UNITED STATES DEPARTMENT OF AGRICULTURE **Northeast NTC**
SOIL CONSERVATION SERVICE **CHESTER, PA 19013**

SUBJECT: Site Assessments with Electromagnetic Induction (EM) Techniques: Pennsylvania May 12 and 13 1994 **DATE:** 4 June 1994

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

Purpose:
To assess selected demonstration sites in Columbia and Lackawanna counties using electromagnetic induction (EM) techniques. The demonstration sites were established as part of a research project entitled "Reducing NPS Pollution through Soil Microbial Enhancement". A primary goal of this project is "to determine whether a significant portion of agricultural non-point source (NPS) pollution is directly linked to the suppression or destruction of the soils aerobic microbial processes." Participants in this project include Bloomsburg University, Columbia SWCD, Lackawanna SWCD, Pocono-Northeast RC&D, and USDA - Soil Conservation Service.

Participants:
Bruce Benton, Geologist, SCS, Harrisburg, PA
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Jim Doolittle, Soil Specialist, SCS, Chester, PA
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Barry Travelpiece, Engineering Technician, SCS, Bloomsburg, PA
Mary Wagner, District Manager, Columbia County SWCD

Activities:
The two selected demonstration sites were surveyed during this field assistance.

Equipment:
The electromagnetic induction meter was the EM38 manufactured by Geonics Limited+. The EM38 meter is portable and requires only one person to operate. The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation

+ Trade names have been used to provide specific information. Their mention does not constitute endorsement.

relative to the ground surface. The EM38 meter integrates values of apparent conductivity over the upper 0.75 m in the horizontal dipole orientation, and over the upper 1.5 m in the vertical dipole orientation.

Measurements of apparent conductivity are expressed as milliSiemens per meter (mS/m). Two-dimensional plots and three-dimensional surface nets of the EM data were prepared using SURFER software developed by Golden Software, Inc.[+]

Discussion:

Columbia County Demonstration Site:

The demonstration site was located about 1.0 mile west-southwest of Rohrsburg, Pennsylvania. The site was located along a terrace line in a cultivated field on a broad upland. The demonstration site was established in an area of Watson silt loam, 3 to 8 percent slopes, moderately eroded (Parrish, 1991). Watson is a member of the fine-loamy, mixed, mesic Typic Fragiudult family. This deep, moderately well drained soil formed in glaciated acid shales and sandstone on uplands.

An irregularly shaped grid was established across the proposed demonstration site. The grid interval was 50 feet (15.2 m). Survey flags were inserted in the ground at each grid intersection. This provided 126 observation sites. At each grid intersection, measurements were taken with the EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At each grid intersection, the relative elevation of the surface was determined. A rotating laser level was used to determine surface elevations. Elevations were not tied to an elevation benchmark; the lowest recorded grid intersection was recorded as the 0.0 m datum.

Figure 1 is a topographic map of the demonstration site. The contour interval is 0.25 m. Relief is about 5.4 m. The spot symbols represent the approximate center line of the terraces.

Figure 2 and 3 are two-dimensional plots of apparent conductivity values collected in the horizontal and vertical dipole orientation, respectively. Figure 2 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the horizontal dipole orientation. Based on 126 observations, the average apparent conductivity was 5.85 mS/m with a range of 3.0 to 8.5 mS/m. One-half of the observations had apparent conductivity values between 5.0 and 6.5 mS/m.

Figure 3 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the vertical dipole orientation. Based on 126 observations, the average apparent conductivity was 4.41 mS/m with a range of 3.0 to 7.5 mS/m. One-half of the observations had apparent conductivity values between 4.0 and 4.5 mS/m.

The EM responses were generally low and invariable across the Columbia County demonstration site. For the EM38 meter, the average apparent conductivity was 5.85 and 4.41 mS/m in the horizontal and vertical dipole orientations, respectively. The range in apparent conductivity values was 5.5 mS/m and 4.5 mS/m in the horizontal and vertical dipole orientations, respectively. The electromagnetic response decreased with increased soil depth. This indicates the presence of slightly more conductive materials near the surface and slightly more resistive materials (i.e. lower clay, soluble salt, and/or water contents) with increasing depth.

Lackawanna County Demonstration Site:
The demonstration site was located about 1.25 miles east-northeast of Wallsville, Pennsylvania. The site was located in cultivated field on a flood plain. Two subsites were established at the demonstration site. Subsite 1 was established in an area of Wyoming gravelly sandy loam, 0 to 3 percent slopes, and Philo silt loam (Eckenrode, 1982). Wyoming soils are members of the loamy-skeletal, mixed mesic Typic Dystrochrept family. This deep, somewhat excessively drained soil formed in outwash deposits on stream terraces. Philo soils are members of the coarse-loamy, mixed, mesic Fluvaquentic Dystrochrept family. This deep, moderately well drained soil formed in alluvial deposits on flood plains.

A 200 by 300 foot (61 by 91.4 m) grid was established across the proposed Subsite 1. The grid interval was 50 feet (15.2 m). Survey flags were inserted in the ground at each grid intersection. This provided 35 observation sites. At each grid intersection, measurements were taken with the EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At each grid intersection, the relative elevation of the surface was determined. A rotating laser level was used to determine surface elevations. Elevations were not tied to an elevation benchmark; the lowest recorded grid intersection was recorded as the 0.0 m datum.

Figure 4 is a topographic map of the Subsite 1. The contour interval is 0.25 m. Relief is about 1.5 m. The soils slope towards an intermittent drainageway located along the lower border of Figure 4.

Figure 5 and 6 are two- dimensional plots of apparent conductivity values across the site collected in the horizontal and vertical dipole orientation, respectively. Figure 5 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the horizontal dipole orientation. Based on 35 observations, the average apparent conductivity was 4.08 mS/m with a range of 0.5 to 35.0 mS/m. One-half of the observations had apparent conductivity values between 1.5 and 4.0 mS/m.

Figure 6 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the vertical dipole orientation. Based on 35 observations, the average apparent conductivity was 4.34 mS/m with a range of 0.5 to 26.0 mS/m. One-

half of the observations had apparent conductivity values between 1.5 and 4.5 mS/m.

The EM responses were generally low and invariable across most of this subsite. For the EM38 meter, the average apparent conductivity was 4.08 and 4.34 mS/m in the horizontal and vertical dipole orientations, respectively. The electromagnetic response remained fairly constant with soil depth. Manure had been stacked in the extreme northwestern corner of the subsite. Electromagnetic responses were conspicuously higher in this portion (upper left-hand corner) of the plots (see Figures 5 and 6). In general, areas of Wyoming soils had lower EM responses than areas of Philo soils.

Subsite 2 was established in an area of Pope soils, rarely flooded (Eckenrode, 1982). Pope soils are members of the coarse-loamy, mixed, mesic Fluventic Dystrochrept family. This deep, well drained soil formed in alluvial deposits on flood plains.

A 250 by 350 foot (76.2 by 106.7 m) grid was established across the proposed Subsite 2. The grid interval was 50 feet (15.2 m). Survey flags were inserted in the ground at each grid intersection. This provided 48 observation sites. At each grid intersection, measurements were taken with the EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

At each grid intersection, the relative elevation of the surface was determined. A rotating laser level was used to determine surface elevations. Elevations were not tied to an elevation benchmark; the lowest recorded grid intersection was recorded as the 0.0 m datum.

Figure 7 is a topographic map of the Subsite 2. The contour interval is 0.25 m. Relief is about 1.25 m. The soils slope towards an intermittent drainageway located near the upper border of Figure 7.

Figure 8 and 9 are two-dimensional plots of apparent conductivity values across the site collected in the horizontal and vertical dipole orientation, respectively. Figure 8 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the horizontal dipole orientation. Based on 48 observations, the average apparent conductivity was 4.29 mS/m with a range of 2.5 to 11.0 mS/m. One-half of the observations had apparent conductivity values between 3.5 and 4.5 mS/m.

Figure 9 is a two-dimensional plot of apparent conductivity values simulated from data collected with the EM38 meter in the vertical dipole orientation. Based on 48 observations, the average apparent conductivity was 3.77 mS/m with a range of 2.5 to 6.5 mS/m. One-half of the observations had apparent conductivity values between 3.0 and 4.0 mS/m.

The EM responses were generally low and invariable across most of this subsite. For the EM38 meter, the average apparent conductivity was 4.29 and 3.77 mS/m in the horizontal and vertical dipole orientations, respectively. Piles of manure were scattered across

the subsite and accounted for most of the higher recorded measurements. The electromagnetic response decreased with increased soil depth. This indicates the presence of more conductive materials near the surface and more resistive materials (i.e. lower clay, soluble salt, and/or water contents) with increasing depth.

Results:
The electromagnetic properties at each site have been characterized. Generally, EM responses were found to be exceedingly low and relatively invariable across each demonstration site. Because of past management practices (stacking of manure), EM responses at the Lackawanna sites were more variable.

This survey provided basic data concerning the variability of electromagnetic conductivity and site conditions. Data were collected prior to treatments. This data will be compared with data collected following treatments. Changes in electromagnetic properties will be related to the types of treatment.

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

With kind regards.

James A. Doolittle
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Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. This technique has been used extensively to monitor groundwater quality and potential seepage from waste sites (Brune and Doolittle, 1990; Byrnes and Stoner, 1988; De 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 milliSiemens per meter (mS/m).

Electromagnetic methods measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified penetration depth (Greenhouse and Slaine; 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990).

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 EM38 meter. 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
EM38	1.0 m	0.75 m	1.5 m

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.

References

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

Brune, D. E. and J. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Science 16(3):195-207.

Byrnes, T. R. and D. W. Stoner. 1988. Groundwater monitoring in karstic terrain; A case study of a landfill in northern New York. IN Proceeding of the FOCUS Conference on Eastern Regional Ground Water Issues. September 27-29 1988. Stamford, Connecticut. National Water Wells Assoc. Dublin, Ohio p. 53-76.

De Rose, N. 1986. Applications of surface geophysical methods to ground water pollution investigations. IN: Evaluation of Pesticides in Ground Water. American Chemical Society, Washington, D.C. p. 118-140.

Eckenrode, Joseph J. 1982. Soil Survey of Lackawanna and Wyoming Counties, Pennsylvania. USDA - Soil Conservation Service. U.S. Government Printing Office, Washington, D. C. 166 pp.

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

Greenhouse, J. P., M. E. Monier-Williams, N. Ellert, and D. D. Slaine. 1987. Geophysical methods in groundwater contamination studies. In Exploration "87 Proceedings. Application of Geophysics and Geochemistry. p. 666-677.

Parrish, Paul H. 1991. Soil Survey of Columbia County, Pennsylvania. USDA - Soil Conservation Service. U.S. Government Printing Office, Washington, D. C. 139 pp.

Siegrist, R. L. and D. L. Hargett. 1989. Application of surface geophysics for location of buried hazardous wastes. Waste Management & Research 7:325-335.

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

Van der Lelij. A. 1983. Use of electromagnetic induction instrument (Type EM-38) for mapping soil salinity. Water Resource Commission, Murrumbidgee Div., N.S.W. Australia. pp. 14.

Williams, B. G. 1983. Electromagnetic induction as an aid to salinity investigations in northeast Thailand. CSIRO Inst. Biological Resources, Div. Water and Land Res. Canberra, Australia. Tech. Memo 83/27. pp. 7.

Williams, B. G. and G. C. Baker. 1982. An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Australian J. Soil Res. 20(2):107-118.

Figure 1

SOIL MICROBIAL ENHANCEMENT PROJECT

COLUMBIA COUNTY DEMONSTRATION SITE
TOPOGRAPHY
CONTOUR INTERVAL = 0.25 M

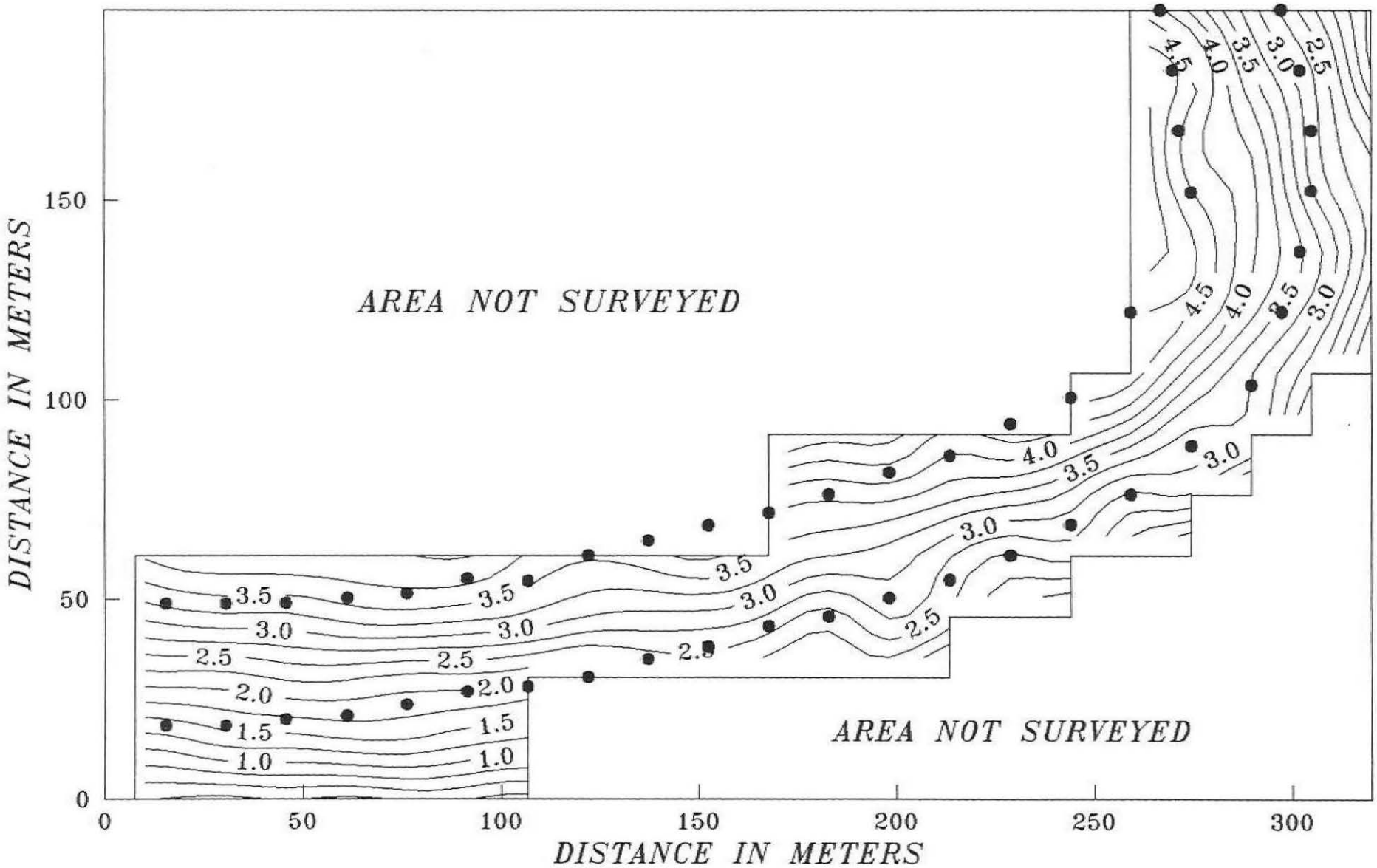


Figure 2

SOIL MICROBIAL ENHANCEMENT PROJECT

COLUMBIA COUNTY DEMONSTRATION SITE
EM38 SURVEY
HORIZONTAL DIPOLE ORIENTATION

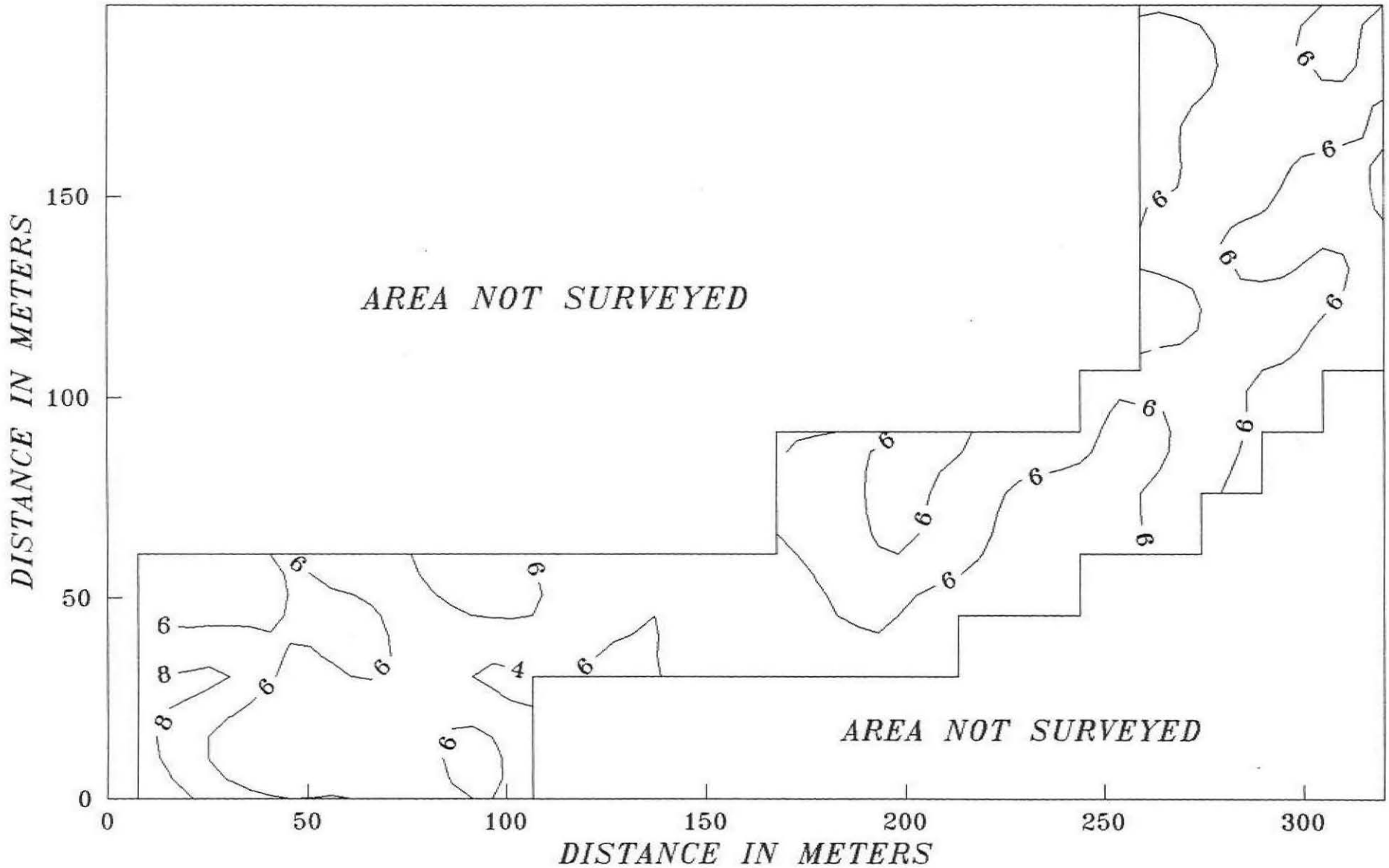
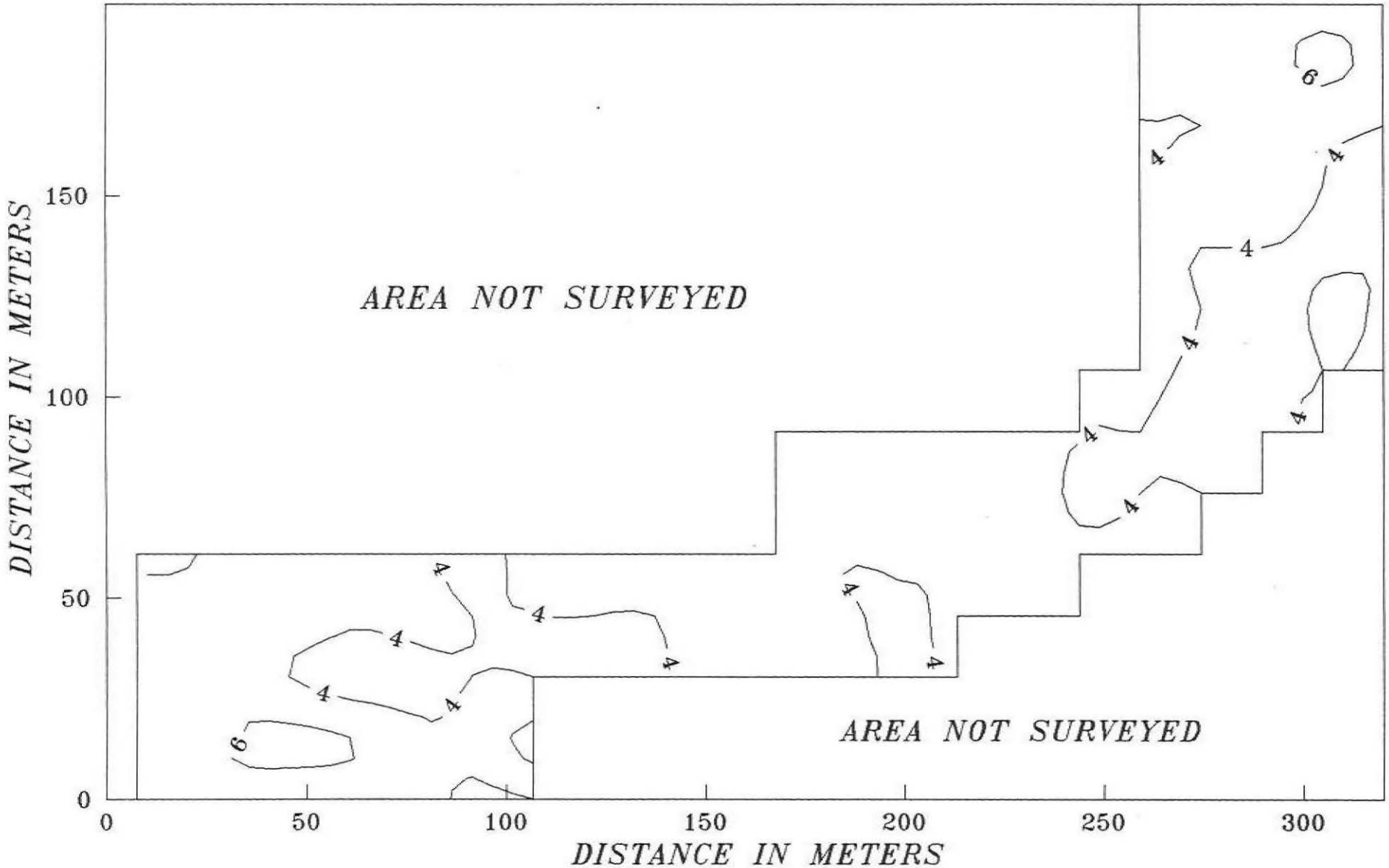


Figure 3

SOIL MICROBIAL ENHANCEMENT PROJECT

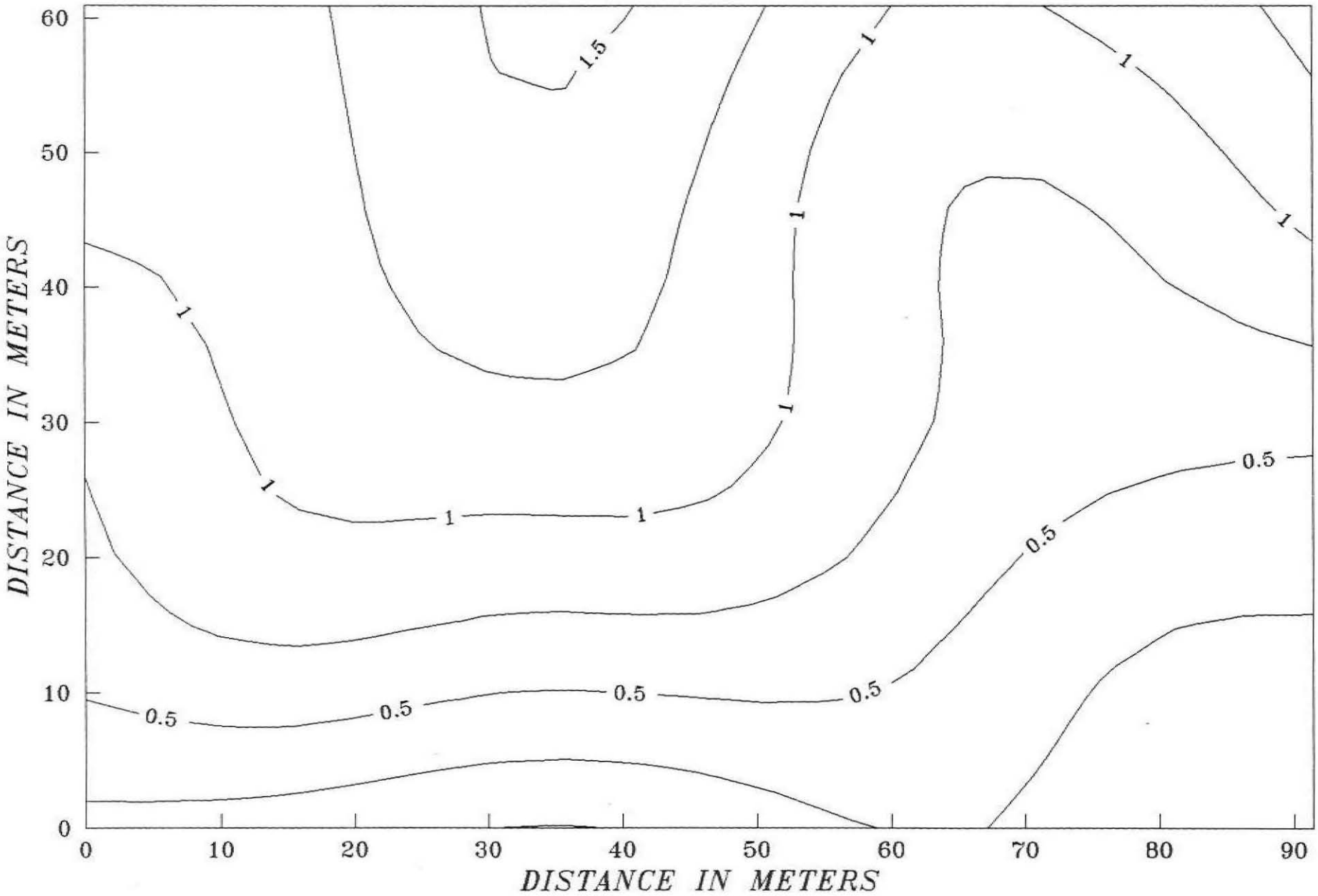
COLUMBIA COUNTY DEMONSTRATION SITE
EM38 SURVEY
VERTICAL DIPOLE ORIENTATION



SOIL MICROBIAL ENHANCEMENT PROJECT

Figure 4

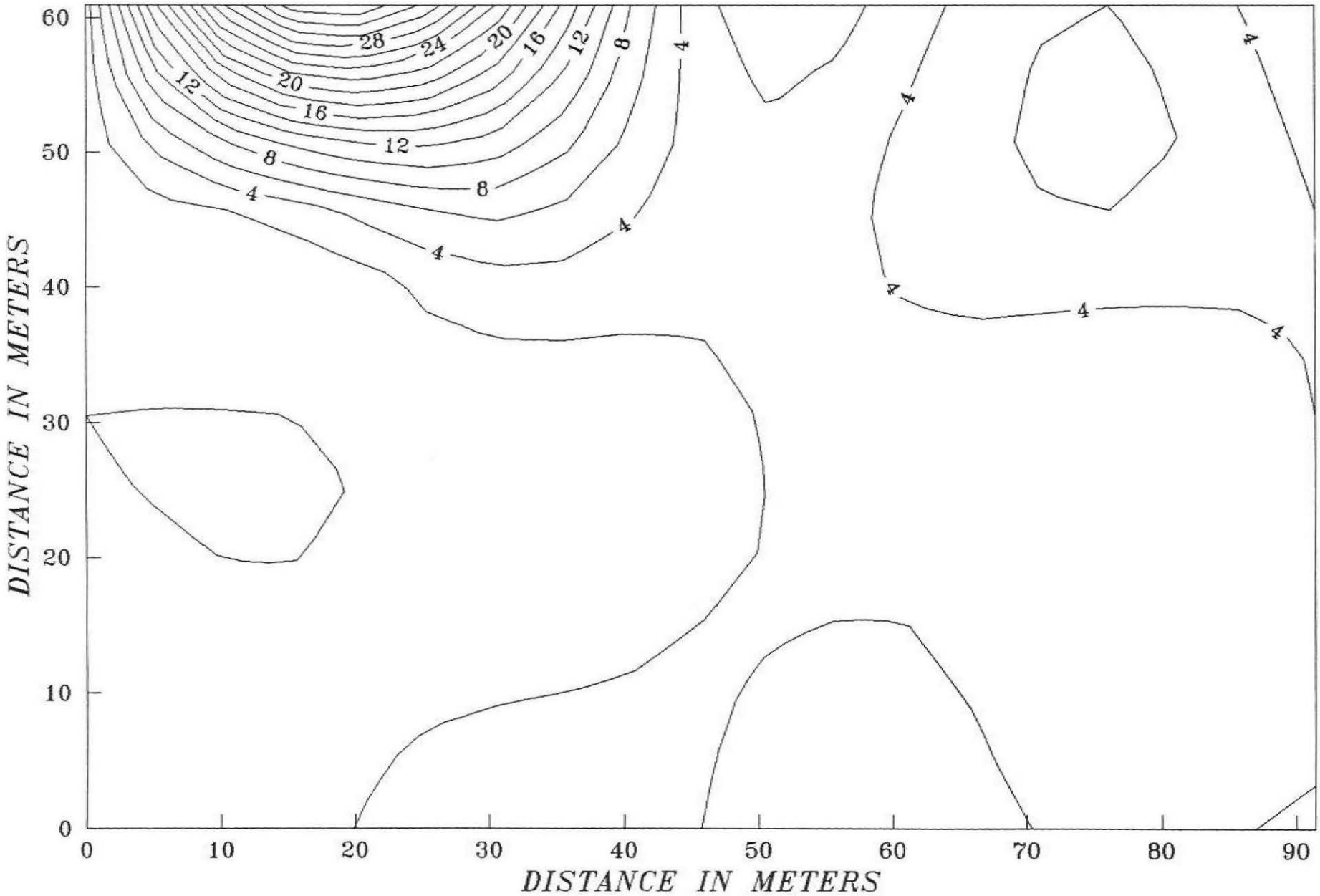
LACKAWANNA COUNTY DEMONSTRATION SITE 1
TOPOGRAPHY
CONTOUR INTERVAL = 0.25 M



SOIL MICROBIAL ENHANCEMENT PROJECT

Figure 5

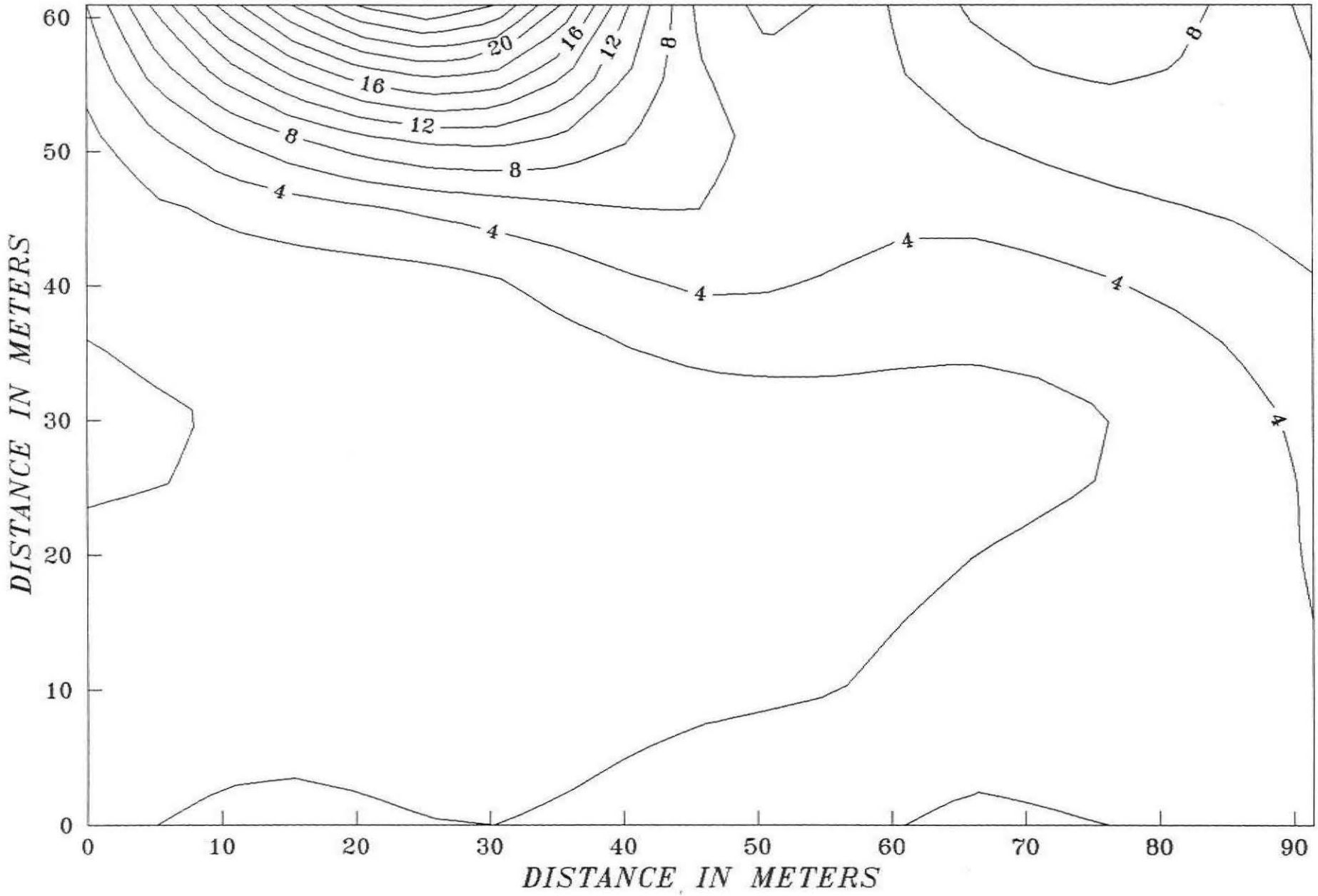
LACKAWANNA COUNTY DEMONSTRATION SITE 1
EM38 SURVEY
HORIZONTAL DIPOLE ORIENTATION



SOIL MICROBIAL ENHANCEMENT PROJECT

Figure 6

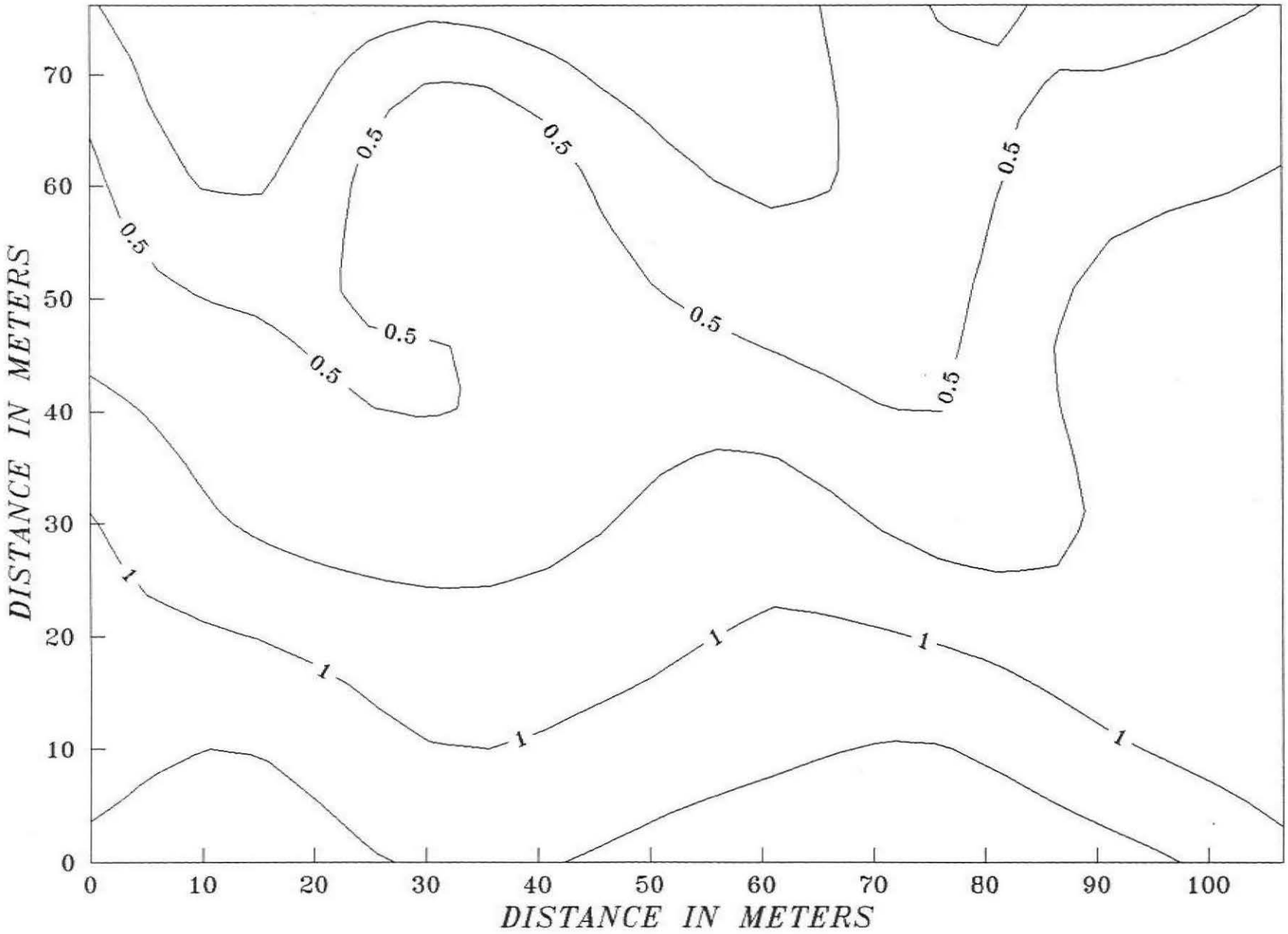
LACKAWANNA COUNTY DEMONSTRATION SITE 1
EM38 SURVEY
VERTICAL DIPOLE ORIENTATION



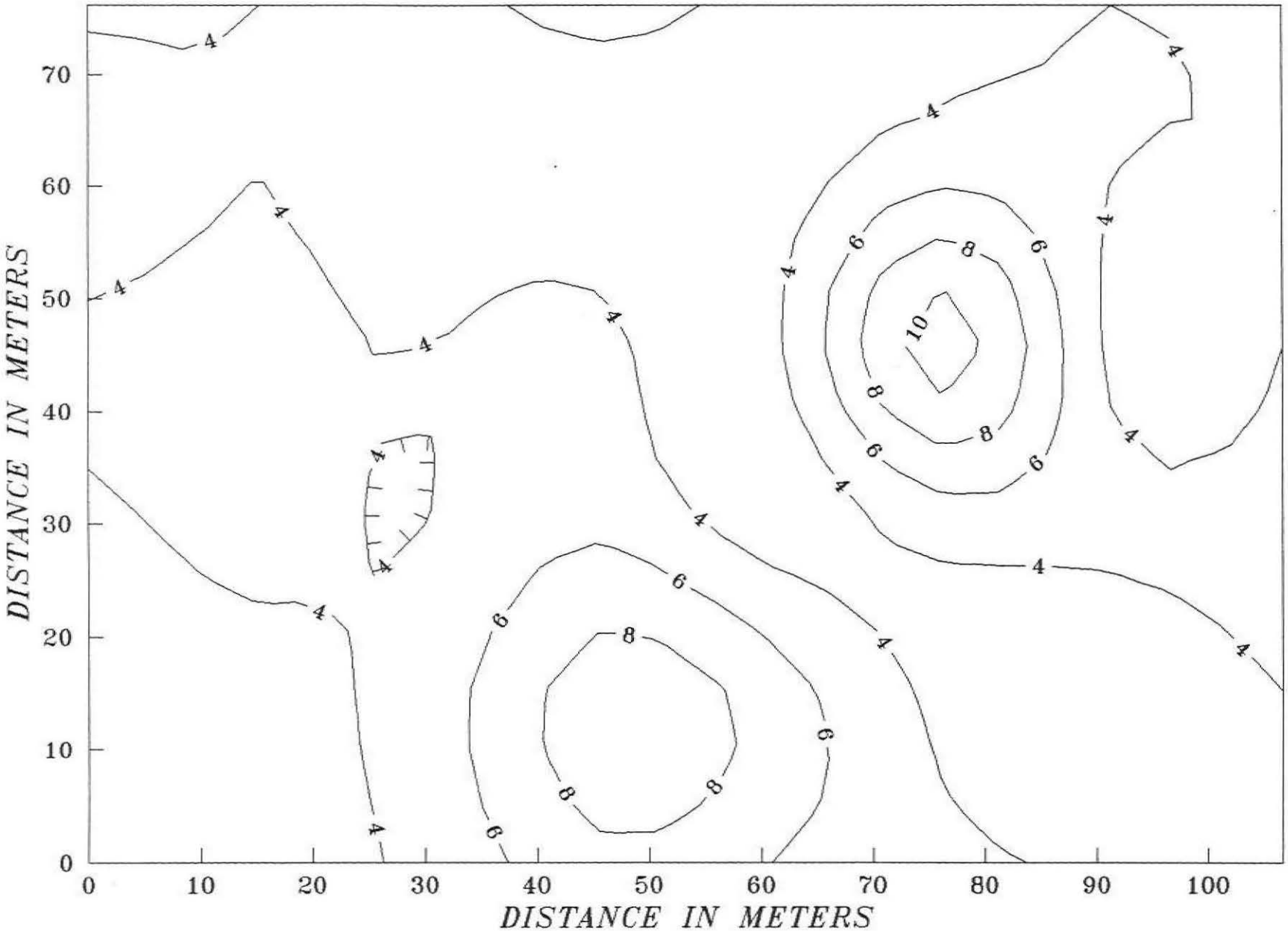
SOIL MICROBIAL ENHANCEMENT PROJECT

Figure 7

LACKAWANNA COUNTY DEMONSTRATION SITE 2
TOPOGRAPHY
CONTOUR INTERVAL = 0.25 M



SOIL MICROBIAL ENHANCEMENT PROJECT

Figure 8

LACKAWANNA COUNTY DEMONSTRATION SITE 2
EM38 SURVEY
HORTIZONTAL DIPOLE ORIENTATION