional isopleth plots of apparent conductivity simulated from EM data collected within the survey area. These figures were prepared from data collected with the EM34-3 meter (with 20-m intercoil spacing) in the horizontal (Figures 3 and 4) and vertical (Figures 5 and 6) dipole orientations. In all plots, the interval is 4 mS/m. The locations of the fourteen identified sinkholes have been approximated in Figures 4 and 6 from those appearing in Figure 8 of the draft ISGS report compiled by Erdmann and Bauer (1993).

These simulations were prepared using the SURFER software program. A kriging algorithm with an octant search of data points was used to construct the grids. Resulting grid matrices were smoothed using a cubic spline technique.

In Figures 3 to 6, the maximum isopleth is 40 mS/m. Values greater than 40 mS/m occurred within the survey area, but were attributed to interference from nearby cultural features. These elevated values were ascribed to "cultural noise" caused by overhanging power and telephone cables which paralleled the roadway in the southeast corner of the survey area. In the southeast portion of each plot, a noticeable east-west trending finger of elevated EM responses caused by overhanging power lines is still evident as the roadway bends to the west (left) and crosses the survey area.

DISCUSSION

Electromagnetic techniques produce qualitative results. Results depend on the adequacy of interpretations. Interpretations are based on available information concerning the nature and complexity of soil, geologic, and terrain conditions at a site, and the number and types of observations used to support or verify the inferences drawn from EM survey.

Electromagnetic induction interpretations can be ambiguous unless supported with the results of exploratory drilling. As no drilling was used to confirm interpretations made in this report, assessments can be summarized only in the most general of terms. These assessments, however, do improve our ability to characterize the relocation site. While EM techniques at this site were of little value in quantifying the depth to bedrock or the thickness of the drift mantle, they were useful in predicting where changes in the physical properties of earthen materials occur and where the bedrock is deep, shallow, or more variable.

The ability of EM techniques to locate solution features requires a favorable size to depth ratio (small features can not be resolved) and a significant contrast in apparent electrical conductivity across the solution features (large air-filled voids or plugged solution cavities are more detectable than smaller voids or cavities filled with bedrock rubble). In addition, detection depends on local ground conditions, absence of interfering cultural features, and the sensitivity and observation depths of a particular meter.

Interpretations of the EM data are based on the identification of spatial patterns within the data set. Several inferences can be made from the data appearing in accompanying figures. Comparing Figures 3 and 5, it is apparent that values of apparent conductivity, as a rule, decrease with increasing observation depth (responses in the horizontal dipole orientation are typically greater than those in vertical dipole orientation). The average apparent conductivity was 30 and 26 mS/m in the horizontal and vertical dipole orientations, respectively. The EM response ranges from 18 to 44 in the horizontal and from 10 to 50 in the vertical dipole orientations. In the horizontal dipole orientation, one-half of the observations had responses between 26 and 34 mS/m. In the vertical dipole orientation, one-half of the observations had responses between 21 and 30 mS/m.

These measurements agree with the basic conceptual model of the site. For the purpose of this investigation, the site was assumed to consist of two layers: drift and limestone bedrock. The underlying limestone bedrock is more resistive (less conductive) than the overlying, moderately-fine textured loess and fine-textured till deposits. The limestone bedrock would have lower values of apparent conductivity than the drift.

In a separate experiment, an EM38 meter was used to compare the apparent conductivity of the upper 1.5 m of the Alford soil with an exposure of limestone bedrock. The loessial soil had apparent conductivity values ranging from 28 to 30 mS/m. The limestone bedrock had an apparent conductivity value of about 5 mS/m.

General trends can be seen in the accompanying figures. Areas having lower values of apparent conductivity were assumed to have shallower depths to bedrock. These areas occur in the northern, west-central, and more sloping portions of the relocation site. Areas having higher values were associated with thicker mantles of drift deposits or (if greater than 40 mS/m) interference from cultural sources. These areas occurred in the southern portion of the survey area.

The EM measurements collected in the shallower-sensing (upper 50 feet), horizontal dipole orientation reflect relatively conductive (30 mS/m) and, for a large portion of the survey area, seemingly homogeneous materials. In this orientation, the EM34-3 meter responds principally to variations in soil types, drainage, and loess and till thicknesses.

Across most of the site, measurements collected in the horizontal dipole orientation were relatively invariable (28 to 36 mS/m). Responses were generally lower and depths to bedrock were assumed to be shallower in the more topographically diverse or more sloping areas. It is probable, that lower values of apparent conductivity in these areas reflect the occurrence of bedrock within the observation depth of the meter in the horizontal dipole orientation. In addition, responses were noticeably higher in areas suspected of being influenced by "cultural noise."

The EM measurements collected in the deeper-sensing (upper 98 feet), vertical dipole orientation reflect slightly less conductive (26 mS/m) and more variable (10 to 50 mS/m) materials. In this orientation, the EM34-3 meter responds principally to variations in the thickness of loess and till deposits or the depth to bedrock. Generally, when the meter was orientated in the vertical dipole mode, responses were relatively more variable over short distances. Responses were more variable in the "northern arm," the eastern portion of the survey area, and in the more sloping areas near the bluff. These areas are believed to be shallower and more variable in depth to bedrock, and perhaps more susceptible to the development of solution features.

It was hypothesized that areas underlain by major solution features would exhibit a highly irregular and complex patterns of apparent conductivity values. Higher values of apparent conductivity could indicate the migration of finer-textured materials into solution features, or greater depths to bedrock and moist soil conditions within solution features. Lower values of apparent conductivity could reflect shallower depths to bedrock or possible air-filled voids. More variable patterns are evident in the plots of the deeper, vertical dipole measurements (Figures 5 and 6).

In Figures 5 and 6, highly complex patterns of apparent conductivity values occur in the "northern arm" and in the eastern portion of the relocation site. These anomalous patterns suggest the possible occurrence of several, fairly large, subsurface solution features. The areas with complex EM responses includes most of the sinkholes identified by ISGS.

CONCLUSIONS

Electromagnetic induction techniques were used at the proposed relocation site for the town of Valmeyer, Illinois in an attempt to better understand the presence and extent of subsurface dissolution features. The purpose of this reconnaissance survey was to attempt to capture broad subsurface patterns and trends and not to identify or resolve all karst features.

This technique provided interpretative plots of apparent conductivity values. These plots can be used as an planning tool by town officials, planners, and developers. The presence of anomalous subsurface patterns, suggested the possible occurrence of additional solution features and the locations of several areas which may be more susceptible to the development of sinkholes. These plots also suggest areas considered to be more "structurally sound" and in less apparent danger of developing solution cavities. However, in the absence of exploratory drilling, the results of this survey are interpretative.

This extensive and relatively detail EM survey has hopefully provided additional information and perhaps better insight into subsurface conditions within the proposed relocation site. This survey has provided interpretative base maps of the proposed relocation site. These maps can be used to help summarize subsurface conditions, guide exploratory drilling, and assists site selection.

A topographic map of the survey area is being prepared and upon completion, will be forwarded to your office. The Design Section of the Engineering Staff at the NENTC is preparing enhanced drawings of the enclosed plots on Versacad. Copies of these plots and files will be forwarded to your office. Both Sam Indorante and I will respond to any questions concerning this survey.

It has been my pleasure to assist in this project.

With kind regards

James A. Doolittle
Soil Specialist

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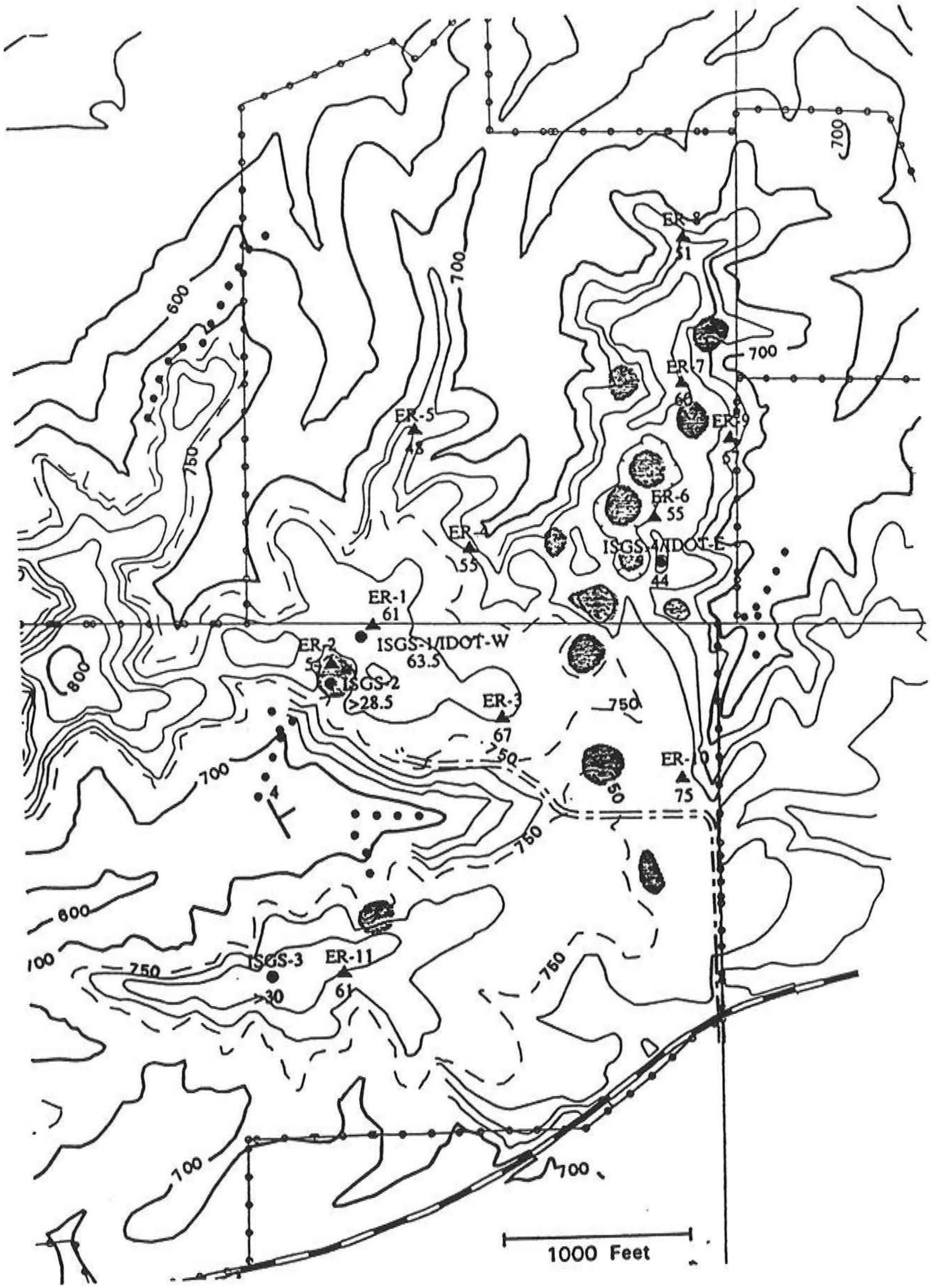
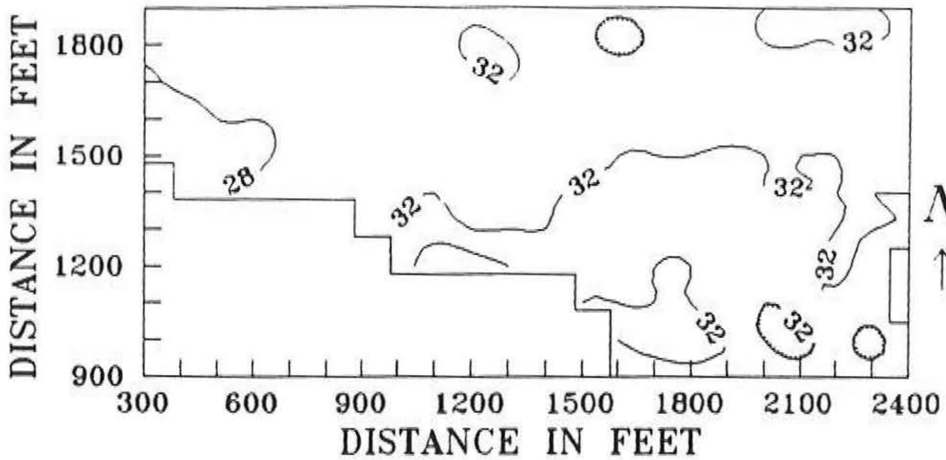
Figure 1



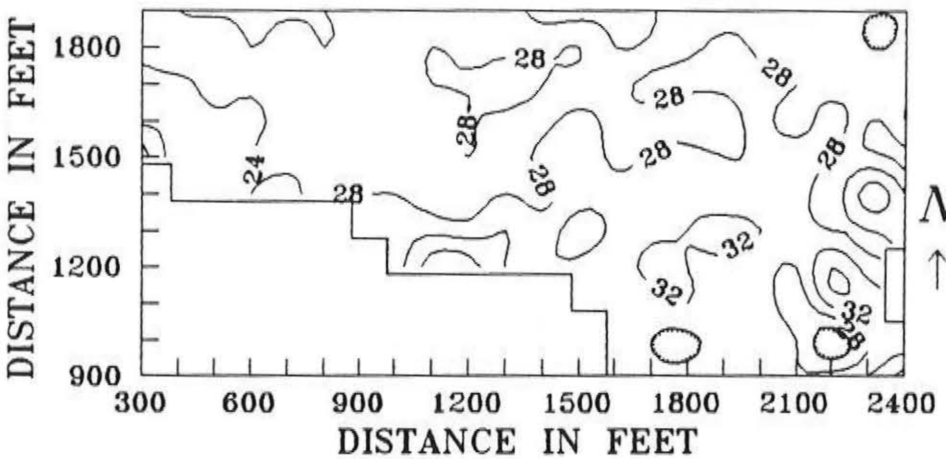
ER-8
51
700
ER-7
60
ER-9
ER-5
48
600
750
ER-6
55
ER-4
55
ISGS-4/IDOT-E
44
ER-1
61
ER-2
ISGS-1/IDOT-W
63.5
800
ISGS-2
>28.5
ER-3
67
750
700
ER-10
75
600
ISGS-3
ER-11
>30
61
1000 Feet

Figure 2

HORIZONTAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING



VERTICAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING



HORIZONTAL DIPOLE ORIENTATION
40-METER INTERCOIL SPACING

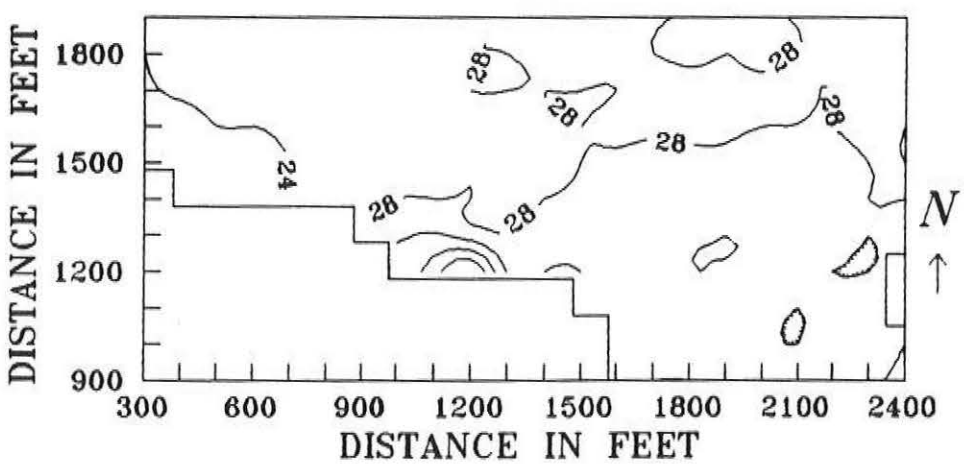
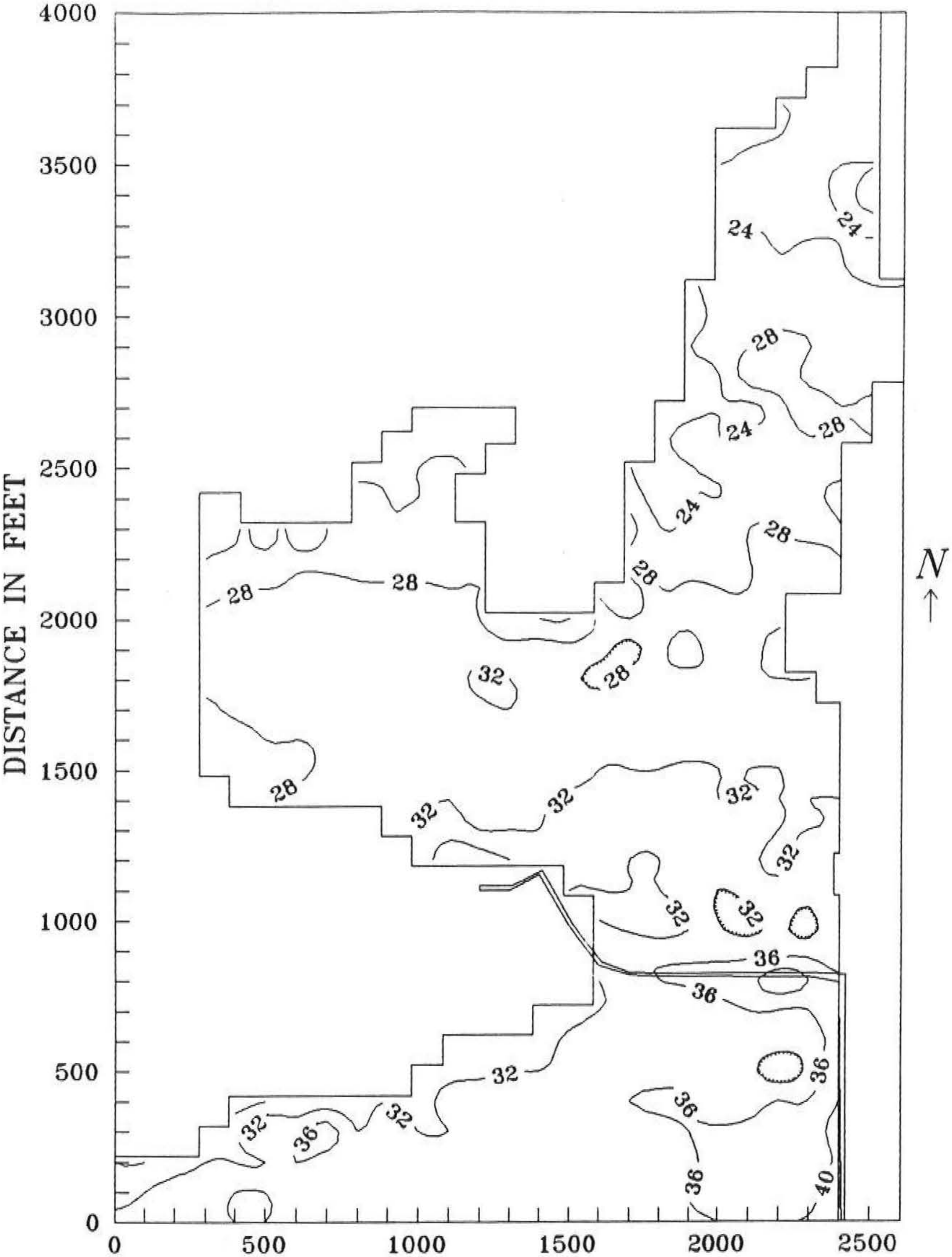


Figure 3

EM34 SURVEY OF PROPOSED SITE FOR VALMEYER, ILLINOIS

HORIZONTAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING



EM34 SURVEY OF PROPOSED SITE FOR VALMEYER, ILLINOIS

HORIZONTAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING

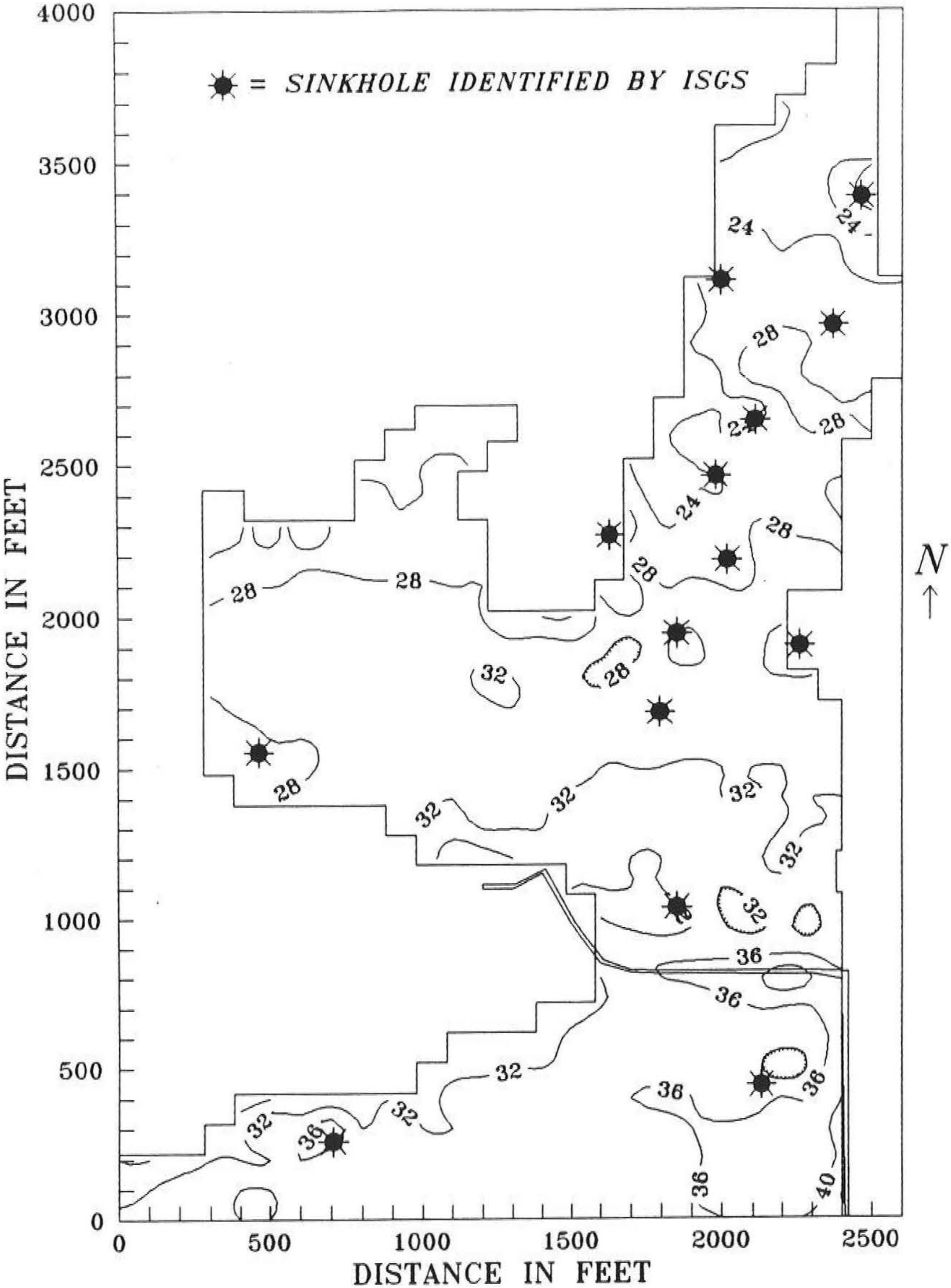


Figure 5

EM34 SURVEY OF PROPOSED SITE FOR VALMEYER, ILLINOIS

VERTICAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING

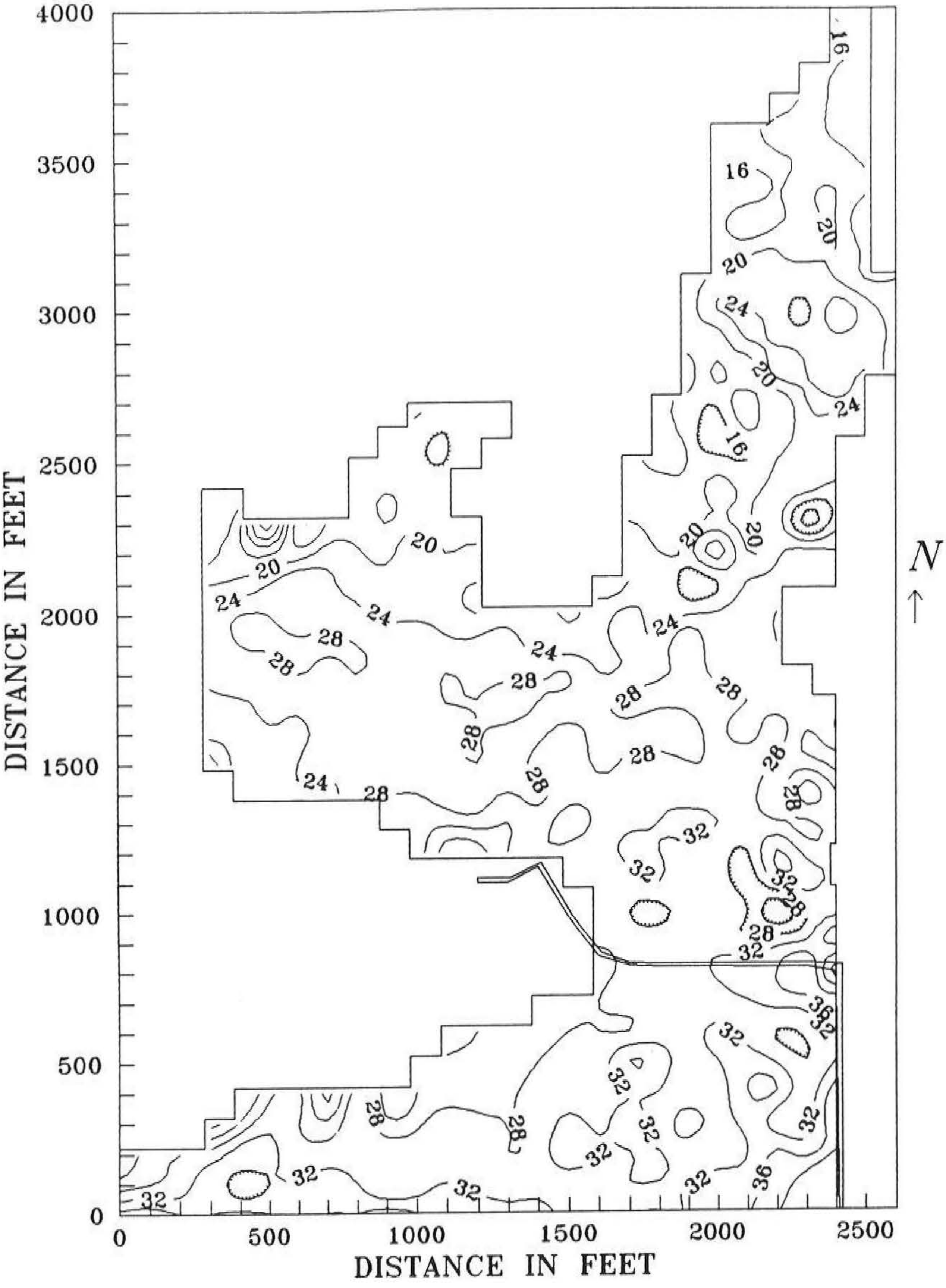


Figure 6

EM34 SURVEY OF PROPOSED SITE FOR VALMEYER, ILLINOIS

VERTICAL DIPOLE ORIENTATION
20-METER INTERCOIL SPACING