United States Department of Agriculture

Natural Resources Conservation Service

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Subject: ENG -- Electromagnetic Induction (EMI) Assistance **Date:** 1 November 1996

To: Janet Oertly
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Purpose:
The purpose of this investigation was to conduct EMI surveys at several animal waste facilities in northeast and south-central Pennsylvania.

Participants:
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Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA
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Donald Haines, Engineering Technician, USDA-NRCS, Bloomsburg, PA
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Edward Sokoloski, District Conservationist, USDA-NRCS, Clarks Summit, PA

Activities:
All field activities were completed during the period of 21 to 22 October 1996. Three waste facilities were surveyed; one in Lackawanna County and two in Dauphin County.

Equipment:
The electromagnetic induction meters used in this study were the EM38, EM31 and EM34-3, manufactured by Geonics Limited. These meters are portable and require either one or two persons to operate. Principles of operation have been described by McNeill (1980a, 1986). No ground contact is required with these meters. Each meter provides limited vertical resolution and depth information. For each meter, lateral resolution is approximately equal to the intercoil spacing. The observation depth of an EMI meter is dependent upon intercoil spacing, transmission frequency, and coil orientation. Table 1 lists the anticipated observation depths for the meters with different intercoil spacing and coil orientations. Observation depths can be varied by changing coil orientation, intercoil spacing, and/or frequency.

The EM38 meter has a fixed intercoil spacing of about 1.0 meter. It operates at a frequency of 13.2 kHz. The EM38 meter has theoretical observation depths of about 0.75 and 1.5 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of about 3.67 meters. It operates at a frequency of 9.8 kHz. The EM31 meter has theoretical observation depths of about 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980a). The EM34-3 meter consists of two coils and three

reference cables with intercoil spacings of about 10, 20, and 40 meters. One of the coils serves as the transmitter, the other as the receiver. Observation depths range from about 7.5 to 60 meters (McNeill, 1980a). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

TABLE 1

Depth of Measurement
(All measurements are in meters)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM38	1.0	0.75	1.5
EM31	3.6	3.0	6.0
EM34-3	10.0	7.5	15.0
	20.0	15.0	30.0
	40.0	30.0	60.0

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc.,* was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search. All grids were smoothed using a cubic spline interpolation. In most of the enclosed plots, to help emphasize spatial patterns, shadings and filled contour lines have been used. Other than showing trends and patterns in values of apparent conductivity (i.e., zones of higher or lower electrical conductivity), no significance should be attached to the shades themselves.

Discussion:

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the volumetric water content, type and concentration of ions in solution, temperature and phase of the soil water, and amount and type of clays in the soil matrix (McNeill, 1980b). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and earthen materials. Interpretations of the EMI data are based on the identification of spatial patterns within data sets. To assist interpretations, two- and three-dimensional computer simulations of the EMI data are normally developed.

Advantages of EMI include speed of operation, flexible observation depths, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This technique can provide in a relatively short time the large number of observations needed for the characterization and assessment of sites. Simulations prepared from correctly interpreted EMI data provide the basis for assessing site conditions and for designing sampling and monitoring schemes.

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* Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

Electromagnetic induction is not suitable for use in all investigations. Generally, the use of EMI has been most successful in areas where subsurface properties are reasonably homogeneous. This technique is most effective in areas where the effects of one property (e.g., clay, water, or salt content) dominate over the other properties and variations in EMI response can be related to changes in the dominant property (Cook et al., 1989). Electromagnetic induction has been used in groundwater investigations (McNeill, J. D. 1991) and to investigate the migration of contaminants from waste sites (Brune and Doolittle, 1990; Radcliffe et al., 1994; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988).

Results:

Lackawanna County -- 21 October 1996

Site # 1

The site was located near Milwaukee in Lackawanna County. The site consisted of a filter strip and a diversion. Principal soils mapped within the site include members of the Bath, Lackawanna, and Wellsboro series. These soils are members of the coarse-loamy, mixed, mesic Typic Fragiochrepts family. At the time of the survey, soils were saturated.

The owner has a hog and chicken operation. This operation is confined to a relatively small parcel of land. The filter-strip has been in operation for less than one year and supports a large hog operation. From May to November, about 350 to 400 hogs are cycled through this operation.

An irregularly shaped grid was established across the site. Grid intervals were 25 and 50 feet. At each of the ninety-six grid intersections, survey flags were inserted in the ground and served as observation point. At each observation point, the surface elevation was determined with a level and stadia rod. Elevations were tied into a benchmark. At most observation points, measurements were taken with an EM38 meter and an EM31 meter placed on the ground surface. Measurements were taken with the EM38 meter in the vertical dipole orientation. Measurements were taken with the EM31 meter in both the horizontal and vertical dipole orientations. At several observation points EMI measurements were not taken or were later removed from the data set because of noticeable interference from cultural features (metallic objects, fence lines, buried utility line, or buildings). These features were most numerous near the filter field.

The topography of the survey area has been simulated in the two-dimensional contour plot shown in Figure 1. In Figure 1, the contour interval is 2 feet. Relief was about 48 feet. The locations of the hog shed, manifold pipe, and chicken barn are shown in Figure 1 (and in each succeeding plot of the site). The landowner's home is located immediately below the lower right-hand corner of the survey area. The filter field extends about 100 feet down slope from the manifold pipe. A diversion forms the upper right-hand boundary (about 200 feet) of the survey area. Before the construction of the filter field, manure had been piled in the area to the immediate right of the hog sheds.

Figure 2 represents the spatial distribution of apparent conductivity within the upper 1.5 of the soil profile. In this plot, the isoline interval is 3 mS/m. Values of apparent conductivity decrease in a down slope direction away from the hog sheds and the manifold pipe. The pattern is plume-like and suggests overland flow and the deposition of waste products in the surface layers. The plume is about 50 to 100 feet wide and can be traced down slope nearly 200 feet from the hog shed and nearly 125 feet from the manifold pipe. This is an extensive area. As manure had been previously piled (possibly for fifteen years) in the area to the right of the hog sheds, the source of this plume is unclear (previous manure piles, present waste disposal system, or both). The plume may be a relic feature from early land use. At the time of the survey, the right-hand end of the manifold pipe was open allowing wastes to flow. The high values of apparent conductivity (>24 mS/m) near this outlet are attributed to this source. Several anomalous values within the filter field were attributed to large metallic objects that were scattered on the surface and to a buried utility line.

Figures 3 and 4 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters, respectively. In both plots, a plume can be traced down slope from the hog sheds and the manifold pipe. These patterns suggest the possibility of overland flow and/or seepage of waste products from these structures. Theoretically, seepage and overland flow patterns should be plume-like, with decreasing values away from their sources. In the shallower-sensing, horizontal dipole orientation (see Figure 3) a fairly lengthy plume extends from these features to near the upper right-hand corner of the chicken barn. This delineation approximates overland flow patterns that were apparent in the field at the time of the survey. In the deeper-sensing, vertical dipole orientation (see Figure 4) the plume extends from the hog sheds to near the upper left-hand corner of the chicken barn. The alignment of this delineation closely parallels a buried utility line. Anomalies within this delineation may reflect metallic objects that littered the surface, proximity to the buried utility line, or possible seepage.

The EMI surveys of this site indicate that some wastes have probably been carried down slope by surface wash. In addition, the surveys suggest that potential for some deeper translocation of waste products near the hog sheds and beneath the filter field.

Figures 5, 6, and 7 provide alternative presentation of the data collected with the EMI meter. In each of these figures, a two-dimensional plot of apparent conductivity values has been overlaid upon a three-dimensional surface net diagram of the site. In each of these plots, the isoline interval is 3 mS/m. These figures hopefully provide a better opportunity to visualize the data and to appreciate the extent of the plume-like patterns.

Dauphin County -- 22 October 1996

Site # 1

The site was located northeast of Middletown, Dauphin County. The site contained an animal waste-holding facility for a dairy operation. A neighbor, whose house was located about 200 to 250 feet north of the waste-holding facility, had reported that his well was contaminated. The purpose of this survey was to assess the site for any indication of seepage from the waste-holding facility.

Principal soils mapped within the site include members of the Neshaminy series. Neshaminy soils are members of the fine-loamy, mixed, mesic Ultic Hapludalfs family. At the time of the survey, soils were saturated.

The survey area was located principally on the north side of the waste-holding facility. An irregularly shaped grid was established across the site. The grid interval was 25 feet. The survey area was extended about 75 to 100 feet into the neighbor's land. At each of the eighty-one grid intersections, a survey flag was inserted in the ground and served as an observation point. At each observation point, the surface elevation was determined with a level and stadia rod. Elevations were not tied into a benchmark. The lowest observation point was the 0.0 foot datum. At each observation point, measurements were taken with an EM31 meter, placed on the ground surface, in both the horizontal and vertical dipole orientations. At thirty-four observation points, measurements were taken with an EM34-3 meter (10-meter intercoil spacing) placed on the ground surface, in both the horizontal and vertical dipole orientations. These observation points were spaced at 50 foot intervals along each survey line. With both meters, some observations were omitted from the data set. At these observation points, interference from cultural features (fence lines or buried utility line) caused anomalous EMI response.

The topography of the survey area has been simulated in Figure 8. In Figure 8, the contour interval is 2 feet. Relief was about 21 feet. Within the survey area, the waste-holding facility occupied the highest-lying positions. The waste facility is located on the nose of a ridge that distributes surface runoff into two opposing directions. The locations of the waste-holding facility and fence lines have been shown in Figure 8 and each succeeding two-dimensional plot of the survey area. The lower-most fence line forms the boundary with the neighbor's property.

Figures 9 and 10 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters, respectively. In each plot, the isoconductivity interval is 5 mS/m. For these depth intervals, values of apparent conductivity decreased with increasing observation depths. Measurements averaged 38.6 mS/m and 35.9 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation, one-half of the observations had values of apparent conductivity between 30.7 and 46.9 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 31.2 and 40.5 mS/m. This trend is believed to principally reflect the concentration of animal waste on the soil surface. Within the survey area, salts, contained in animal wastes, are believed to be the dominant factor influencing the spatial and vertical distributions of apparent conductivity values.

The spatial patterns appearing in figures 9 and 10 are complex. These patterns are believed to reflect variations in soluble salt contents, moisture contents, soil depth (or depth to diabase bedrock), and to a lesser degree interference from cultural features. Some interference was caused by the fence lines. A buried utility line (to the house) is located in the lower left-hand corner of the study area. The location and orientation of the buried utility line were easily detected in the field with the EM31 meter. This feature is believed to be responsible for elevated measurements collected with the EM31 meter in these portions of the survey area (see figures 9 and 10).

In Figure 9, a belt of high apparent conductivity values (>40 mS/m) meanders across the survey area. The EM31 meter in the horizontal dipole orientation is highly sensitive to features and properties near the surface. Therefore, it is presumed that the source(s) of these elevated conductivity values was located in the surface layers. The sinuous zone of high apparent conductivity values (see Figures 9) closely follows an area that has been heavily trafficked by dairy cows. This area contains noticeably greater amounts of wastes and some ponded water. If waste products and excess water are the principal factors responsible for the higher conductivity values, it must be inferred from Figure 9 that overland flow is causing some waste products to be carried into the neighbor's land.

In Figure 10, several distinct, but detached zones of high apparent conductivity values (>40 mS/m) appear with the survey area. Along the left-hand margin of the plot (see Figure 10), a linear belt of high apparent conductivity values closely follows a wet area. Most of this area has been heavily trafficked by dairy cows. As relatively high values extend towards the waste-holding facility, this belt represents the best expression of a potential plume. What is lacking is a noticeable increase in conductivity near the structure. In the left-hand corner of Figure 10, a buried utility line is partially responsible for the higher apparent conductivity values (>50 mS/m). No clear explanation can be offered for the three separate areas of high (>40 mS/m) apparent conductivity values in the right-hand portion of Figure 10.

The EM31 meter provided little evidence of seepage from the waste-holding facility. Theoretically, seepage patterns should appear plume-like, with values of apparent conductivity increasing towards the waste-holding facility. As these patterns were not apparent and values often decreased towards the waste-holding facility, seepage could not be inferred from the EM31 data alone.

Figures 11 and 12 provide alternative presentation of the data collected with the EM31 meter. In each of these figures, a two-dimensional plot of apparent conductivity values has been overlaid upon a three-dimensional surface net diagram of the site. In each of these plots, the isoline interval is 5 mS/m. In each plot the location of the waste-holding facility has been shown. Also shown is the fence line that forms the boundary between the two neighbors' properties. These figures hopefully provide a better opportunity to visualize the data and to assess the site.

The EM31 meter provided little information suggesting seepage from the waste-holding facility. The theoretical maximum observation depth of the EM31 meter is 6 meters. Seepage could be occurring below this depth. However, such seepage would be undetectable with the EM31 meter. To help clarify whether deep seepage was occurring, a survey was conducted with an EM34-3 meter. This meter,

with a 10-meter intercoil spacing, provides theoretical observation depths of 7.5 and 15 meters in the horizontal and vertical dipole orientation, respectively.

Figures 13 and 14 represent the spatial distribution of apparent conductivity for the upper 7.5 meters and the upper 15 meters, respectively. In each plot, the isoconductivity interval is 5 mS/m. For the depth intervals, values of apparent conductivity decreased with increasing observation depths. Measurements averaged 26.1 mS/m and 20.1 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation, one-half of the observations had values of apparent conductivity between 24.0 and 28.5 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 16.0 and 22.5 mS/m. This trend is believed to principally reflect the thickness of the residual soil and the depth to diabase bedrock.

In Figure 13, a zone of comparatively high apparent conductivity values (>30 mS/m) extends away from the waste-holding facility. This zone is perpendicular to the slope contours (see Figure 8) and extends from the top of the embankment into a wet swale. The higher apparent conductivity values within this zone could be attributed to seepage, deeper depths to bedrock, or less likely, interference from the nearby fence lines. The pattern is confined to an area within about 50 feet of the waste-holding facility. Within the upper 7.5 meter, apparent conductivity drop to values of less than 20 mS/m before the property line.

In Figure 14, a zone of comparatively high apparent conductivity (>25 mS/m) extends away from the waste facility. Compared with the plume-like pattern evident in the horizontal dipole data, (see Figure 13), this plume-like pattern extends outwards from the structure on the opposite side of the ridge. This deeper zone of high conductivity values extends outwards from the structure as two coalescing plumes. In the larger plume, values of apparent conductivity increase toward the waste facility. A broad zone of moderate conductivity (20 to 25 mS/m) forms a belt surrounding most of the structure. In the left-hand portion of the survey area, this belt of moderate conductivity extends as a linear feature directly away from the structure and across the property line. Without some borehole observations, no interpretations of this feature can be offered.

The EM34-3 meter provided qualitative data that could support assumptions of deep seepage from the waste-holding facility. The data collected in the deeper-sensing vertical dipole orientation suggest seepage. However, these are merely interpretations that must be confirmed through borehole observations.

Figures 15 and 16 provide alternative presentation of the data collected with the EM34-3 meter. In each of these figures, a two-dimensional plot of apparent conductivity values has been overlaid upon a three-dimensional surface net diagram of the site. In each of these plots, the isoline interval is 5 mS/m. These figures hopefully provide a better opportunity to visualize the data and to assess the site.

Dauphin County -- 22 October 1996

Site # 2

The site was located near Royalton, Dauphin County. The site contained an animal waste-holding facility for a dairy operation. An EMI survey had been conducted on the site in September, 1990. Subsequent to this survey, the earthen structure had been completely lined with concrete.

Principal soils mapped within the site include members of the Duncannon series. Duncannon soils are members of the coarse-silty, mixed, mesic Ultic Hapludalfs family. At the time of the survey, soils were saturated.

The survey area was located in approximately the same location as the 1990 survey. An irregularly shaped grid was established across the site. The grid interval was 50 feet. [The 1990 survey had intervals of 25 and 50 feet, and a larger number of observations.] At each of the thirty-six grid

intersections, a survey flag was inserted in the ground and served as an observation point. At each observation point, the surface elevation was determined with a level and stadia rod. Elevations were not tied into a benchmark. The lowest observation point was the 0.0 foot datum. At each observation point, measurements were taken with an EM31 meter, placed on the ground surface, in both the horizontal and vertical dipole orientations.

The topography of the survey area has been simulated in Figure 17. In Figure 17, the contour interval is 2 feet. Relief was about 19.4 feet. The survey area contained a small intermittent drainageway. In the 1990 survey, higher values of apparent conductivity were observed within the drainageway. The location of the waste-holding facility has been shown in Figure 17 and each succeeding plot of the survey area.

Figures 18 and 19 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters, respectively. In each plot, the isoconductivity interval is 5 mS/m. In general, for these depth intervals, values of apparent conductivity decreased slightly with increasing observation depths. Measurements averaged 24.5 mS/m and 22.9 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation, one-half of the observations had values of apparent conductivity between 17.3 and 27.7 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 16.8 and 24.95 mS/m.

Compared with the 1990 data, measurements collected during the present survey were appreciable higher. In 1990, measurements collected with the EM31 meter in the horizontal dipole orientation ranged from 4 to 29 mS/m. For this survey, measurements collected with the EM31 meter in the horizontal dipole orientation ranged from 8 to 60 mS/m. In 1990, measurements collected with the EM31 meter in the vertical dipole orientation ranged from 3 to 26 mS/m. For this survey, measurements collected with the EM31 meter in the vertical dipole orientation ranged from 8 to 69 mS/m. Compared with 1990, soils were more saturated during the present survey. Greater moisture contents will increase values of apparent conductivity. However, the large increase in apparent conductivity values observed during the present survey cannot be attributed to increased moisture contents alone. In addition, greater shifts in the range of apparent conductivity values were observed in the deeper-sensing, vertical dipole orientations. The higher values measured during the present survey can be attributed to more saturated soils, higher concentrations of salts within the drainageway, seepage of wastes from the facility, and near the waste-facility, possible interference from cultural noise associated with the structure (rebar, fence line). However, without some borehole or well logs, these are merely tentative assumptions.

In both plots (see figures 18 and 19), a conspicuous plume emanates from the eastern (right-hand) side of the waste facility. This plume was not apparent in 1990. The plume is better expressed with increased observation depth. In the shallower-sensing horizontal dipole orientation (Figure 18), the plume is detectable only within 50 feet of the waste-holding facility. With increased distance (>50 feet) the plume blends with the higher apparent conductivity (30 to 35 mS/m) associated with the drainageway and becomes indistinct. The plume is best expressed in the deeper-sensing vertical dipole orientation. In Figure 19, the plume appears fairly broad (>150 feet) and can be traced 25 to 150 feet away from the structure.

The EM31 meter provided qualitative data suggesting the occurrence of seepage from the waste-holding facility. Seepage was inferred from a large plume-like pattern that emanated from the waste-holding facility. Within this plume, conductivity decreased with increasing distance away from the waste-holding facility. This plume is best expressed in the plot of the deeper-sensing vertical dipole orientation.

The alteration of the structure has confused the interpretations. Change has introduced new variables (Was material moved? What is the effect of wire mesh or rebar within the concrete on EMI responses?). New and additional variables lead to uncertainties. Without more knowledge of the site

or well logs, these inferences are inconclusive. Does the present structure leak? Are the plume-like patterns related to the former structure? Are the plume-like patterns related to earth-moving and construction activities associated with the present structure? It is to be hoped that, Agricultural Engineers can use their knowledge, experiences, and insight to evaluate the EMI data and improve these interpretations.

Figures 20 and 21 provide alternative presentation of the data collected with the EMI meter. In each of these figures, a two-dimensional plot of apparent conductivity values has been overlaid upon a three-dimensional surface net diagram of the site. In each of these plots, the isoline interval is 5 mS/m. In each plot the location of the waste-holding facility has been shown. These figures hopefully provide a better opportunity to visualize the data and to assess the site.

Conclusions:

1. Simulations prepared from correctly interpreted EMI data provide the basis for assessing site conditions and for designing sampling and monitoring schemes.

   a. At the site in Lackawanna County, the EMI surveys indicate that some wastes have probably been carried down slope by surface wash. In addition, the survey suggested the potential for some deeper translocation of waste products near the hog sheds and beneath the filter field. A distinct, near-surface, plume-like pattern was evident in several data sets. The plume-like pattern was extensive. The plume was about 50 to 100 feet wide and could be traced down slope nearly 125 to 200 feet from the inferred sources. The pattern suggested overland flow and the deposition of waste products in the surface layers. As manure had been previously piled (possibly for fifteen years) near the present hog sheds, the source of this plume is unclear (previous manure piles, present waste disposal system, or both). The plume may be a relic feature from early land use.

   b. At Site # 1 in Dauphin County, apparent conductivity values were high in the surface layers. Areas of highest conductivity were in areas that had been heavily trafficked by dairy cows. This area contains noticeably greater amounts of wastes and some ponded water. The waste products and excess water were presumed to be the principal factors responsible for the higher conductivity values. Based on spatial patterns appearing in the computer simulations, it was inferred that overland flow is causing some waste products to be carried into a neighbor's land.

   The EMI surveys provided qualitative data that could support assumptions of deep seepage from the waste-holding facility. However, without some borehole observations, this is merely an interpretation. Zones of comparatively high apparent conductivity values appearing at greater observation depths could be attributed to seepage, different strata, deeper depths to bedrock, or less likely, interference from the nearby fence lines. Results remain ambiguous.

   c. At Site # 2 in Dauphin County, the EMI surveys provided qualitative evidence suggesting the occurrence of seepage from the waste-holding facility. Seepage was inferred from a large plume-like pattern that emanated from the waste-holding facility. Within this plume conductivity decreased with increasing distance away from the waste-holding facility. This plume is best expressed in the plot of the deeper-sensing vertical dipole orientation. A comparison of present data with 1990 data would suggest that the effects of seepage are more apparent and extensive today. However, because of recent construction, I feel uneasy with this interpretation.

2. Interpretations must be confirmed with borehole observations or monitoring wells.

3. Additional surveys are recommended to assist engineers evaluate the integrity of our designs and practices in Pennsylvania.

As always, it was sincere pleasure to work in our state and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

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LACKAWANNA COUNTY
SITE #1

RELATIVE TOPOGRAPHY

Contour Interval = 2 Feet

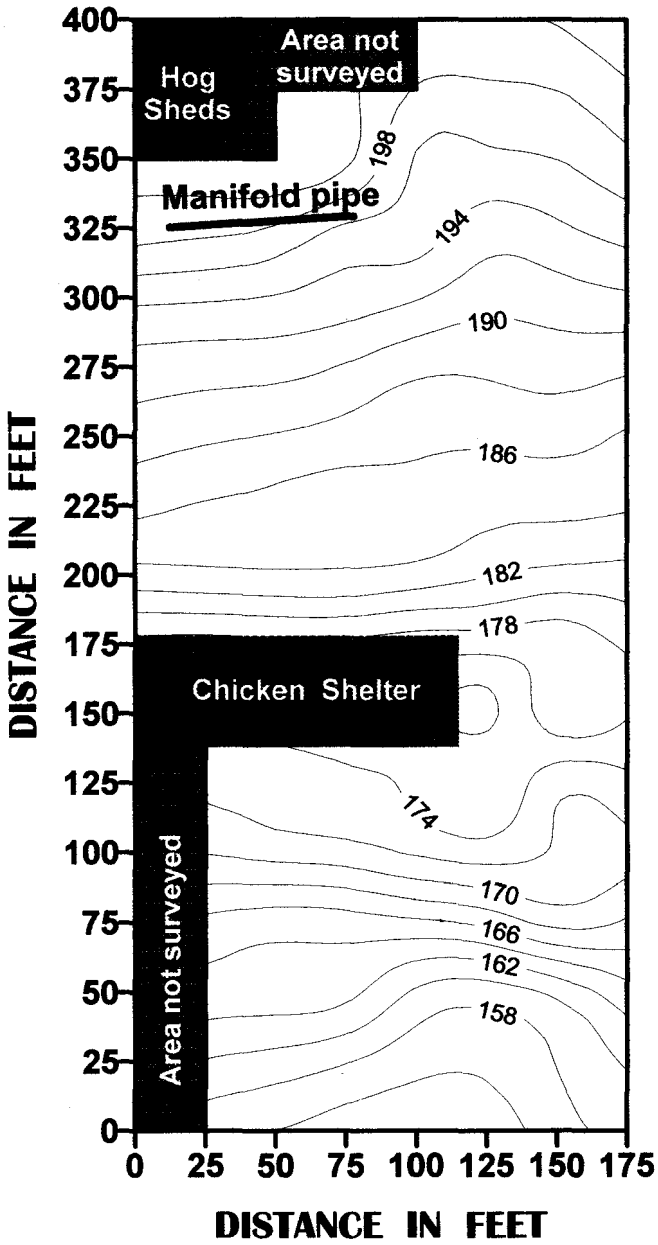


Figure 1

LACKAWANNA COUNTY
SITE #1

EM38 METER
VERTICAL DIPOLE ORIENTATION

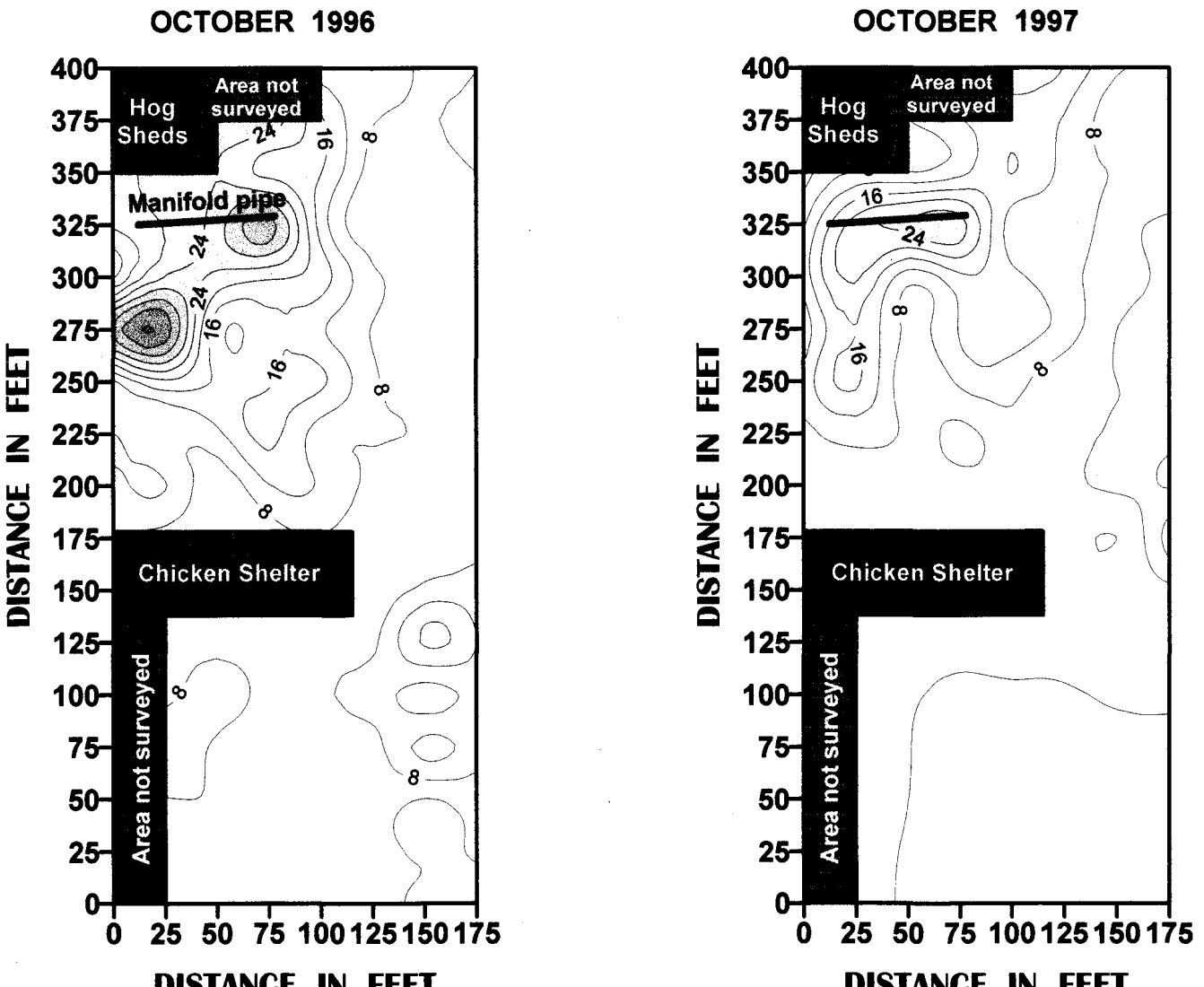


Figure 2

LACKAWANNA COUNTY
SITE #1

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

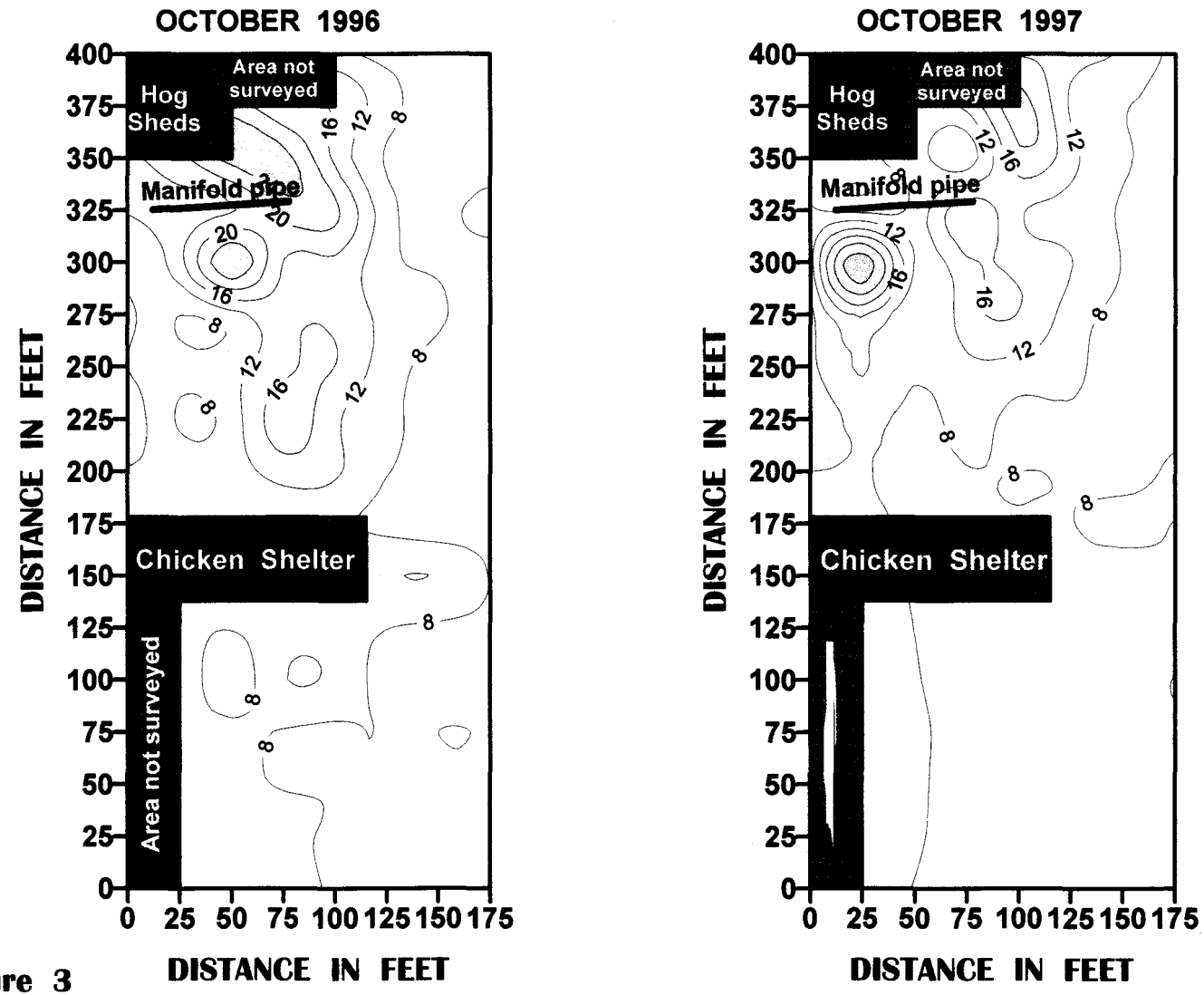


Figure 3

LACKAWANNA COUNTY
SITE #1

EM31 METER
VERTICAL DIPOLE ORIENTATION

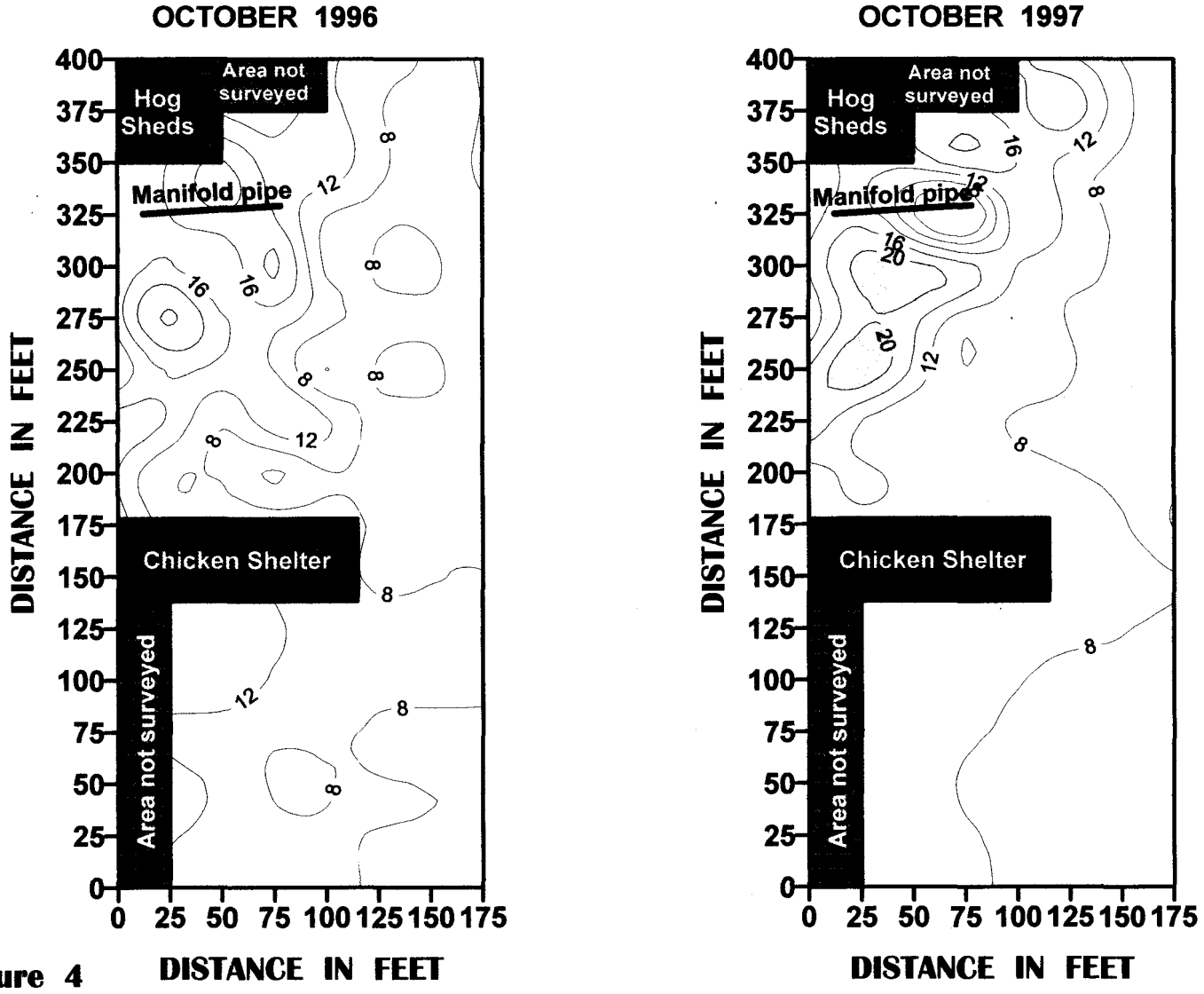


Figure 4

NORTHUMBERLAND COUNTY
SITE # 1

RELATIVE TOPOGRAPHY

Contour Interval = 1 foot

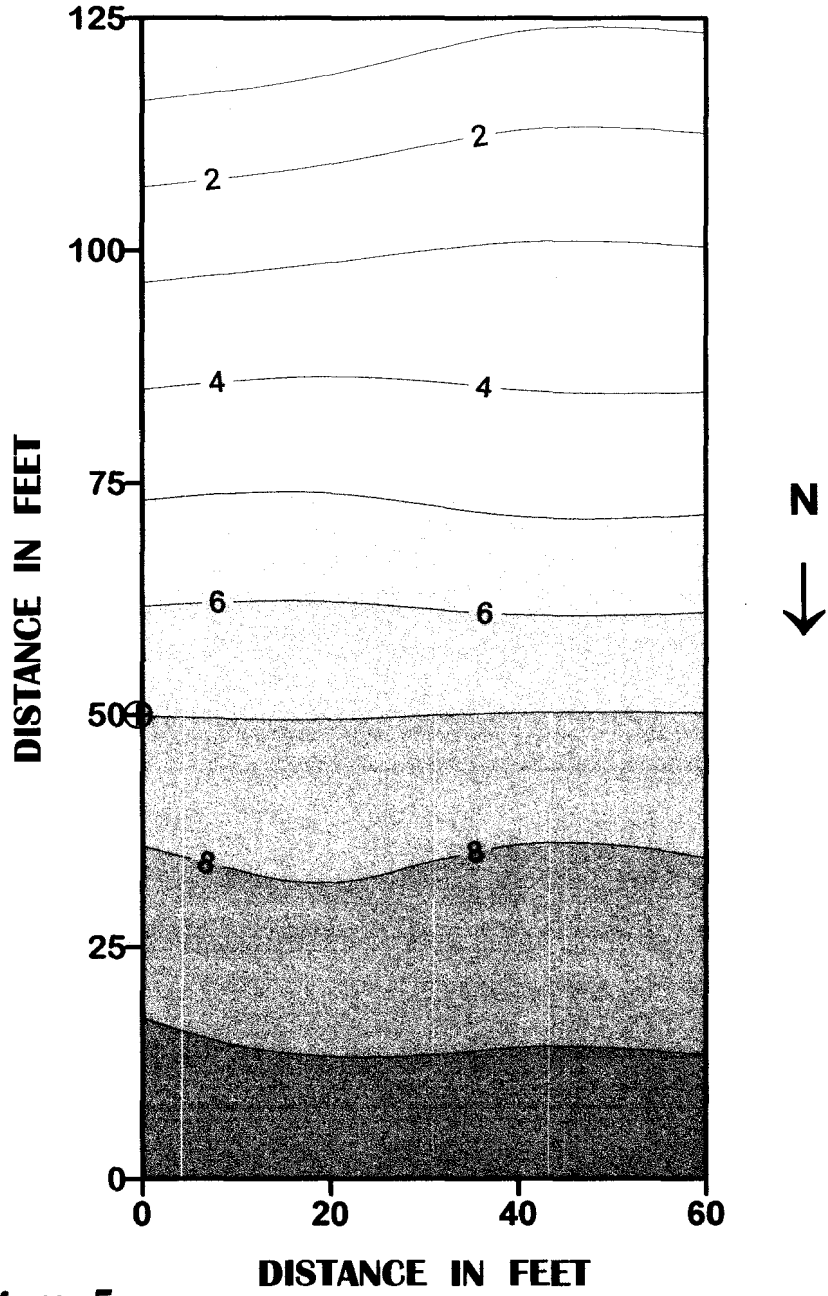


Figure 5

⊕ Power pole

NORTHUMBERLAND COUNTY
SITE # 1

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

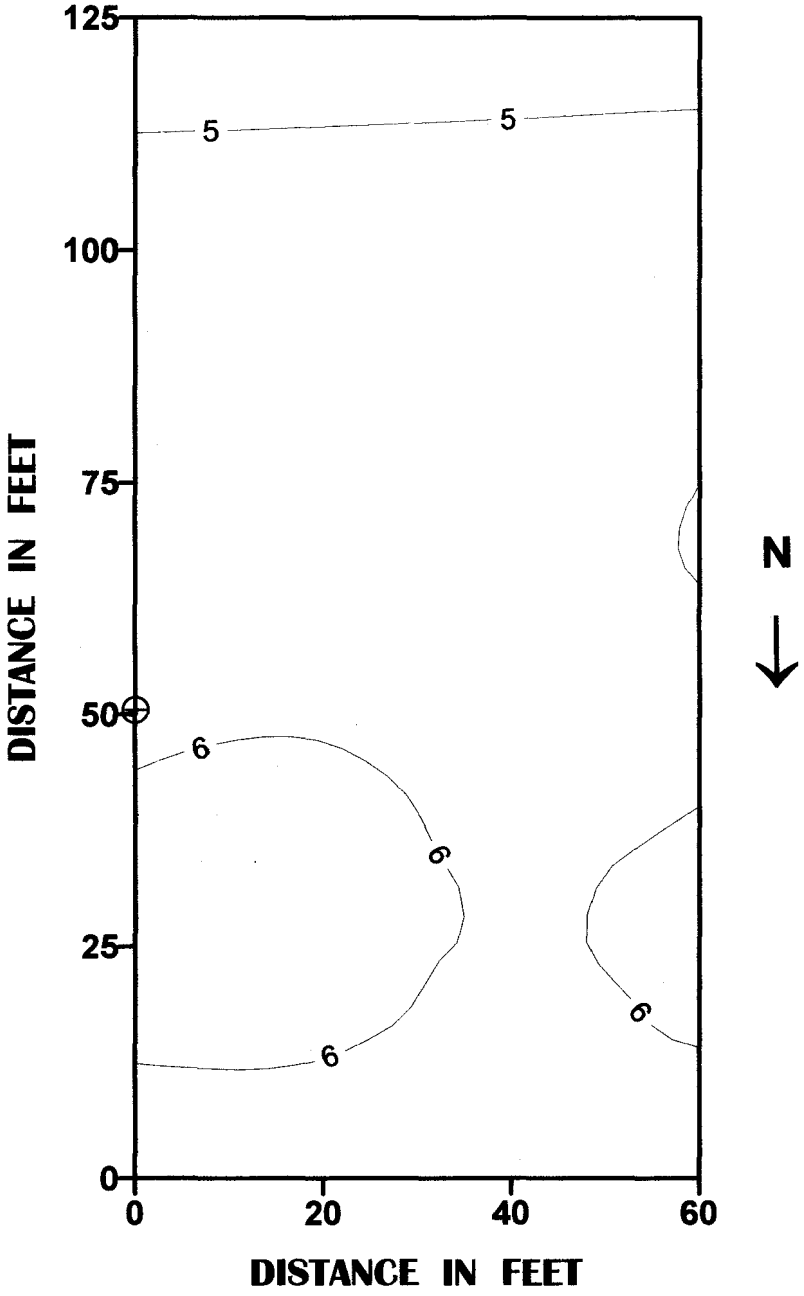


Figure 6

⊕ Power pole

NORTHUMBERLAND COUNTY
SITE # 1

EM31 METER
VERTICAL DIPOLE ORIENTATION

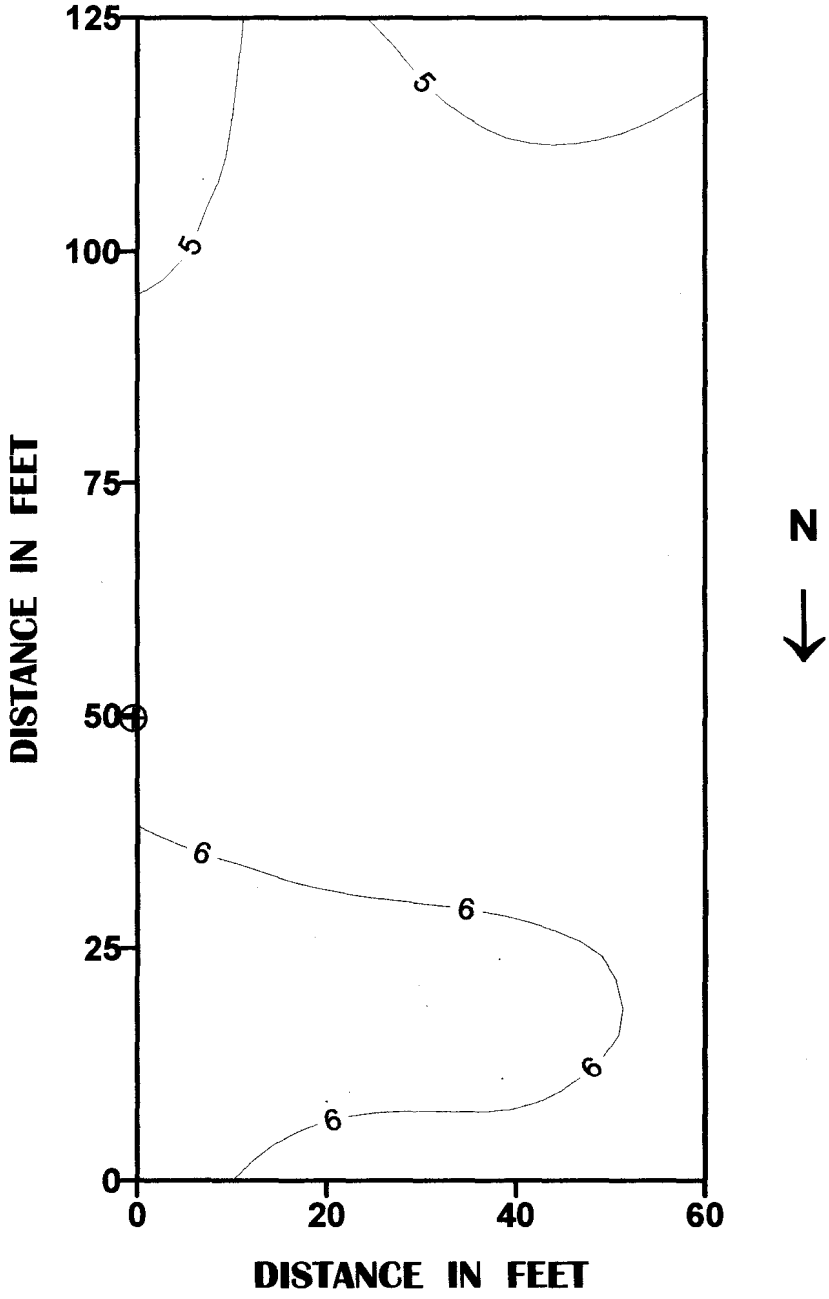


Figure 7

⊕ Power pole

DAUPHIN COUNTY
SITE # 1

RELATIVE TOPOGRAPHY

Contour Interval = 2 feet

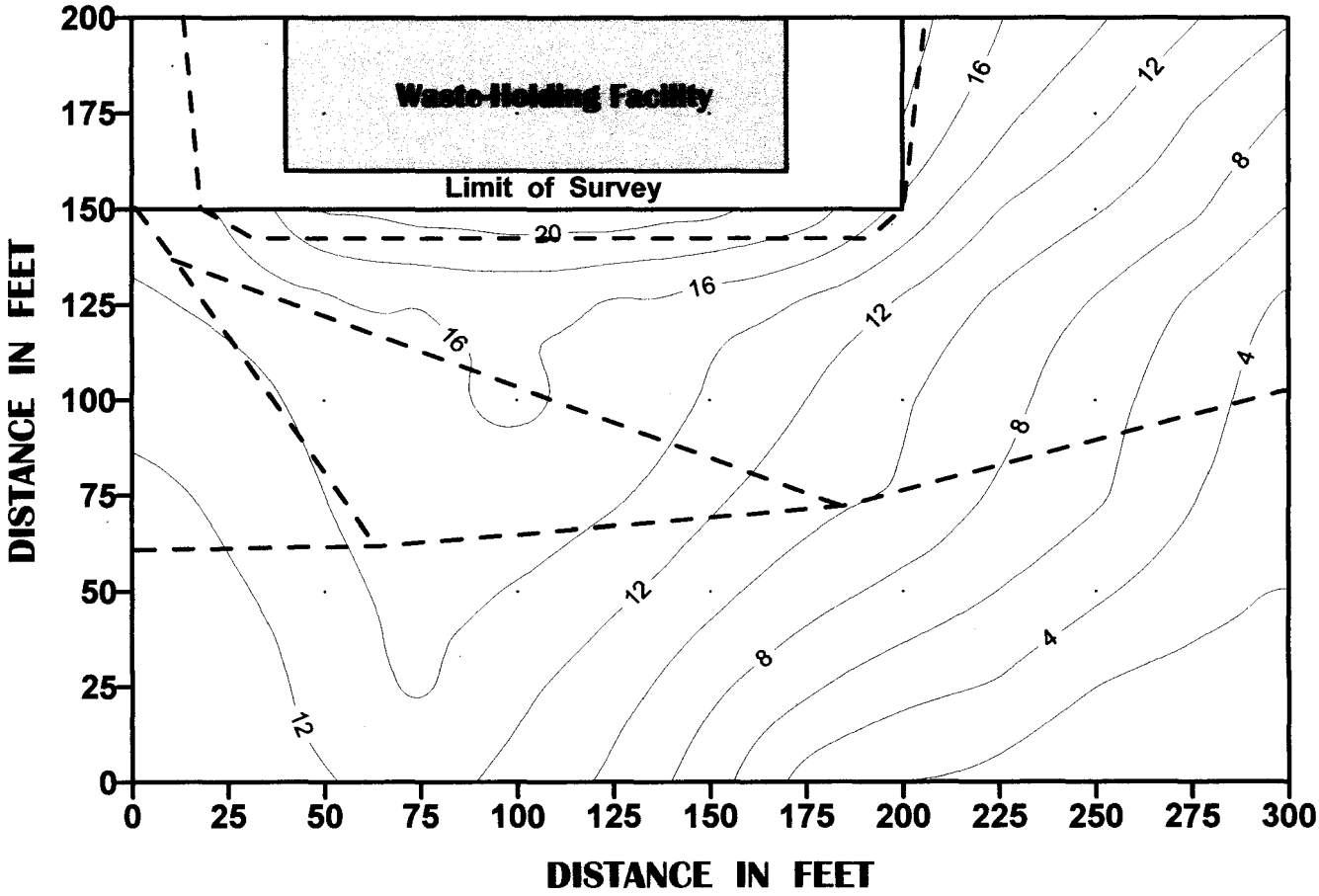


Figure 8

DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM31 METER
HORIZONTAL DIPOLE ORIENTATION

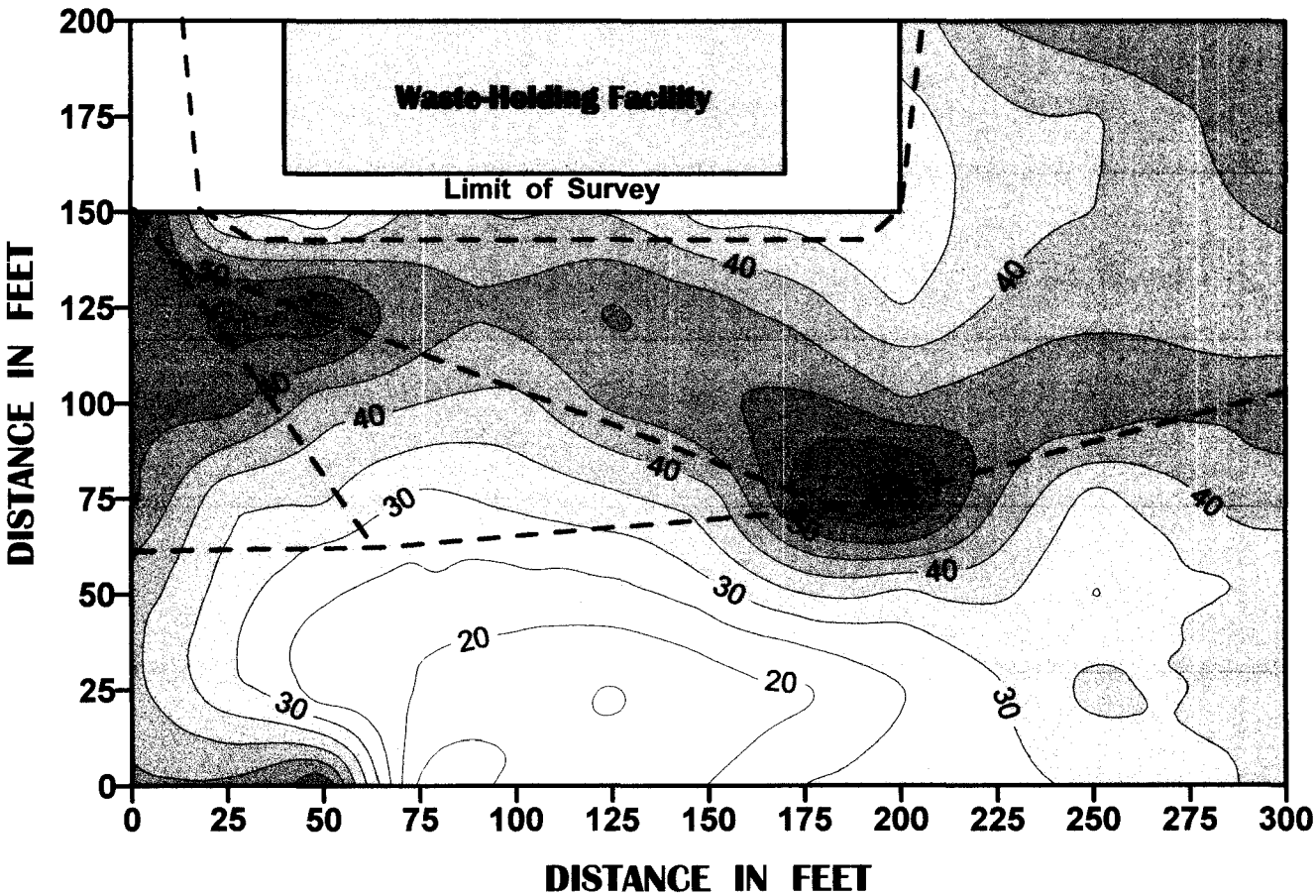


Figure 9

DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM31 METER
VERTICAL DIPOLE ORIENTATION

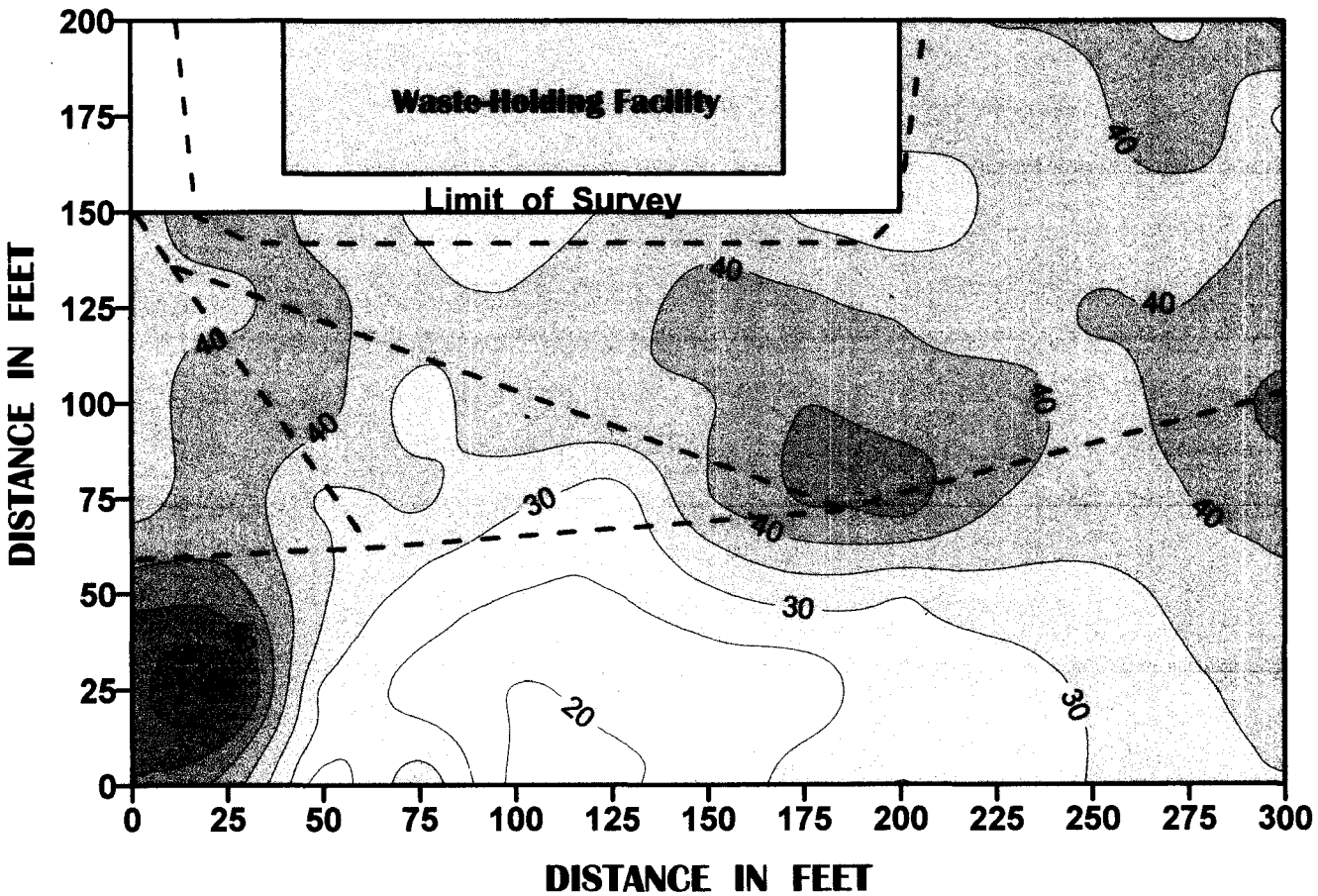


Figure 10

DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM31 METER
HORIZONTAL DIPOLE ORIENTATION

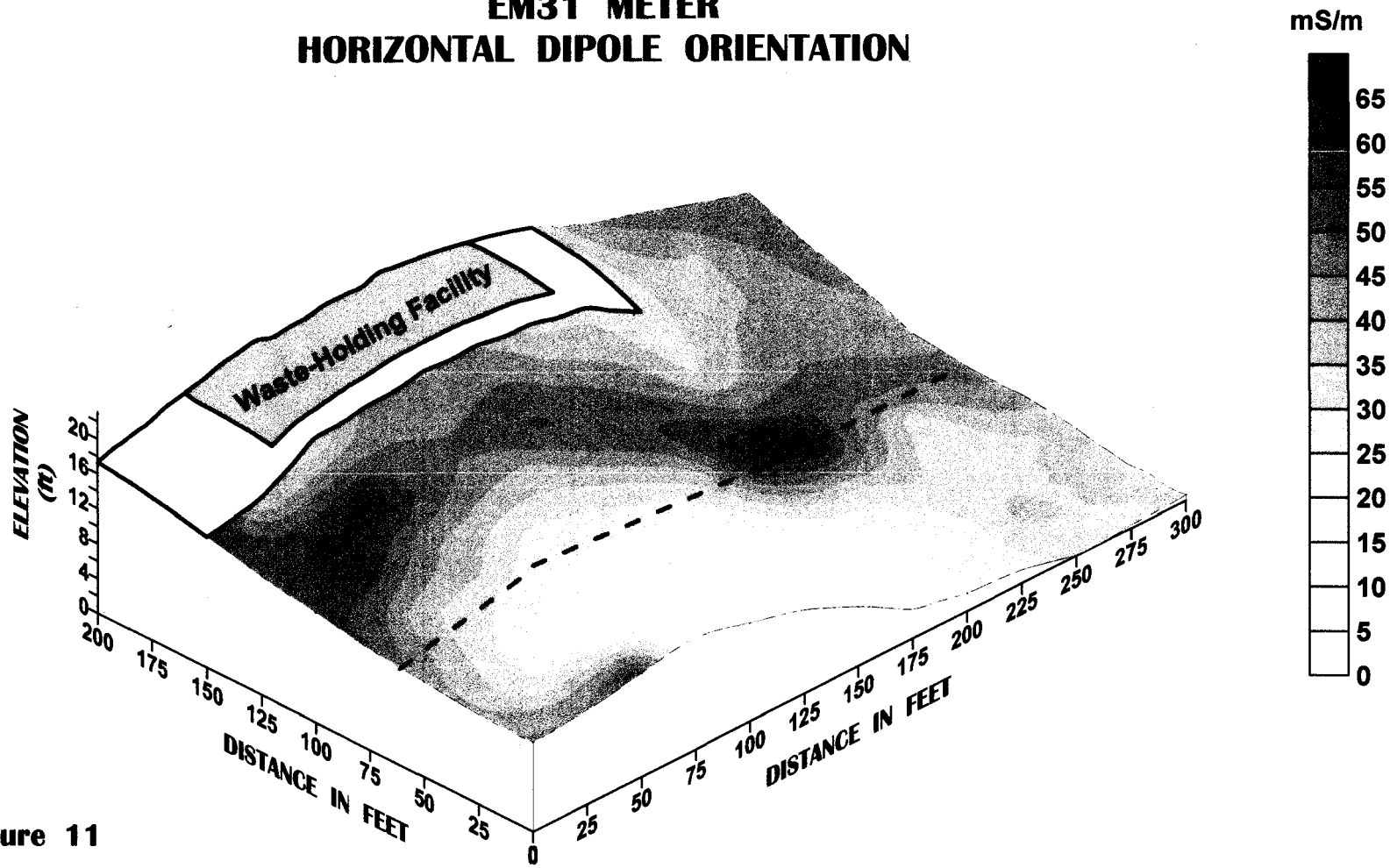


Figure 11

DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM31 METER
VERTICAL DIPOLE ORIENTATION

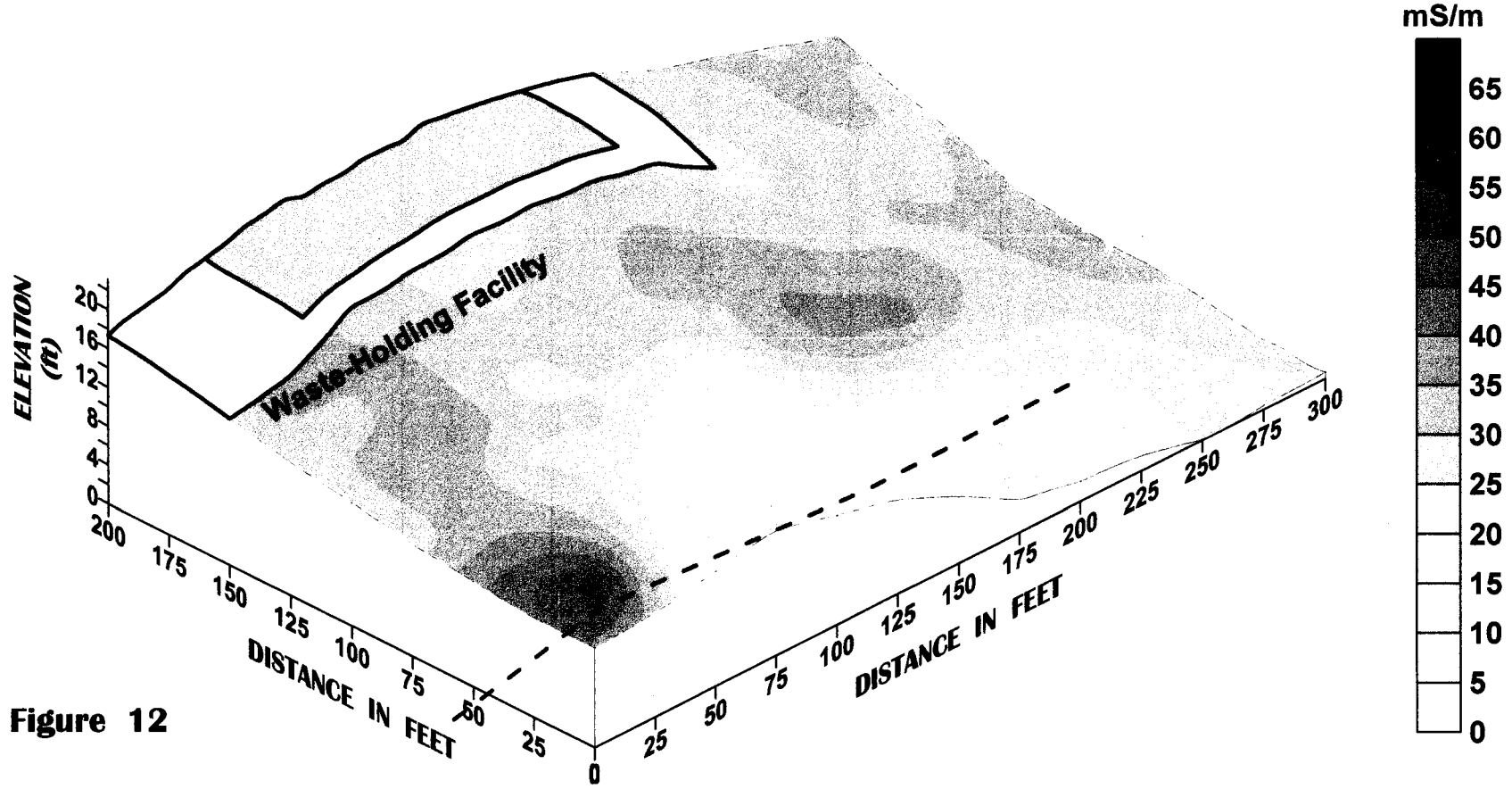
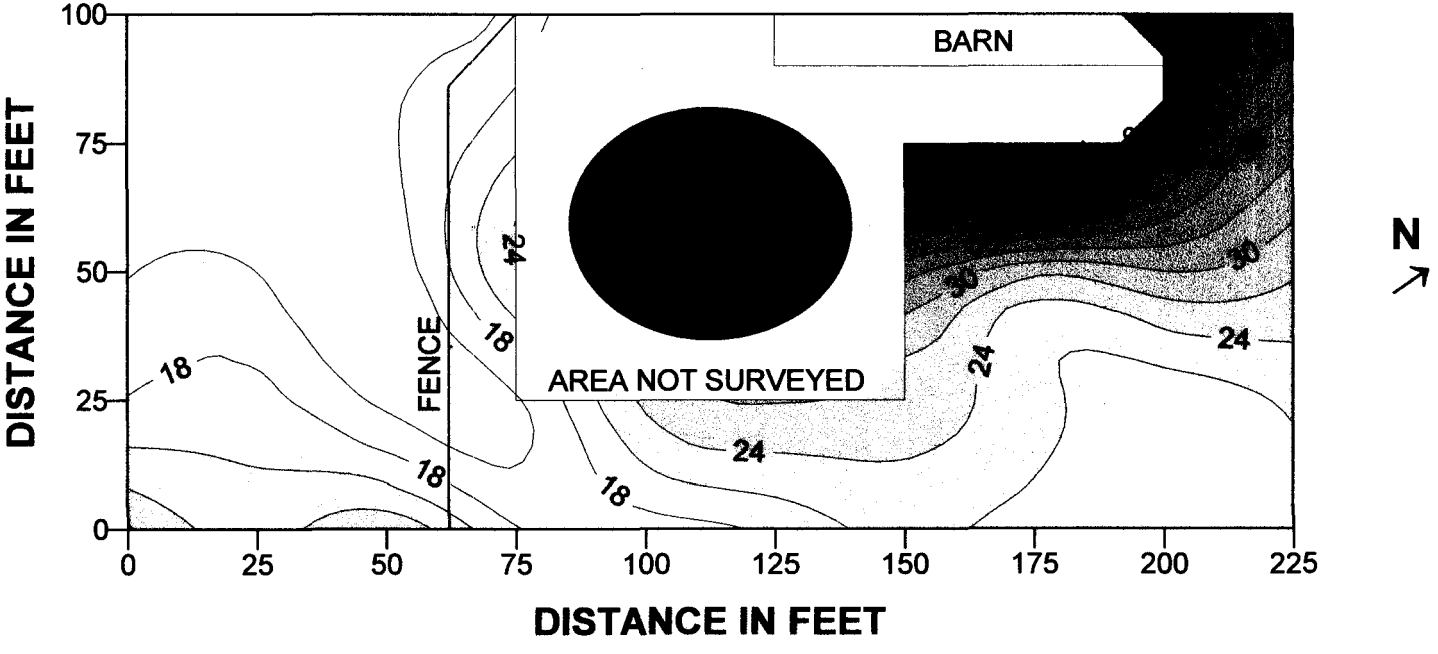
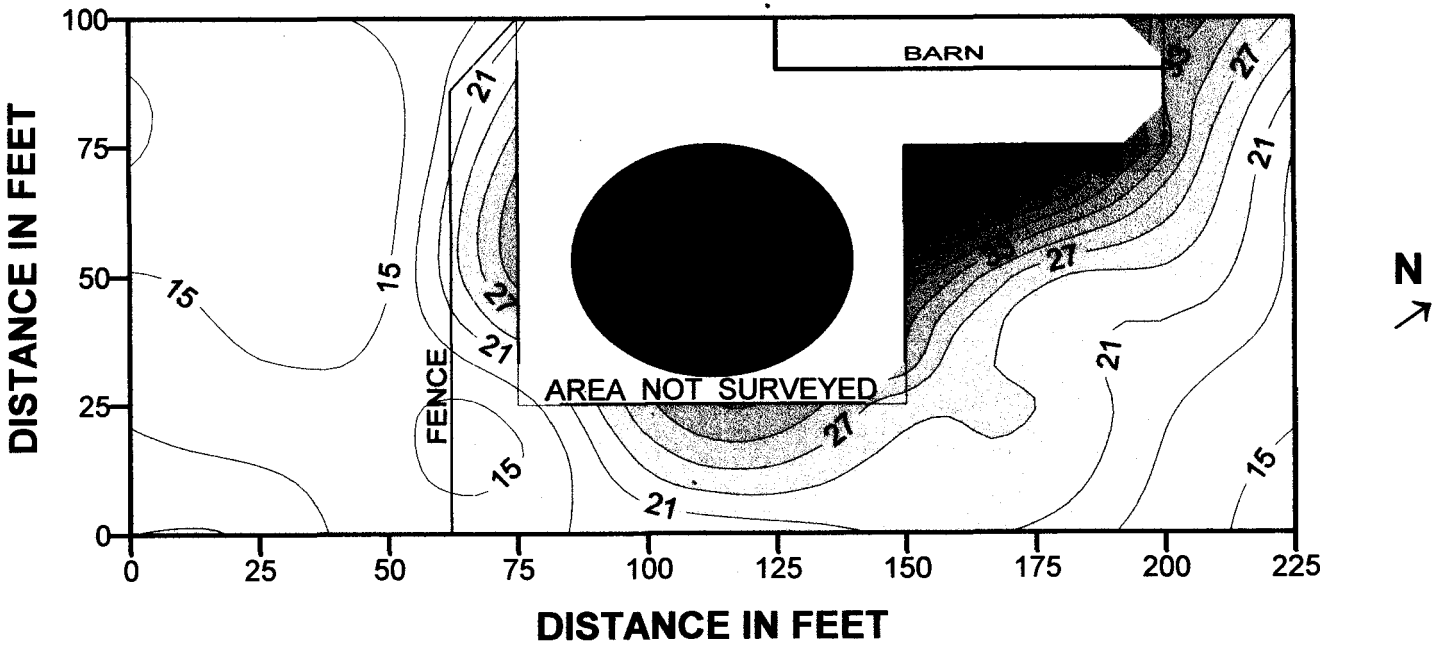


Figure 12

EM SURVEY AT ARNOLD'S FARM
EM31 METER
HORIZONTAL DIPOLE ORIENTATION



EM SURVEY AT ARNOLD'S FARM
EM31 METER
VERTICAL DIPOLE ORIENTATION



DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM34-3 METER
HORIZONTAL DIPOLE ORIENTATION
10 METER INTERCOIL SPACING

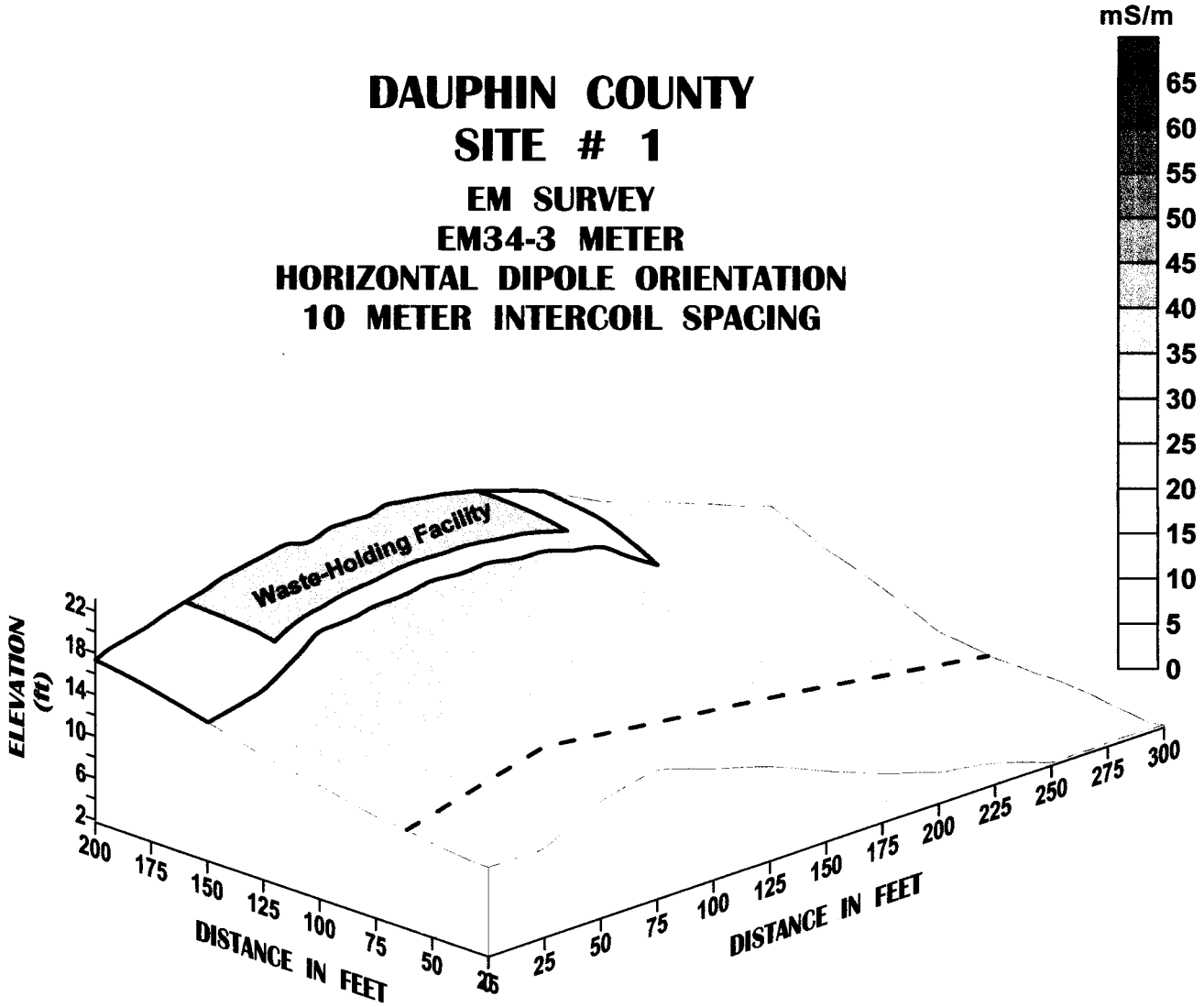


Figure 15

DAUPHIN COUNTY
SITE # 1

EM SURVEY
EM34-3 METER
VERTICAL DIPOLE ORIENTATION
10 METER INTERCOIL SPACING

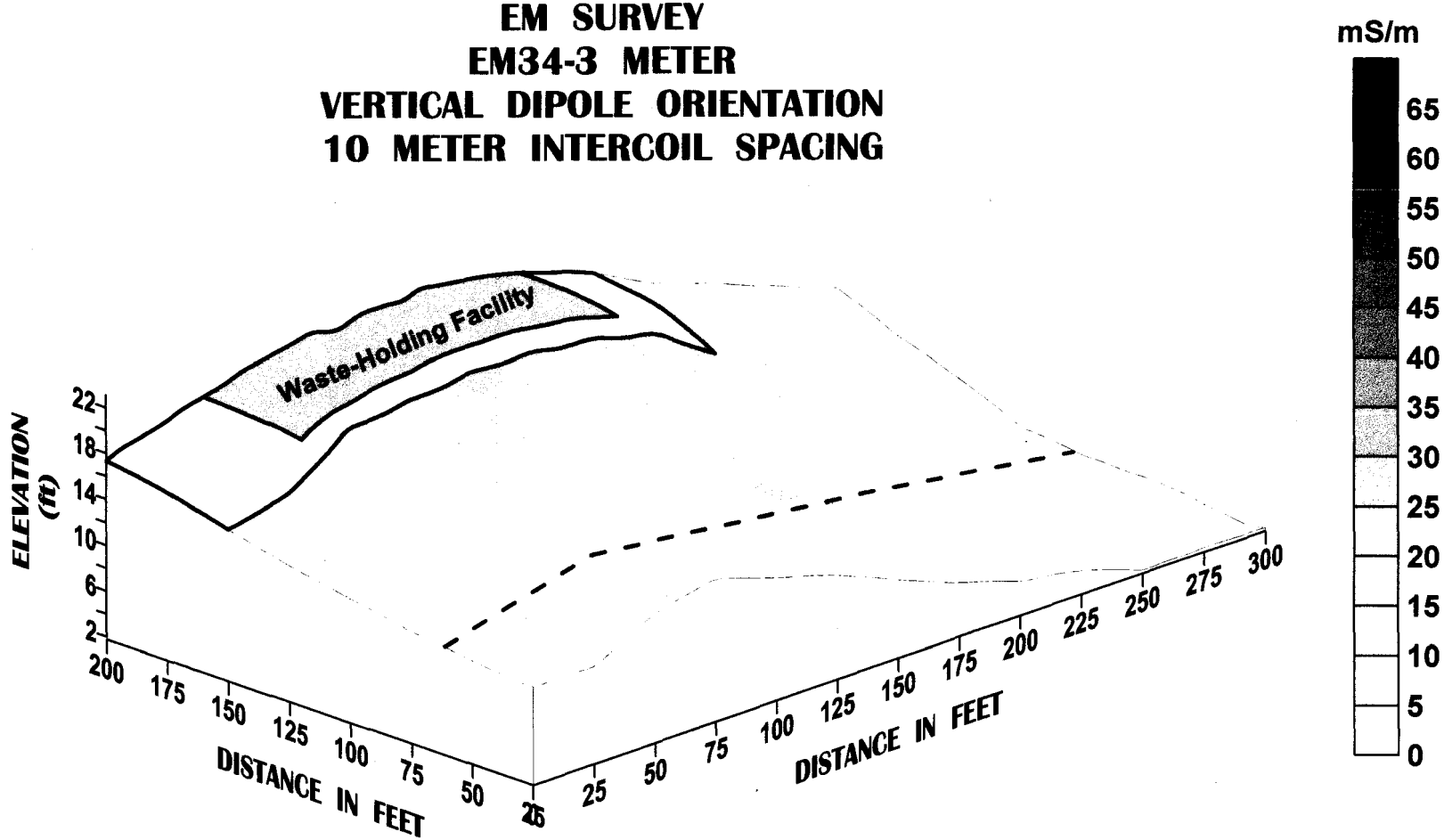


Figure 16

DAUPHIN COUNTY
SITE # 2

RELATIVE TOPOGRAPHY

Contour Interval = 2 feet

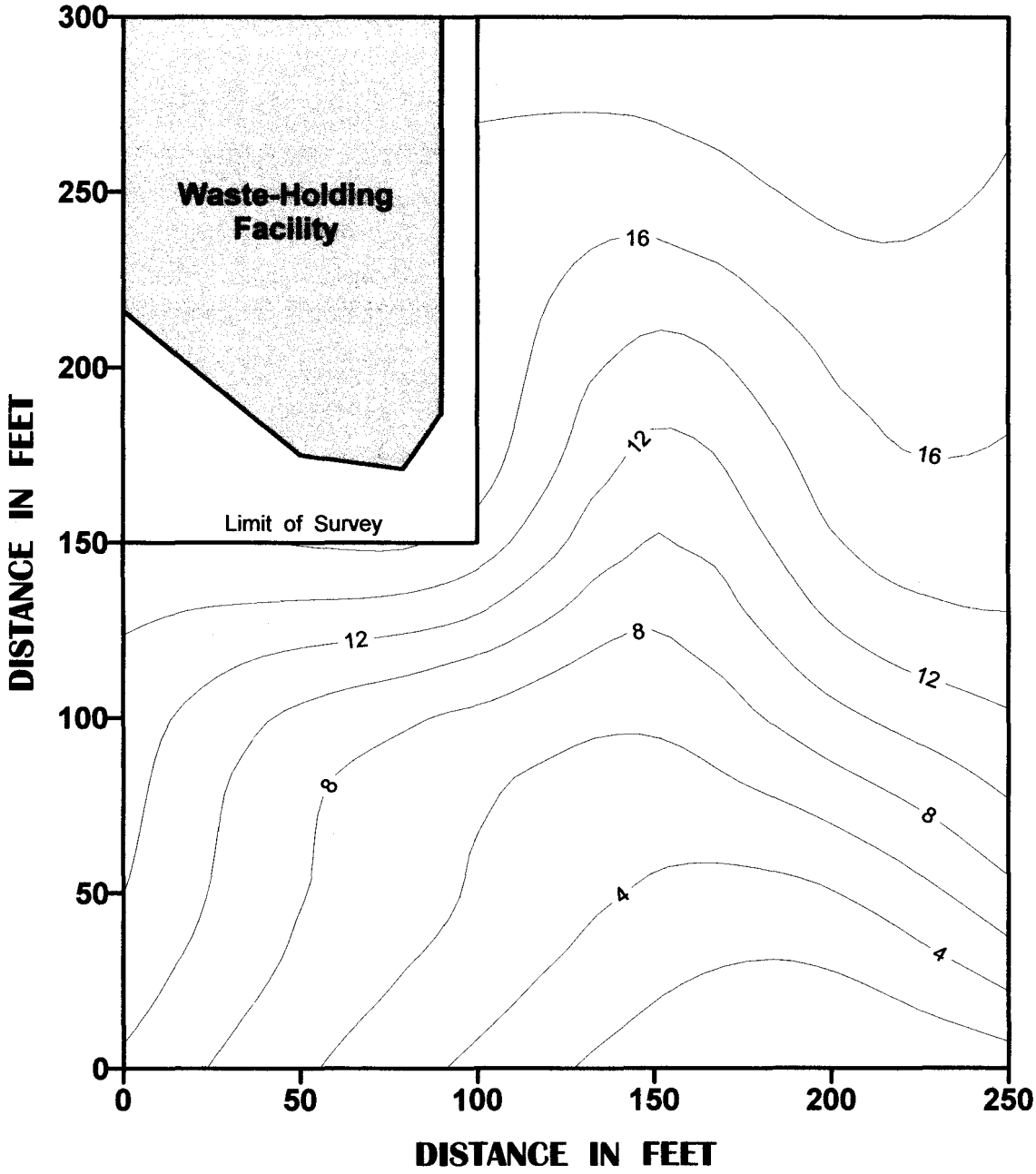


Figure 17

DAUPHIN COUNTY
SITE # 2

EM SURVEY
EM31 METER
HORIZONTAL DIPOLE ORIENTATION

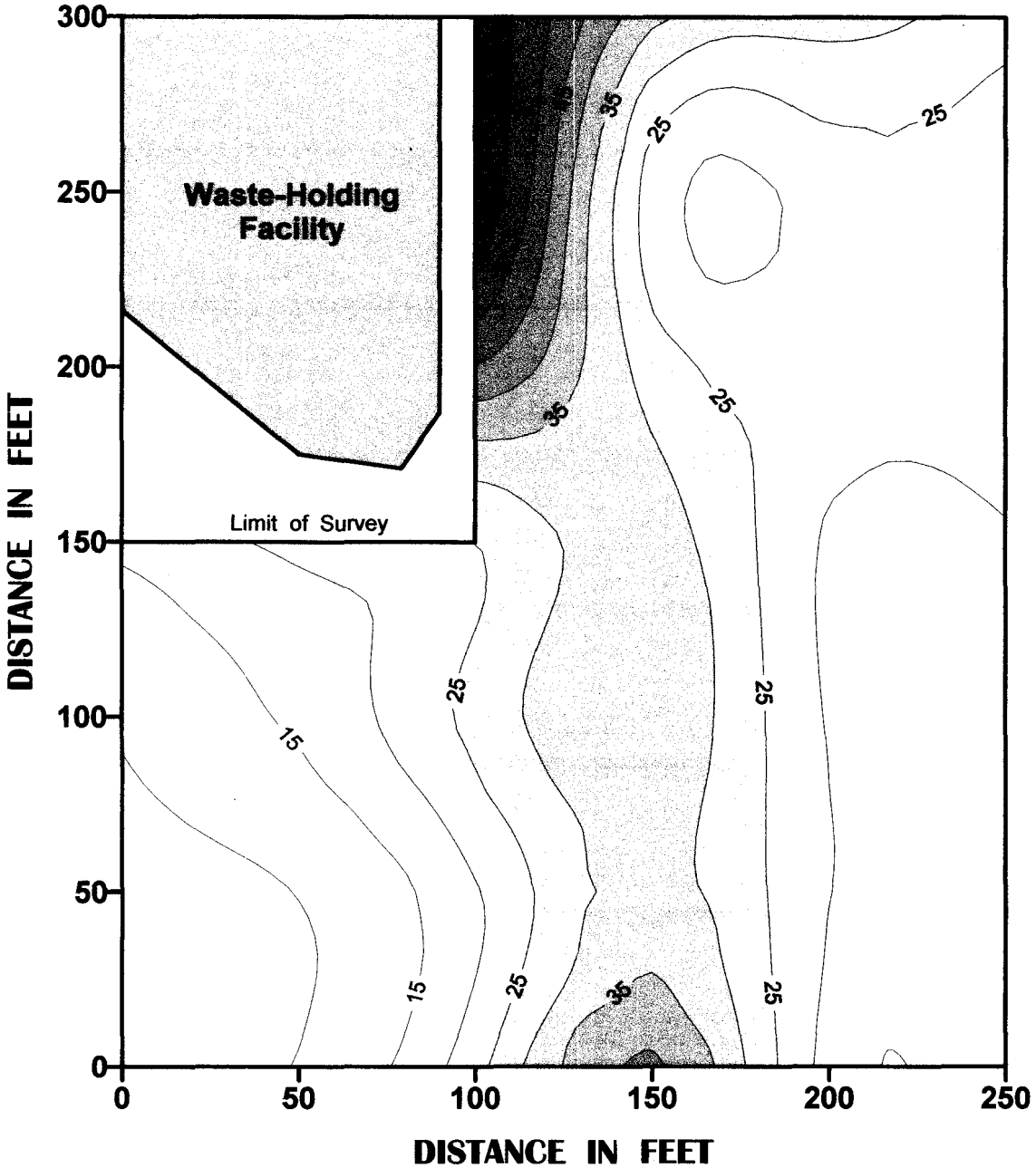


Figure 18

DAUPHIN COUNTY
SITE # 2

EM SURVEY
EM31 METER
VERTICAL DIPOLE ORIENTATION

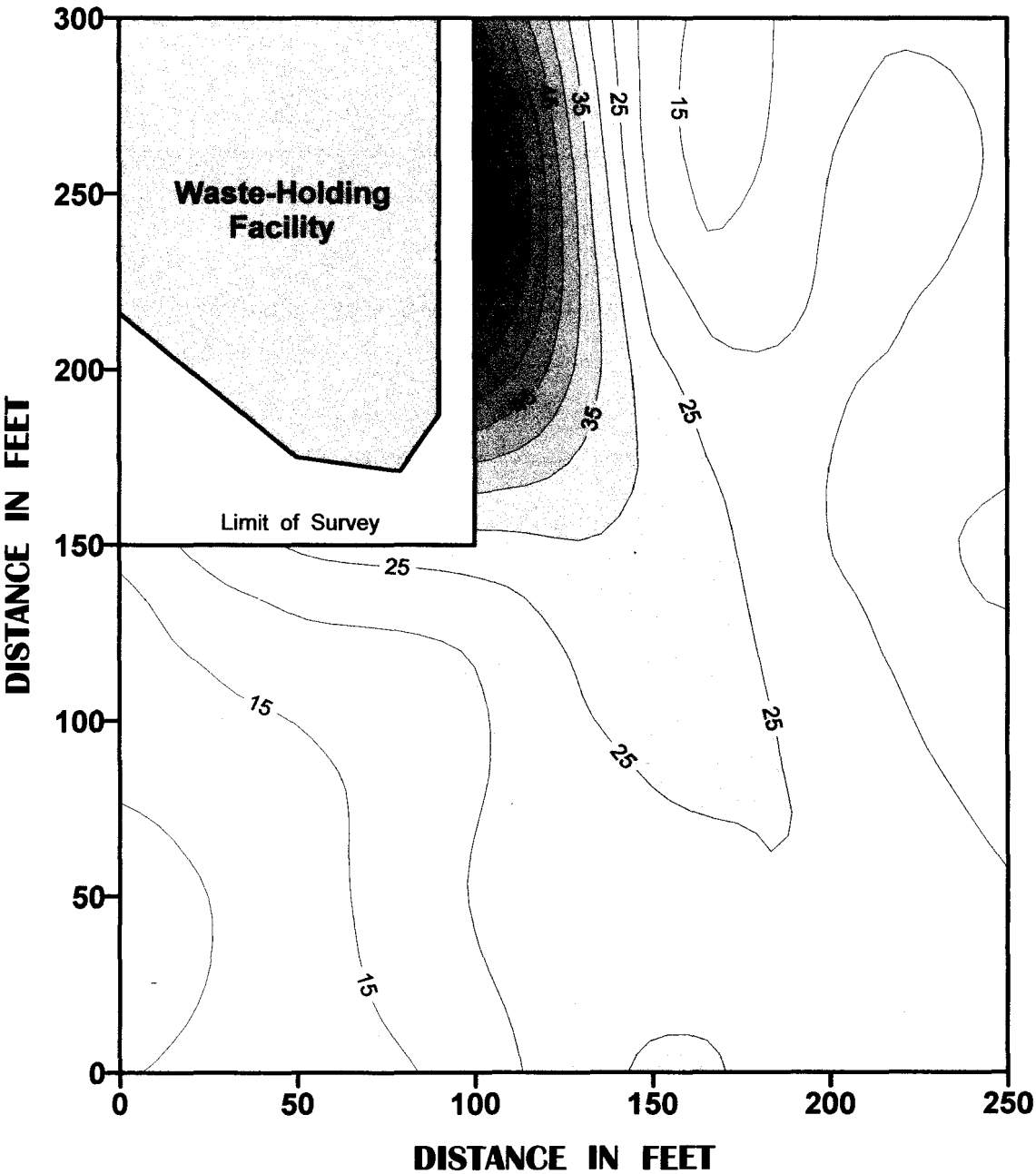


Figure 19

DAUPHIN COUNTY
SITE # 2

EM SURVEY
EM31 METER
HORIZONTAL DIPOLE ORIENTATION

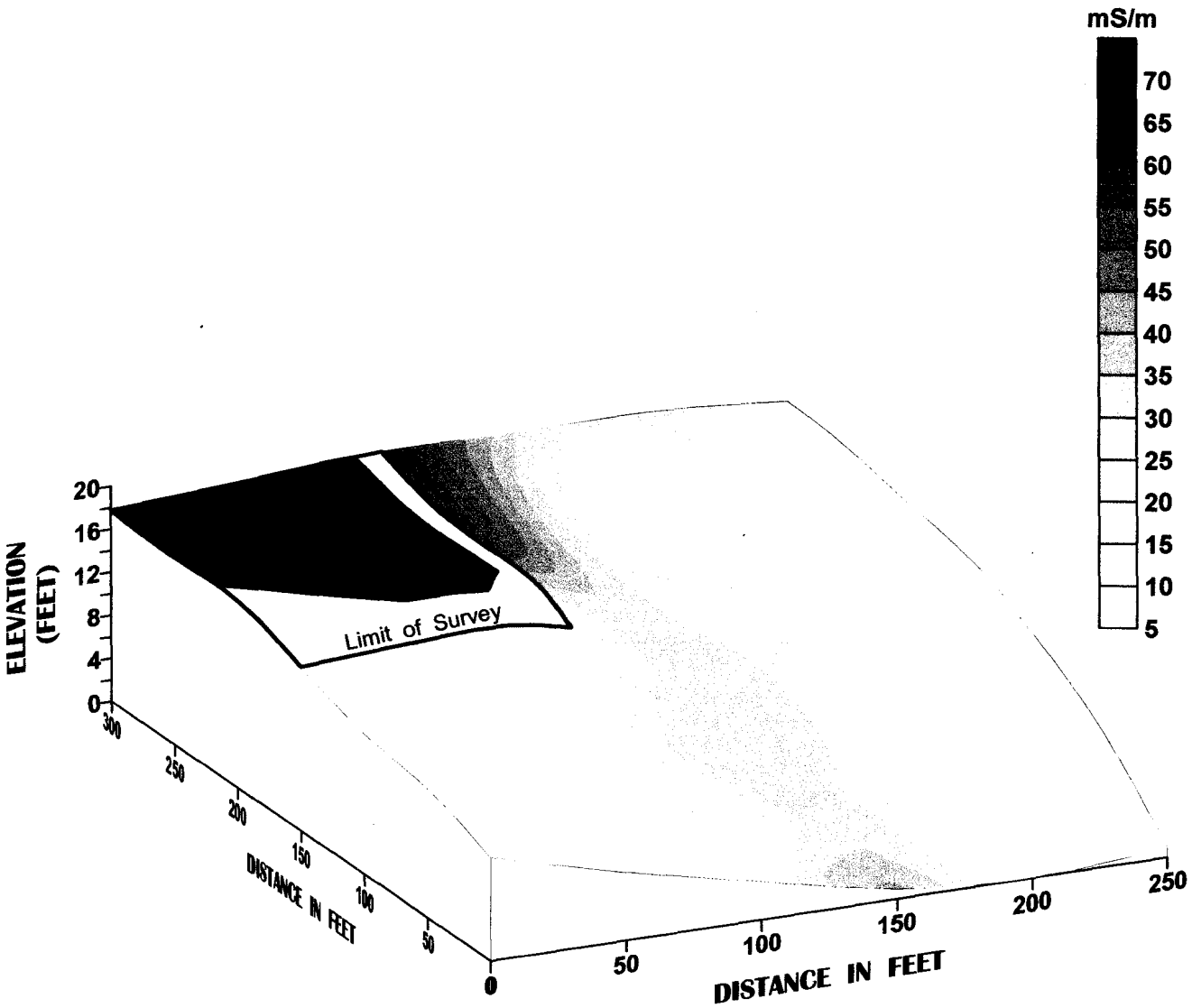


Figure 20

DAUPHIN COUNTY
SITE # 2

EM SURVEY
EM31 METER
VERTICAL DIPOLE ORIENTATION

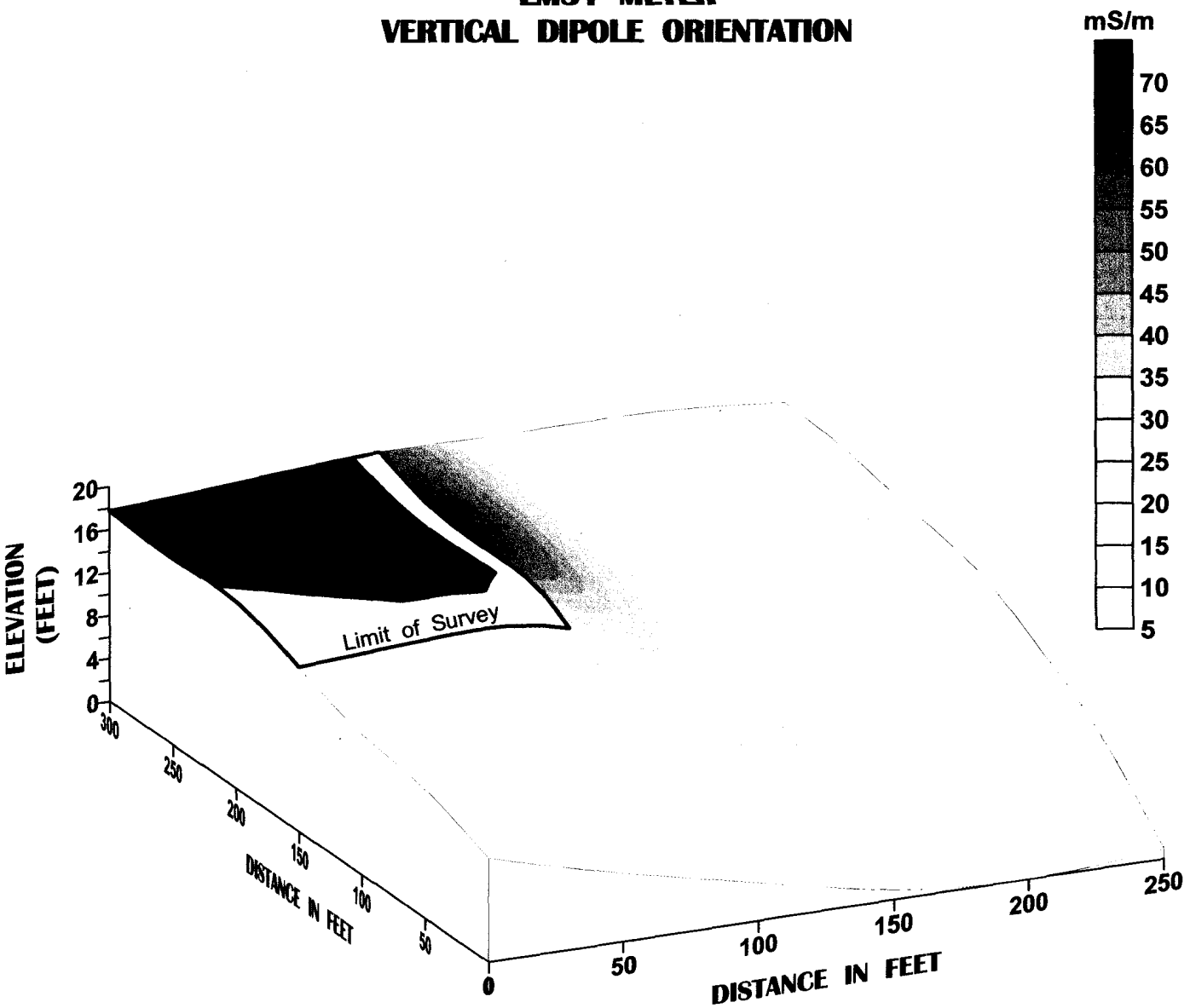


Figure 21