UNITED STATES DEPARTMENT OF AGRICULTURE **160 East 7th Street**
SOIL CONSERVATION SERVICE **CHESTER, PA 19013**

SUBJECT: SOI - Electromagnetic Induction
Induction (EM) Training: Kentucky
April 26-30 1993

DATE: 6 May 1992

To: William Craddock
State Soil Scientist
USDA-Soil Conservation Service
771 Corporate Drive, Suite 110
Lexington, Kentucky 40503-5479

Purpose:
To provide training in the use of the EM31 meter and to evaluate the performance and applicability of EM techniques for specific applications within Kentucky.

Participants:
Fred Alcott, District Conservationist, SCS, Bowling Green, KY
Scott Aldridge, Soil Scientist, SCS, Hindman, KY
George Ballard, District Conservationist, SCS, Princeton, KY
Steve Blanford, Soil Survey Party Leader, SCS, Paintsville, KY
Loren Boggs, District Conservationist, SCS, Hopkinsville, KY
Ed Campbell, Soil Scientist, SCS, Bowling Green, KY
Jim Christian, Soil Conservation Engineer, SCS, Russellville, KY
Bill Craddock, State Soil Scientist, SCS, Lexington, KY
Doug Dotson, Soil Survey Party Leader, SCS, London, KY
Joe Dykes, Engineering Technician, SCS, Morehead, KY
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Phillip Gregory, Soil Scientist, SCS, Mayfield, KY
Harry Evans, Soil Survey Party Leader, Somerset, KY
Rudy Forsythe, Resource Soil Scientist, SCS, Princeton, KY
Jackie Franklin, Soil Conservationist, SCS, Princeton, KY
Steve Jacobs, Soil Survey Party Leader, SCS, Mayville, KY
Bill Johnson, District Conservationist, SCS, Russellville, KY
Rick Jones, Soil Scientist, SCS, Mayville, KY
Paul Knemmel, Soil Survey Party Leader, Waterloo, IL
Jim Hamilton, Civil Engineer, SCS, Princeton, KY
Jim Hagen, Soil Survey Party Leader, SCS, Hardinsburg, KY
Doug Hines, SWRS, SCS, Cynthiana, KY
Paul Howell, State Geologist, SCS, Lexington, KY
Sam Indorante, MLRA Update Leader, SCS, Belleville, IL
Marty Lewis, Soil Conservation Technician, SCS, Cadiz, KY
Martha Marsh, Soil Conservation Technician, SCS, Carlisle, KY
Doug McIntosh, Soil Survey Party Leader, Hindman, KY
Jerry McIntosh, Soil Survey Party Leader, SCS, Mayfield, KY
David McMillen, Ass't. State Soil Scientist, SCS, Nashville, TN
Mike Mitchell, Soil Survey Party Leader, SCS, Bowling Green, KY
Alan Moore, Soil Scientist, SCS, Paintsville, KY
Wesley Moran, Soil Conservation Technician, SCS, Bowling Green, KY

Participants (continued):
Nathan Morgon, Soil Scientist, London, KY
Darwin Newton, State Soil Scientist, SCS, Nashville, TN
Randal Rock, District Conservationist, SCS, Versailles, KY
John Robbins, Ass't. State Soil Scientist, SCS, Lexington, KY
Jerry Richardson, Soil Scientist, London, KY
Ed Scott, Engineering Technician, SCS, Cynthiana, KY
Ken Scott, Soil Scientist, Mayfield, KY
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Ruthi Steff, RC&D Coordinator, SCS, Bowling Green, KY
Bill Thomas, Area Engineer, SCS, Cynthiana, KY
Charles Turner, RC&D Coordinator, SCS, Hopkinsville, KY
Charles Vaughn, Resource Conservationist, SCS, Princeton, KY
Bruce Waters, Resource Soil Scientist, SCS, Morehead, KY

Activities:
During the week of 26 to 30 April 1993, training in the use of the EM31 meter was given to 46 participants at nine sites in central and western Kentucky. Sites were visited in accordance with the schedule specified in Bill Craddocks letter of 7 April 1993 (see enclosure 1). At each of the nine sites, surveys were completed by the participants with the EM31 meter.

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 plots of the EM data were prepared using SURFER software developed by Golden Software, Inc.[1.]

Field Methods:
Grids were established at each site. Grid intervals varied with the size of the survey area and the time and resources available. Survey flags were inserted in the ground at each grid intersect. At each grid intersect, measurements were obtained with the EM31 meter in both the horizontal and vertical dipole orientations.

Two-dimensional plots of the apparent conductivity measurements were prepared for each site. Most figures contained in this report consist of an upper and lower plot. Typically, the upper and lower plots represent computer simulations of data obtained with the EM31 in the horizontal and vertical dipole orientations, respectively. The EM31 meter scans depths of 0.0 - 2.75 meters in the horizontal and 0.0 - 6.0 meters in the vertical dipole orientations.

Discussion:

University of Kentucky Pin Oak Farm - Woodford County (26 April 1993)

The purpose of this survey was to evaluate the potential of using EM techniques to chart the depth to bedrock. A 300 by 300 foot grid had been established across a representative landscape. The grid interval was 100 feet. At each of the grid intersects (16), a soil probe had been used to determine the depth to limestone bedrock. Depths to bedrock ranged from 6 to 137 inches at the grid intersects.

The survey site was composed of the soils and soil map units listed in Table 1. Also included in mapping were small areas of Sandview (fine-silty, mixed, mesic Typic Hapludalfs).

Table 1
Soils Mapped within the Pin Oak Farm Site

Symbol	Name	Taxonomic classification
MlC	Maury silt loam	clayey, mixed, mesic Typic Paleudalfs
Mnc	McAfee silt loam	fine, mixed, mesic Mollic Hapludalfs
Nn	Nolin silt loam	fine-silty, mixed, mesic Dystric Fluventic Eutrochrepts
RL	Rock ledge	fine-silty, mixed, mesic Lithic Hapludalfs

Variations in electromagnetic response are produced by changes in the ionic concentration of earthen materials. Factors influencing the ionic concentration and conductivity of earthen materials include: (i) volumetric water content, (ii) amount and type of ions in the soil water, and (iii) amount and type of clays in the soil matrix. The apparent conductivity of soils increases with exchange capacity, moisture content, and clay content. EM techniques have been most effective in areas where the effects of one of these factors dominates over the others. In the study at the Pin Oak Farm, it was anticipated that EM response would correlate with changes in the depth to limestone or thickness of the soil mantle. Although soil moisture conditions were assumed to be fairly uniform across the site, clay content varied from fine-silty to fine. Variations in clay content influenced the EM response.

In Figure 1, the responses of the EM31 meter in the horizontal (upper) and vertical (lower) dipole orientations are shown. In the upper left-hand corner of the lower figure, a pipeline has been detected when the dipoles were vertically orientated. As the pipeline was not detected when the dipoles were orientated horizontally, it was assumed that this feature was buried at depths below the maximum sensitivity of the EM31 meter. The presence of this feature has introduced high amounts of undesired "cultural noise" into the plot. This noise has disrupted patterns associated with changes in soil types and depths to bedrock.

Generally, values of apparent conductivity decrease and become less variable with depth. This trend reflects the presence of limestone.

In each plot, the lowest EM response is in the upper-central portion of the survey area. This area was assumed to have the shallowest depths to bedrock.

No correlation was found between the depth to bedrock and the EM response when the dipoles were oriented vertically. This lack of correlation was attributed to variations in lithology or to the relatively thin soil mantle at this site. The underlying bedrock were members of the Tanglewood and Brannon limestone formations. The Brannon member is interbedded with shale, is less permeable, and probably more conductive.

In Figure 2 comparable patterns can be discerned in the two-dimensional plots of the horizontal dipole measurements and the depths to limestone. Figure 3 shows the relationship between depth to bedrock and response of the EM31 meter when the dipoles were orientated horizontally. For the 16 grid intersects, the coefficient of determination, r^2, between these two measurements was exceedingly low (0.07). However, r^2 was improved to 0.60 when only those intersects having depths of 2.0 m or less to bedrock were considered in the analysis.

Variations in soil types and lithologies within the Pin Oak Farm site resulted in a weak correlation between the EM response and the depth to bedrock. A stronger correlation was found between the depth to bedrock and EM response when measurements were taken in the horizontal rather than the vertical dipole orientations. The lack of a stronger correlation between measurements taken in the vertical dipole orientation and depth to bedrock were attributed to the thinness of the soil mantle and variations in the underlying lithologies.

<u>Western Kentucky University Farm - Bowling Green, Warren County (27 April 1993)</u>
The purpose of this survey was to further evaluate the potential of using EM techniques to chart the depth to bedrock. A 400 by 400 foot grid had been established across a representative site within the Western Kentucky University Farm. The grid interval was 100 feet.

The site was topographically diverse and contained a sinkhole. Soil texture and depth to bedrock varied within the site. The dominant soil within the study site was Pembroke (fine-silty, mixed, mesic Mollic Paleudalfs). At each of the grid intersects (25), observations depth to bedrock were collected. Observed depths to bedrock ranged from 0 to > 100 inches. However, at 24 % of the observation sites, the depth to bedrock was recorded as "greater than" a specified depth. This statistic demonstrates the inadequacy of traditional soil survey tools.

In Figure 4, the responses of the EM31 meter in the horizontal (upper) and vertical (lower) dipole orientations are shown. The sinkhole was located in the center of the study site. A small pond was located immediately above the upper left-hand corner of each plot. Seepage from this structure may be responsible, in part, for the elevated EM responses in this portion of the plots. Anomalous features have been identified with the letters "A" and "B." The reversal of EM responses (high versus low response) for the horizontal and vertical orientations near "A" suggest a possible buried cultural feature or cavity filled with either water or soil materials. The low EM response in the vertical dipole orientation near "B" suggests a possible air-filled cavity.

No correlation was found between EM response and depth to bedrock. Variations in soils and soil moisture were known to exist at this site. These factors would weaken the correlation between the EM responses and the depths to bedrock. In addition, the EM31 meter integrates values of apparent conductivity within a fairly large, 3.9 m long by either 3.0 or 6.0 m deep, cross-sectional area. Observations made with an auger or probe are for a specific point rather than an area. The poor correlation can be partially attributed to the fact that the depth to bedrock was not determined at 24 % of the grid intersects. In addition, it was unclear at observation sites whether the recorded depth reflected the "true" bedrock surface or whether the probe had entered a fracture or solution cavity, or encountered a coarse fragment in the soil.

At the Pin Oak Farm and Western Kentucky University's Farm the EM31 provided interpretative maps of spatial distribution of apparent conductivity values. These studies indicate that the EM response is influenced by the depth to bedrock. In order for EM techniques to be used effectively to estimate the depths to bedrock, restrictions must be placed on the variability of factors affecting conductivity within sites. Proper selection of suitable sites for the use of EM techniques and proper interpretations of terrain conditions are invaluable to EM surveys. It is clear that more work needs to be done in order to interpret depths to limestone bedrock with the EM31 meter.

<u>Robey's Dairy Lagoon - Russellville, Logan County (27 April 1993)</u>
The purpose of this survey was to evaluate the potential of using EM techniques to located, chart, and assess the extent of seepage from an animal waste lagoon.

The grid interval was 25 feet. The lagoon was located on the edge of an upland area which descended onto a flood plain which was located in the lower part of each plot (see Figure 5). At each grid intersect, measurements were made with the EM31 meter in both the horizontal (Figure 5, upper) and vertical (Figure 5, lower) dipole orientations.

In Figure 5, lower, a fairly broad zone of relatively high apparent conductivity values (labelled "B") appears to emanate from the lagoon and extends in a downslope direction (towards lower margin of study area). Within this zone, values of apparent conductivity decrease in a downslope direction away from the structure. In Figure 5, upper, a zone of higher apparent conductivity values is detected at the footslope of the embankment area. This detached zone was believed to reflect the phreatic surface which become shallower and is detected in the horizontal dipole measurements near "A." These pattern suggest possible seepage of animal wastes from the lagoon. Considering the length of use, seepage is considered limited. Areas of high conductivity are restricted to within about 80 feet from the upper edge of the lagoon.

A zone of higher apparent conductivity values was detected near and emanating from a portion of the lagoon. While the factors producing this zone of higher apparent conductivity values could not be verified at the time of the survey, the location and characteristic pattern suggested an area of potential seepage. EM techniques can be used to assess seepage from animal waste storage facilities, evaluate the need for monitoring wells, and determine the placement and number of observation wells needed to monitor a site.

Cave Spring Cemetery - Hopkinsville, Christian County (28 April 1993)
The objectives of this survey was to evaluate the potential of using the EM31 meter to chart internal features within a cemetery. A representative site was selected within the Cave Spring Cemetery in Hopkinsville. In this cemetery, many of the early burials had not been adequately registered or marked. As a consequence, many of the earlier burials are encountered during the excavation of contemporary grave site. A noninvasive technique is needed to locate these unmarked burials.

The grid interval was 10 feet. At each grid intersect, measurements were made with the EM31 meter in both the horizontal (Figure 6, upper) and vertical (Figure 6, lower) dipole orientations. The spatial patterns displayed in Figure 6 are complex and highly variable. Generally such patterns are indicative of highly disturbed or variable soil conditions. While the factors producing these patterns could not be verified at the time of the survey, the complexity of these patterns suggested the presence of several closely-spaced anomalies within the depths of observation.

The EM31 meter is an excellent tool for identifying areas of disturbed soils and defining the boundaries of cemeteries. However, the EM31 meter lacks sufficient resolution to resolve individual burials. The EM38 meter would be a more suitable tool for this type of investigation. Compared with the EM31 meter, the EM38 meter provides improved resolution of subsurface features but shallower depths of observation (<1.5 m).

Land-Fill Site - Hopkinsville, Christian County (28 April 1993)
The EM31 was used to assess leakage from a land fill. In most cases, the boundaries of a land-fill site can be readily identified in the field or through the use of aerial photographs. However, in some instance, boundaries have been masked by vegetational or land use changes and must be located using geophytsical techniques. The location and boundaries of landfill or waste disposal sites can be defined with EM techniques.

Values of apparent conductivity were noticeably higher over the landfill site than adjacent, non- or less-disturbed areas. Within the landfill site, values of apparent conductivity ranged from 57 to 145 mS/m in the horizontal dipole orientation and from 60 to 180 mS/m in the vertical dipole orientation. Values of apparent conductivity declined rapidly as site boundaries were approached and crossed. In areas immediately adjoining the land-fill site, values of apparent conductivity ranged from 32 to 44 mS/m in the horizontal dipole orientation and from 42 to 59 mS/m in the vertical dipole orientation.

Seepage Study - Princeton, Caldwell County (28 April 1993)
The purpose of this survey was to evaluate the use EM techniques to located, chart, and assess the source of ponding in a residential area of Princeton.

Three closely-spaced exploratory trenches had been excavated at the site. Two of these trenches were dry; one trench contained water. A 80 by 120 foot grid was established across the site. The grid interval was 20 feet. Soils were saturated in the central portion of the survey area (see Figure 7). Because of the inaccessibility of grid intesects within the wet area, EM measurements were not obtained at several intersects.

Measurements were made with the EM31 meter in both the horizontal (Figure 7, upper) and vertical (Figure 7, lower) dipole orientations. A road and buried utility lines produced the anomalously high values along the left-hand portion of the plots in Figure 7. These features produced a fairly broad zone (@ 20 feet) of "cultural noise" which interfered with interpretations.

In the upper plot, a zone of higher apparent conductivity values envelopes the "wet area." Values within this zone increase toward the left. The higher values within this zone were attributed to more saturated soil conditions. In the lower plot, a linear belt of lower apparent conductivity values (<14 mS/m) is noticeable and extends into the right-hand portion of the "wet area." The one "dry" trench was located within an extension of this linear belt immediately adjacent to the lower plot boundary. This linear belt of lower apparent conductivity values may represent an area with shallower depths to bedrock. Areas with higher values may represent soils that have thicker, relatively impervious mantles overlying bedrock.

Seepage Study - Cadiz, Trigg County (29 April 1993)
The objective of this survey was to use EM techniques to locate the origin of seepage from a constructed pond. A 300 by 300 foot grid was established across the site. The grid interval was 50 feet. In Figure 8, the upper-most grid line in each plot was located along the top of the earthen embankment. A large pool of water was impounded immediately above the embankment in the central portion of the survey area. Measurements were not obtained within the pool area.

Measurements were made with the EM31 meter in both the horizontal (Figure 8, upper) and vertical (Figure 8, lower) dipole orientations. In both plots a zone of relatively high (>14 mS/m) apparent conductivity values was measured in the lower-central portion of the study area. This zone was located within the former pool area. The relatively high values within this area were attributed to wetter soil materials. Indications of increased soil wetness were evident and resulted from the lateral movement into and the downward percolation of waters through this area.

Fragipan Study - Mayfield, Graves County (29 April 1993)
The objectives of this study were to evaluate the potential of using EM techniques to assess the thickness of loess mantles and the depth to underlying coarser textured sediments. In many areas, the presence of fragipans restricts the depths of observation and the number of observations which can be made. Frequently, the thickness of the loess mantle and the presence of contrasting materials within the soil profile have had to be estimated.

The study site was located in an area of Grenada (fine-silty, mixed, thermic Glossic Fragiudalfs) and Lax (fine-silty, siliceous, thermic Typic Fragiudults) soils. A 120 by 60 foot grid was established across the site. The grid interval was 30 feet. At each grid intersect the depth to pan, thickness of loess mantle, and/or depth to gravels were recorded by soil scientists. Figure 9 was prepared by the Graves County Soil Survey Party and provides the observed data for each grid intersect.

Measurements were made with the EM31 meter in both the horizontal (Figure 10, upper) and vertical (Figure 10, lower) dipole orientations. Site A1 in Figure 9 is the origin (intersect 0,0) in Figure 10. A comparison of the two plots in Figure 10 shows that values of apparent conductivity decrease with increasing observation or soil depth. This relationship reflects the relatively higher conductivity of the loess compared with the underlying gravel deposits. Comparing the two plots in Figure 10, with the data in Figure 9, values of apparent conductivity generally increase with loess thickness.

A higher correlation was found between loess thickness or depth to gravel and EM31 measurements obtained in the vertical rather than those obtained in the horizontal dipole orientation. The coefficient of determination, r^2, for the relationship between the EM31 response in the vertical dipole orientation and depth to gravel was 0.6030. Figure 11 graphs this relationship.

Results:
1. Forty-six people received training on the operation of the EM31 meter, procedures for conducting surveys, and interpretation of electromagnetic induction data. Participants represented SCS staff members from the states of Illinois, Kentucky, and Tennessee. Each participant has developed insight into the proper use and limitations of this techniques.

2. An EM31 meter (serial number 8906013) was left in the custody of John Robbins. John Robbins and Paul Howell will evaluate the appropriateness of this tool for field investigations and site assessments in Kentucky. The multidisciplinary use of this meter is

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2. An EM31 meter (serial number 8906013) was left in the custody of John Robbins. John Robbins and Paul Howell will evaluate the appropriateness of this tool for field investigations and site assessments in Kentucky. The multidisciplinary use of this meter is

encouraged. At the conclusion of a three month period (1 May to 2 August 1993), the equipment will be delivered to Sam Indorante (Soil Project Leader, USDA-Soil Conservation Service, 25B Center Plaza Drive, Belleville, Illinois 62220), for a similar three-month evaluation period (2 August to 1 November 1993) in Illinois. At a later date, Sam Indorante will be directed to forward the meter to either another state or back to Chester, PA.

3. The EM31 meter is highly suited to ground water studies in Kentucky. Results from this study support the use of the EM31 meter to assess seepage of contaminants from lagoons. Additional studies are needed to assess (i) the levels of contamination which are detectable in various soils, (ii) the influence of temporal variations in soil temperature and soil moisture on EM response, and (iii) the adequacy of sampling designs.

4. The use of EM techniques provides interpretative maps of the variation in apparent conductivity values at selected sites. However, ground truth verification is needed to confirm the nature and magnitude of inferences made from these maps.

Recommendations:
Electromagnetic induction offers a promising, facile, noninvasive method to assess sites, extend the depth of observation, and collect large amounts of information in a relatively short period of time. This technique appears to be suitable for bedrock and soil investigations. However, more field research is needed to verify the appropriateness of this technique for these applications and the validity of EM measurements. I would like to recommend the following action:

a. Kentucky will use the EM31 meter and become familiar with its operation, areas of successful applications, and limitations.

b. In areas of karst, the EM34 meter with a observation depth of 7.5 to 60 meters, may be a more appropriate tool for locating cavities and other solution features. Following the use of the EM31 meter, and if considered desirable, field training (in Kentucky) on the use of the EM34 meter can be scheduled for next fiscal year in Kentucky. An EM34 meter would be loaned to Kentucky following the training period.

c. The use of EM techniques for the investigation, mapping, and description of soil map units containing fragipans should be pursue further. Additional studies are needed to assess (i) the accuracy of this technique (ii) the influence of temporal variations in soil temperature and soil moisture on EM response, (iii) the adequacy of sampling designs, and (iv) the advantages and limitations of using either the EM31 or the EM38 meters.

d. The use of EM techniques for soil investigations could impact soil survey updates in MLRA 134, the Southern Mississippi Valley Silty Uplands. The cooperation and participation of soil staffs from other states and the National Soil Survey Center

(Soil Survey Investigation and Quality Assurance staffs) is encouraged.

It is my pleasure to work with the members of your fine staff.

With kind regards.

James A. Doolittle
Soil Specialist

cc:
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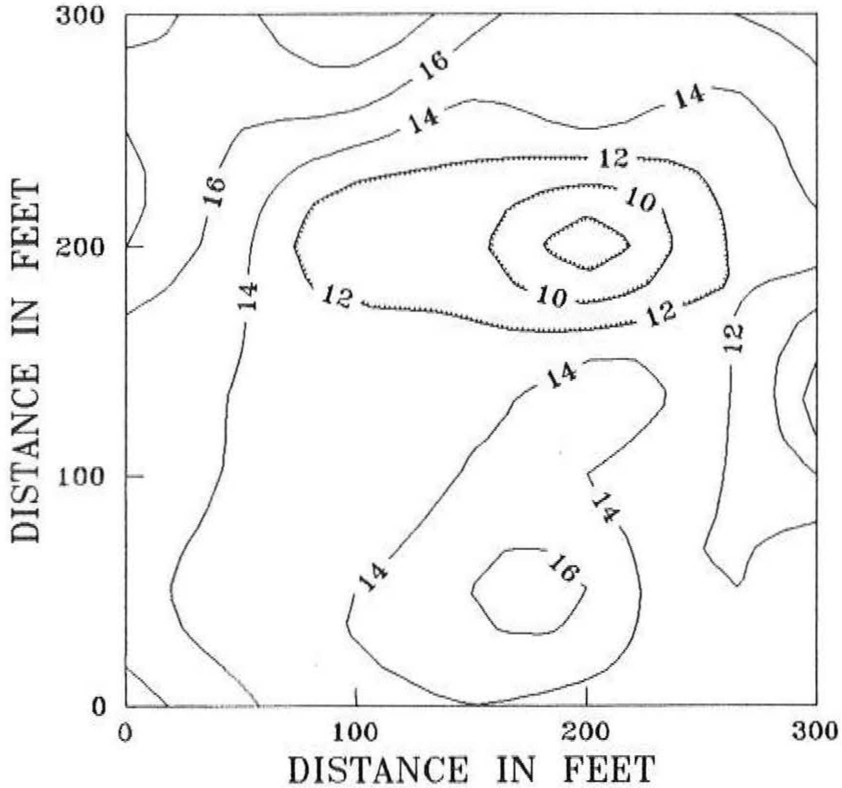
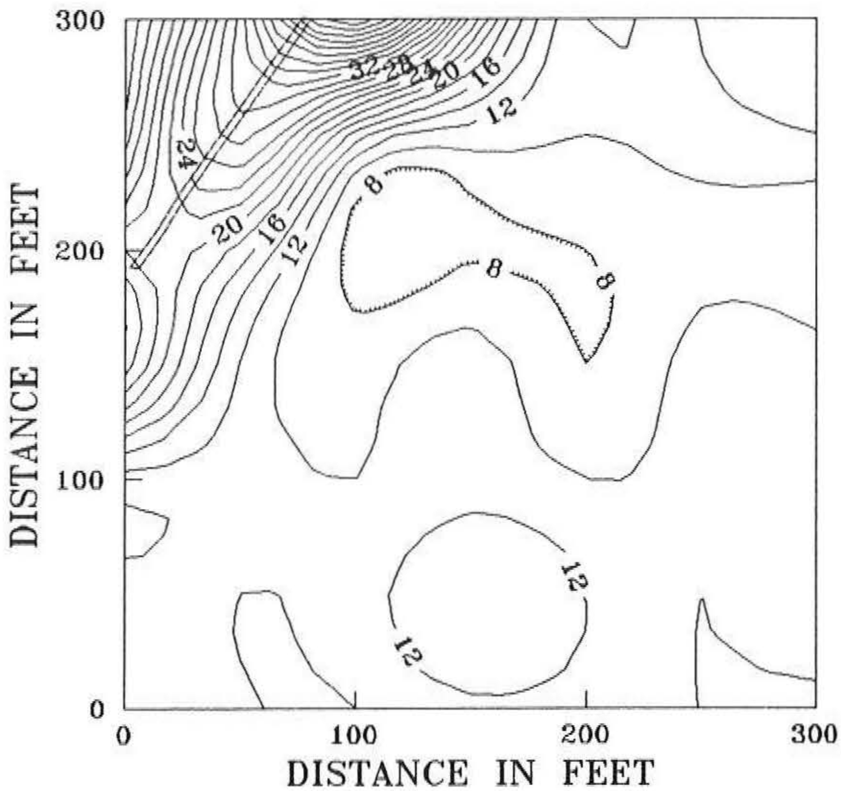
EM31 SURVEY PIN OAK FARM

HORIZONTAL DIPOLE ORIENTATION

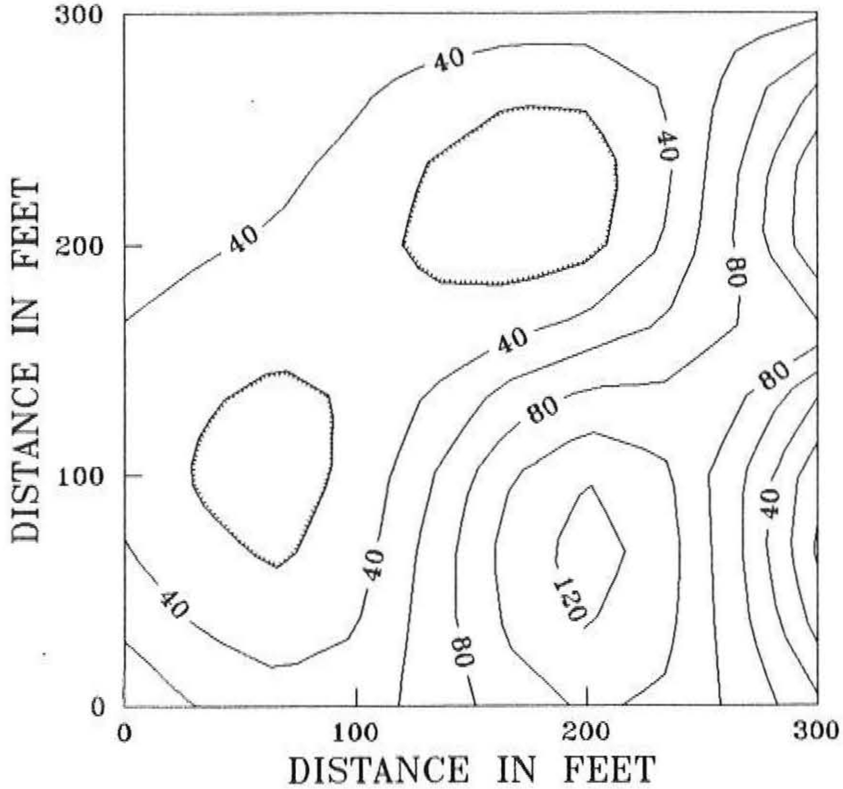


VERTICAL DIPOLE ORIENTATION



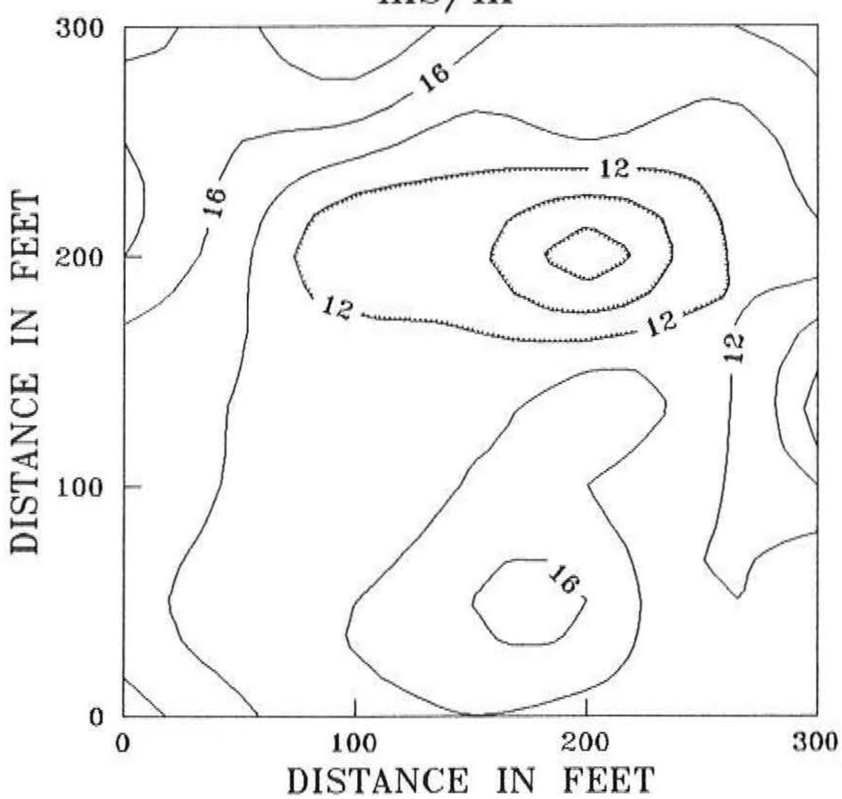
PIN OAK FARM, VERSAILLES, KY

DEPTH TO BEDROCK (INCHES)



EM31 - HORIZONTAL DIPOLE ORIENTATION

mS/m



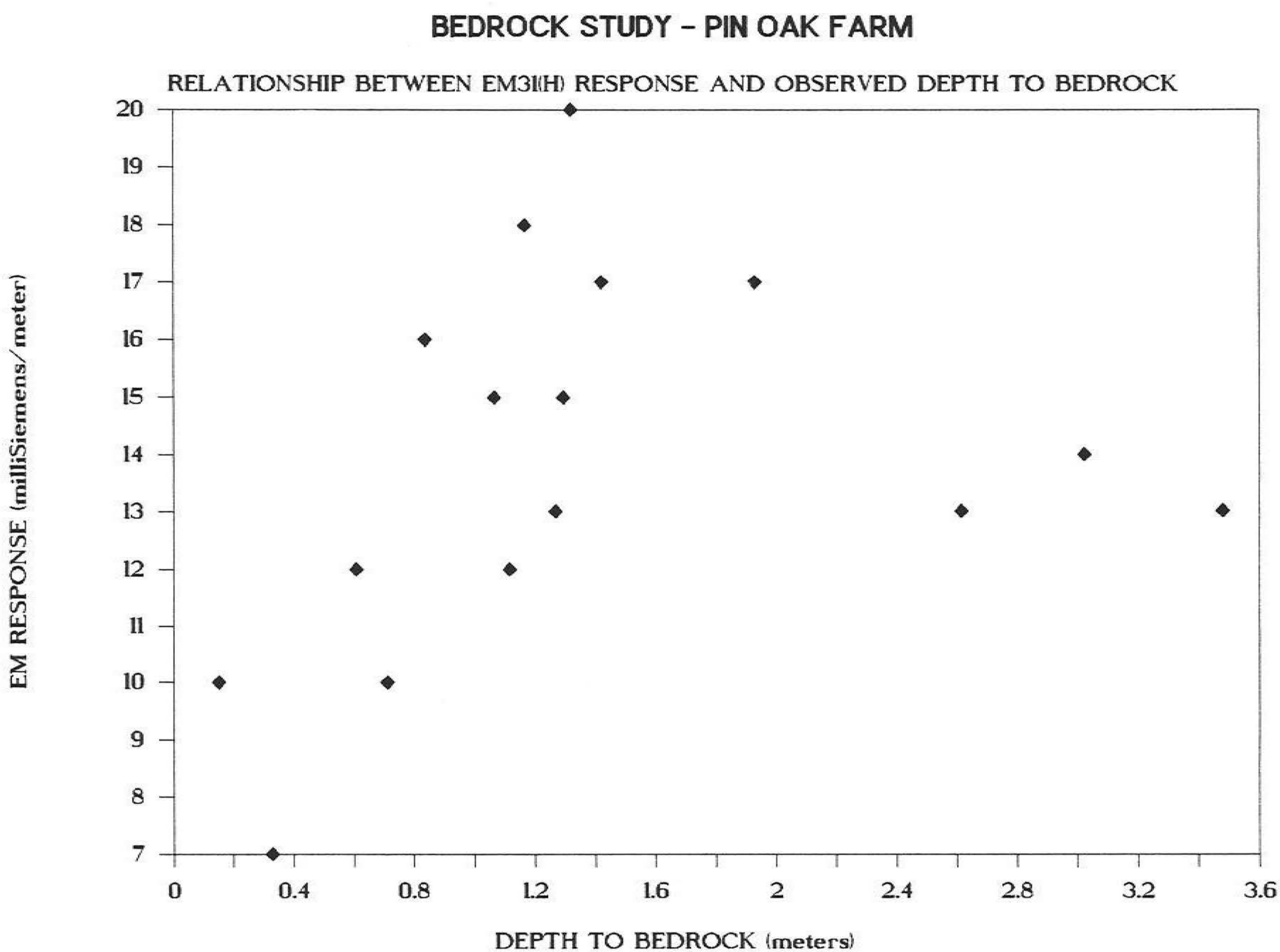

BEDROCK STUDY - PIN OAK FARM
RELATIONSHIP BETWEEN EM31(H) RESPONSE AND OBSERVED DEPTH TO BEDROCK
EM RESPONSE (milliSiemens/meter)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
DEPTH TO BEDROCK (meters)

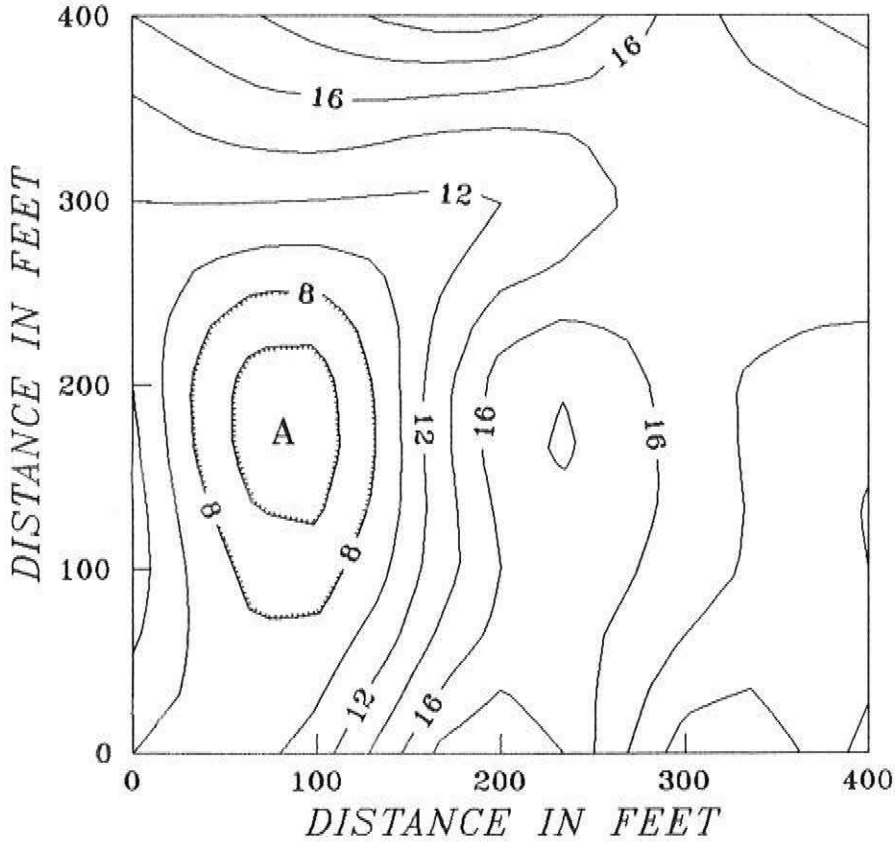
FIGURE 3

EM31 SURVEY

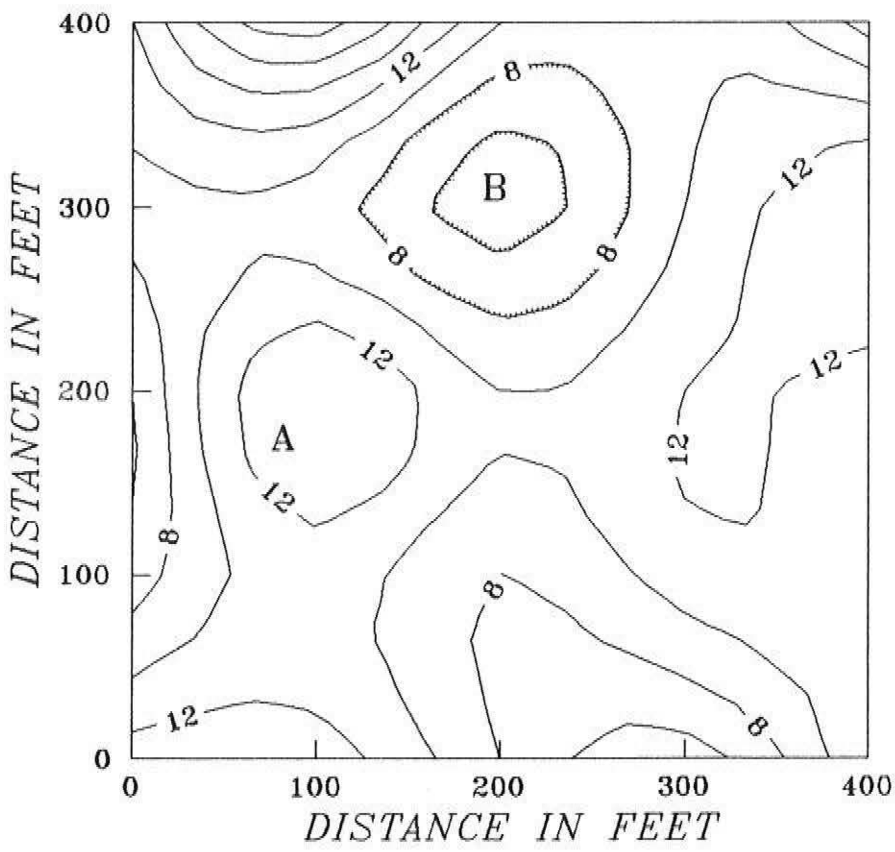
FIGURE 4

WESTERN KENTUCKY UNIVERSITY

HORIZONTAL DIPOLE ORIENTATION

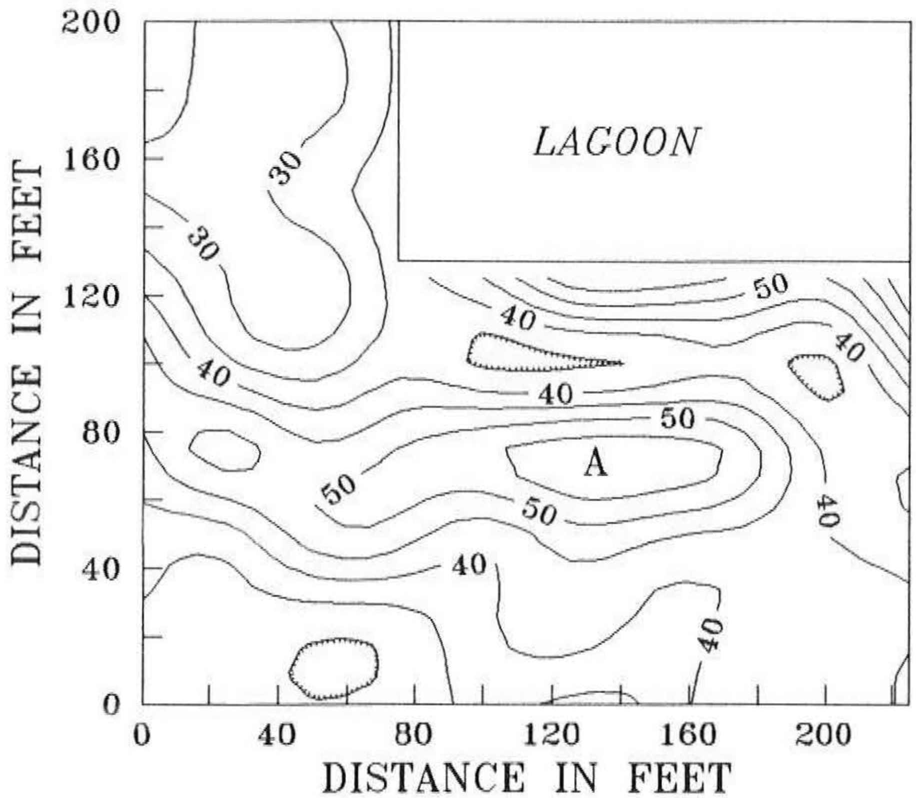


VERTICAL DIPOLE ORIENTATION

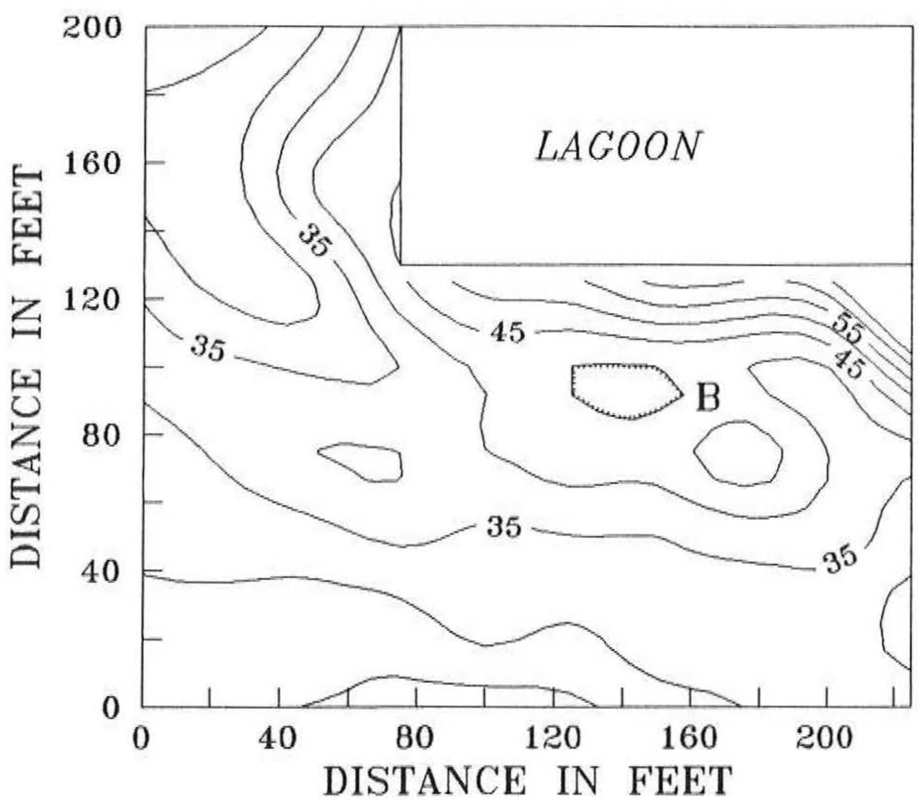


EM31 SURVEY – SEEPAGE STUDY

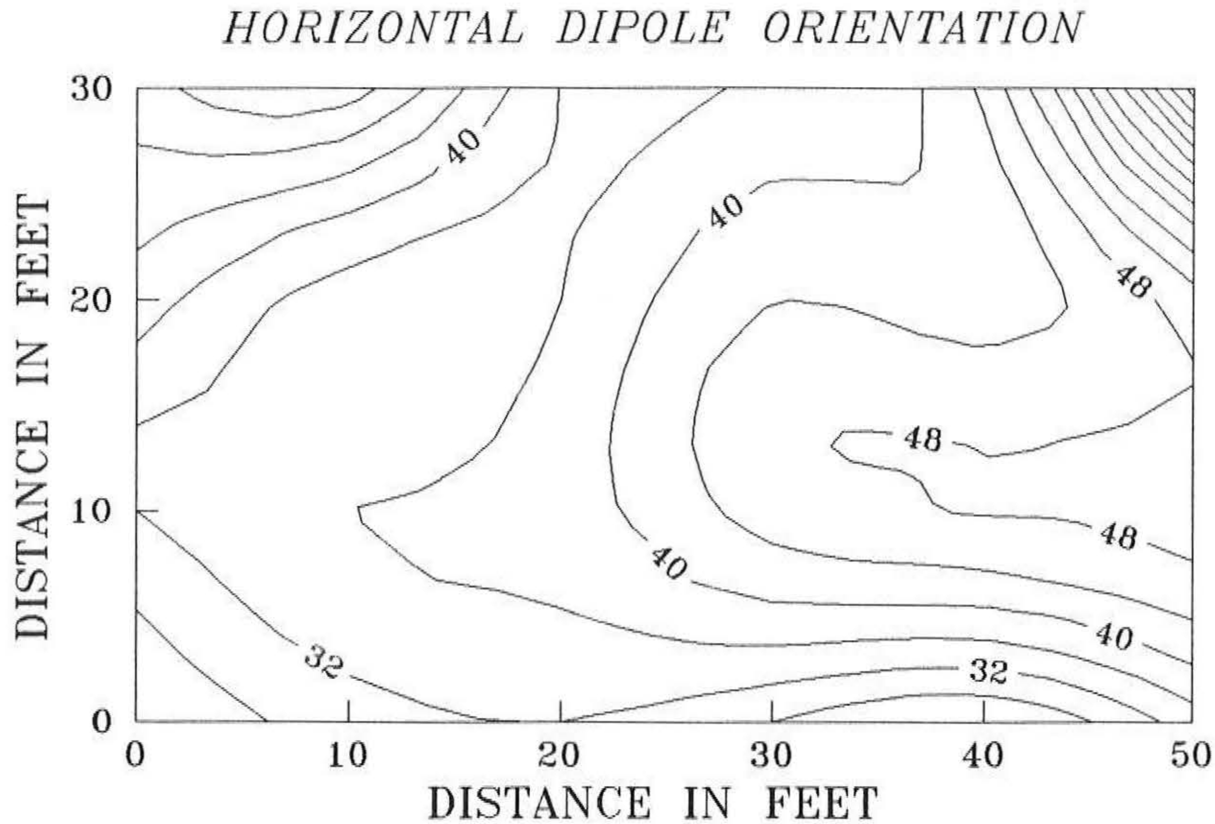
HORIZONTAL DIPOLE ORIENTATION

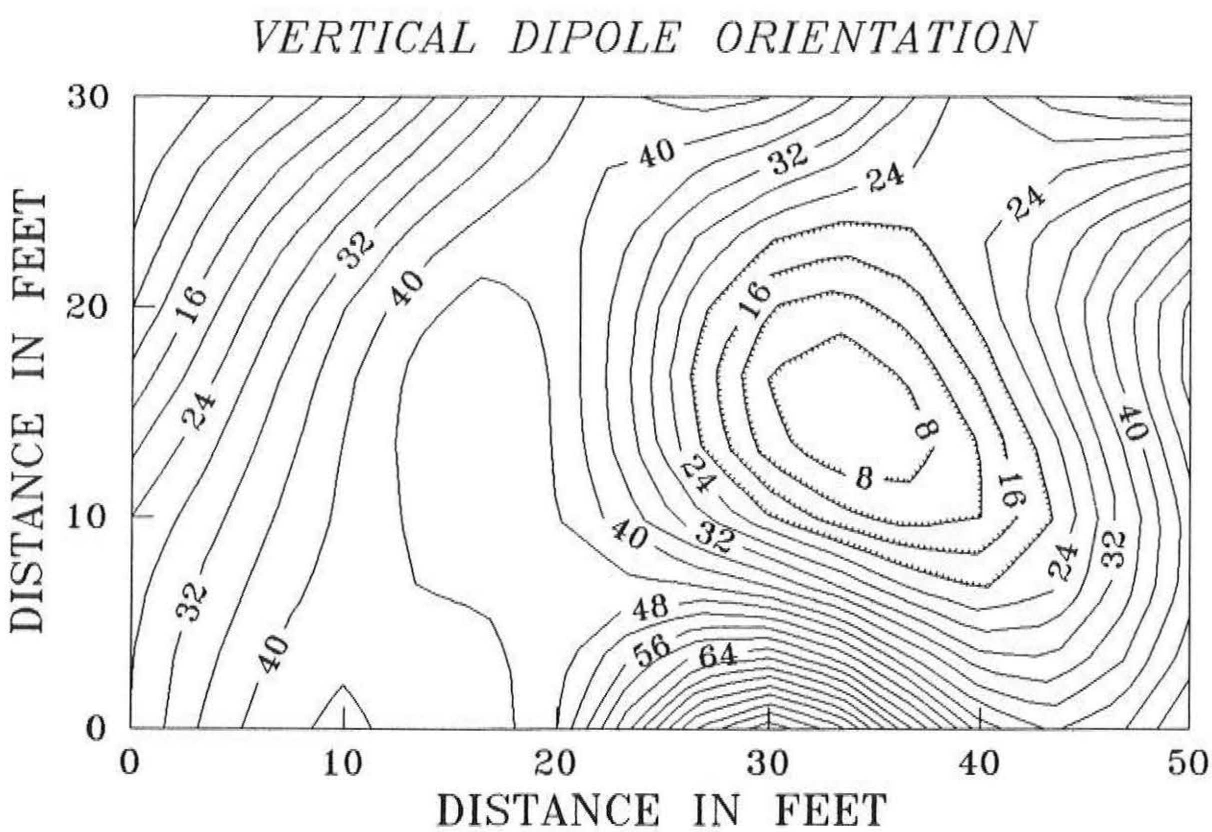


VERTICAL DIPOLE ORIENTATION



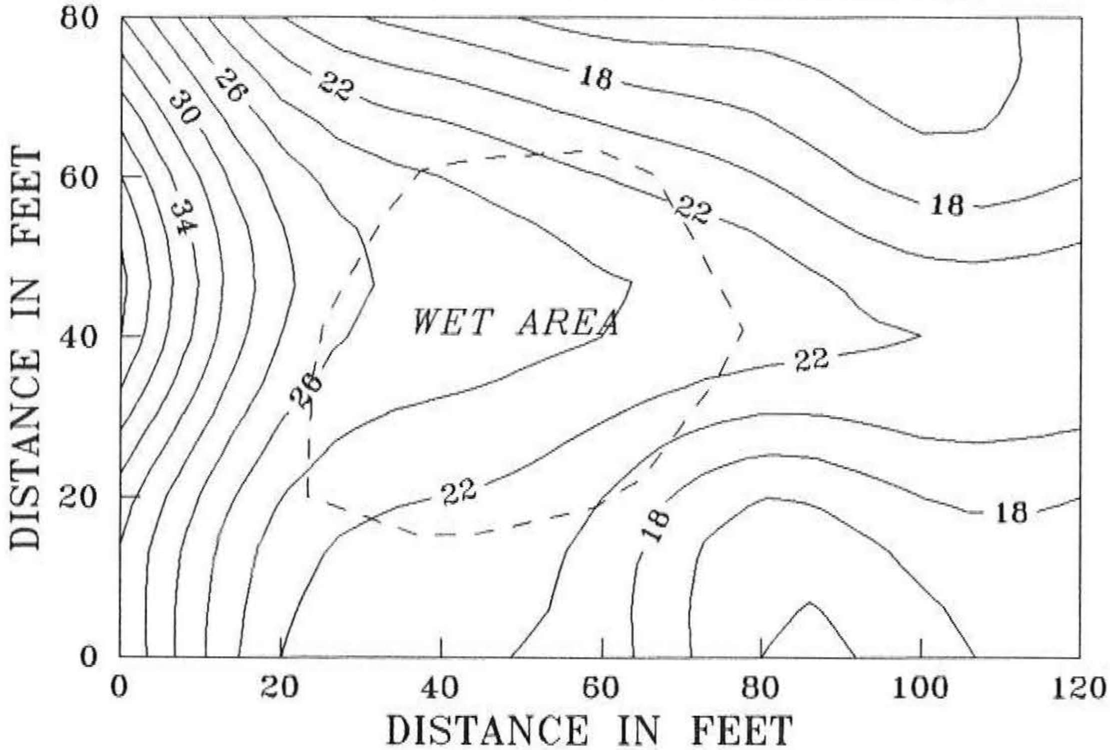
EM31 SURVEY - CAVE SPRING CEMETERY



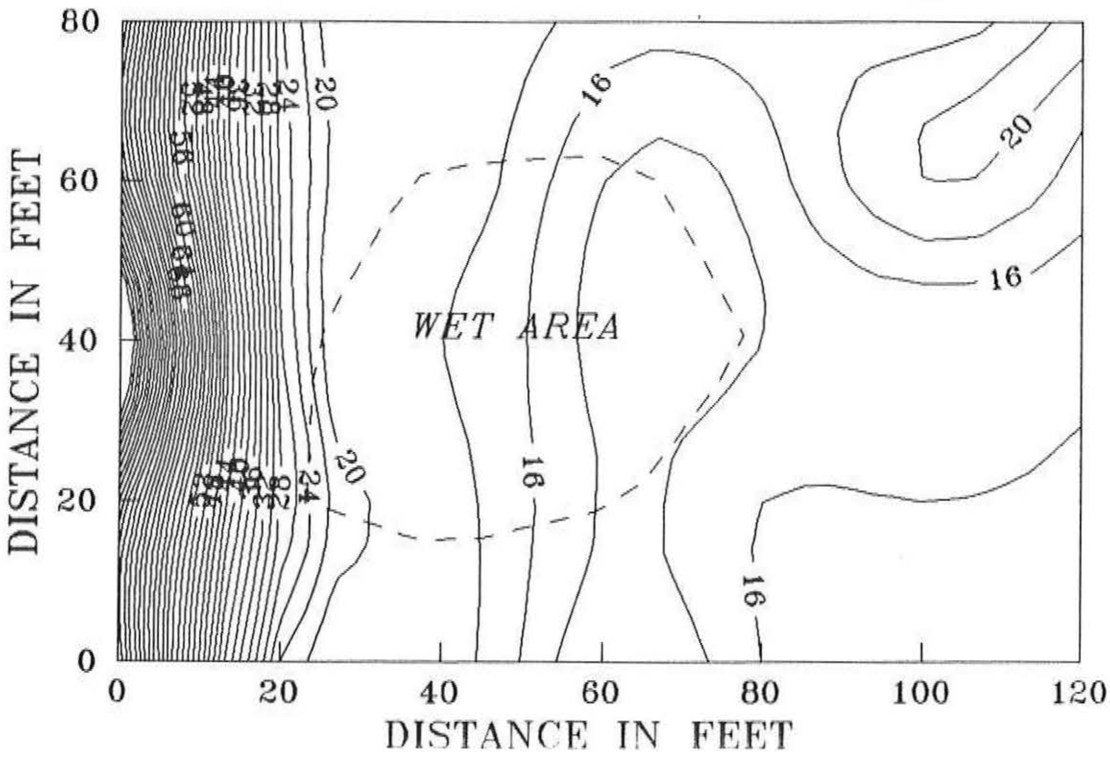


EM31 SURVEY - PRINCETON SEEPAGE STUDY

HORIZONTAL DIPOLE ORIENTATION

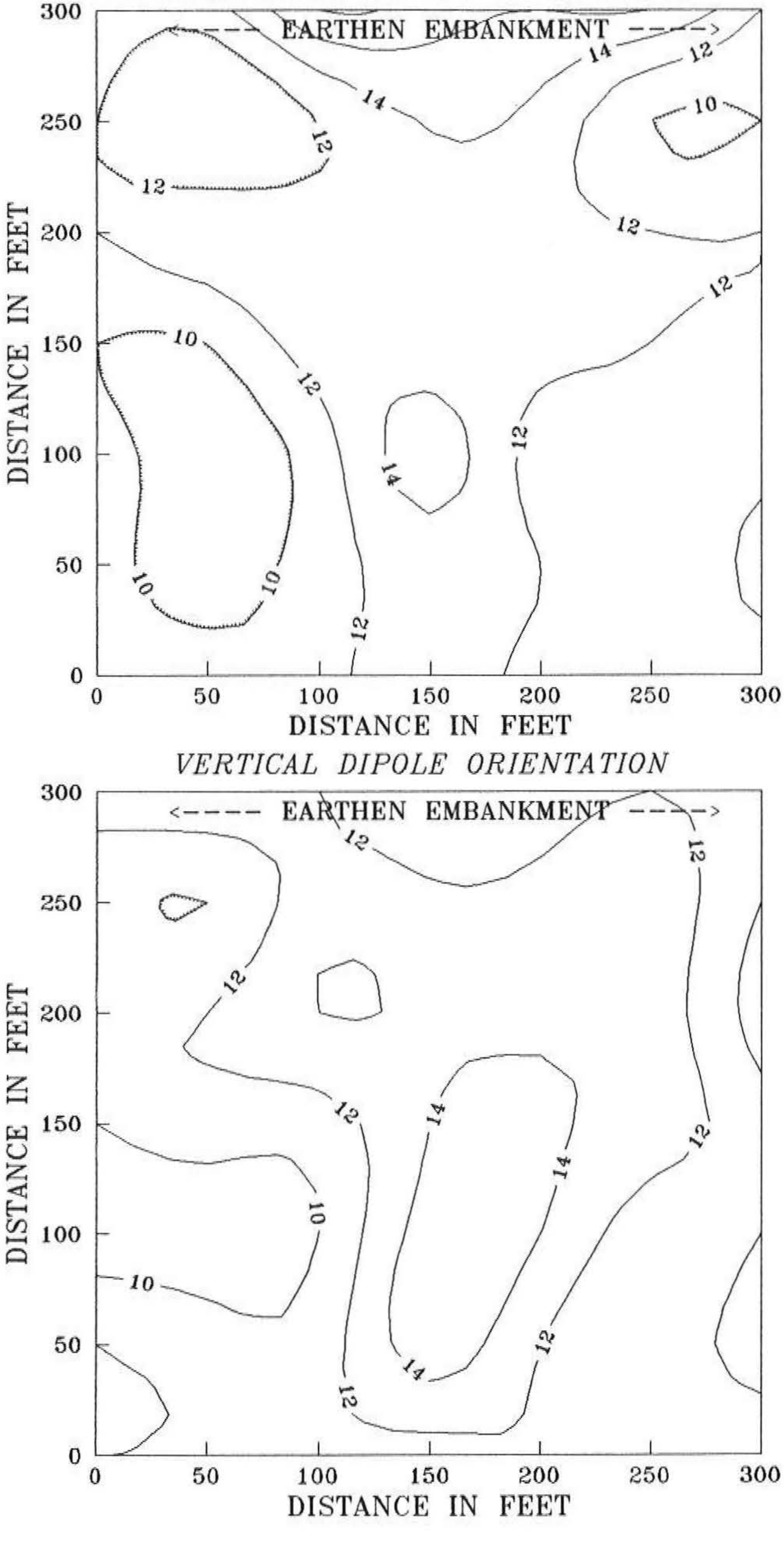


VERTICAL DIPOLE ORIENTATION



EM31 SURVEY - STEWART'S POND

HORIZONTAL DIPOLE ORIENTATION



EM Demonstration
Heath Farms

Graves County, Kentucky

N

A1

Fragipan 22-40"
No gravel 66" TDH

9

Fragipan 22-40"
Roxanna loess 40-60"
Gravel @60"

10

Fragipan 24-38"
Roxanna loess 40-64" TDH

1

Fragipan 17-33"
33-65" Roxanna loess
Encountered gravel @59"

8

Fragic character 19-37"
Roxanna loess contact @24"
Gravel @56"

11

Fragipan 19-34"
Roxanna loess 24-62" TDH
Trace of small pebbles
in lower 4"

2

Fragipan 6-17"
Gravel at 25"

7

Weak fragipan 13-32"
Roxanna loess @32-40"
Gravel @40"

12

Fragipan @7-23"
Roxanna loess 23-64" TDH
No Gravel

3

Weak fragic character
from 10-24"
Gravel at 25"

6

Weak fragic character
from 21-34"
Gravel at 37"

13

Fragic properties 11-16"
Roxanna loess 16-31"
Gravel below 31"

4

Loess alluvium 0-42"
Gravel at 42"

5

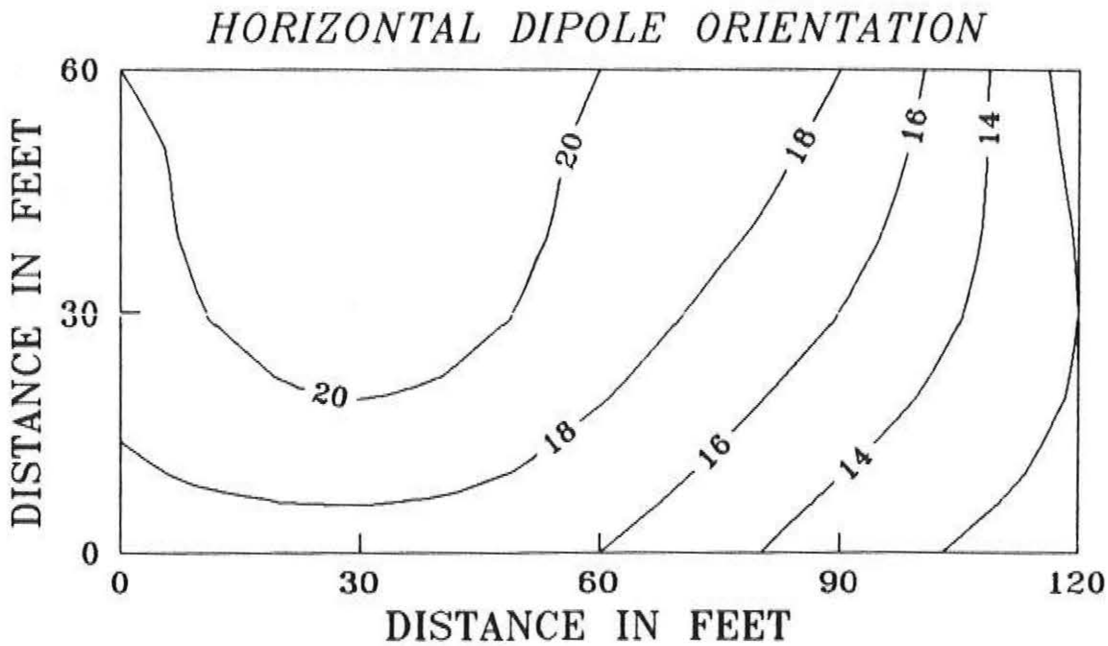
Silty alluvium 0-40"
Gravel at 40"

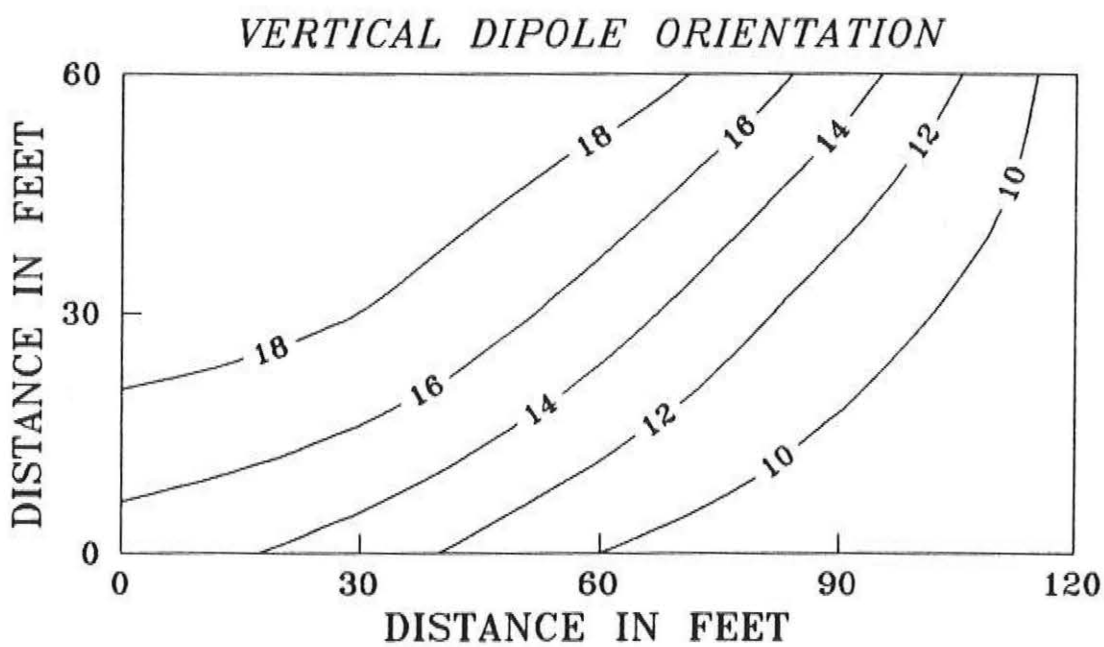
14

Lower sideslope/footslope
No Pan...loess to 34"
Gravel below 34"

FIGURE 10

EM31 SURVEY - FRAGIPAN STUDY





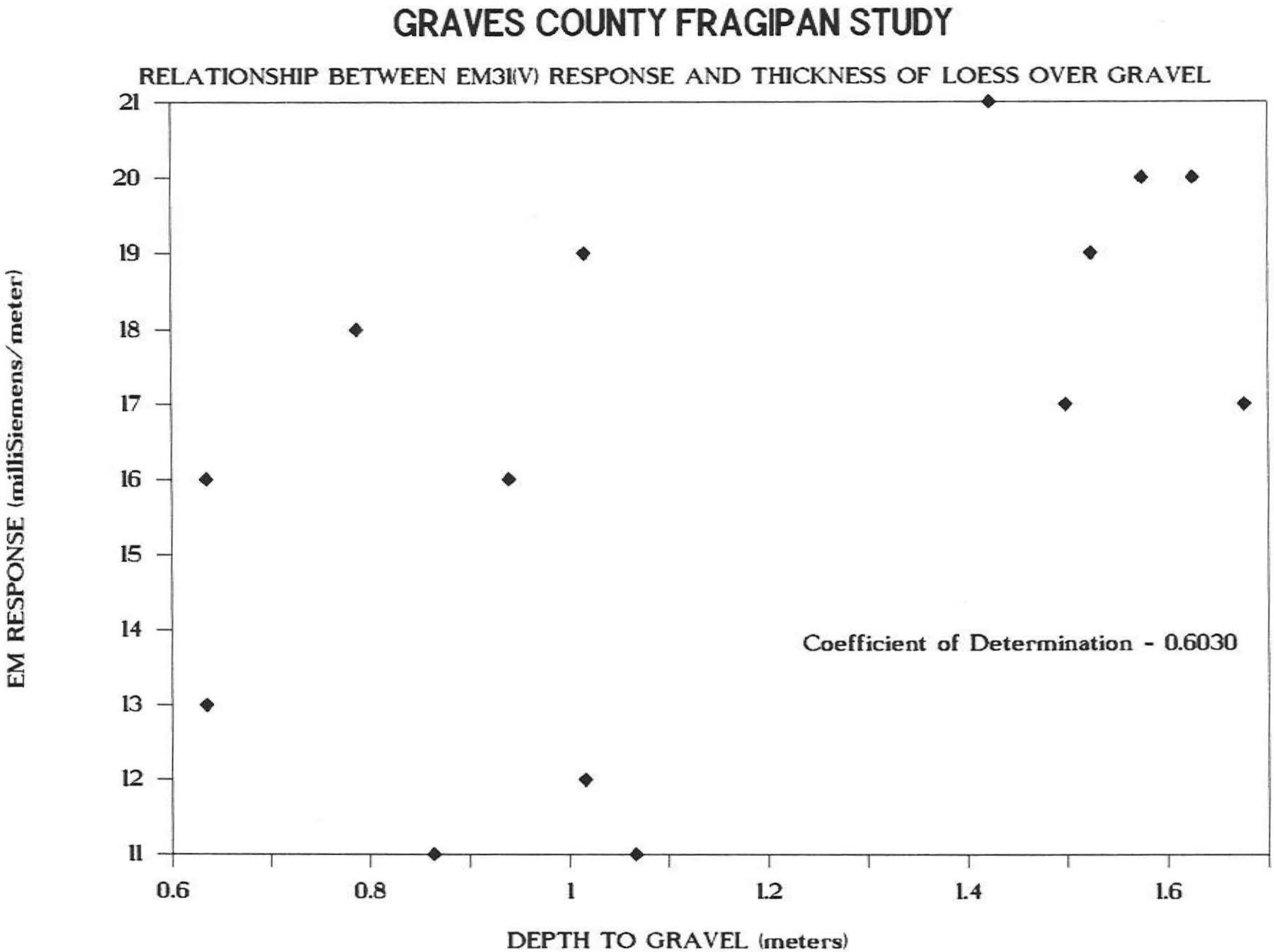

GRAVES COUNTY FRAGIPAN STUDY
RELATIONSHIP BETWEEN EM31(V) RESPONSE AND THICKNESS OF LOESS OVER GRAVEL
EM RESPONSE (milliSiemens/meter)
21
20
19
18
17
16
15
14
13
12
11
0.6
0.8
1
1.2
1.4
1.6
DEPTH TO GRAVEL (meters)
Coefficient of Determination - 0.6030

FIGURE 11

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. This technique has been used extensively to monitor groundwater quality and potential seepage from waste sites (Brune and Doolittle, 1990; Byrnes and Stoner, 1988; Be Rose, 1986; Greenhouse and Slaine, 1983; Greenhouse et al., 1987; and Siegrist and Hargett, 1989)

For surveying, the 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 milliSiemen 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).

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. Williams and Baker (1982), and Williams (1983) observed that, in areas of salt affected soils, 65 to 70 percent of the variation in measurements could be explained by the concentration of soluble salts. However, as water provides the electrolytic solution through which the current must pass, a threshold level of moisture is required in order to obtain meaningful results (Van der Lelij, 1983).

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 and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

TABLE 1

Depth of Measurement

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM31	3.7m	2.75m	6.0m
EM38	1.0	0.75	1.5m

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.

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