United States Department of Agriculture	Natural Resources Conservation Service	5 Radnor Corporate Center, Suite 200 Radnor, PA 19087-4585

Subject: ENG -- Electromagnetic Induction (EMI) Assistance **Date:** 7 November 1997

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Purpose:
The purpose of this investigation was to conduct EMI surveys of two filter strip sites in northeast and south-central Pennsylvania.

Participants:
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Donald Haines, Engineering Technician, USDA-NRCS, Bloomsburg, PA
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George Philips, Soil Conservationist, Northumberland County Conservation District, Sunbury, PA
Steven Werner, Resource Conservationist, Wayne County Conservation District, Honesdale, PA

Activities:
All field activities were completed on 9 October 1997. Two filter strip sites were surveyed; one in Lackawanna County and one, a proposed site, in Northumberland County.

Equipment:
The electromagnetic induction meters used in this study were the EM38 and EM31 manufactured by Geonics Limited. These meters are portable and require one person 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 coil orientations.

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). 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	Depth of Measurement Vertical
EM38	1.0	0.75	1.5
EM31	3.6	3.0	6.0

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. Shadings and filled isolines have been used in the enclosed plots to emphasize spatial patterns. 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 soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

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.

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, 1991) and to investigate the migration of contaminants from waste sites (Brune

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

and Doolittle, 1990; Radcliffe et al., 1994; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988).

Results:

Lackawanna County; Site # 1

The site was located near Milwaukee in Lackawanna County. The site consisted of a filter strip and a diversion. The filter strip is confined to a relatively small parcel of land. The filter-strip has been operated for about two years and supports a large hog operation. From May to November, about 350 to 400 hogs are cycled through this operation. 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 this survey, soils were relatively dry.

An electromagnetic induction survey was conducted on this site in October 1996. The original survey grid was reestablished across the site. Grid intervals were 25 and 50 feet. Seventy-nine of the original ninety-six grid intersections were reestablished. Survey flags were inserted in the ground and served as observation point. 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 and with the EM31 meter in both the horizontal and vertical dipole orientations. The area between the manifold pipe and the chicken shelter was littered with a vehicle, farm implements, metallic objects, fence lines, buried utility line, and a small shed. These objects interfered with induced electromagnetic fields and produced erroneous measurements of the soil's apparent conductivity. At observation points where this *cultural noise* was apparent, measurements were not recorded or were later removed from the data set.

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 is about 48 feet. The locations of the hog sheds, manifold pipe, and chicken shelter 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.

At the time of the 1996 survey, soils were saturated and water was observed to seep from several portions of the slope. In 1997, the site was substantially drier. As discussed above, the apparent conductivity of soils decreases with decreases in water contents. Comparing the 1997 with the 1996 data sets, the lower soil moisture contents in 1997 should be reflected in lower apparent conductivity values at each observation point. Apparent conductivity measurements at most observation points supported this relationship. Higher apparent conductivity values were observed in the 1997 data set at several observation points. These higher apparent conductivity values could indicate an increased concentration of soluble salt contents (nitrates and chlorides from animal wastes) or slight discrepancies in meter placement and interference from cultural features.

Table 2 summarizes apparent conductivity measurements recorded for the two sampling periods. The averaged apparent conductivity values were lower and less variable in 1997 for the shallow-sensing EM38 meter (0 to 1.5 m) and EM31 meter in the horizontal dipole orientation (0 to 3 m). This was principally attributed to the lower soil water contents in 1997. The averaged apparent conductivity was slightly higher and more variable in 1997 than 1996 for the deeper sensing EM31 meter in the vertical dipole orientation (0 to 6 m). This relationship suggests possibly higher moisture contents at lower soil depths or deep seepage of contaminants. Negative apparent conductivity values appearing in Table 2 are presumed to reflect proximity to metallic objects.

a conspicuous plume of high apparent conductivity values appears to emerge from the right-hand end of the manifold pipe. The closure cap was missing from this end of the manifold pipe. The absence of the closure cap could be responsible for the deposition of waste products and the higher apparent conductivity near the end of the manifold pipe.

Figure 3A represents the change in apparent conductivity measurements recorded in 1996 and 1997 for the upper 3 m of the soil profile. The isoline interval is 4 mS/m. This plot was prepared by subtracting the 1996 from the 1997 apparent conductivity measurements (EM31 meter, horizontal dipole orientation) at each observation point. Positive values indicate an increase in apparent conductivity with the passage of time. At most observation points, the 1997 measurements are lower than the 1996 measurements. This difference is believed to primarily reflect differences in soil moisture contents. The site was noticeably wetter in October of 1996. Higher moisture contents cause higher apparent conductivity. When the data sets for upper 3 m of the soil profile are compared, no noticeable increases in apparent conductivity were measured near the manifold pipe (see Figure 3A). An isolated area of high apparent conductivity values is evident between the manifold pipe and the chicken shelter. This area is believed to reflect cultural feature. As this area of higher apparent conductivity is separated from the manifold pipe, seepage of contaminants is not suspected. Apparent conductivity values have increased along an intermittent drainageway (see Figure 1) in the upper right-hand portion of Figure 3A. The cause of this plume is believed to be soluble salts from a previous manure pile or runoff and seepage from existing sources.

Comparative plots of the spatial distribution of apparent conductivity within the upper 6 m of the soil profile are shown in Figure 4. In each plot, the isoline interval is 4 mS/m. Although the patterns are different, areas of high apparent conductivity are evident in the upper-left portion of each plot. This portion of the survey area is near the hog sheds and contains the manifold pipe and the filter field. In general, values of apparent conductivity decrease in a down slope direction away from the hog sheds and the manifold pipe. The general pattern is plume-like and suggests overland flow and the deposition of waste products in the surface layers. However, to some extent, the chaotic pattern of high and low apparent conductivity values in the upper-left hand portion of each plot is believed to reflect interference from cultural features. The alignment of several anomalous areas of apparent conductivity closely parallels the location of a buried utility line. In 1997, a conspicuous area of negative apparent conductivity values appears near right-hand end of the manifold pipe. These values are believed to reflect interference from the manifold pipe or other cultural features.

Figure 4A represents the change in apparent conductivity measurements recorded in 1996 and 1997 for the upper 3 m of the soil profile. The isoline interval is 4 mS/m. This plot was prepared by subtracting the 1996 from the 1997 apparent conductivity measurements (EM31 meter, horizontal dipole orientation) at each observation point. Positive values indicate an increase in apparent conductivity with the passage of time. At most observation points, the 1997 measurements are lower than the 1996 measurements. This difference is believed to principally reflect differences in soil moisture contents. The site was noticeably wetter in October of 1996. Higher moisture contents cause higher apparent conductivity. No noticeable increases in apparent conductivity were measured near the manifold pipe (see Figure 4A). A zone of higher apparent conductivity appears along the intermittent drainageway (see Figure 1) in the upper right-hand portion of Figure 4A. In 1997, values of apparent conductivity increased in areas next to the chicken shelter. This increase could reflect meter placement and proximity to the chicken shelter (cultural noise).

Northumberland County; Site # 1

The site was located east of Sunbury. This survey provided baseline information on the apparent conductivity of soils. A filter strip will be constructed this year within the surveyed site.

A rectangular grid was established across the site. The grid was tied into a power pole (see Figure 5). The grid intervals were 20 and 25 feet. Survey flags were inserted in the ground at each grid intersection. This provided 24 observation points. The relative elevation of each grid intersection was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as the 0.0 foot datum.

The topography of the survey area has been simulated in the two-dimensional contour plot shown in Figure 5. In Figure 5, the contour interval is 1 foot. Relief is about 9.8 feet. The surface slopes towards the south. The location of the power pole is shown in Figure 5.

Apparent conductivity data from the site was invariable and nondescript. Figure 6 shows the spatial distribution of apparent conductivity as measured with the EM31 meter in the horizontal dipole orientation. The averaged apparent conductivity was 5.19 mS/m with a range of 4.0 to 6.5 mS/m. One-half of the observations had an apparent conductivity between 5.0 and 5.9 mS/m.

Figure 7 shows the spatial distribution of apparent conductivity as measured with the EM31 meter in the vertical dipole orientation. The averaged apparent conductivity was 5.26 mS/m with a range of 4.5 to 6.4 mS/m. One-half of the observations had an apparent conductivity between 5.1 and 5.8 mS/m.

Conclusions:

1. Simulations prepared from correctly interpreted EMI data provide the basis for assessing site conditions. At the site in Lackawanna County, no significant changes in apparent conductivity were observed within the survey area. Conditions within the site were noticeably drier than they were for an earlier survey of the site in October 1996. The lower soil moisture contents at the time of the present survey were responsible for a general lowering of apparent conductivity within the site. A comparison of the two survey data revealed similar spatial patterns. Data collected with the shallow-sensing (0 to 1.5 m) EM38 meter in the vertical dipole orientation revealed a slight increase in apparent conductivity near the manifold pipe. This pattern was anticipated. The affected area is small and not extensive (see Figures 2 and 2A). The EMI surveys indicate that some wastes have probably been carried down slope by surface wash especially in a drainageway located to the west of the hog sheds. Manure had been previously piled (possibly for fifteen years) near the present hog sheds. The detected plume-like area is considered a product from early land use and is not related to the filter strip.

2. The EMI survey at the Sunbury site provided baseline data concerning the variability of apparent conductivity within a proposed filter-strip site. Apparent conductivity was found to be low and invariable within the site. Apparent conductivity measured with the EM31 meter averaged about 5.2 mS/m in both the horizontal and vertical orientation. The range of apparent conductivity measurements (4.0 to 6.5 mS/m) was within normal observation errors (2 mS/m). The compiled data will be compared with data collected following the installation and use of the filter strip. Comparisons should provide a measure of the effectiveness of the filter strip.

As always, it was sincere pleasure to work in our state and with members of your fine staff. I want to express my deepest thanks to George Philips, Don Haines, and Bill Bowers for looking after me during my stay in the Sunbury Hospital.

With kind regards,

James A. Doolittle
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LACKAWANNA COUNTY
SITE #1

RELATIVE TOPOGRAPHY

Contour Interval = 2 Feet

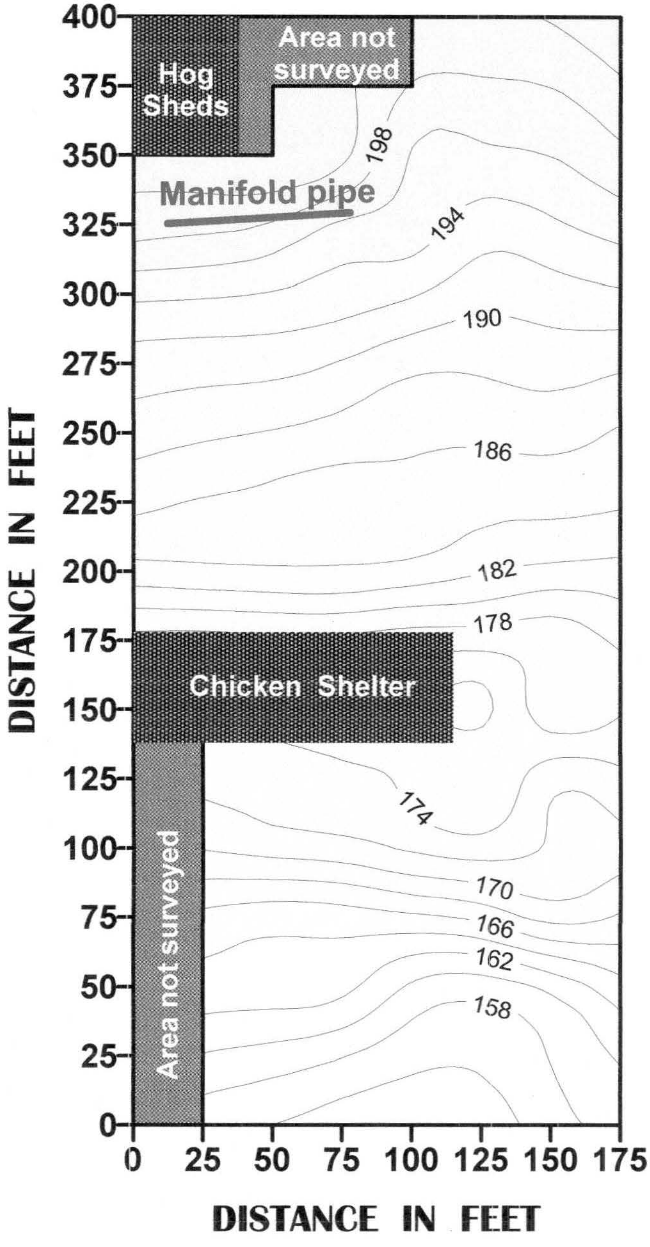

Figure 1

LACKAWANNA COUNTY
SITE #1

EM38 METER
VERTICAL DIPOLE ORIENTATION

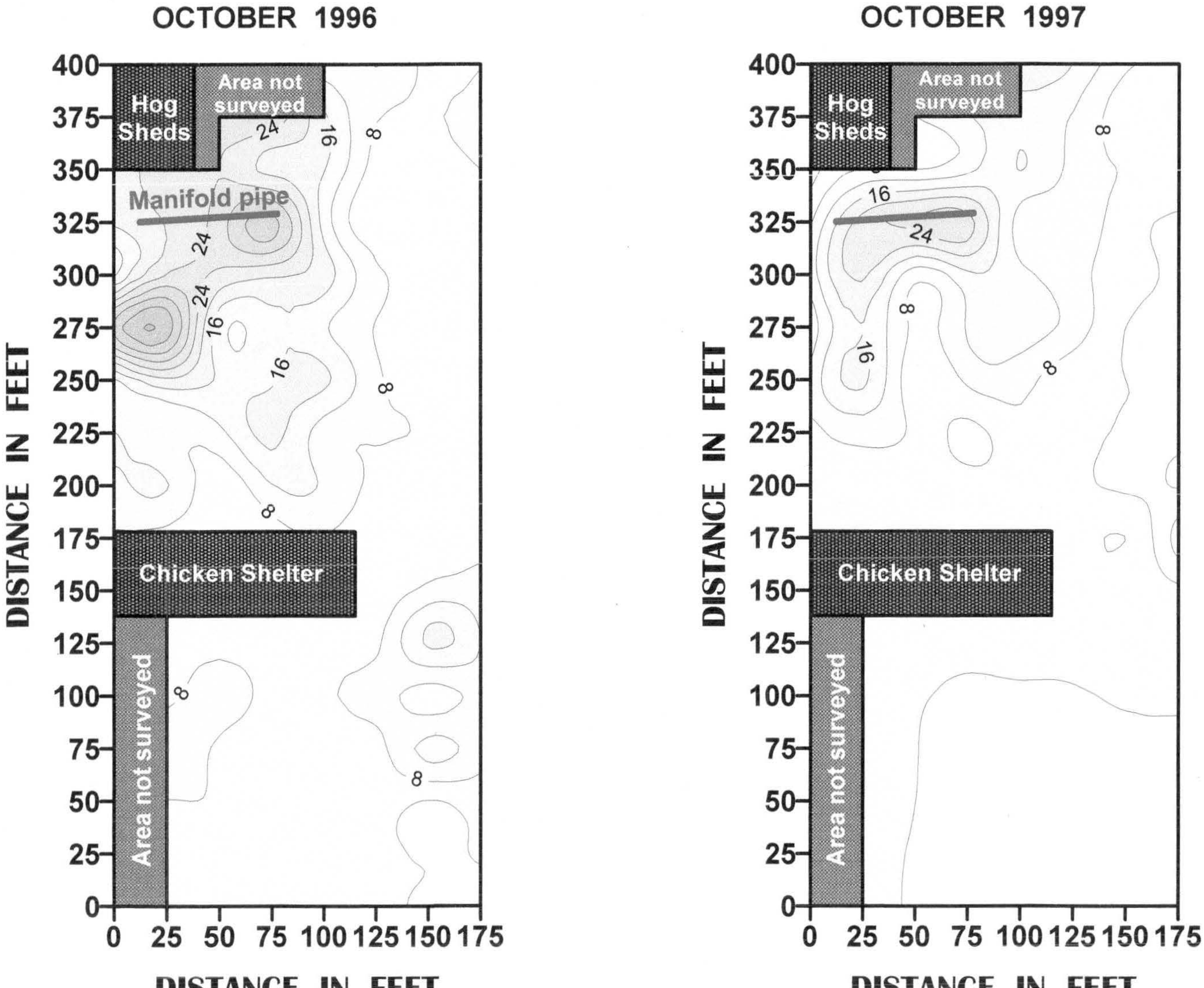

Figure 2

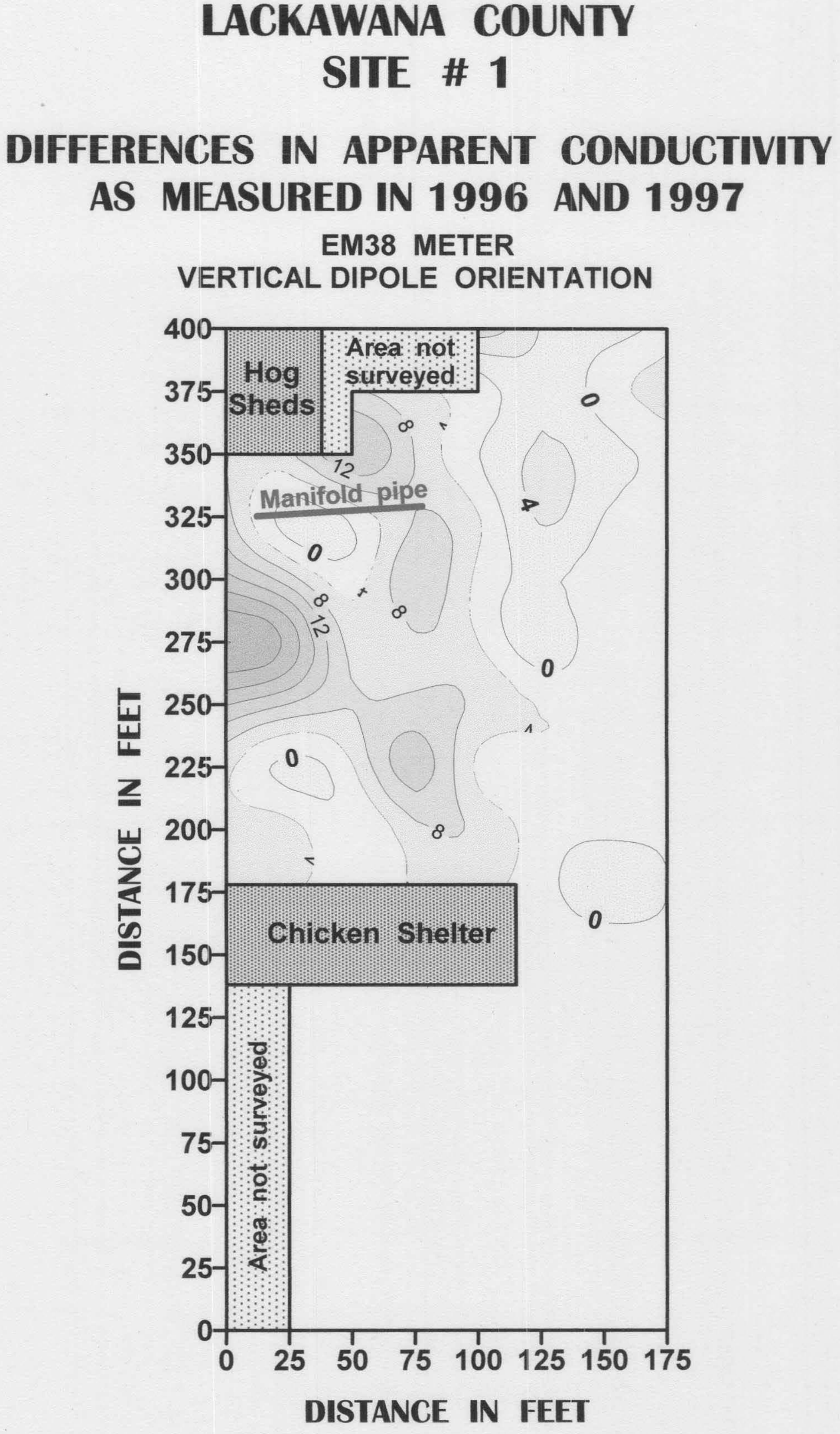
LACKAWANA COUNTY
SITE # 1
DIFFERENCES IN APPARENT CONDUCTIVITY
AS MEASURED IN 1996 AND 1997
EM38 METER
VERTICAL DIPOLE ORIENTATION
Hog Sheds
Area not surveyed
Manifold pipe
Chicken Shelter
Area not surveyed
0
4
8
12
DISTANCE IN FEET
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
DISTANCE IN FEET

Figure 2A

LACKAWANNA COUNTY
SITE #1

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

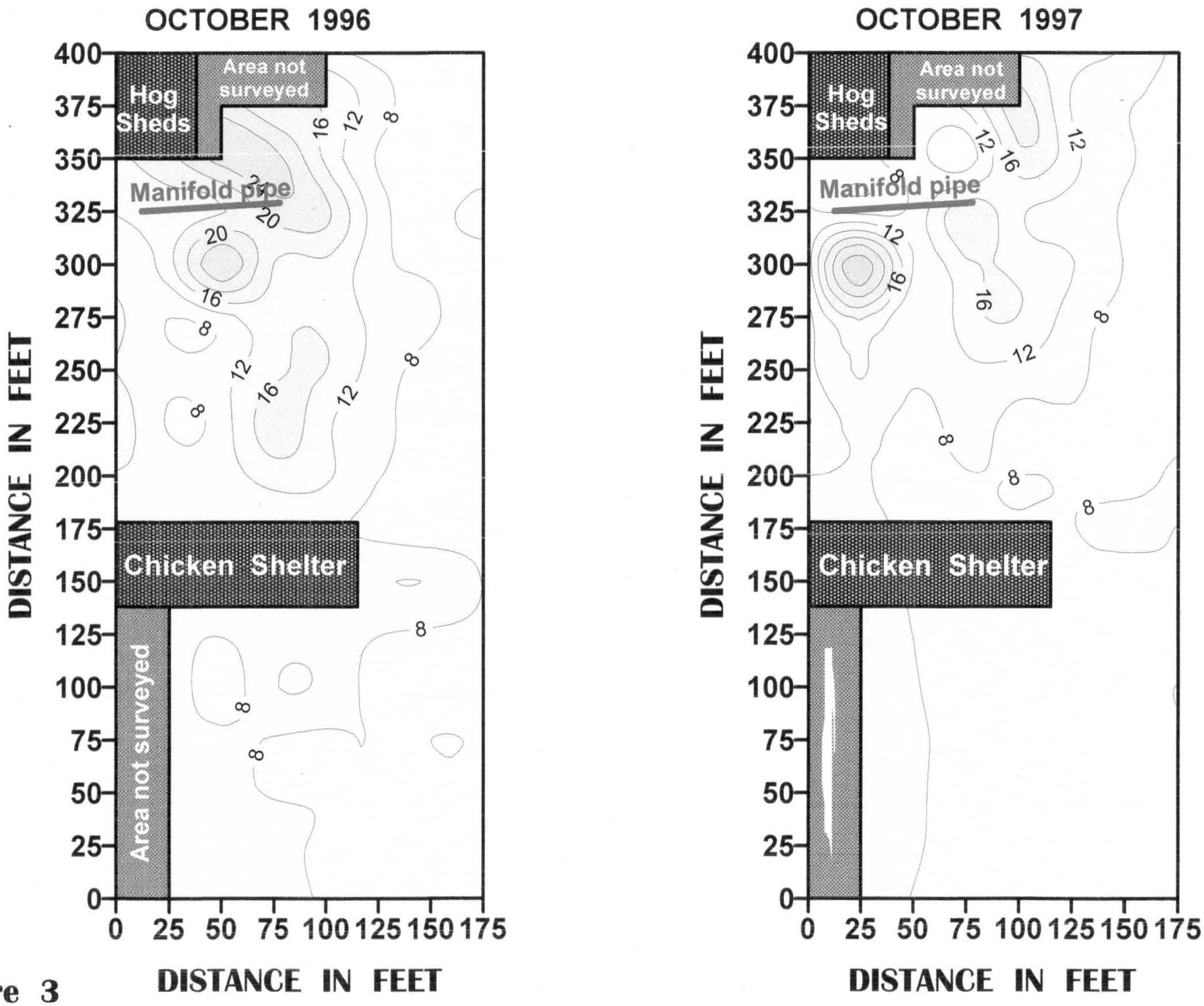

Figure 3

LACKAWANA COUNTY
SITE # 1

DIFFERENCES IN APPARENT CONDUCTIVITY AS MEASURED IN 1996 AND 1997

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

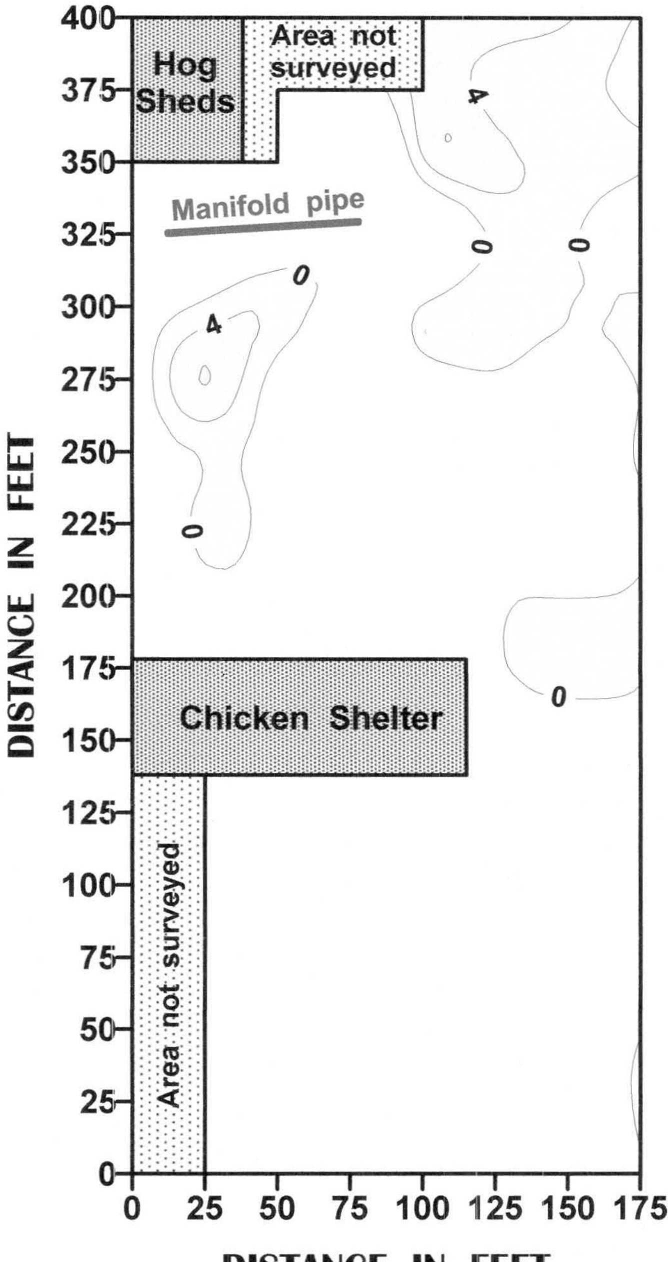

Figure 3A

LACKAWANNA COUNTY
SITE #1

EM31 METER
VERTICAL DIPOLE ORIENTATION

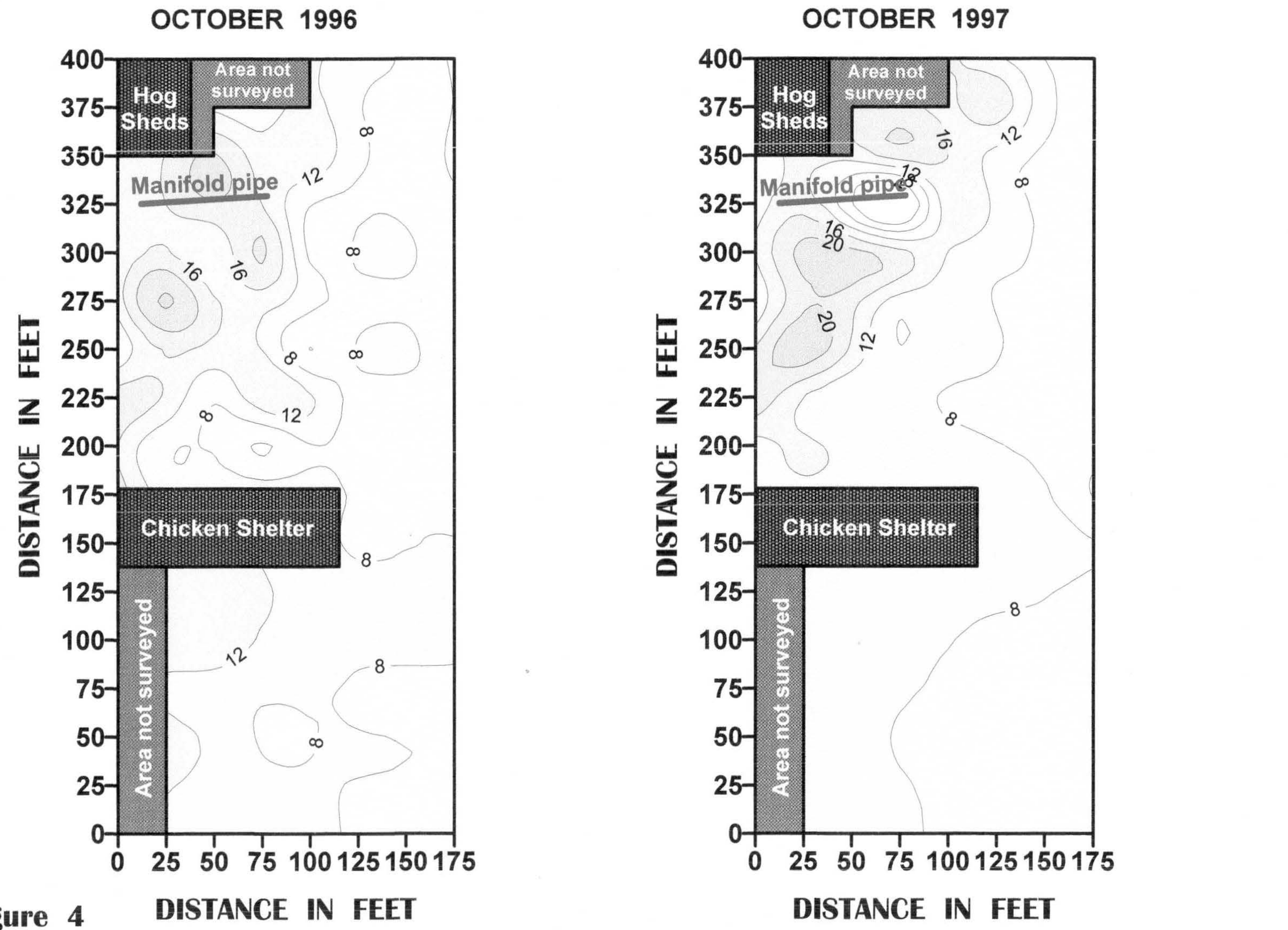

Figure 4

LACKAWANA COUNTY
SITE # 1

DIFFERENCES IN APPARENT CONDUCTIVITY AS MEASURED IN 1996 AND 1997

EM31 METER
VERTICAL DIPOLE ORIENTATION

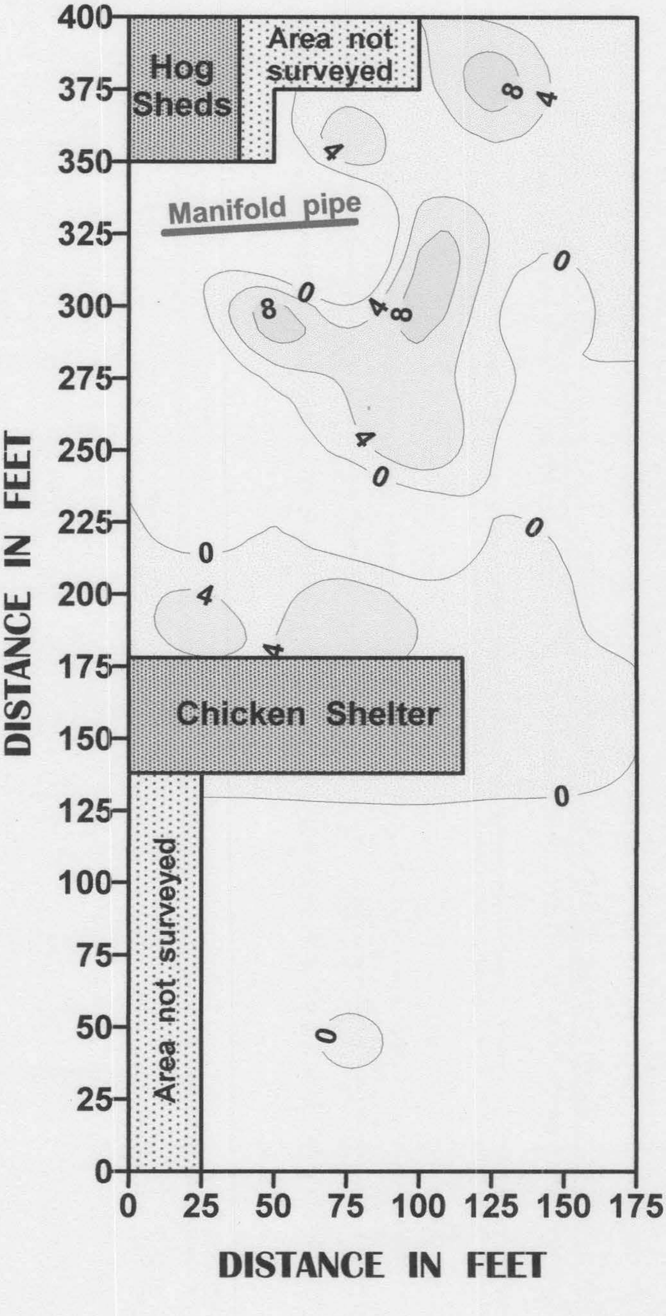

Figure 4A

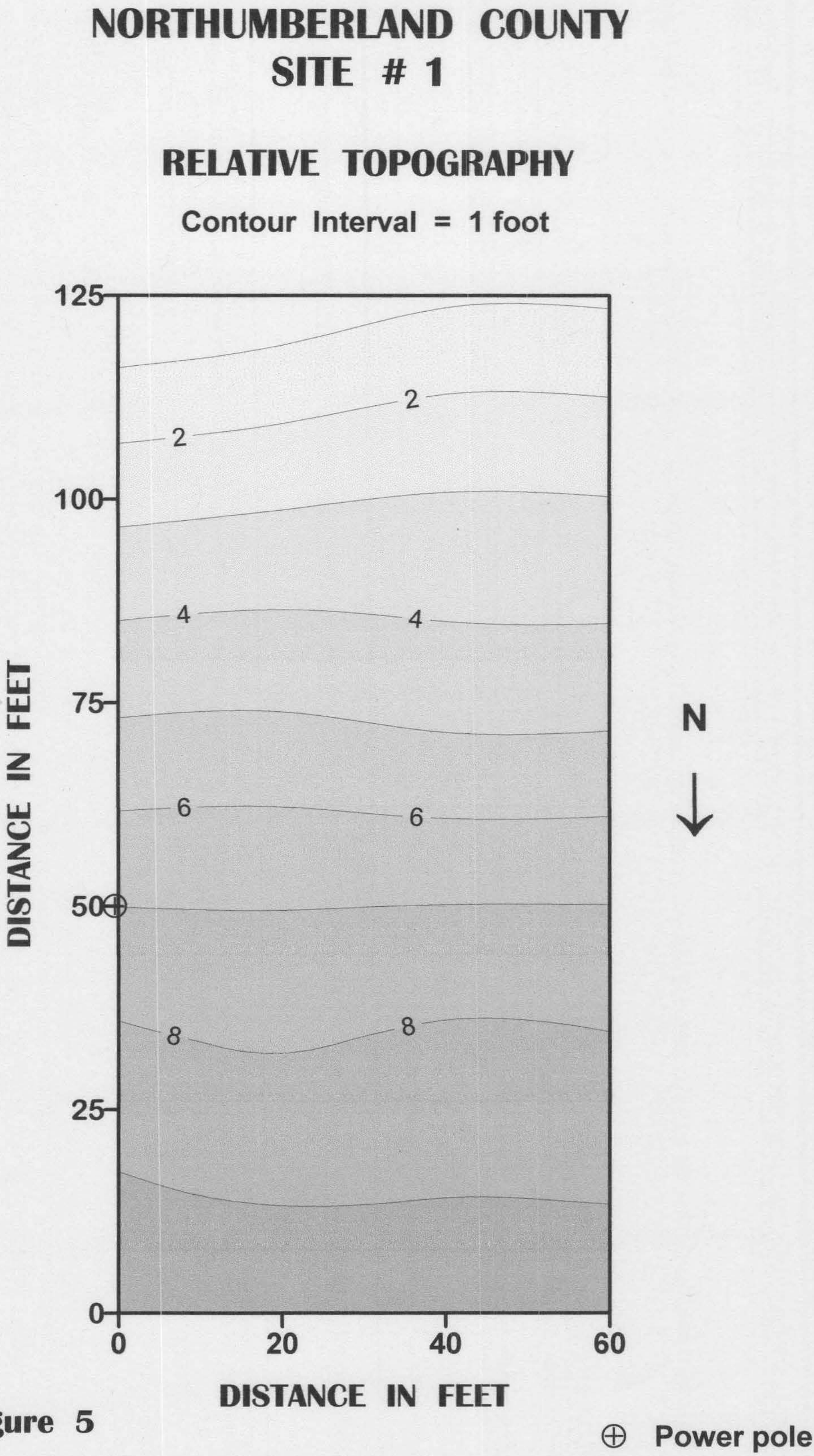
NORTHUMBERLAND COUNTY
SITE # 1
RELATIVE TOPOGRAPHY
Contour Interval = 1 foot
125
100
75
50
25
0
0
20
40
60
2
2
4
4
6
6
8
8
DISTANCE IN FEET
DISTANCE IN FEET
N
Power pole

Figure 5

NORTHUMBERLAND COUNTY
SITE # 1

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

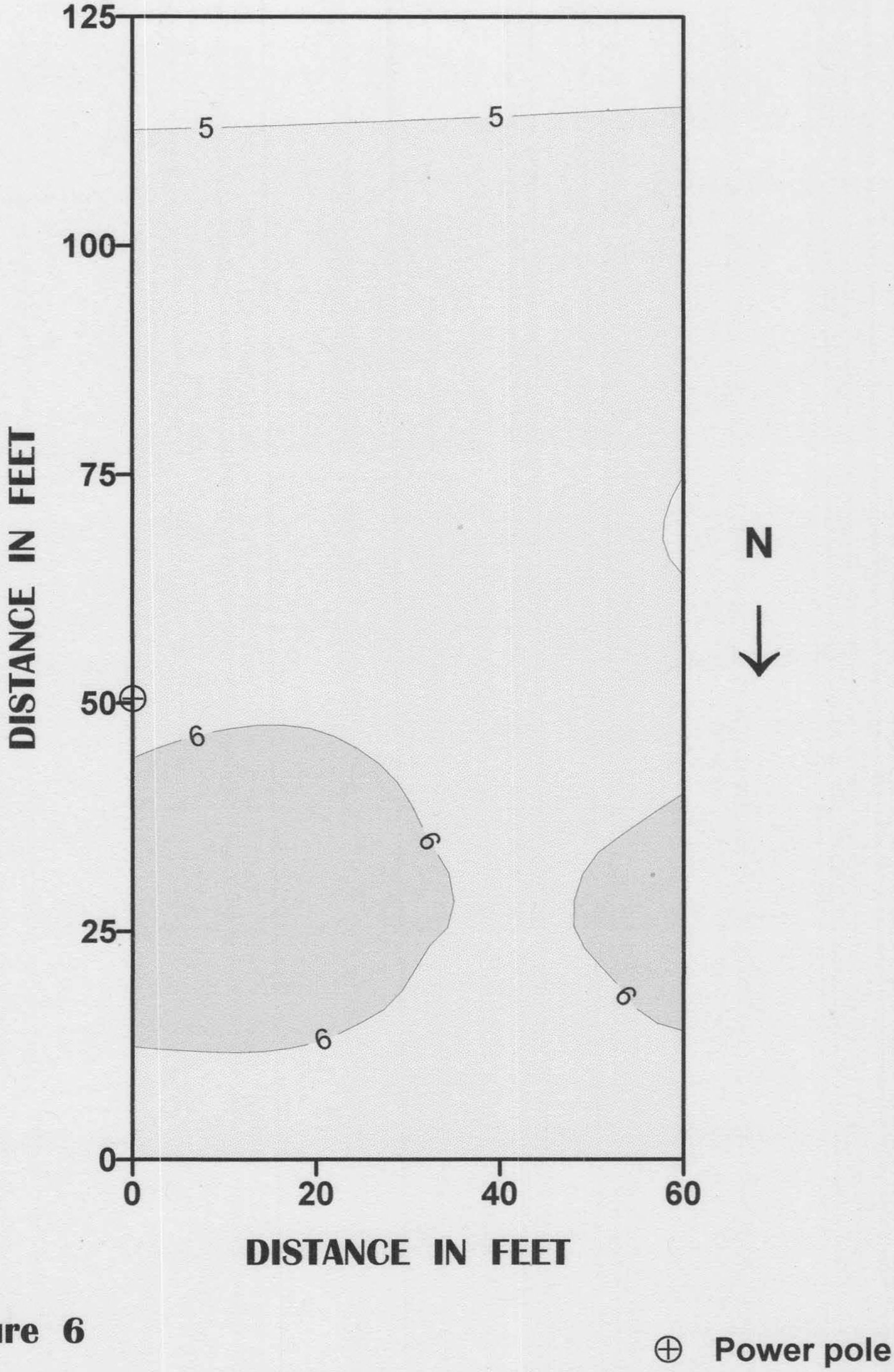

Figure 6

NORTHUMBERLAND COUNTY
SITE # 1

EM31 METER
VERTICAL DIPOLE ORIENTATION

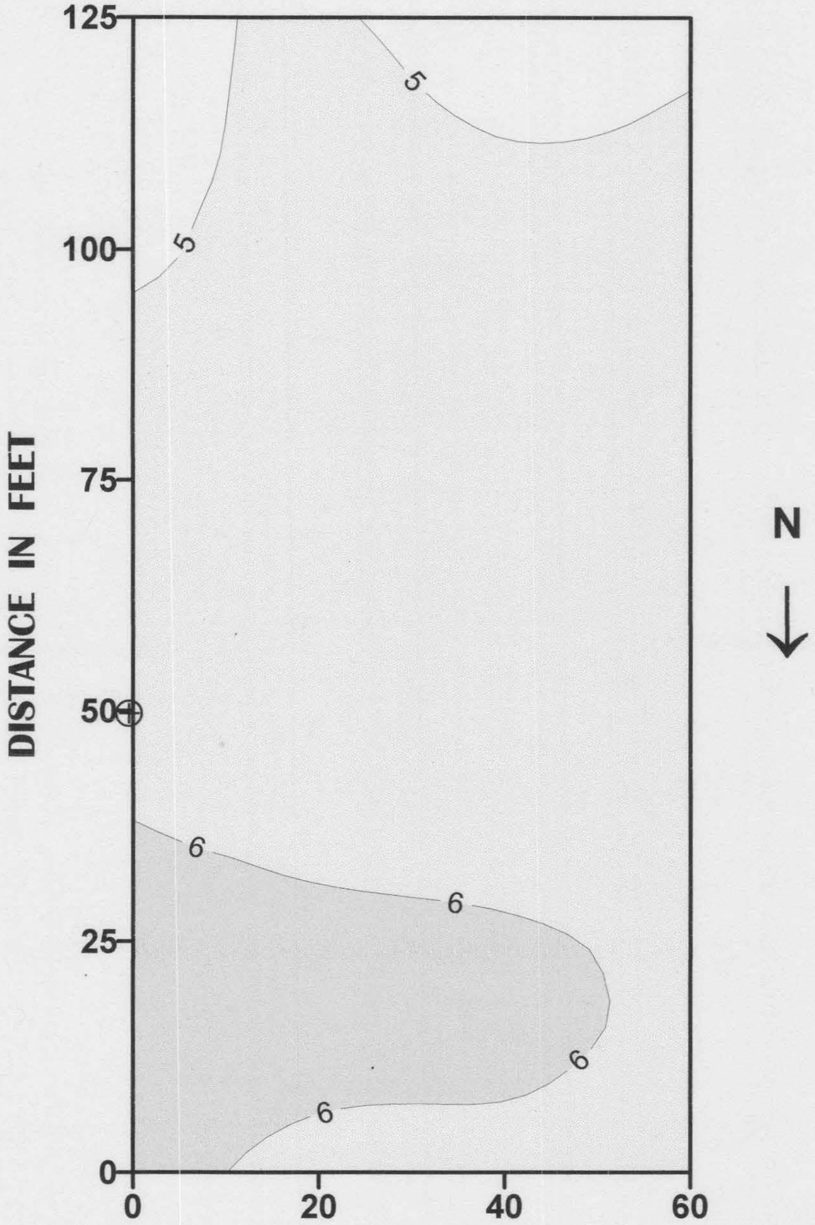

Figure 7

⊕ Power pole

TABLE 2

Comparison of Apparent Conductivity Measurements
(All measurements are in mS/m)

	1996			1997		
	EM38V	**EM31H**	**EM31V**	**EM38V**	**EM31H**	**EM31V**
Minimum	3.1	4.0	3.1	-1.9	3.7	-2.4
Maximum	38.6	27.5	24.8	25.8	31.0	23.0
Average	10.5	10.3	10.0	7.8	9.2	10.3
SD	7.1	4.8	4.0	5.4	4.3	4.6

Comparative plots of the spatial distribution of apparent conductivity within the upper 1.5 m of the soil profile are shown in Figure 2. In each plot, the isoline interval is 4 mS/m. Although the patterns are different, an area of high apparent conductivity is evident in the upper-left portion of each plot. This portion of the survey area is near the hog sheds and contains the manifold pipe and the filter field. 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. Manure had been previously piled (possibly for fifteen years) in the area to the right of the hog sheds. Contaminants from these piles of manure are considered probably sources for this plume. The plume may be a relic feature from early land use.

The area between the manifold pipe and the chicken shelter was littered with a vehicle, farm implements, metallic objects, fence lines, buried utility line, and a small shed. These objects interfered with the electromagnetic fields and produced erroneous measurements of the soils apparent conductivity. The chaotic pattern of high and low apparent conductivity is partially attributable to interference from these cultural features.

Figure 2A represents the change in apparent conductivity measurements recorded in 1996 and 1997 for the upper 1.5 m of the soil profile. This plot was prepared by subtracting the 1996 from the 1997 apparent conductivity measurements at each observation point. Positive values indicate an increase in apparent conductivity with the passage of time. At most observation points, the 1997 measurements were lower than the 1996 measurements. This difference is believed to principally reflect differences in soil moisture contents. The site was noticeably wetter in October of 1996. Higher moisture contents will produce higher apparent conductivity measurements. Apparent conductivity appears to have increased slightly (<4 mS/m) near the manifold pipe (see Figure 2A). This increase may reflect increase concentrations of soluble salts near the manifold pipe; an expected phenomenon. Apparent conductivity values also increased along an intermittent drainageway (see Figure 1) in the upper right-hand portion of Figure 2A. The plume-like patterns suggest a source near the edge of the area that was labeled “not surveyed.” The cause of this plume is believed to be soluble salts. Manure had been piled (possibly for fifteen years) in the area labeled “not surveyed.”

Comparative plots of the spatial distribution of apparent conductivity within the upper 3 m of the soil profile are shown in Figure 3. Although the patterns are different, areas of high apparent conductivity are evident in the upper-left hand portion of each plot. This portion of the survey area is near the hog sheds and contains the manifold pipe and the filter field. In general, values of apparent conductivity decrease in a down slope direction away from the hog sheds and the manifold pipe. The general pattern is plume-like and suggests overland flow and the deposition of waste products in the surface layers. To some extent, the chaotic pattern of high and low apparent conductivity values in the upper-left hand portion of each plot is believed to reflect interference from cultural features. In the 1997 data,