UNITED STATES DEPARTMENT OF AGRICULTURE **SOIL CONSERVATION SERVICE**

Northeast NTC **CHESTER, PA 19013**

SUBJECT: Electromagnetic Induction (EM) and Ground-penetrating Radar (GPR) Field Assistance, Clinton, Tioga, Luzerne, and Lackawanna Counties, Pennsylvania; October 5-9, 1992

DATE: 15 October 1992

To: Richard N. Duncan
State Conservationist
USDA-Soil Conservation Service
Harrisburg, PA

Purpose:
To use electromagnetic induction (EM) and ground-penetrating radar (GPR) techniques for soil, geologic, water-quality, and engineering site assessments.

Participants:
Bruce Benton, Geologist, SCS, Harrisburg, PA
Carl Dick, Senior Aid, Luzerne County, Plymouth, PA
Ellen Dietrich, District Conservationist, SCS, Mill Hall, PA
Jim Doolittle, Soil Specialist, SSQAS, SCS, Chester, PA
Joseph Eckenrode, Soil Scientist, SCS, State College, PA
Joseph Hollowich, Soil Scientist, SCS, Bloomsburg, PA
Richard Maculaitis, District Conservationist, SCS, Plymouth, PA
Howard Rutledge, SCT, SCS, Wellsboro, PA
Fred Schuetz, Construction Engineer, NENTC, SCS, Chester, PA
Paul Shaffer, District Conservationist, SCS, Wellsboro, PA
Edward Sokoloski, District Conservationist, Clark Summit, PA
John Zaginaylo, Area Engineer, SCS, Bloomsburg, PA

Activities:
Electromagnetic induction and ground-penetrating radar techniques were used to delineate subsurface geologic and soil features in areas of karst in Clinton County on 5 and 6 October. On 5 October, students from Lock Haven University were provided with a brief introduction and field exercise on the use of EM techniques. Electromagnetic inductions surveys of animal waste holding facilities were conducted in Tioga County (7 October) and in Luzerne County (8 October). In addition, on 8 October, EM techniques were used in Lackawanna County to locate trenches filled with poultry manure.

Equipment:
The electromagnetic induction meter was the EM31 manufactured by GEONICS Limited.[1] Measurements of conductivity are expressed as milliSiemens per meter (mS/m). Two-dimensional isopleth plots and three-dimensional surface nets of the EM data were prepared using SURFER software developed by Golden Software, Inc.[1]

The ground-penetrating radar unit used in this study is the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical

Survey Systems, Inc. [1]. Components of the SIR System-8 used in this study were the model 4800 control unit, ADTEK SR 8004H graphic recorder, power distribution unit, transmission cable (30 m), and the model 3110 (120 MHz) antenna. The system was powered by a 12-volt vehicular battery.

Results:

1. Electromagnetic induction techniques can be used effectively in most areas of Pennsylvania as a rapid, reconnaissance tool for archaeological, soil, geological, and engineering site assessments. This technique can be integrated with GPS and GIS to provide both general and site specific information. On each succeeding field study, it is my intent to train members of your staff on the uses and operation of this equipment. During field investigations, Bruce Benton, Ellen Dietrich, and Jake Eckenrode received training on the operation of the EM31 meter.

2. In areas of deep and very deep, moderately-fine and fine textured soils underlain by limestone or shale, GPR signals are rapidly attenuated and present systems are inappropriate tools for depth to bedrock determinations. In these soils, the use of EM techniques is recommended to increase the frequency and extend the depth of observation. GPR techniques are believed to be best suited for determining the depth to bedrock in upland areas underlain by sandstone. A one-day study (November) in either Centre or Clinton counties is recommended. This study will address the efficiency of this technique as a quality control tool in upland areas underlain by sandstone bedrock. Data will be used to help characterize the depth to bedrock and soil map unit composition.

3. EM techniques are well suited for soil, geologic and engineering site assessments in areas of karst. Electromagnetic inductive techniques appear to be suitable for detecting some (larger) cavities in carbonate rocks. On the basis of the EM response, anomalous patterns suggest the occurrence of potentially cavernous areas.

4. Based on patterns and magnitudes of EM response , seepage at surveyed animal-waste holding structure appears limited and, where observable, is generally restricted to the embankment area. However, results from EM survey indicate that surface runoff of animal waste is a more extensive and serious concern of management.

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1. Use of trade names in this report is for identification purposes only and does not constitute endorsement.

It was my pleasure to work with members of your fine staff. Their enthusiasm and concerns for monitoring the integrity of structural designs and ground water quality with EM techniques are appreciated.

With kind regards.

James A. Doolittle
Soil Specialist

cc:
B. Benton, Geologist, SCS, Harrisburg, PA
W. Bowers, State Conservation Engineer, SCS, Harrisburg, PA
J. Culver, National Leader, SSQAS, NSSC, SCS, Lincoln,
C. Holzhey, Assistant Director, Soil Survey Division, NSSC, SCS, Lincoln, NE
G. Lipscomb, State Soil Scientist, SCS, Harrisburg, PA
E. White, Soil Correlator, SCS, Harrisburg, PA

Discussion

<u>EM survey on Karst:</u>
The survey site was located in Nittany Valley, near Mackeyville, Clinton County, in an area of Murrill (fine-loamy, mixed, mesic Typic Hapludults) soils. Murrill soils were described as being deep to very deep over limestone bedrock. Within the study area, depths to bedrock were expected to be very deep. A backhoe pit revealed a depth to bedrock greater than 15 feet.

The grid covered a 700 by 700 foot area (approximately 11 acre). Survey flags were inserted in the ground at 100 and 50 foot intervals. This provided 142 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical dipole orientations (figures 1 and 2, respectively). Surface water is believed to be entering a solution feature through an opening identified with a point symbol in these figures.

Figures 1 and 2 are two-dimensional isopleth plots of apparent conductivity measurements within the survey area. In each plot, the interval is 2 mS/m. The profiling depth of an EM meter is a function of frequency, intercoil spacing, and coil orientation. With the EM31 meter, values of apparent conductivity are integrated over the upper 2.75 meters in the horizontal dipole orientation, and over the upper 6 meters in the vertical dipole orientation.

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 type of observations used to support or verify the inferences drawn from EM survey. 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 are more detectable than voids filled with rubble). In addition, detection depends on local ground conditions, presence of interfering cultural features, and the sensitivity and penetration depths of a particular meter.

Interpretation 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 figures 1 and 2. In each figure, values of apparent conductivity decrease with increasing elevations (towards upper margins or south). This "terrain affect" results from changes in moisture contents and lithology. Points at higher elevations generally have drier soil conditions and may be underlain at shallower depths by strata which are lithologically different than strata in lower-lying positions.

The underlying limestone bedrock was assumed to be more resistive (less conductive) than the overlying, moderately-fine textured soil materials. It was anticipated that area underlain by major solution features would have higher values of apparent conductivity. Higher values of apparent conductivity could be produced by the migration of finer-textured materials into solution features, or greater depths to bedrock and moist soil conditions within solution features. In figures 1 and 2, three anomalies have been identified with stars. As these features are more evident in the deeper, vertical dipole measurements (Figure 2), they are assumed to represent deep geologic rather than shallow soil features. These anomalous EM values may delineate large, subsurface solution features. The suspected solution feature, complex isopleth patterns, and noticeable concentrations of anomalies occur in the northeast corner of the study area. These patterns and features delineate a potentially "high risk" area which should, in the absence of further ground truth boring information, be avoided as a site for construction. As no apparent feature underlies the identified surface solution feature, lateral flow into an adjoining solution feature is inferred from these figures.

Figure 2A was prepared using a 1 mS/m interval. This interval is seldom used as, at this level, observation errors are conspicuous in the data sets. However, the referenced anomalies are also more distinct and may facilitate interpretations.

Use of EM and GPR techniques in soil survey:
The use of EM and GPR techniques to determine the depth to bedrock in areas of Hagerstown (fine, mixed, mesic Typic Hapludalfs) and Murrill soils was investigated in Sugar Valley near Loganton, Clinton County. The moderately-fine and fine textures of these soils limited the profiling depth of GPR. Using GPR, soil/bedrock interfaces were resolved in areas of shallow and moderately deep soils. Soil/bedrock interfaces were not apparent below depths of 1.0 meters. However, soils were distinguishable on the basis of their aggregated graphic signatures. As in other areas of the Appalachians underlain by shale and limestone bedrock, relatively high concentrations of clays, silts, and soluble salts limit the effectiveness of GPR.

Ground-penetrating radar techniques are suited for applications in areas of moderately-coarse and coarse soils underlain by sandstone bedrock. Electromagnetic induction techniques appears to be a more suitable tool than GPR in areas of moderately-fine and fine textured soil materials. Variations in lithology, mineralogy, and soil type can be distinguished in many areas using EM techniques. In non-saline soils, EM techniques can be used to determine the depth to bedrock or limiting layers. In tables 1 and 2, EM response varies with soil type and landscape position. In areas of Hagerstown soil, higher-lying slope segments were generally drier and shallower to bedrock than lower-lying areas. Values of apparent conductivity reflect these relationships. Areas of Murrill soils are distinguished from areas of Hagerstown soils by higher values of apparent conductivity. In Table 1, in areas of Murrill soil, the influence of the underlying shale bedrock on the EM response is evident in the last five observation points. As the thickness of colluvium thins and the depth to shale bedrock lessens, values of apparent conductivity increase. In Table 2, variations in EM response in areas of Hagerstown soils are related to changes in soil depth.

TABLE 1
SCHRACK FARM

LANDSCAPE POSITION	EM31(H)	EM31(V)	SOILS
	2.7	7.2	
	2.8	3.5	
UPPER BACK SLOPE	2.0	4.0	HAGERSTOWN
	3.1	4.8	
	0.5	3.2	
	8.5	8.5	
TOESLOPE	5.8	5.6	HAGERSTOWN
	9.3	8.8	
	5.2	4.2	MURRILL(?)
	5.0	3.2	
LOWER FOOTSLOPE	5.0	5.8	
	11.0	10.0	
	12.0	10.0	
	13.0	13.0	
	22.0	17.0	
	29.0	23.0	

TABLE 2
LOGAN MILL ROAD

LANDSCAPE POSITION	EM31(H)	EM31(V)	SOILS
	6.5	10.4	
	1.6	6.2	
UPPER BACK SLOPE	4.6	8.2	HAGERSTOWN
	0.8	1.2	
	4.2	6.4	
	1.4	10.2	
	2.0	3.2	
	8.0	9.8	

EM Survey of John Painter's Ag Waste Holding Facility:
The purpose of this survey was to assess the structural integrity of an existing waste-holding area. The waste-holding area was not designed by SCS.

The grid covered an irregularly shaped 150 to 500 by 250 to 500 foot area. Survey flags were inserted in the ground at 50 foot intervals. This provided 108 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (figures 4 and 5, respectively).

Figure 3 is a two-dimensional contour plot of the ground surface. The contour interval is 2 feet. The lowest point in the survey area was selected as datum. The site has been disturbed by the construction of the existing facility. Two elongated mounds of soil materials are along the left-hand border of the study area. In figures 4 and 5, a small drainageway crosses the right-hand portion of the study area.

Figures 4 and 5 are two-dimensional isopleth plots of apparent conductivity measurements within the survey area. In each plot, the interval is 2 mS/m. The profiling depth of an EM meter is a function of frequency, intercoil spacing, and coil orientation. With the EM31 meter, values of apparent conductivity are integrated over the upper 2.75 meters in the horizontal dipole orientation, and over the upper 6 meters in the vertical dipole orientation.

Several inferences can be made from the data simulated in figures 4 and 5. The site is disturbed. Buildings, fences, and power lines interfered with measurements (elevated values of apparent conductivity) in the strip area immediately adjacent to the lower edge of the waste-holding facilities.

In the area surrounding the waste facility, minor patterns suggesting possible seepage of contaminants are evident but generally restricted in both figures 4 and 5. In both figures, values of apparent conductivity are highest along the right-hand border of the waste facility. This is the side of the waste facility that slopes directly into a drainageway. A conspicuous zone of higher apparent conductivity values extends outwards from the lower right-hand boundary of the facility. As the highest values are adjacent to the facility and values decrease away from the structure, seepage of contaminants is suggested by this pattern. However, seepage is not extensive as this broad, plume-like area is restricted to a fifty-foot zone. In both figures a zone of higher apparent conductivity values extends outwards from the upper right-hand corner of the facility to "A." However, as values increase away from the structure, a source other than seepage is probable. Several fence lines near "A" may be responsible for the elevated EM response in this area. Soil probes in each of these areas will help to confirm both sources and levels of contaminants.

In figures 4 and 5, manure has been piled in the lower right-hand corner of the survey area. These piles are responsible for the high apparent conductivity values near "B." As values of apparent conductivity are higher and more extensive than in areas adjoining the waste facility, these manure piles represent the more significant source of contamination within the survey area. A stream passes through the area adjoining the manure piles. Steps should be taken to reduce the contamination of surface waters from this source.

<u>EM Survey of Bob Dagostin's Lagoon:</u>
The purpose of this survey was to assess the structural integrity of an existing lagoon in an area underlain by coarse-textured glacial outwash deposits. The study site was located in areas of Braceville (coarse-loamy, mixed, mesic Typic Fragiochrepts) and Chenango (loamy-skeletal, mixed, mesic Typic Dystrochrepts) soils north of East Berwick in Luzerne County.

The grid covered an irregularly shaped 400 by 390 foot area. Survey flags were inserted in the ground at 50 foot intervals. This provided 61 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (figures 6 and 7, respectively).

Figures 6 and 7 are two-dimensional isopleth plots of apparent conductivity measurements within the survey area. In each plot, the interval is 2 mS/m. The profiling depth of an EM meter is a function of frequency, intercoil spacing, and coil orientation. With the EM31 meter, values of apparent conductivity are integrated over the upper 2.75 meters in the horizontal dipole orientation, and over the upper 6 meters in the vertical dipole orientation.

Several inferences can be made from the data simulated in figures 6 and 7. Values of apparent conductivity are low across the site and reflect the resistive nature of the underlying coarse textured outwash deposits. Generally, areas of Braceville soils had apparent conductivity values greater than 2 mS/m; areas of Chenango soils had apparent conductivity values less than 2 mS/m. The boundary separating these soils has been approximated by this isopleth in figures 6 and 7.

A conspicuous zone of higher apparent conductivity values is evident along the southwest border of the lagoon. This zone may represent seepage, a buried cultural feature, or non-compacted soil materials. The zone does not appear to be extensive. However, values within this zone are 12 times higher than those observed in areas of Chenango soils. This zone is not detectable with the EM31 meter at distances greater than 100 feet from the lagoon. In each figure, "P" denotes the approximate location of the overflow pipe.

EM Survey of Richard Ruebe's Site:
The purpose of this survey was to verify the existence and delineate the location of filled trenches suspected of containing poultry manure. This EM survey was completed in one afternoon and provide a comprehensive overview of the site.

The grid covered a 350 by 550 foot area (approximately 4.4 acres). Survey flags were inserted in the ground at 50 foot intervals. This provided 93 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (figures 8 and 9, respectively).

Figures 8 and 9 are two-dimensional isopleth plots of apparent conductivity measurements within the survey area. In each plot, the interval is 2 mS/m. The profiling depth of an EM meter is a function of frequency, intercoil spacing, and coil orientation. With the EM31 meter, values of apparent conductivity are integrated over the upper 2.75 meters in the horizontal dipole orientation, and over the upper 6 meters in the vertical dipole orientation.

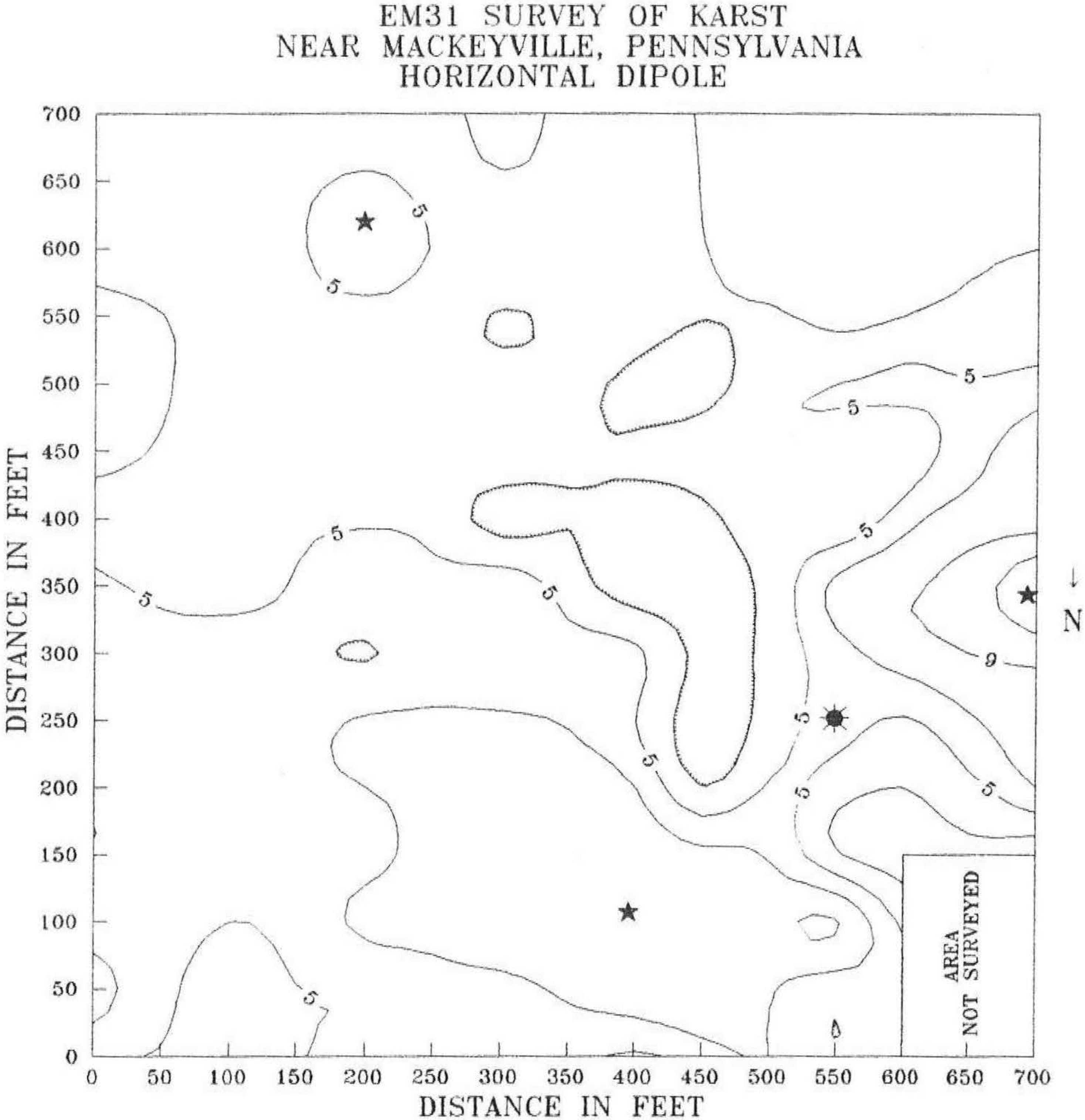
Several inferences can be made from the data simulated in figures 8 and 9. Values of apparent conductivity were expected to be highest over the buried trench, moderate in areas where waste were spread across the surface, and lowest in unaffected or undisturbed areas. Several linear mounds which crossed the site were believed to be composed of poultry wastes. Interpretation of the survey data did not support this belief. Em responses suggest that these mounds are composed principally of soil materials.

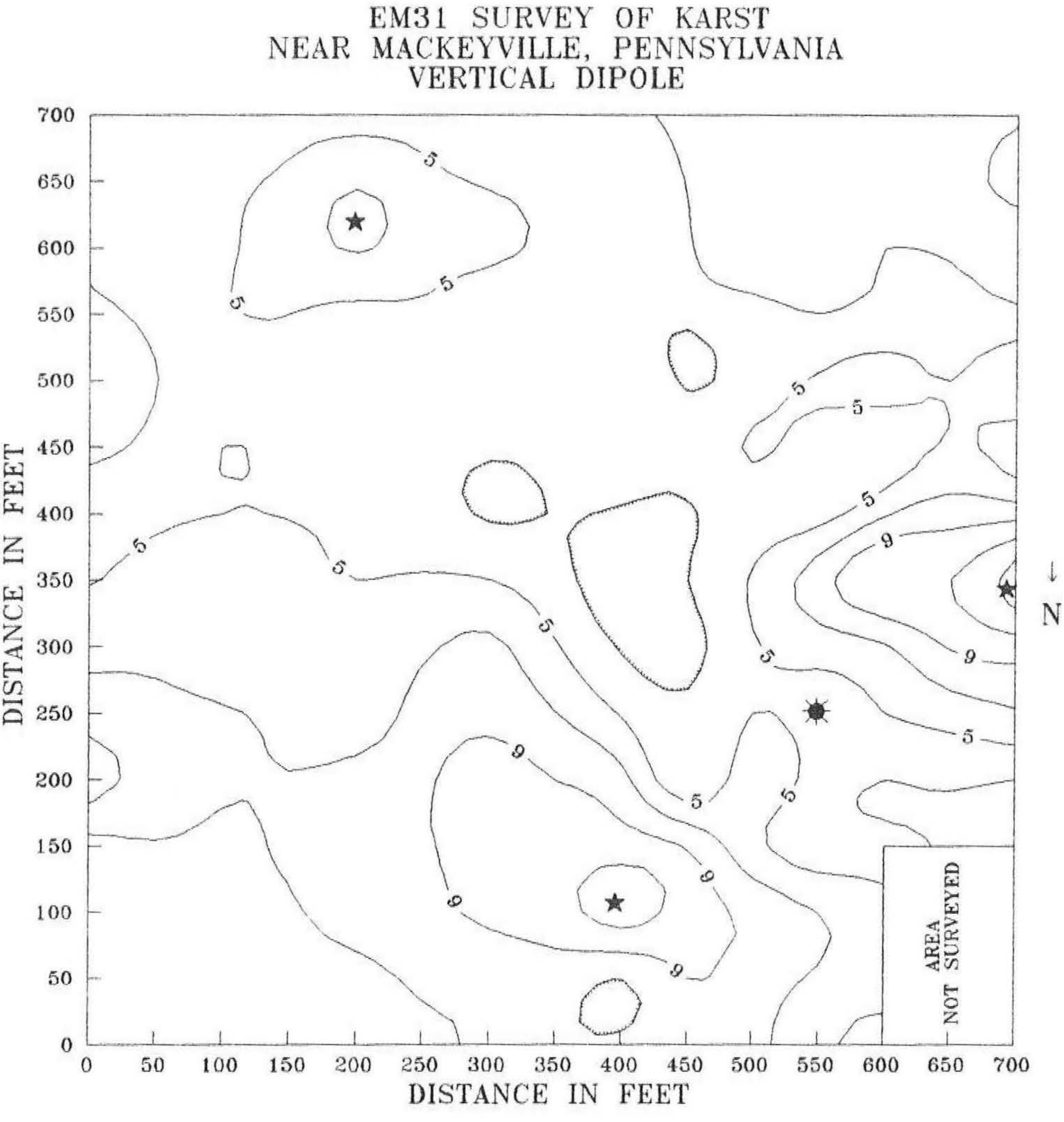
The most probably location of a buried trench is in the northern part of the survey area. A trench appears to consist of two legs: one approximately parallel with the baseline, one running north-south and at a 45^{o} angle to the first portion. In the area of the suspected trench, values of apparent conductivity were high with maximum values of 35 in the horizontal and 19 in the vertical dipole modes. Generally values were highest in the horizontal dipole orientation (see Fig. 8) and decreased with depth (see Fig. 9).

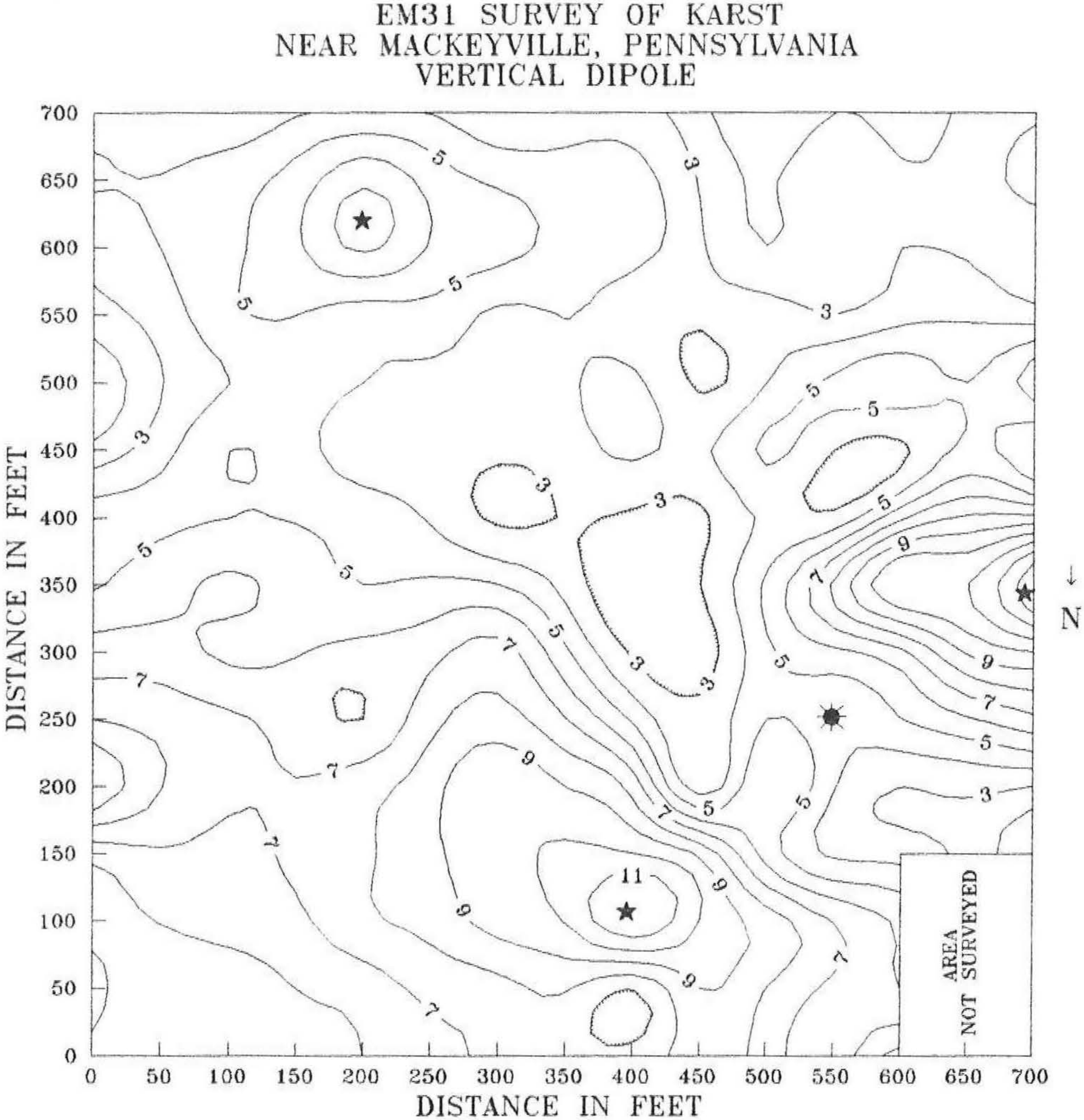
Patterns suggesting possible seepage of contaminants in a down-slope direction (south) from the trench are evident in Figure 9. This pattern appears to extend from the trench to within 100 feet of the baseline near the center of the survey area. As this pattern was not evident in Figure 8, relatively deep (>3-6 meters) seepage is inferred.

A second area of high apparent conductivity values is apparent along the eastern portion of the baseline. This zone occurs in an area which was previously excavated for poultry manure.

Figure 1


EM31 SURVEY OF KARST
NEAR MACKEYVILLE, PENNSYLVANIA
HORIZONTAL DIPOLE
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
5
9
N
AREA
NOT SURVEYED


EM31 SURVEY OF KARST
NEAR MACKEYVILLE, PENNSYLVANIA
VERTICAL DIPOLE
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
5
9
AREA NOT SURVEYED
N


EM31 SURVEY OF KARST
NEAR MACKEYVILLE, PENNSYLVANIA
VERTICAL DIPOLE
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
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3
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7
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11
N
AREA NOT SURVEYED

RELATIVE SURFACE ELEVATION
JOHN PAINTER'S SITE

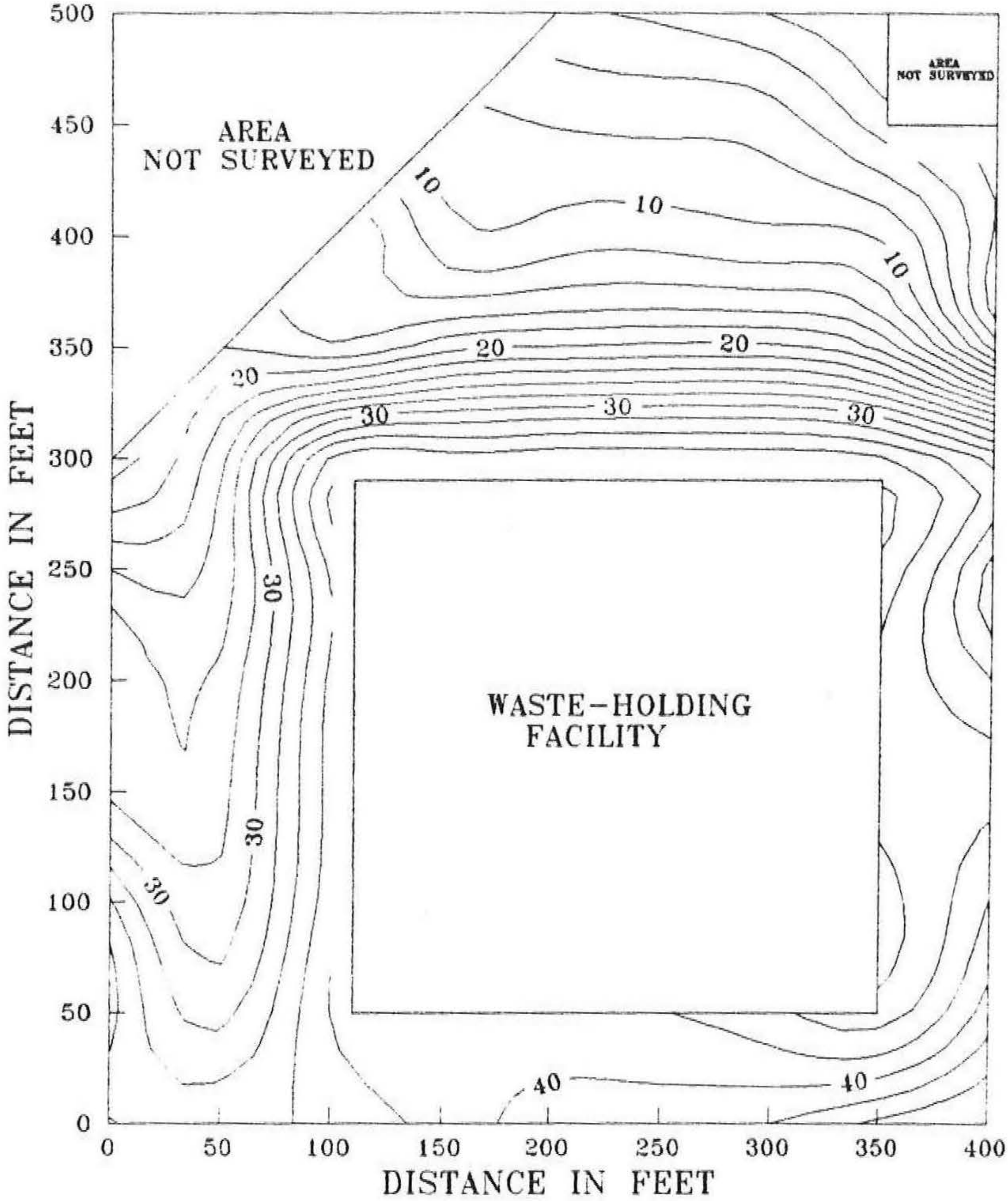
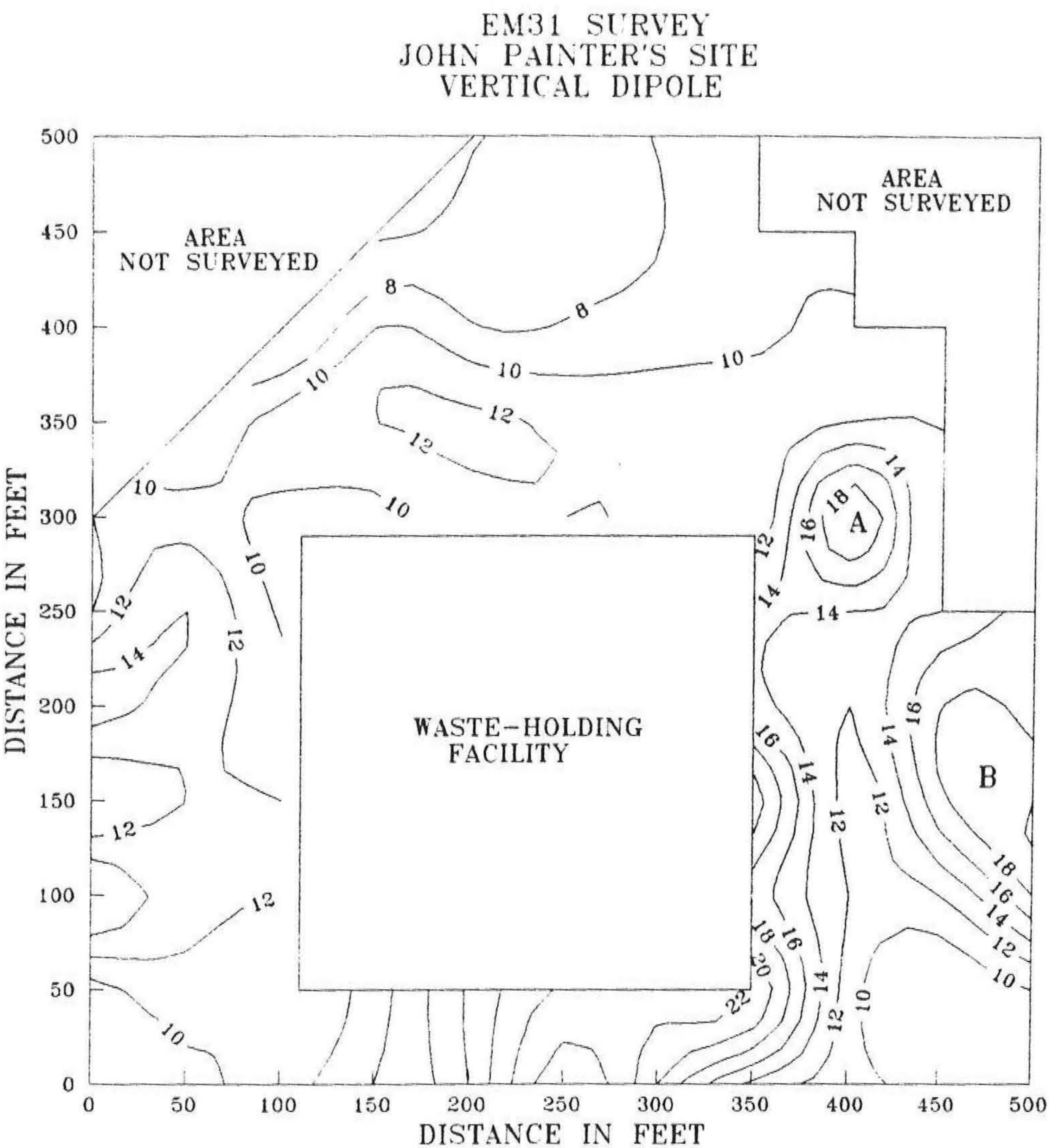


Figure 5


EM31 SURVEY
JOHN PAINTER'S SITE
VERTICAL DIPOLE
AREA NOT SURVEYED
AREA NOT SURVEYED
WASTE-HOLDING FACILITY
A
B
DISTANCE IN FEET
DISTANCE IN FEET
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12
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16
18
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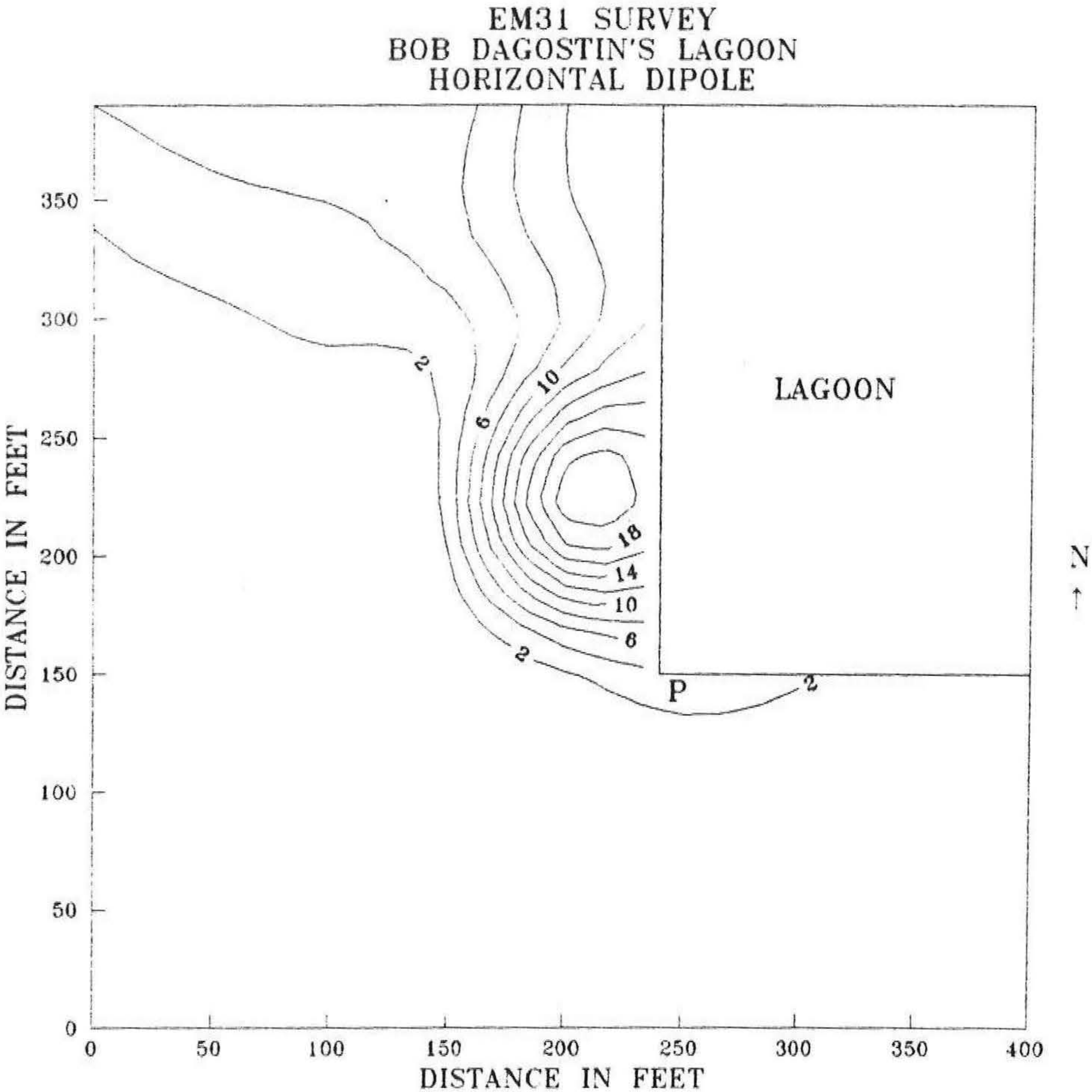
EM31 SURVEY
BOB DAGOSTIN'S LAGOON
HORIZONTAL DIPOLE
LAGOON
P
N
DISTANCE IN FEET
DISTANCE IN FEET
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6
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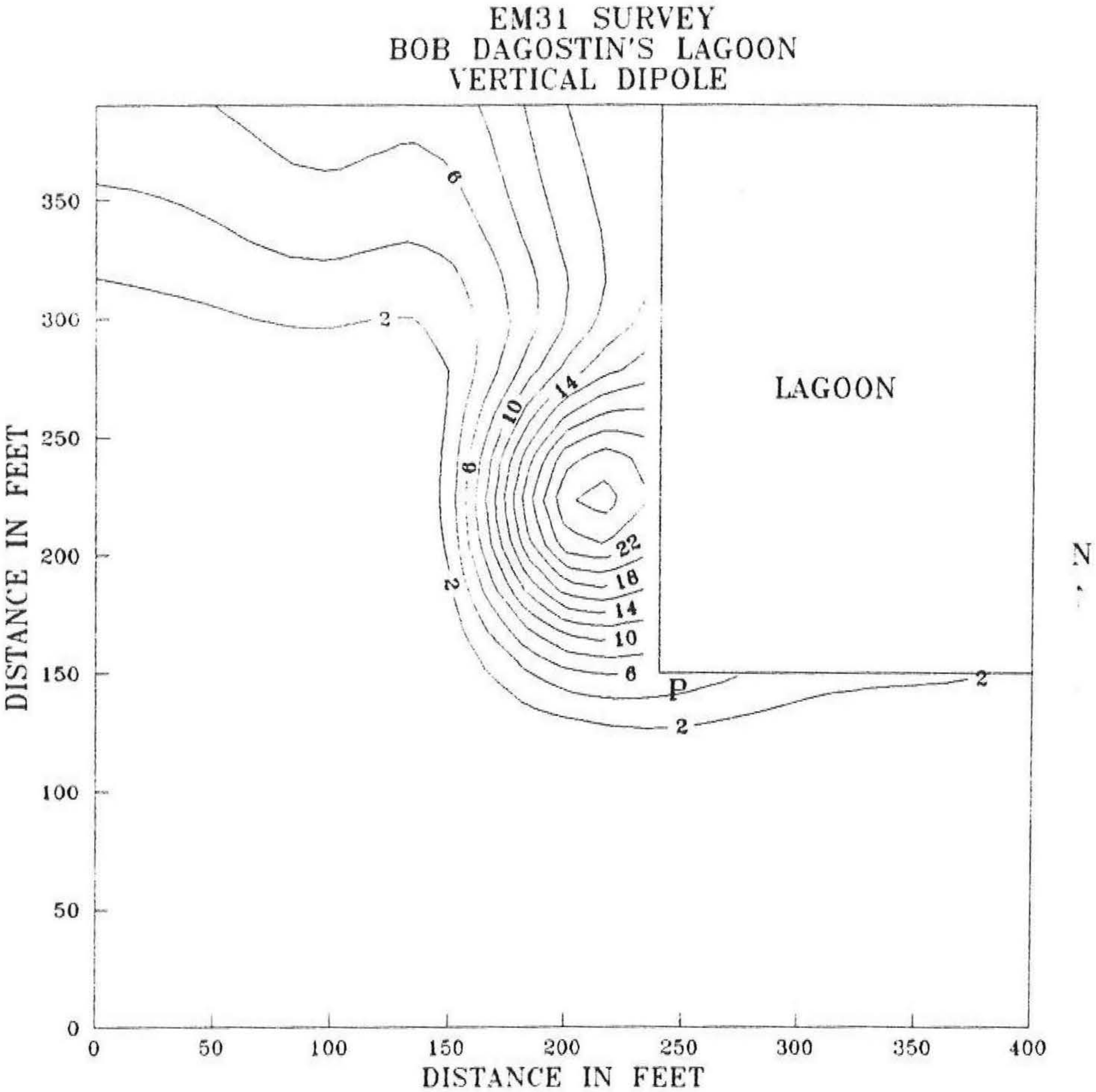
EM31 SURVEY
BOB DAGOSTIN'S LAGOON
VERTICAL DIPOLE
LAGOON
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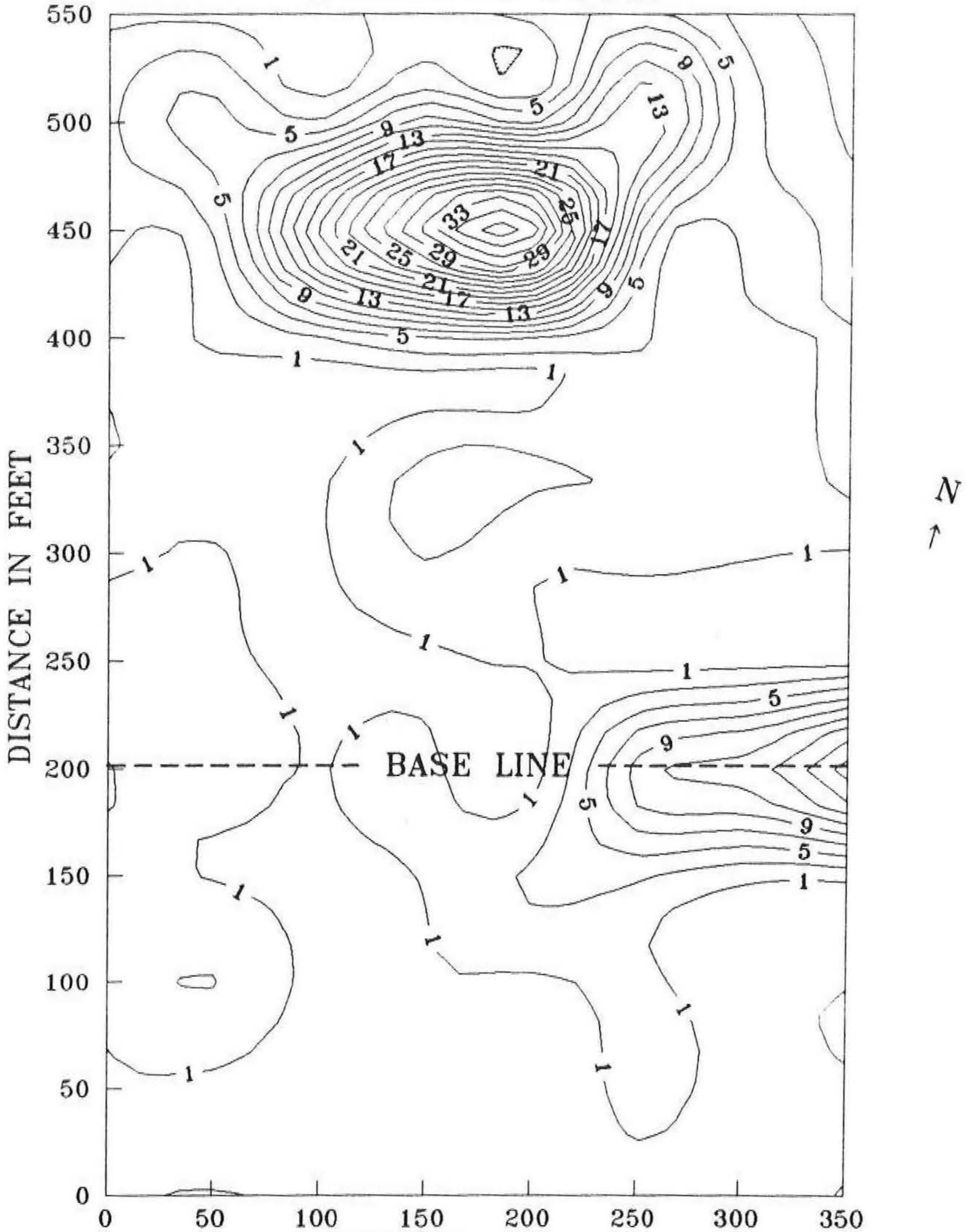
RICHARD RUEBE'S SITE, LACKAWANNA COUNTY, PA

EM31 SURVEY
HORIZONTAL DIPOLE



RICHARD RUEBE'S SITE, LACKAWANNA COUNTY, PA

EM31 SURVEY
VERTICAL DIPOLE