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

Subject: Electromagnetic Induction Surveys near East Carondelet, Illinois; 23 to 24 August 1993.

Date: 26 August 1993

To: Charles Whitmore
State Conservationist
USDA-Conservation Service
1902 Fox Drive
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Purpose:
To assess the feasibility of using electromagnetic induction (EM) techniques to chart subsurface conditions responsible for the development of sand boils in areas adjacent to levees.

Participants:
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Activities:
On 23 August, a section of a levee on the western edge of East Carondelet was surveyed using electromagnetic induction techniques. The purpose of this survey was to examine the potential of using EM techniques to characterize the internal structure and composition of levees. On the morning of 24 August, several sites were examined and the use of geophysical techniques were discussed with personnel from the U.S. Army Corps of Engineers. During the afternoon of 24 August, an area of Landes fine sandy loam, 1 to 6 percent slopes, was surveyed using electromagnetic induction techniques. The purpose of this survey was to improve our understanding of the occurrence of sand boils within map units and to assess the relationship of sand boils with soil, stratigraphic, and topographic features.

Equipment:
The electromagnetic induction meters used were the EM31 and EM34-3 manufactured by GEONICS Limited. General theory on the operation and use of these meters is contained in the addendum to this report. Measurements of conductivity are expressed as milliSiemens per meter (mS/m). Two-dimensional contour plots of the survey areas were prepared using SURFER software developed by Golden Software, Inc.

Discussion:

Levee near East Carondelet

A 40 by 480 foot grid was established on the protected side of the levee. The grid intervals were 10 feet perpendicular and 30 feet parallel to the long axis of the levee. A rotating laser level was used to determine surface elevations at each of the 85 grid intersects. At each site, elevations were not tied to an elevation benchmark; the lowest recorded grid intersect was chosen as the 0.0 datum. Figures 1 and 2 are a three-dimensional surface net and a two-dimensional contour plot of the study area, respectively. A paved road parallels the base of the levee. The road had been heaved from sand boil activities between the 300 foot and the 420 foot markers. In Figure 2, the location of a major sand boils has been identified with a point symbol.

The grid covered a 19,200 square foot area (approximately 0.4 acre). At each grid intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (Figure 3) and the EM34-3 meter in the horizontal mode with 10 and 20 meter intercoil spacings (Figure 4). Table 1 (in the compendium to this report) lists the effective profiling depths of these meters with varied orientations and/or intercoil spacings.

Generally, the use of EM methods has been most successful in areas where subsurface properties are fairly homogeneous, the effects of one factor (texture, moisture, or salt content) dominates over other factors, and variations in the EM response can be related to changes in the dominant factor. As observed in a break, levees are composed of relatively nonhomogeneous, stratified materials. Although clay content was considered a dominant factor, EM responses could not be attributed to a single factor

The EM survey revealed a complex pattern of responses within and along the levee. Interpretation of the EM data are based on the identification of spatial patterns in the data set. Generally, sand boils occurred in lower-lying areas of the adjoining roadway (between the 300 foot and the 420 foot markers). In this area, the EM response was lowest along the crest and upper side slopes of the levee. In addition, values of apparent conductivity were higher in the upper left-hand portion of each plot. The higher response in this portion of the plots could be a indication of the presence of strata with higher clay contents or a clay core. Values of apparent conductivity are lower in the upper right-hand portion of the each plot. This could indicate the present of coarser-textured dredged materials or the absence of a clay core.

In each plot (see figures 3 and 4), values of apparent conductivity increase towards the lower right-hand corner. This response could be attributed to strata with higher clay contents, accumulation of soluble salts (roadway adjoins lower margin of plots), or cultural noise (overhead utility or buried pipe lines). However, without supporting ground-truth observations, these inferences are highly speculative.

Area of Landes fine sandy loam, 1 to 6 percent slopes
A 400 by 500 foot grid was established in a representative area of map unit 304B near East Carondelet. The grid interval was 50 feet. A rotating laser level was used to determine surface elevations at each of the 99 grid intersects. At each site, elevations were not tied to an elevation benchmark; the lowest recorded grid intersect was chosen as the 0.0 datum.

Figure 5, is a two-dimensional contour plot of the study area. A road and levee adjoin the lower margin of this figure. The general locations of two areas with noticeable concentrations of sand boils have been outlined with a segmented line. Generally, sand boils were more conspicuous in the lower-lying areas alongside the levee.

The grid covered approximately 4.6 acres. At each grid intersect, measurement were taken with the EM31 meter in both the horizontal (Figure 6) and vertical modes (Figure 7). The EM response was fairly uniform across the site and provided little information about the subsurface stratigraphy. The response was slightly higher (> 60 mS/m) near the lower margin of the study site. This area had noticeable sand boils. The slightly higher EM response could be attributed to wetter soil conditions in this lower-lying area, proximity to the road (road salts), and/or cultural noise from utility lines. The EM response increased (> 60 mS/m) towards the upper margin of each plot. As water was ponded in the area immediately bordering the upper margin of the plots, the slightly elevated EM response could be attributed to wetter soil conditions.

The results of this survey are interpretative and should be verified with ground-truth observations (auger or probe). A basis assumption of this investigation was that areas underlain by coarser-textured, more electrically resistive materials should have a lower EM response than areas underlain by finer-textured materials. The recent flood has created saturated, nutrient enriched conditions. These conditions may have diluted some electromagnetic gradients making detection of subsurface strata difficult.

Additional EM surveys are encouraged. The intent of these surveys would be to assess variations in subsurface materials within map units and associate discernable patterns with the distribution of sand boils. Additional sites should be examined with EM techniques to assess the utility of this tool.

Recommendations:
1. Variations in EM response were observed within and along the surveyed portion of the levee. Difference were assumed to reflect variations in the type or composition of dredged materials and volumetric water content. The EM survey revealed a complex pattern of responses within and along the levee. In the absence of some ground-truth verifications, the basis for these patterns could not be adequately assessed. Personnel from the U. S. Army Corp of Engineers expressed interested in the results of any further EM surveys. Surveys conducted along levees could be compared with existing data

and used to assess the structural properties and the utility of using EM techniques.

2. Sand boils are springs of water along levees. These springs most often develop during flood stages when water is forced through permeable layers beneath levees. Sand boils occur in areas of coarse-textured soils. Soil survey information and GIS can be used to assess the distribution of areas which are prone to the development of sand boils. The U. S. Army Corps of Engineers have maps showing the location of sand boils. This information can be used with soil maps to assess the frequency of sand boils within map units and to establish a rating system (low, moderate, high) for site evaluation and planning purposes. This information can be gathered, analyzed, and added to the descriptions and interpretations for relevant map units in MLRA soil survey updates.

3. EM techniques can be used to develop and improve soil-landscape models for the distribution of sand boils within selected map units. Models can be used to develop descriptive statements for soil map unit descriptions. Preliminary observations indicate that sand boils are most likely to occur within 1000 feet of levees in areas of coarse-textured soils. Within areas of coarse-textured soils, sand boils appear to be more common in lower-lying areas adjacent to levees. The distribution of sand boils may be aligned with specific subsurface layers. Recommend the continuation of EM investigations at several sites in Illinois. Results of study would have regional impact.

With kind regards

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Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. For surveying, a meter is placed on the ground surface or held above the surface at a specified distance. A power source within the meter generates an alternating current in the transmitter coil. The current flow produces a primary magnetic field and induces electrical currents in the soil. The induced current flow is proportional to the electrical conductivity of the intervening medium. The electrical currents create a secondary magnetic field in the soil. The secondary magnetic field is of the same frequency as the primary field but of different phase and direction. The primary and secondary fields are measured as a change in the potential induced in the receiver coil. At low transmission frequency, the ratio of the secondary to the primary magnetic field is directly proportional to the ground conductivity. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

Electromagnetic methods measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified penetration depth (Greenhouse and Slaine; 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990). As EM measurements represent weighted averages, they do not reflect the conductivity of any single layer.

Variations in the meters response are produced by changes in the ionic concentration of earthen materials which reflects changes in sediment type, degree of saturation, nature of the ions in solution, and metallic objects. Factors influencing the conductivity of earthen materials include: (i) the volumetric water content, (ii) the amount and type of ions in soil water, (iii) the amount and type of clays in the soil matrix, and (iv) the soil temperature.

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 1 list the anticipated depths of measurements for the EM31, EM34-3, and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

The conductivity meters provide limited vertical resolution and depth information. However, as discussed by Benson and others (1984), the absolute EM values are not necessarily diagnostic in themselves, but lateral and vertical variations in these measurements are significant. The seasonal variation in soil conductivity (produced by variations in soil moisture and temperature) can be added to the statement by Benson. Interpretations of the EM data are based on the identification of spatial patterns in the data set appearing on two-dimensional contour plots.

TABLE 1

Depth of Measurement
(all measurements are in meters)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM31	3.7	2.75	6.0
EM34-3	10.0	7.5	15.0
	20.0	15.0	30.0
	40.0	30.0	60.0
EM38	1.0	0.75	1.5

References

Benson, R. C., R. A. Glaccum, and M. R. Noel. 1984. Geophysical techniques for sensing buried wastes and waste migration: an application review. IN: D. M. Nielsen and M. Curls (eds.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas. p. 533-566.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2):47-59.

Slavich, P. G. and G. H. Petterson. 1990. Estimating average rootzone salinity from electromagnetic induction (EM-38) measurements. Aust. J. Soil Res. 28:453-463.

Figure 1

LEVEE NEAR EAST CARONDELET, ILLINOIS

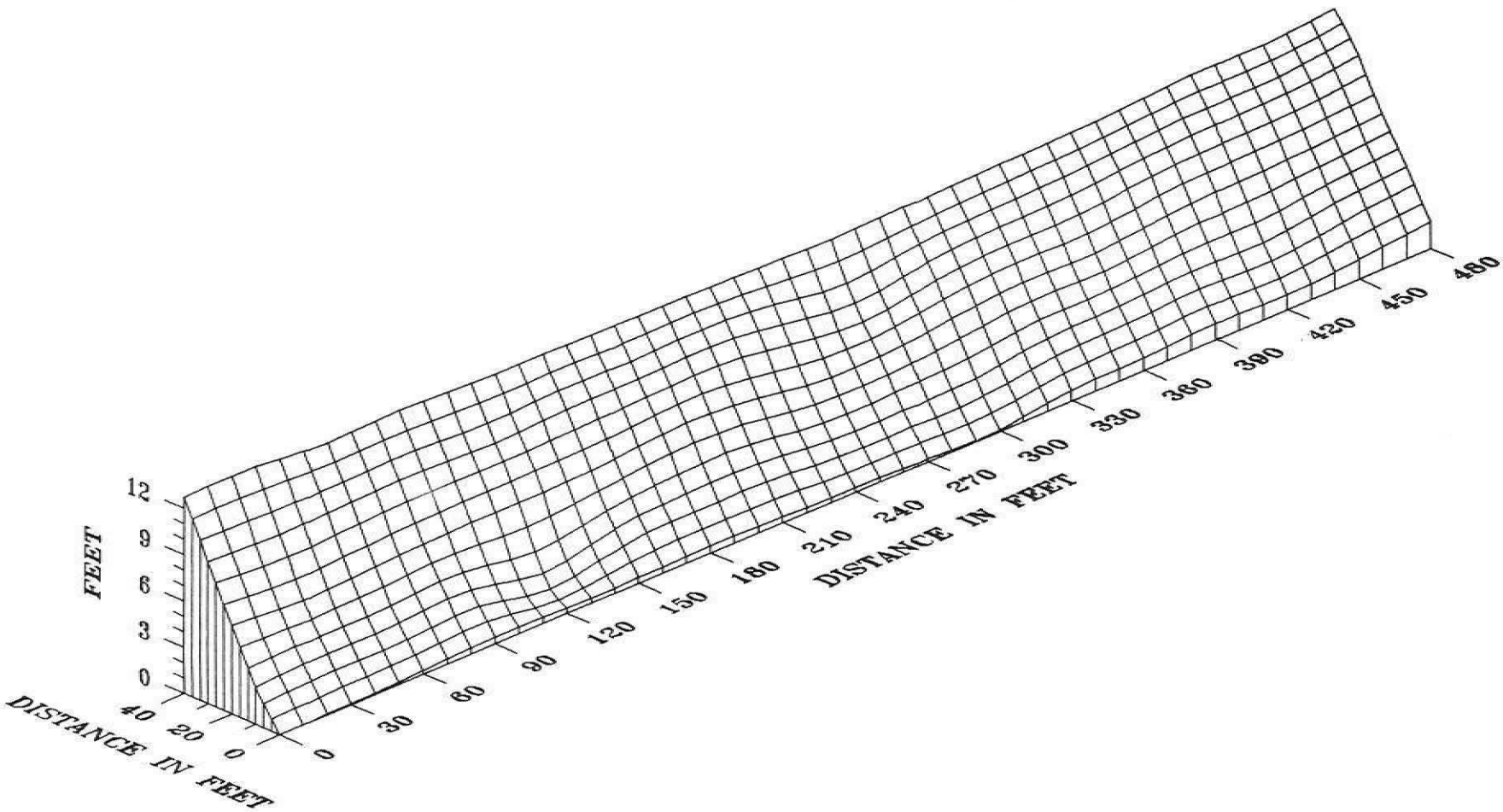


Figure 2

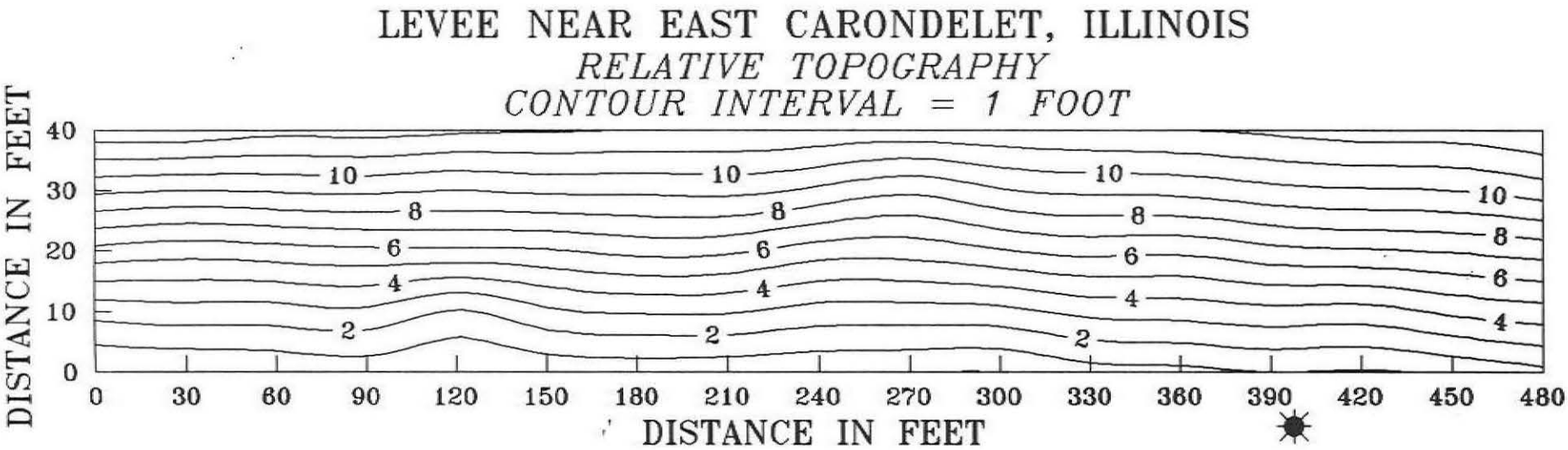
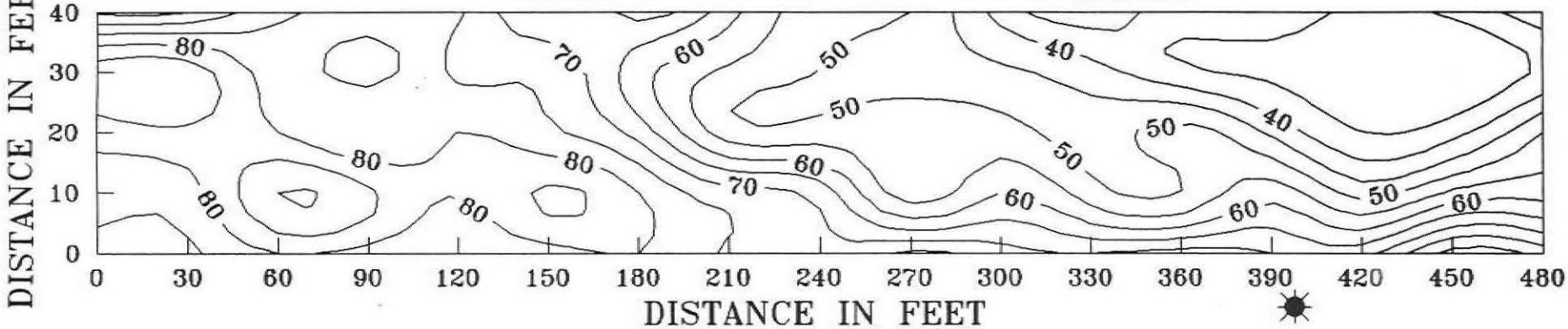

LEVEE NEAR EAST CARONDELET, ILLINOIS
RELATIVE TOPOGRAPHY
CONTOUR INTERVAL = 1 FOOT
DISTANCE IN FEET
40
30
20
10
0
10
8
6
4
2
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
DISTANCE IN FEET

Figure 3

LEVEE NEAR EAST CARONDELET, ILLINOIS

EM31 SURVEY
HORIZONTAL DIPOLE ORIENTATION



EM31 SURVEY
VERTICAL DIPOLE ORIENTATION

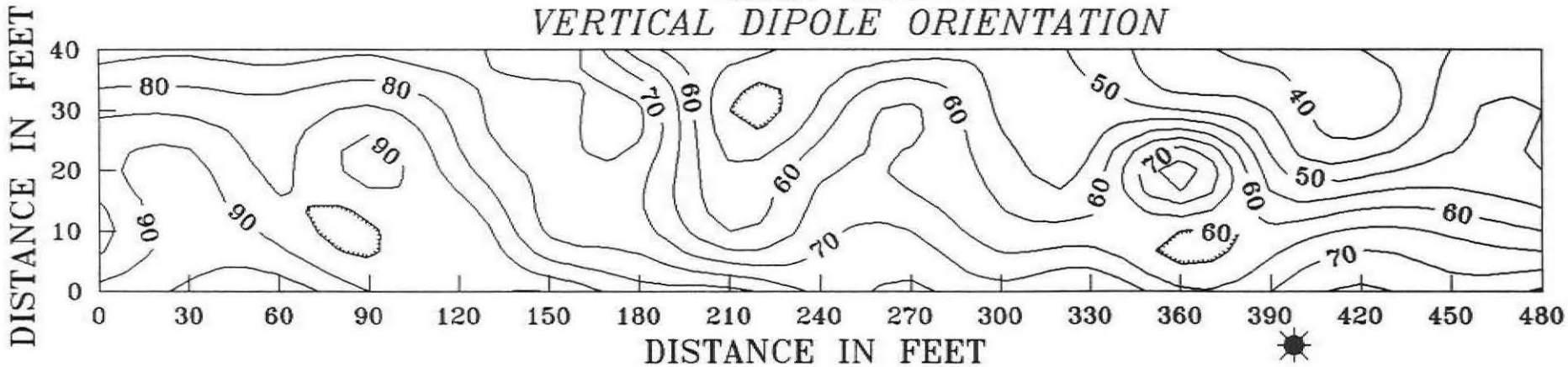
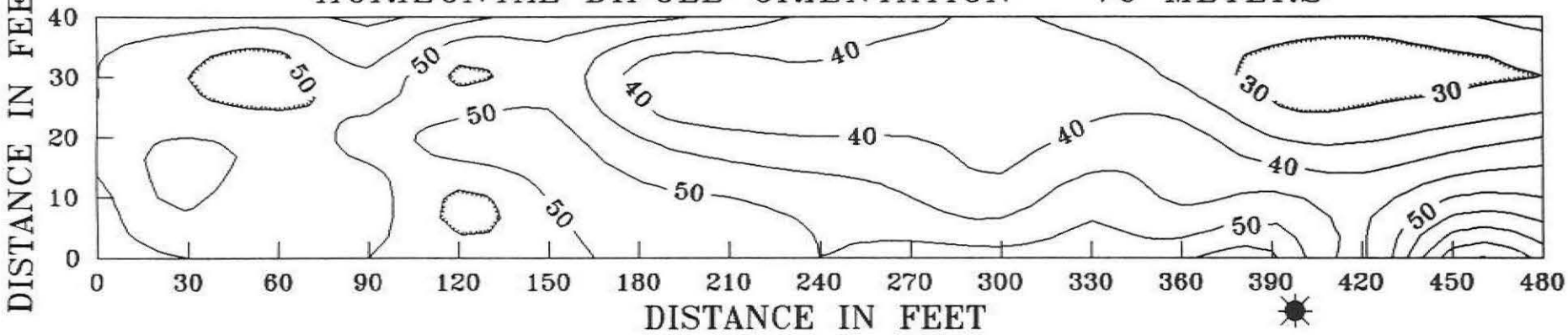


Figure 4

LEVEE NEAR EAST CARONDELET, ILLINOIS

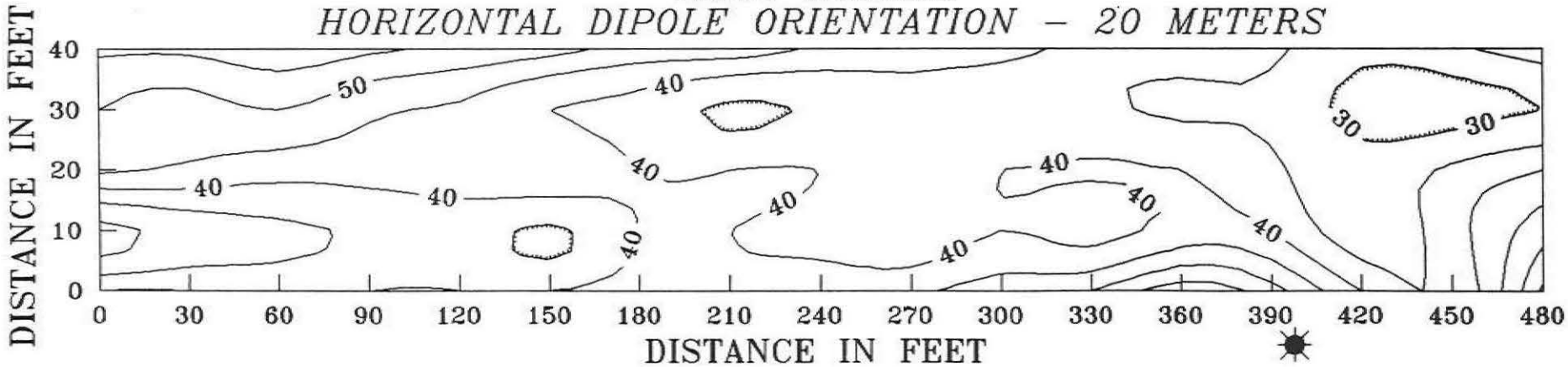
EM34 SURVEY

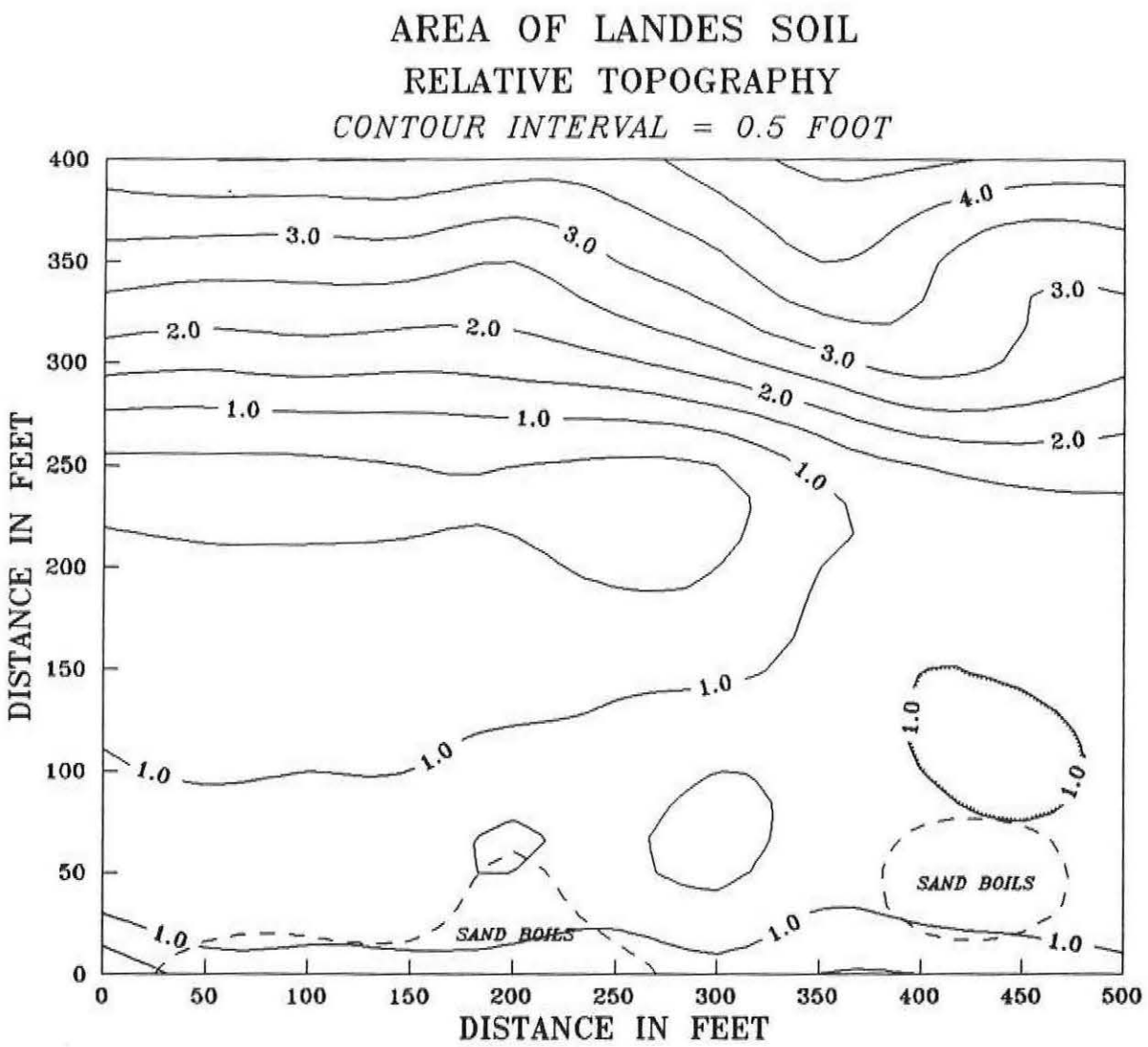
HORIZONTAL DIPOLE ORIENTATION – 10 METERS

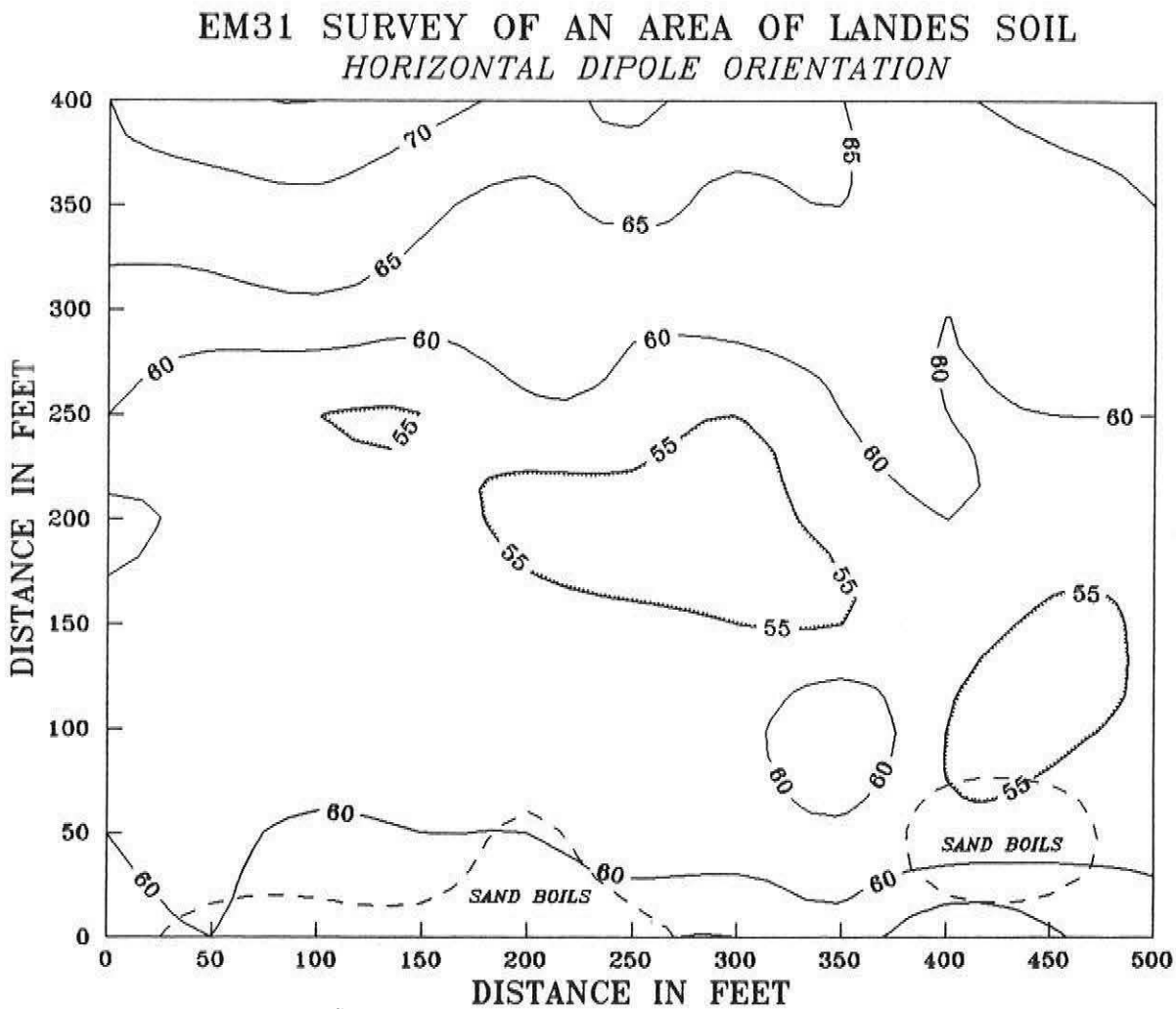


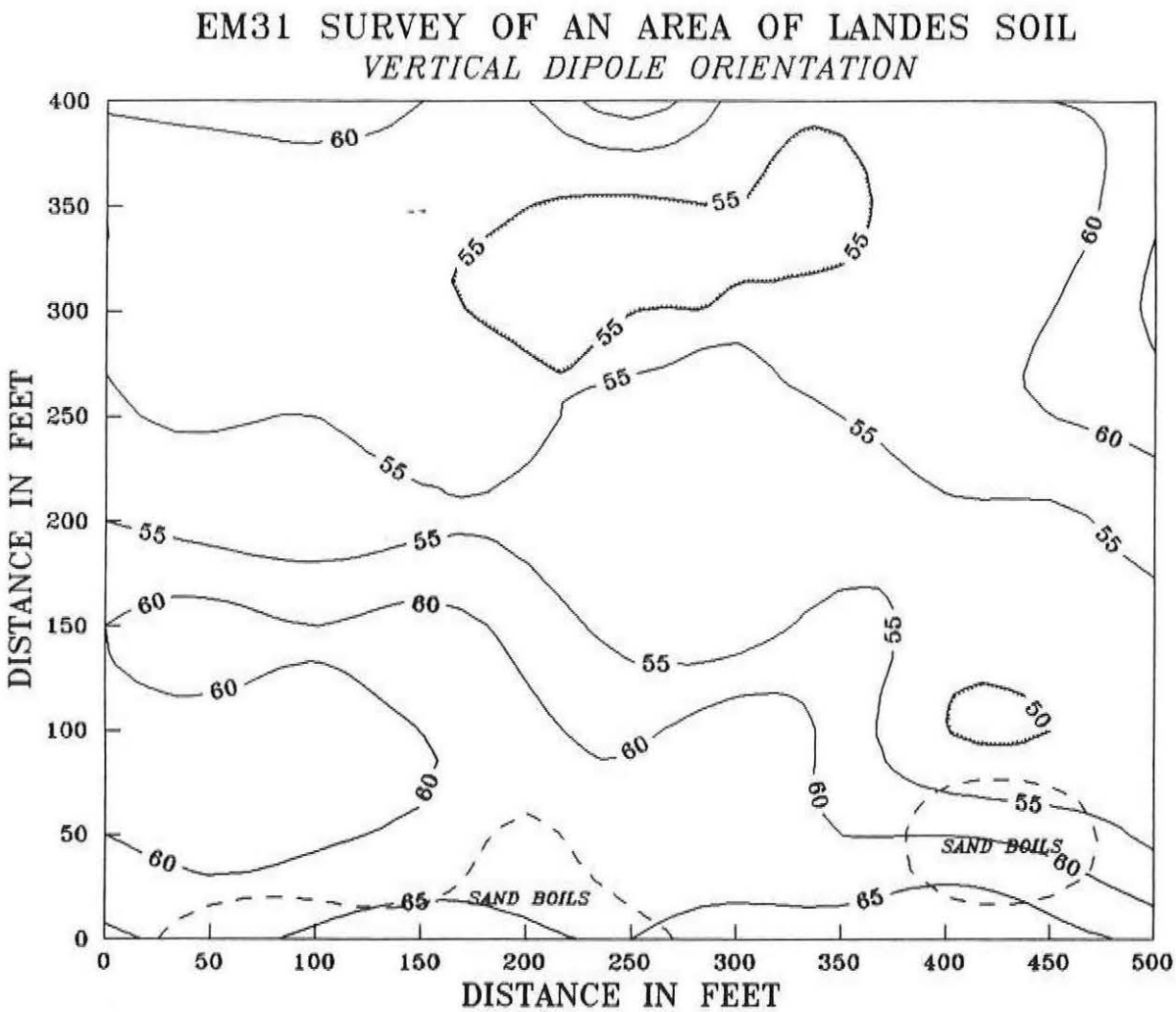
EM34 SURVEY

HORIZONTAL DIPOLE ORIENTATION – 20 METERS




AREA OF LANDES SOIL
RELATIVE TOPOGRAPHY
CONTOUR INTERVAL = 0.5 FOOT
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400
450
500
4.0
3.0
2.0
1.0
SAND BOILS
SAND BOILS


EM31 SURVEY OF AN AREA OF LANDES SOIL
HORIZONTAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400
450
500
70
65
60
55
SAND BOILS
SAND BOILS


EM31 SURVEY OF AN AREA OF LANDES SOIL
VERTICAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400
450
500
60
55
50
65
SAND BOILS
SAND BOILS