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

Subject: SOI -- Electromagnetic Induction (EM) Assistance **Date:** 28 May 1996

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Purpose:
The purpose of this investigation was to provide field assistance and training on the use of electromagnetic induction (EM) techniques.

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Activities:
All field activities were completed during the period of 12 to 16 May 1996. Surveys were conducted in Logan, Phillips, Sedgwick, and Washington counties.

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 (1980, 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 EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. 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.

TABLE 1

Depth of Measurement
(All measurements are in feet)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM38	3.3	2.5	4.9
EM31	12.1	9.8	19.7
EM34-3	32.8	24.6	49.2
	65.6	49.2	98.4
	131.2	98.4	196.7

The EM38 meter has a fixed intercoil spacing of about 40 inches. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 30 and 60 inches in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of about 12 feet. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 10 and 20 feet in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). The EM34-3 meter consists of two coils and three reference cables with intercoil spacings of about 33, 66, and 131 feet. One of the coils serves as the transmitter, the other as the receiver. Observation depths range from about 25 to 200 feet. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

At the first site, a Rockwell Precision Lightweight GPS Receiver (PLGR) * was used to obtain field coordinates. This receiver was operated using an external power source (portable 9 volt battery). During field work, the system was operated in the continuous mode. This mode uses the most power, but is able to acquire and continuously track satellites. Changes in position were continuously displayed. All recorded points had a *figure of magnitude* (FOM) of 1.

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 each of the enclosed plots of the study sites, to help emphasize spatial patterns, colors 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 colors themselves.

Discussion:

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

Electromagnetic induction techniques use 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. 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, 1980). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents.

Electromagnetic inductive methods measure 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 EM data are based on the identification of spatial patterns within data sets. To assist interpretations, two- and three-dimensional computer simulations of investigated sites are normally developed.

Advantages of EM methods include speed of operation, flexible observation depths (with commercially available systems from about 2.5 to 200 feet), and moderate resolution of subsurface features. Results of EM 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 EM data provide the basis for assessing site conditions and for designing sampling and monitoring schemes.

Electromagnetic induction techniques are not suitable for use in all investigations. Generally, the use of EM techniques has been most successful in areas where subsurface properties are reasonably homogeneous. These techniques are most effective in areas where the effect of one property (e.g., clay, water, or salt content) dominates over the other properties and variations in EM response can be related to changes in the dominant property (Cook et al., 1989).

Logan County, Colorado -- 13 May 1996

Site 1 -- Todd Johnson's Irrigated Cropland

The site was located in the northwest quarter of Section 13, T. 9 N., R. 53 W. The topography of the survey area is shown in Figure 1. Relief is 10.5 feet. The surface slopes away from a ridge located along the southwestern and western boundary of the site. Included within this site are the following map units: Haverson loam, 1 to 3 percent slopes; Heldt clay loam, and Manzanola clay loam (Amen and others, 1977). Haverson soils are members of the fine-loamy, mixed (calcareous), mesic Ustic Torrifluvents family. Heldt soils are members of the fine, montmorillonitic, mesic Ustertic Camborthids family. Manzanola soils are members of the fine, montmorillonitic, mesic Ustollic Haplargids family.

The site was cropped to sugar beets. The crop is being irrigated with a gated irrigation system. The irrigation line is located along the western border of the study site. Increased salinization has been noted in the east and northeast portion of the field. These portions of the field are the lowest-lying and furthest removed from the gated irrigation line.

A rectangular grid was established across the site. The grid interval was about 300 feet. At each grid intersection (28), a survey flag was inserted in the ground and served as an observation point. Within this coarse grid a more detailed grid was established. The detailed grid had an interval of about 100 feet. This provided 22 additional observation points. At each observation point, measurements were taken with an EM38 and an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. At each observation point, the relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum.

The coordinates of each of the observation points (28) for the coarse grid were obtained from the GPS receiver. The locations of these points are shown in Figure 2. Except for one observation point, the referenced locations appear aligned and correctly orientated. Except for one point and one line (western most line), the referenced locations appear properly spaced. As these locations were recorded on a tablet and not as *way points* within the GPS receiver, it is possible that these discrepancies were, in part, caused by observation or recording errors. The Rockwell GPS receiver can be used in the autonomous mode to quickly collect the locations of observation points for field data. These data provide the coordinates needed to construct two- and three-dimensional plots of large study areas.

Figures 3 and 4 are two-dimensional plots of the data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 5 and 6 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the isoline interval is 10 mS/m. In addition, in the upper diagram of each of these figures, a small rectangle has been used to show the location of the detailed study plot. In each figure, the lower diagram simulates the EM data collected within the detailed study plot. Within the detailed study plots, spatial patterns reflect the more intense sampling scheme (28 observations; interval of 100 feet). These diagrams can be used to compare the spatial patterns and to assess the adequacy of sampling resulting from differing survey intensities.

Figures 3 and 4 represents the spatial distribution of apparent conductivity for the upper 0.75 meter and the upper 1.5 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 82.5 mS/m and 110.6 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 73 and 91 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 99 and 123 mS/m. This trend is believed to reflect the accumulation of soluble salts and increased moisture and clay contents at intermediate and lower soil depths. If the higher conductivity is caused by increased accumulations of soluble salts, the most saline areas would be located in the northeast and central portions of the site (see figures 3 and 4).

Figures 5 and 6 represents the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. For these depth intervals, values of apparent conductivity increased with increasing observation depths. Measurements averaged 158.6 mS/m and 164.4 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 140 and 175 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 150 and 185 mS/m. This trend is believed to reflect the accumulation of soluble salts, increased moisture and clay contents, and possibly the occurrence of shale bedrock (Pierre formation) at lower soil depths. If the higher conductivity is caused by increased accumulations of soluble salts, the most saline materials (0 to 3 meters, or 0 to 6 meters) are located in the central portion of the site (see figures 5 and 6).

Comparing figures 3 to 6, the zone of highest conductivity appears to shift towards the southwest with increasing observation depths. This zone of maximum conductivity appears to move in a linear and downward fashion towards (southwesterly direction) the base of the ridge (see Figure 1). This trend could reflect the lateral and upward flow of salts and water from the higher-lying ridge area. An irrigation canal is located on the higher-lying ridge.

The measurements obtained with the EM38 meter were processed through the Soil Survey Validation Program developed by the USDA-ARS Soil Salinity Laboratory in Riverside, California. This program provided basic statistics and selected eight representative observation points for sampling. Mike Petersen collected samples from each of these observation points and measured their EC_e.

Washington County, Colorado -- 14 May 1996

Washington County Landfill Site

A landfill site is being developed south of Akron in Washington County. The site is located in the northeast quarter of Section 4, T. 15 N., R. 52 W. Map units included within the site were: Canyon gravelly loam, 2 to 6 percent slopes; and Wages-Canyon complex, 2 to 5 percent slopes (Petersen and others, 1987). Canyon soils are members of the loamy, mixed (calcareous), mesic, shallow Ustic Torrifluvents family. Wages soils are members of the fine-loamy, mixed, mesic Aridic Argiustolls family. The site is underlain by shale mantled by a relatively thick deposit of stratified alluvium and eolian materials. Exploratory drillings revealed that the depth to bedrock was variable across the site. Recorded depths to the water table exceeded the planned depth of excavation. However, during the excavation of the first cell (about 35 to 40 feet deep), water was encountered.

The study site was located at the bottom of the excavated pit. The pit will serve as a cell to receive trash. In one portion of the pit's bottom, water is ponding in a small excavated cavity. A survey grid was established across the site. The grid interval was 50 feet. At each grid intersection (30), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface.

Models constructed from EM data are more accurate in areas having a minimal sequence of dissimilar horizontal layers. The accuracy of models decreases with increasing numbers of layers. The site was conceptualized as consisting of two dissimilar layers: overlying alluvial and eolian deposits, and underlying shale bedrock. The underlying shale was presumed to be more electrically conductive than the overlying alluvial deposits.

Figures 7 and 8 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 5 mS/m. Figures 7 and 8 represents the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. For these depth intervals, values of apparent conductivity increased with increasing observation depths. Measurements averaged 55.2 mS/m and 59.0 mS/m in the horizontal and vertical dipole orientations, respectively. This vertical relationship agrees with the model. This vertical trend is believed to reflect the occurrence of more conductive materials (shale bedrock) at lower depths.

In both figures 7 and 8, the spatial patterns are similar and are believed to reflect the depth to bedrock. Areas with lower apparent conductivity were presumed to have deeper depths to shale and thicker deposits of alluvium. Areas with higher apparent conductivity were presumed to have shallower depths to shale and thinner deposits of alluvium. In both figures, the area with ponded water occurred immediately to the west of the section with the lowest apparent conductivity values (less than 50 mS/m). This section is located in the central portion of the site. As drill logs revealed shallow depths to bedrock on either side of this area, it was postulated that water could be moving laterally into this bedrock "low."

Figure 9 is a graph showing EM measurements along a higher-lying portion of the landfill site. This site was located about 40 feet above and to the west of the previous site. These measurements were collected with an EM34-3 meter and a 20-m intercoil spacing. This intercoil spacing provides an observation depth of about 15 and 20 meters in the horizontal and vertical dipole orientations, respectively. For these depth intervals, values of apparent conductivity increased with increasing observation depths. Measurements averaged 55.2 mS/m and 59.0 mS/m in the horizontal and vertical dipole orientations, respectively. This vertical relationship agreed with the conceptualized model.

In Figure 9, only the measurements obtained with the EM34-3 meter in the vertical dipole orientation are displayed. The graphs show the spatial distribution of apparent conductivity within the upper 30 meters. It is believed that the measured EM responses reflect the occurrence and proximity of more conductive materials (shale bedrock) to the surface. It is believed that the shape of the line in each graph approximates the topography of the bedrock surface.

It was inferred from the brief EM survey at the Washington County landfill site, that the underlying bedrock topography was highly variable. A zone of low conductivity corresponded with an area with ponded water. In similar materials, increased water contents should increase the measured apparent conductivity. The materials underlying the pond of water were consider dissimilar from adjacent areas. The pond of water was presumed to be located in a zone of thicker alluvial deposits with deeper depths to bedrock. It was hypothesized that the water found at the bottom of the pit could represent the perching of water within a trough in the bedrock. These interpretations should be confirmed with coring observations.

Logan County, Colorado -- 15 May 1996

Jerry Michels Irrigated Corn Field

The site was located in the southwest quarter of Section 35, T. 17 N., R. 53 W. . The site was cropped to corn. The topography of the survey area is shown in Figure 10. The relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum. Relief is about 2.3 feet. The surface slopes towards the east. A road parallels and is located immediately to the south of the site. The site is being irrigated from a canal located immediately to the north of the site (in the area marked "area not surveyed").

Included within this site are the following map units: Lebsack silty clay loam and Santana loam, water table (Amen and others, 1977). Lebsack soils are members of the fine, montmorillonitic, mesic Pachic Haplustolls family. Santana soils are members of the fine-loamy, mixed, mesic Aridic Argiustolls family. These soils formed on terraces in calcareous alluvium deposited by the South Platte River.

A irregularly shaped, rectangular grid was established across the site. Grid intervals were 50 (north - south) and 100 feet (east - west). At each grid intersection (68), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface.

Figures 11 and 12 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 7 mS/m. Figures 11 and 12 represents the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. For these depth intervals, values of apparent conductivity increased with increasing observation depths. Measurements averaged 41.5 mS/m and 45.1 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 30 and 52 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 32 and 57 mS/m. This trend is believed to reflect the stratified nature of these deposits and increased moisture and clay contents with increasing soil depths.

Comparing figures 11 and 12, the spatial patterns are very similar. A zone of conspicuously higher conductivity forms a belt in the eastern half of each plot. This belt is orientated in a southwest to northeast direction. As this orientation conforms with the general course of the South Platte River, the zone of higher conductivity was presumed to reflect a depositional feature. Because of its higher conductivity, this feature was presumed to have higher clay contents than adjoining, less conductive areas. A similar pattern can be seen on the soil map of this site (Amen and others, 1977). A narrow strip of fine-textured Ledsack soils conforms with the belt of higher apparent conductivity values shown in figures 11 and 12. The techniques used in this study can be used to improve the characterization of soils within selected sites.

Phillips County, Colorado -- 15 May 1996

Animal Waste-holding Facility at the D & D Farms, Inc., Holyoke, CO

The purpose of this investigation was to explore the potentials of using EM techniques to characterize waste-holding sites, assess the integrity of existing structures, and to identify potential areas of seepage. While this technique has been successfully and repeatedly used by NRCS in eastern portions of the United States, this agency has conducted few studies in arid portions of the country. We greatly appreciate the cooperation of D & D Farms in providing a suitable test site.

The waste-holding facility is about five years old and supports a large hog operation. The site was located in the southern half of Section 23, T. 6 N., R. 45 W. Map units included within the site were Haxtum sandy loam, 0 to 3 percent slopes, Pleasant loam, Rago and Kuma loams, and Valentine fine sand, rolling (Brubacher and others, 1971). Haxtum soils are members of the fine-loamy, mixed, mesic Pachic Argiustolls family. Kuma soils are members of the fine-silty, mixed, mesic Pachic Argiustolls family. Pleasant soils are members of the fine, montmorillonitic, mesic Pachic Argiustolls family. Rago soils are members of the fine, montmorillonitic, mesic Aridic Argiustolls family. Valentine soils are members of the mixed, mesic Ustic Torripsamments family. These soils formed in lower-lying areas on sandhill uplands.

An irregularly shaped grid was established across the site. Grid intervals were 50 feet (east - west) and 25 feet (north - south). At each grid intersection (68), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. The survey was restricted to two sides (north and east) of the structure.

The topography of the survey area has been simulated in the three-dimensional net diagram shown in Figure 13. The relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum. In Figure 13, the contour interval is 2 feet. Relief was about 14 feet. The contour lines bend around the constructed waste-holding facility. As can be seen in this figure, the survey extended to the top of the embankment but not into the waste-holding pond. A wire fence was near and formed the northern and most of the eastern border of the grid site.

Figures 14 and 15 provide an alternative presentation of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these figures, the two-dimensional patterns of apparent conductivity values have 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.

Figures 17 and 18 represents the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 32.4 mS/m and 38.3 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation (0 to 3 meters), one-half of the observations had values of apparent conductivity between 26 and 30.1 mS/m. For the deeper-sensing vertical dipole orientation (0 to 6 meters), one-half of the observations had values of apparent conductivity between 33 and 43 mS/m. This trend is believed to reflect strata with higher clay and moisture contents at lower soil depths.

In figures 14 and 15, values of apparent conductivity appear highly variable across the site. In both figures, values of apparent conductivity increased with increasing distances away from the waste-holding facility. These patterns do not support nor are they indicative of seepage of contaminants from the structure. Seepage patterns should be plume-like, with decreasing values away from the structure. If seepage is occurring, the highest values of apparent conductivity should occur on and within the embankment. In addition, values should decrease with increasing distances away from the structure. The EM survey revealed no indication of seepage from the structure. Higher values of apparent conductivity in the lower-lying areas and in the northeast corner of the grid site are believed to reflect the higher clay contents of the included soils.

Additional waste-holding structures should be surveyed in northeastern Colorado. These studies will clarify the appropriateness of using EM techniques for seepage studies in arid environments, the suitability of various meters, and scope and magnitude of the problem.

Sedgwick County, Colorado -- 16 May 1996

Surge Irrigation, Sedgwick, CO

The site was located in the northwest quarter of Section 7, T. 11 N., R. 46 W. The site was cropped to corn. The crop is being irrigated with a surge irrigation system.

The topography of the survey area is shown in Figure 16. Two simulations of the surface topography are shown in this figure: a two-dimensional contour plot (upper) and a three-dimensional surface net diagram (lower). Relative elevations were determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum. Relief is about 8.0 feet. The surface slopes towards the south and in the direction of the South Platte River. A road parallels and is located immediately to the east of the site. The site is being irrigated from a line located immediately to the north of the site.

Included within this site are the following map units: Bridgeport loam, 0 to 1 percent slopes; Haverson loam, 0 to 1 percent slopes; and Keith and Tripp loams, 0 to 1 percent slopes (Brubacher and Moore, 1969). Bridgeport soils are members of the fine-silty, mixed, mesic Entic Haplustolls family. Haverson soils are members of the fine-loamy, mixed (calcareous), mesic Ustic Torrifluvents family. Keith soils are members of the fine-silty, mixed, mesic Typic Argiustolls family. Tripp soils are members of the coarse-silty, mixed, mesic Typic Haplustolls family. These soils formed on terraces in silty eolian deposits and calcareous alluvium from the South Platte River.

A rectangular grid was established across the site. The grid intervals were about 400 feet (north - south) and 100 feet (east - west). At each grid intersection (31), a survey flag was inserted in the ground and served as an observation point. Within this coarse grid a more detailed grid was established. The detailed grid had an interval of about 100 feet. This provided 27 additional observation points. At each observation point, measurements were taken with an EM38 and an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface.

Figures 17 and 18 are two-dimensional plots of the data collected with the EM38. Figures 19 and 20 are two-dimensional plots of the data collected with the EM31 meter. In each plot, the isoline interval is 10 mS/m. Figure 17 and 19 simulates data collected with the meters for the larger, less intensively sampled grid site. Figure 18 and 20 simulates data collected with the meters within the smaller, more intensively sampled grid site. Within the detailed study plots, spatial patterns reflect the more intense sampling scheme (28 observations; interval of 100 feet). These diagrams can be used to compare the spatial patterns and to assess the adequacy of sampling resulting from differing survey intensities.

Figures 17 and 18 represents the spatial distribution of apparent conductivity for the upper 0.75 meter and the upper 1.5 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 56.2 mS/m and 66.4 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 48 and 62 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 57 and 71 mS/m. This trend is believed to reflect the accumulation of soluble salts and increased moisture and clay contents at intermediate and lower soil depths.

If the higher conductivity is caused by increased accumulations of soluble salts, the most saline areas would be located in the southern portion of the site (see figures 17). This could indicate that salts are being more effectively leached from soil profiles in the northern portion of the field (area closest to surge irrigation line). This portion of the field receives greater amount of irrigation water and has longer saturation time. In the southern portion of the field, soils have higher conductivity. If higher levels of conductivity are attributed to salinity, soluble salts appear to accumulating in this portion of the field. If these assumptions are correct, longer periods of saturation would be needed to leach the salts from soil profiles in this portion of the field.

Figures 19 and 20 represents the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. For these depth intervals, values of apparent conductivity decreased with increasing observation depths. Measurements averaged 77.8 mS/m and 71.4 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 69 and 82 mS/m. For the deeper-sensing vertical dipole orientation, one-half of the observations had values of apparent conductivity between 64 and 78 mS/m. This trend is believed to reflect the accumulation of soluble salts in layers near the soil surface, and/or decreasing clay contents with increasing soil depths. If the zones of higher conductivity are caused principally by increased accumulations of soluble salts, the most saline materials (0 to 3 meters, or 0 to 6 meters) are located in the southern portion of the site (see Figure 19).

Results:

1. I was most encouraged by the enthusiasm of the participants and the involvement of various agencies in this study. All participants are in search of better tools to assess potential sources of groundwater contamination or to characterize and monitor the extent of salinization in the lower South Platte River Valley. Judging from their responses, an appropriate tool has been found.

2. NRCS in Colorado has several EM38 meters, but presently no EM31 meter. The EM38 was designed specifically for salinity appraisal. I am very pleased by the commitment of your staff to use EM techniques to characterize and monitor salinity. The EM38 meter can be used for other applications. As an agency, we are increasingly encountering issues relating to soil health and point sources of pollution. One application for the EM38 meter is the characterization and delineation of areas affected by overland flow of waste products and other contaminants from animal-holding areas. For the investigation of the deeper seepage of contaminants from point sources, such as animal waste-holding facilities, the EM31 or EM34-3 meters are more appropriate tools.

3. Additional waste-holding structures should be surveyed in northeastern Colorado. These studies will clarify the appropriateness of using EM techniques for seepage studies in arid environments, the suitability of various meters, and scope and magnitude of the problem.

4. This study has attempted to demonstrate the integration of various technologies: electromagnetic induction, global positioning systems, computer software and hardware. Through integration we provide a better product to our customers. The computer graphics displayed in this report were often prepared and printed in the field for immediate on site evaluation by the participants. Similar services could be provided by area staffs with the purchase of suitable software (Surfer for Windows) and a 486 lap-top computer that can be taken into the field.

5. An EM31 meter (serial # 8906013) has been loaned to Mike Petersen. I have encouraged Mike to evaluate the potentials of this meter for irrigation water management support, salinity appraisals, groundwater contamination assessments, and soil survey investigations. Other agencies have expressed their willingness to explore and use this technology. These agencies include the Northeast Colorado Health Department and the Cooperative Extension Service.

Unless other arrangements are made, I will pick up this meter from Mike in early July.

6. It was sincere pleasure to work in your state and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:

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EM SURVEY
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

RELATIVE TOPOGRAPHY

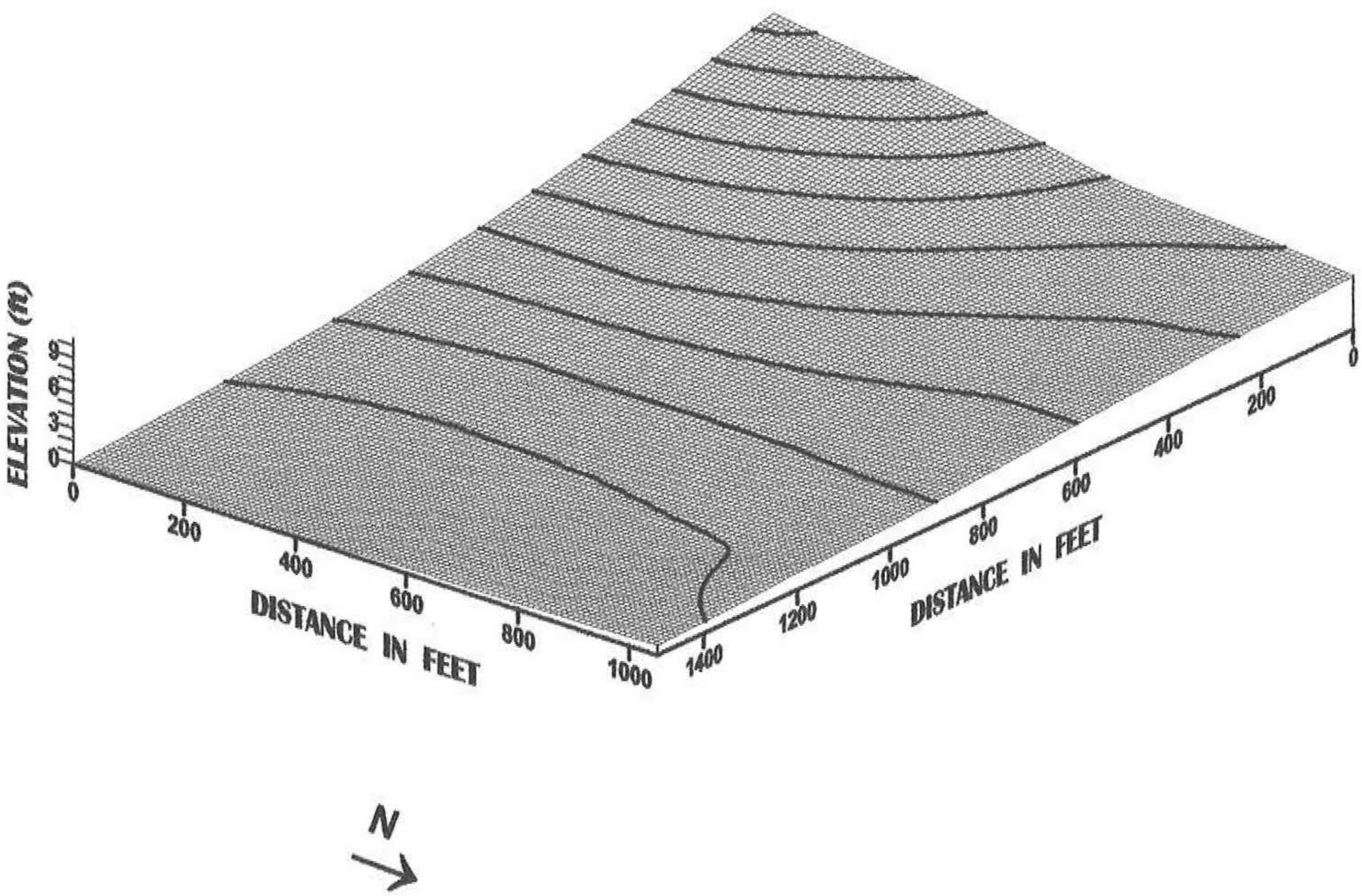


Figure 1

LOCATION OF OBSERVATION POINTS
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

COORDINATES OBTAINED WITH ROCKWELL GPS RECEIVER

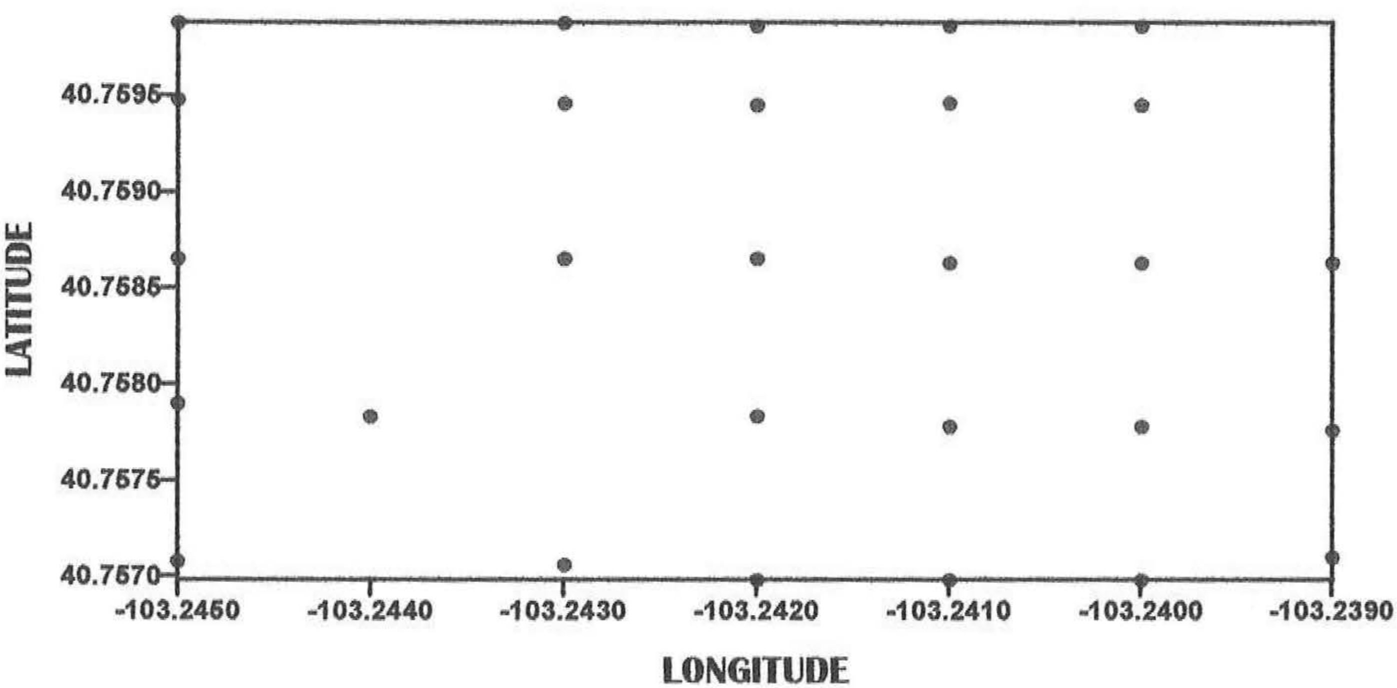
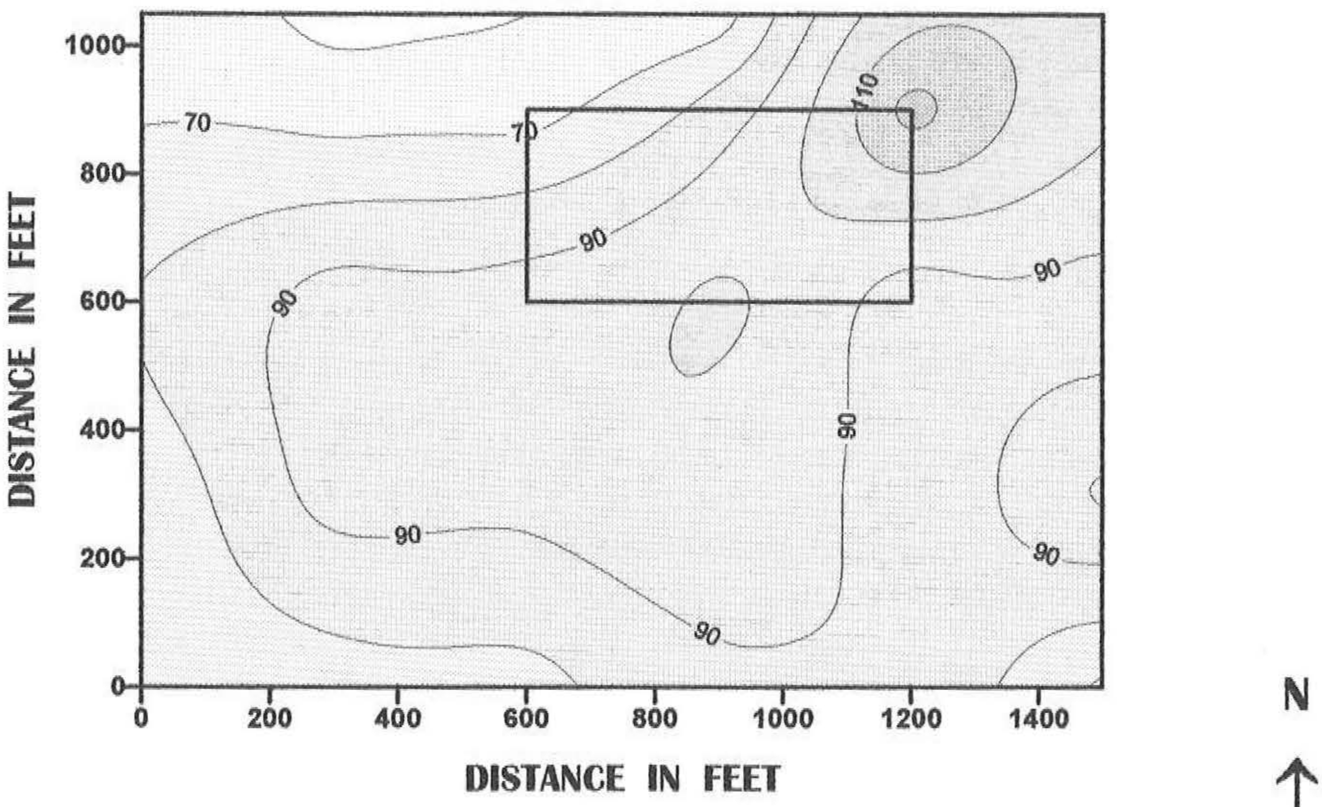


Figure 2

EM SURVEY
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

EM38 METER
HORIZONTAL DIPOLE ORIENTATION



DETAILED PLOT

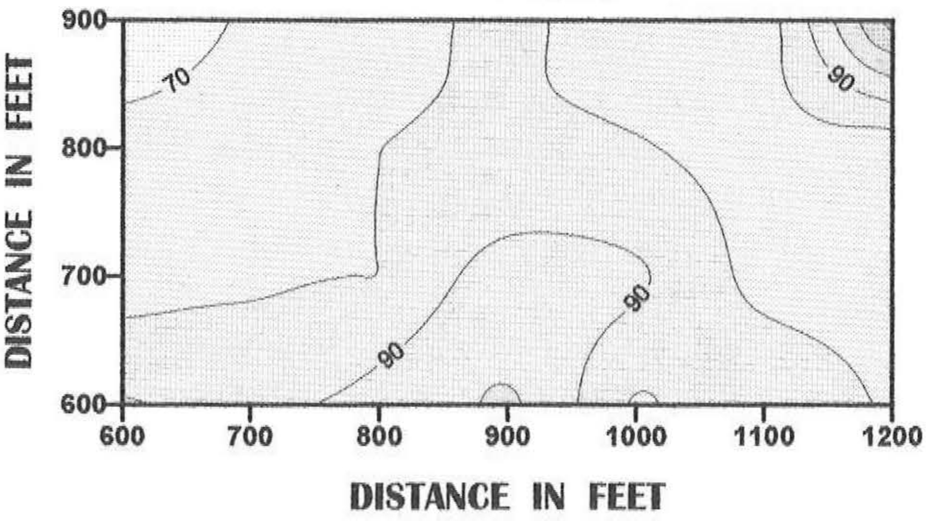
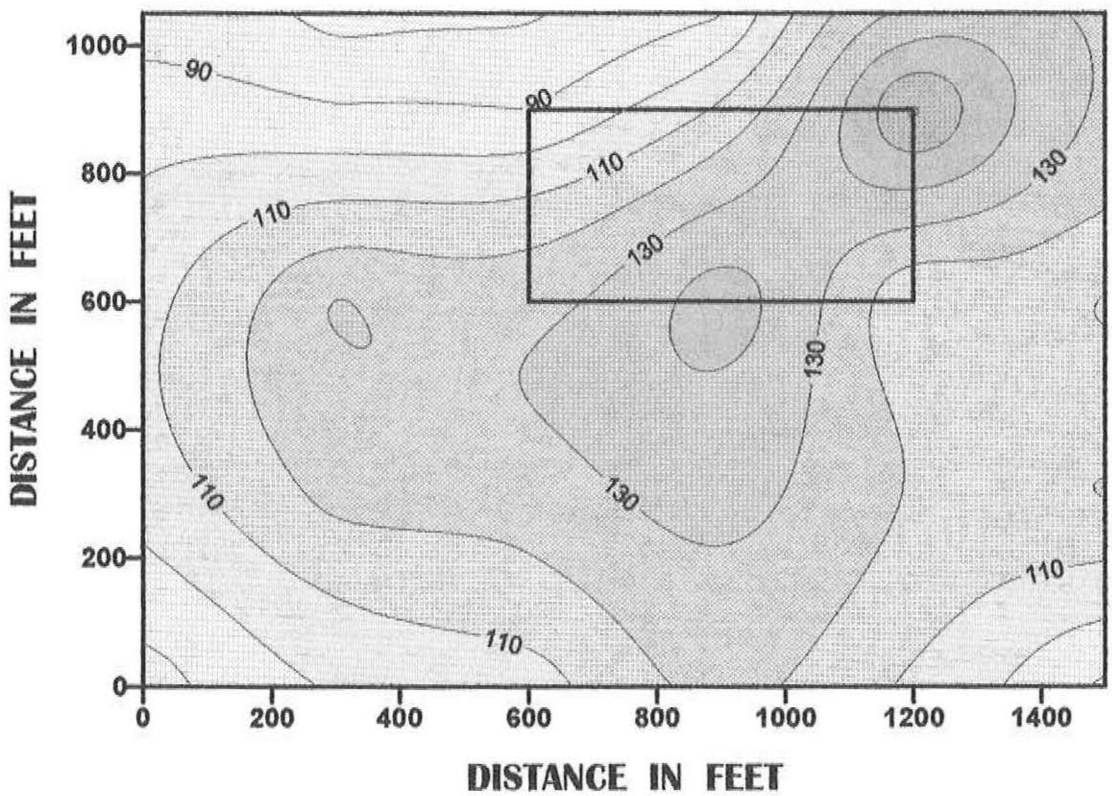


Figure 3

EM SURVEY
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

EM38 METER
VERTICAL DIPOLE ORIENTATION



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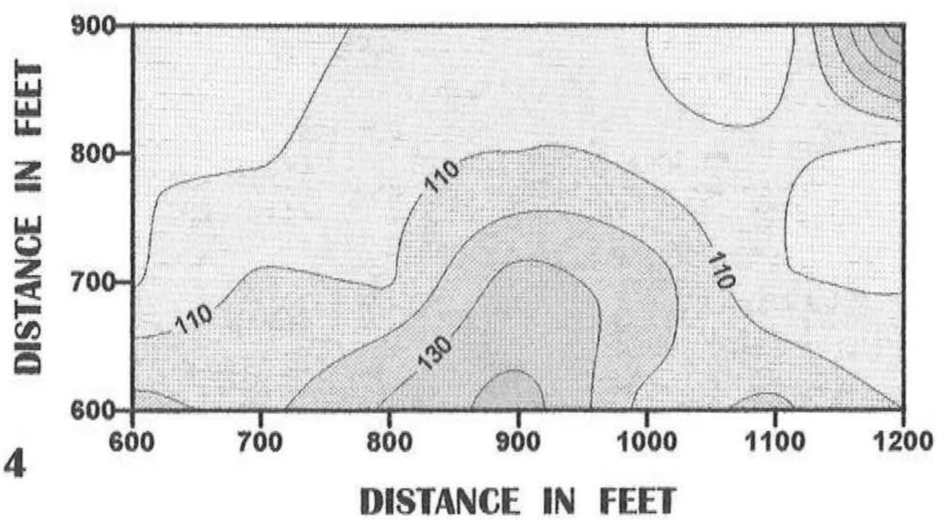
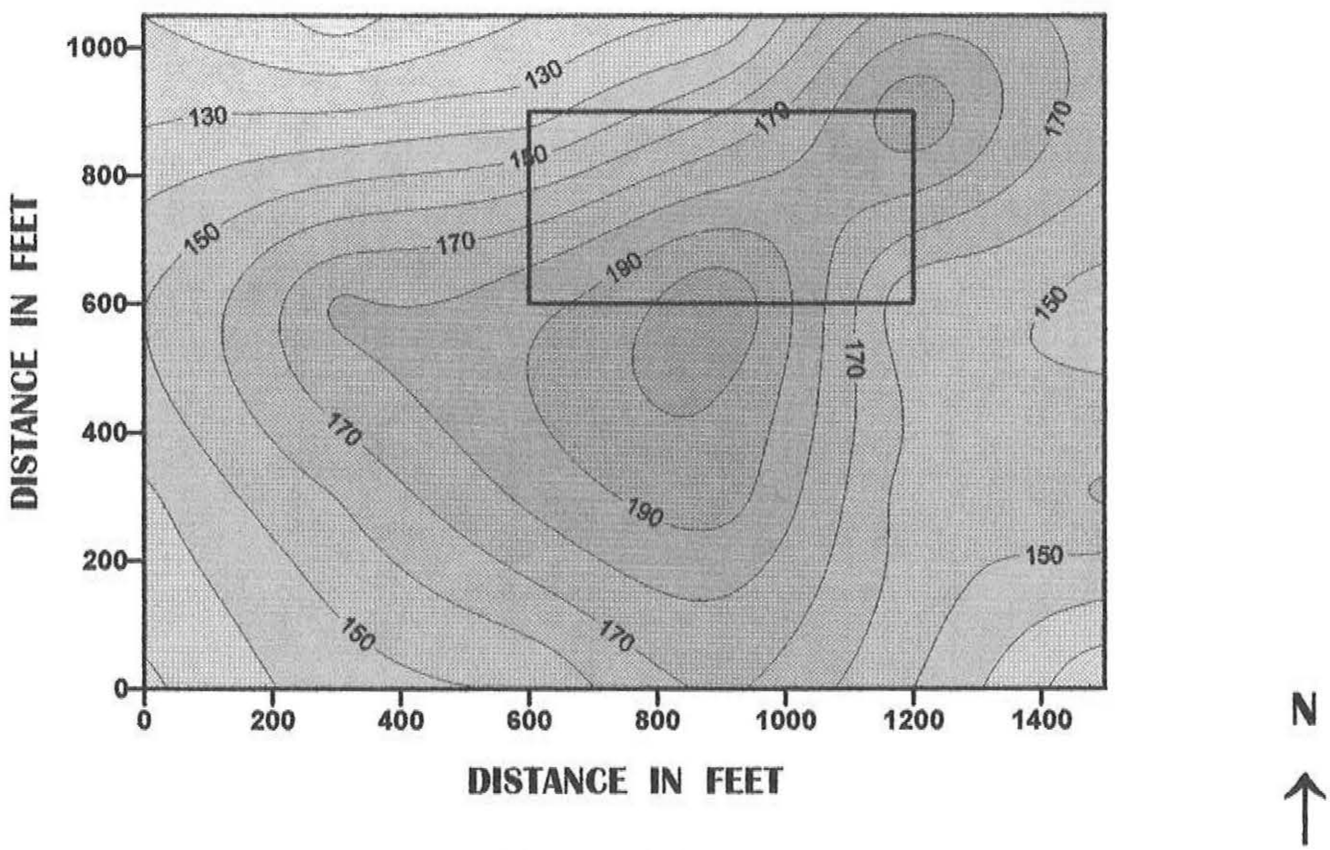


Figure 4

EM SURVEY
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

EM31 METER
HORIZONTAL DIPOLE ORIENTATION



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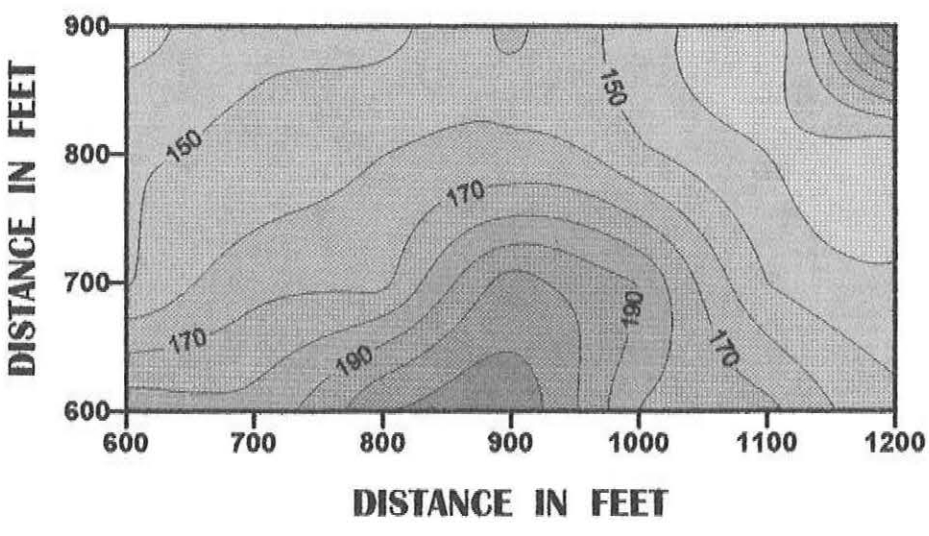
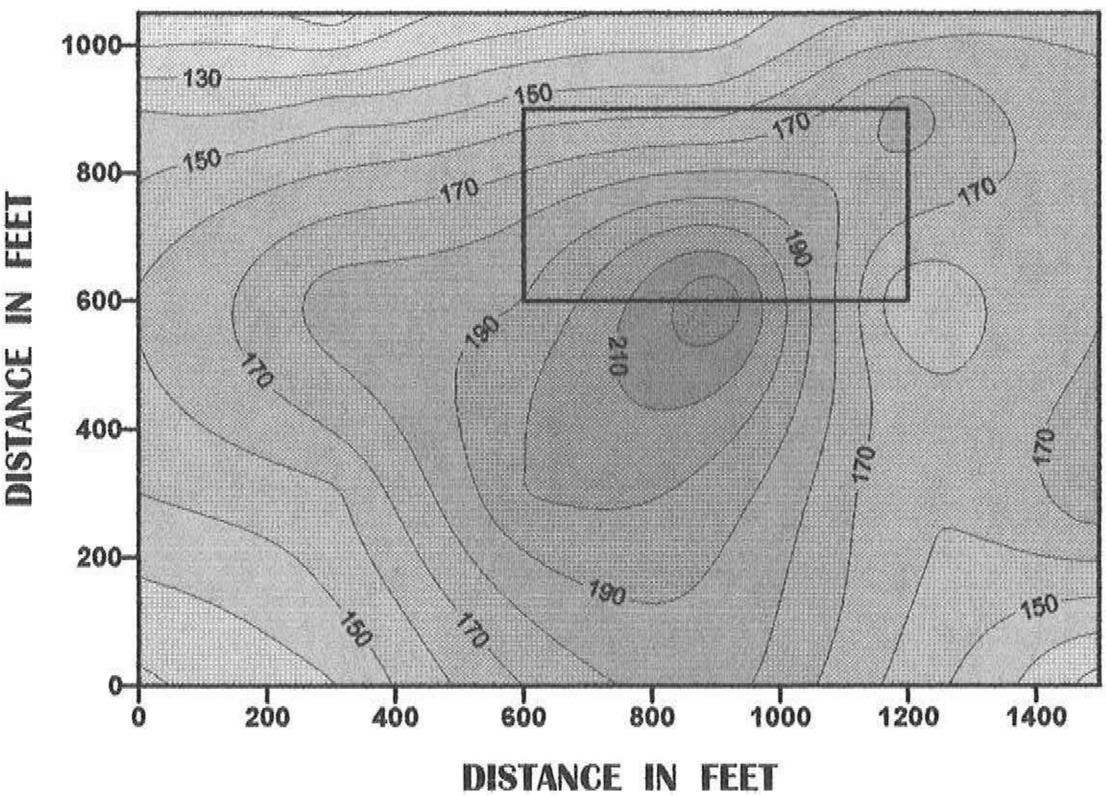


Figure 5

EM SURVEY
IRRIGATED SUGAR BEET FIELD
LOGAN COUNTY, COLORADO

EM31 METER
VERTICAL DIPOLE ORIENTATION



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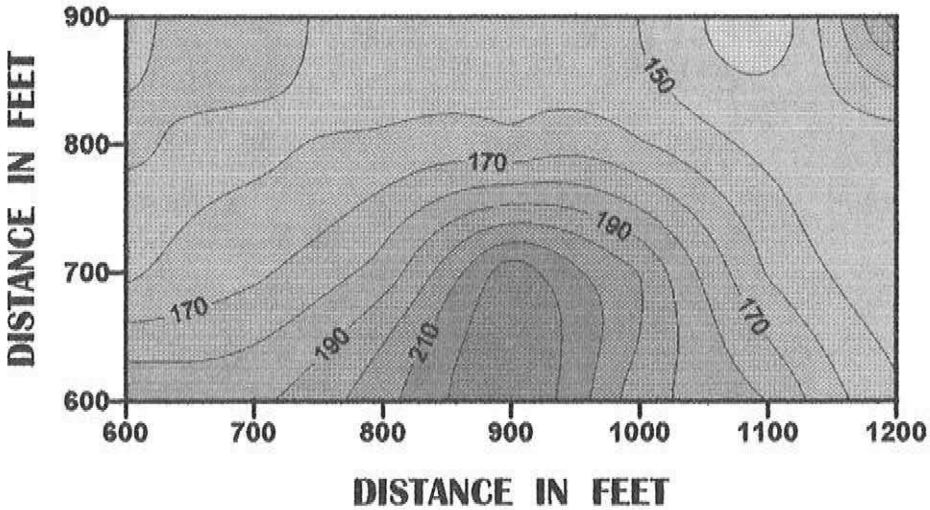


Figure 6

EM SURVEY
WASHINGTON COUNTY LANDFILL

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

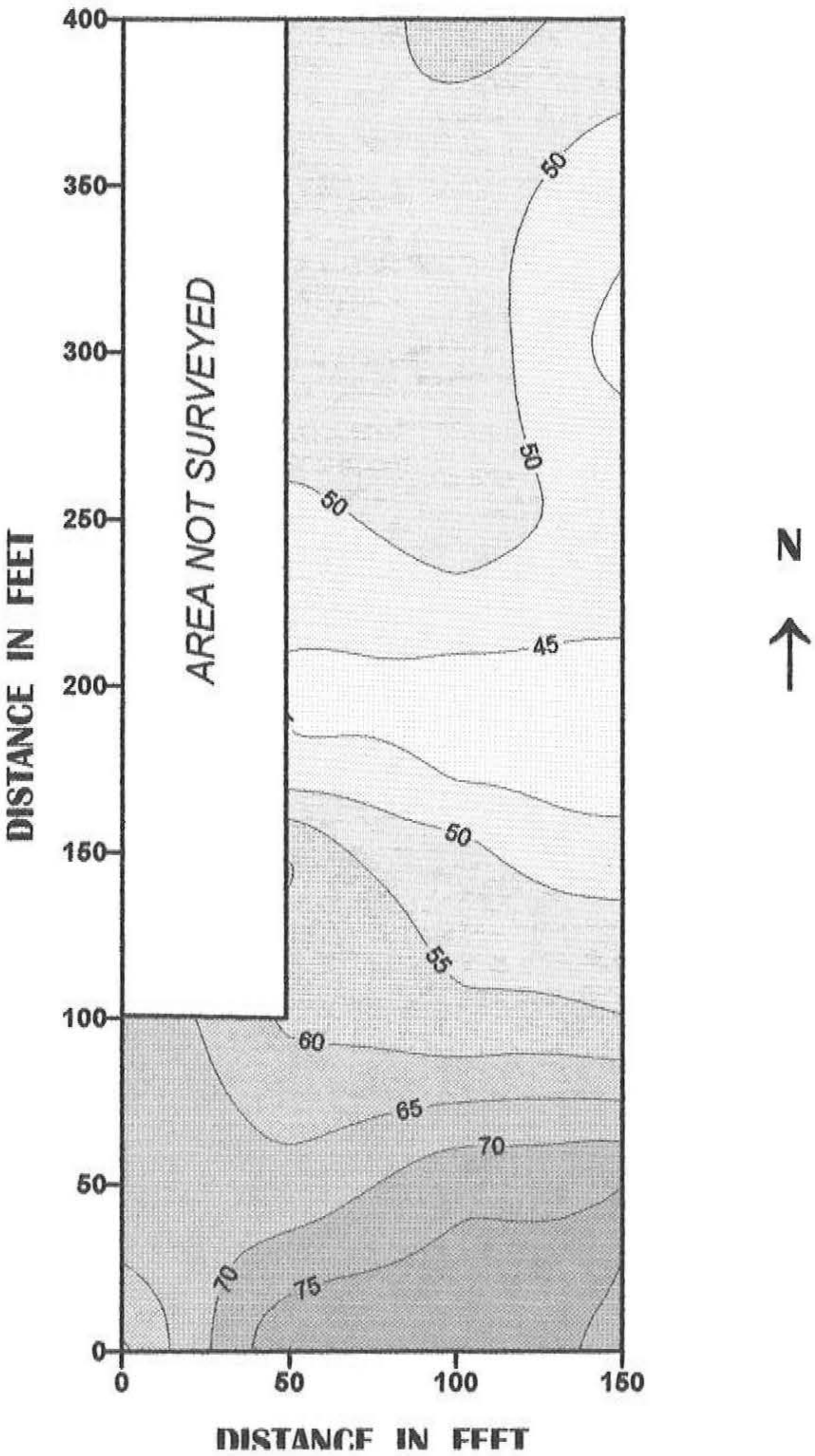


Figure 7

EM SURVEY
WASHINGTON COUNTY LANDFILL

EM31 METER
VERTICAL DIPOLE ORIENTATION

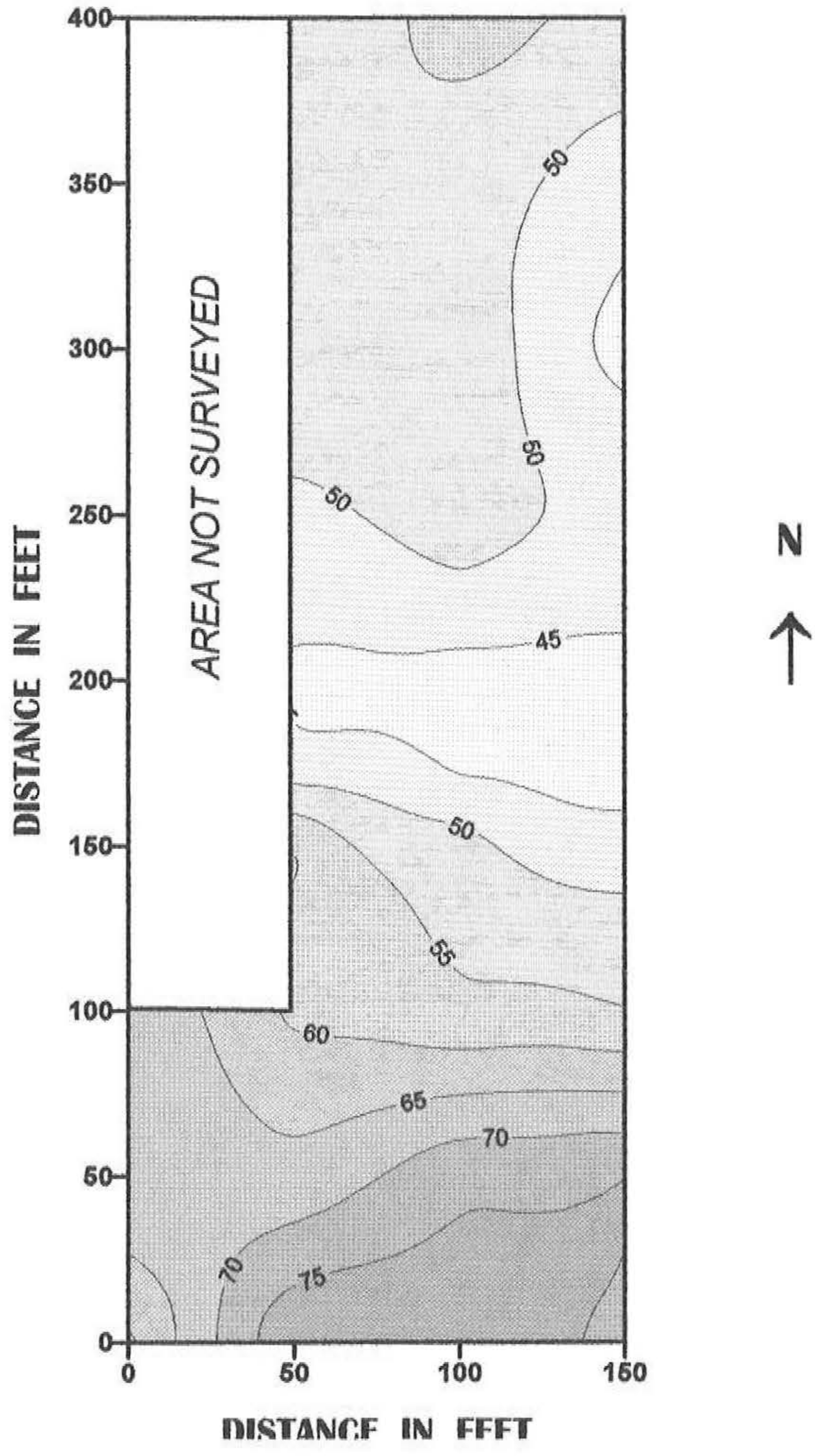
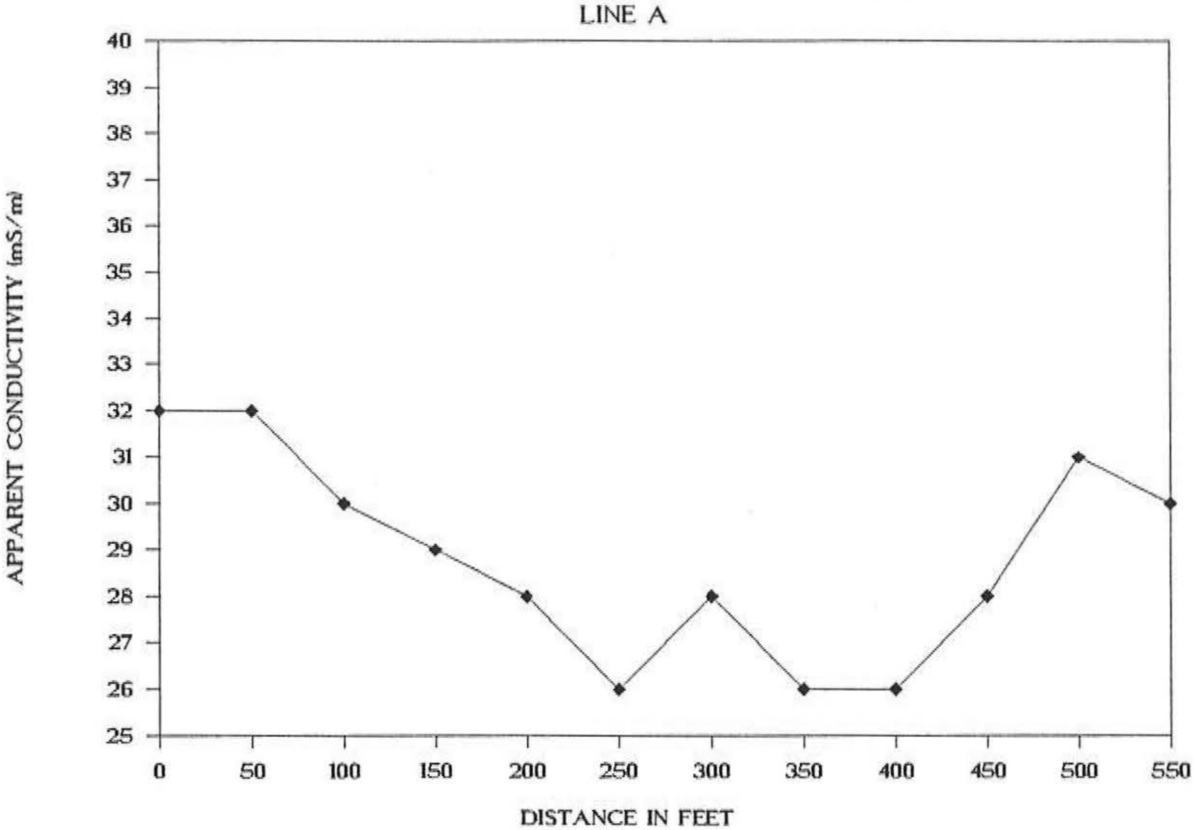
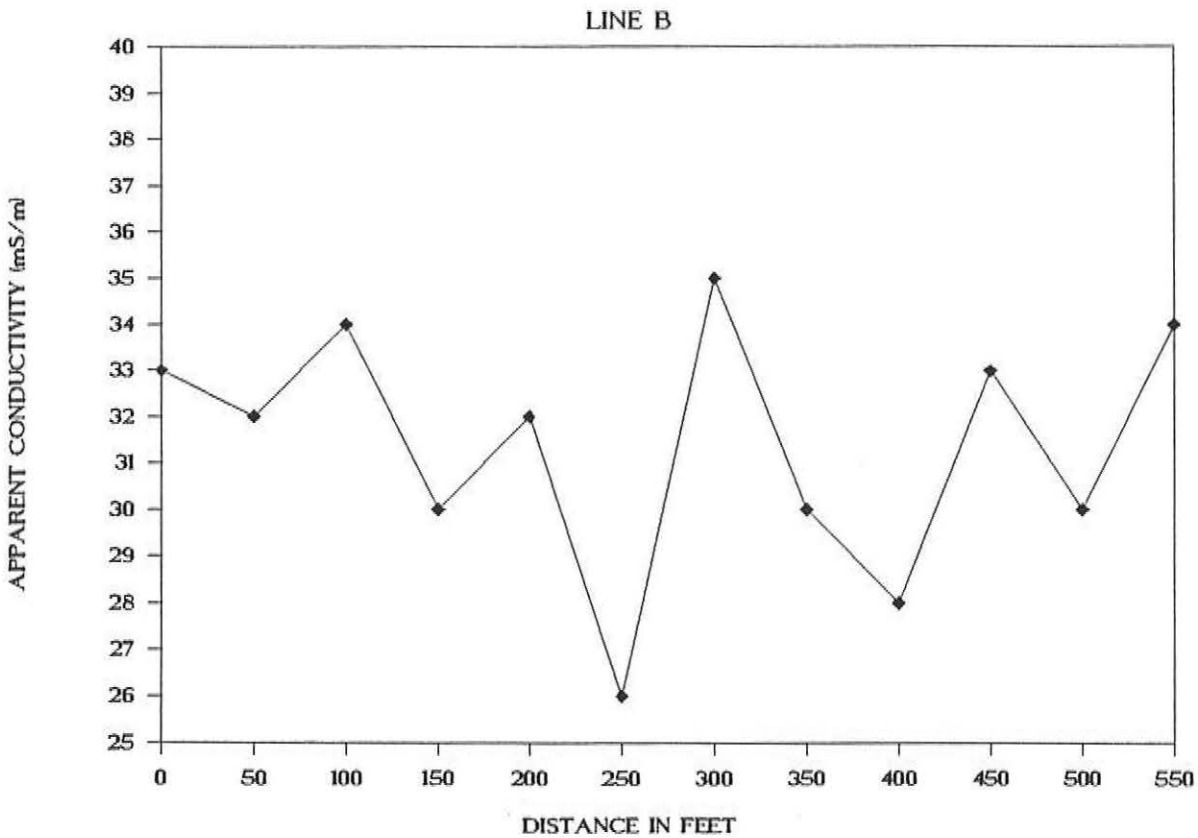


Figure 8

WASHINGTON COUNTY LANDFILL





RELATIVE TOPOGRAPHY
CULTIVATED FIELD
LOGAN COUNTY, COLORADO

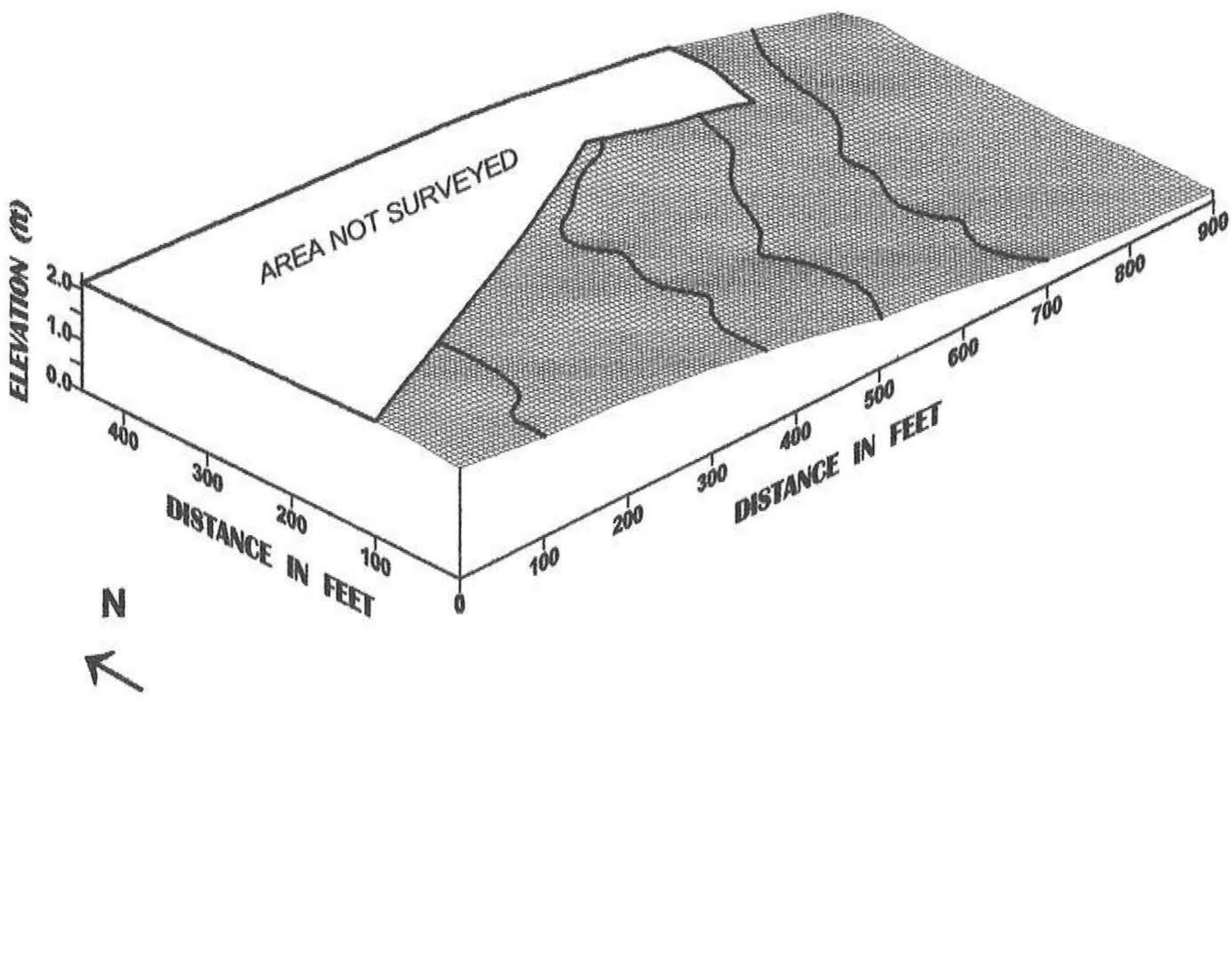


Figure 10

EM SURVEY
CULTIVATED FIELD
LOGAN COUNTY, COLORADO

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

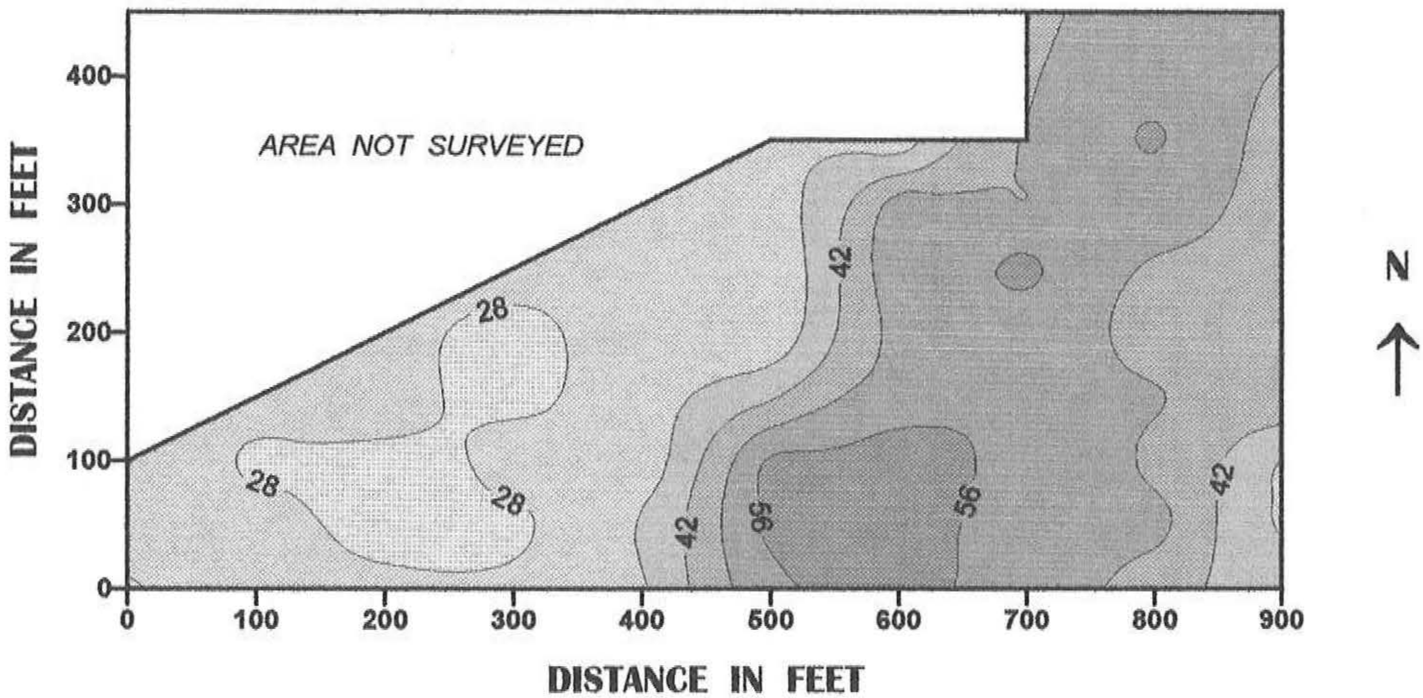


Figure 11

EM SURVEY
CULTIVATED FIELD
LOGAN COUNTY, COLORADO

EM31 METER
VERTICAL DIPOLE ORIENTATION

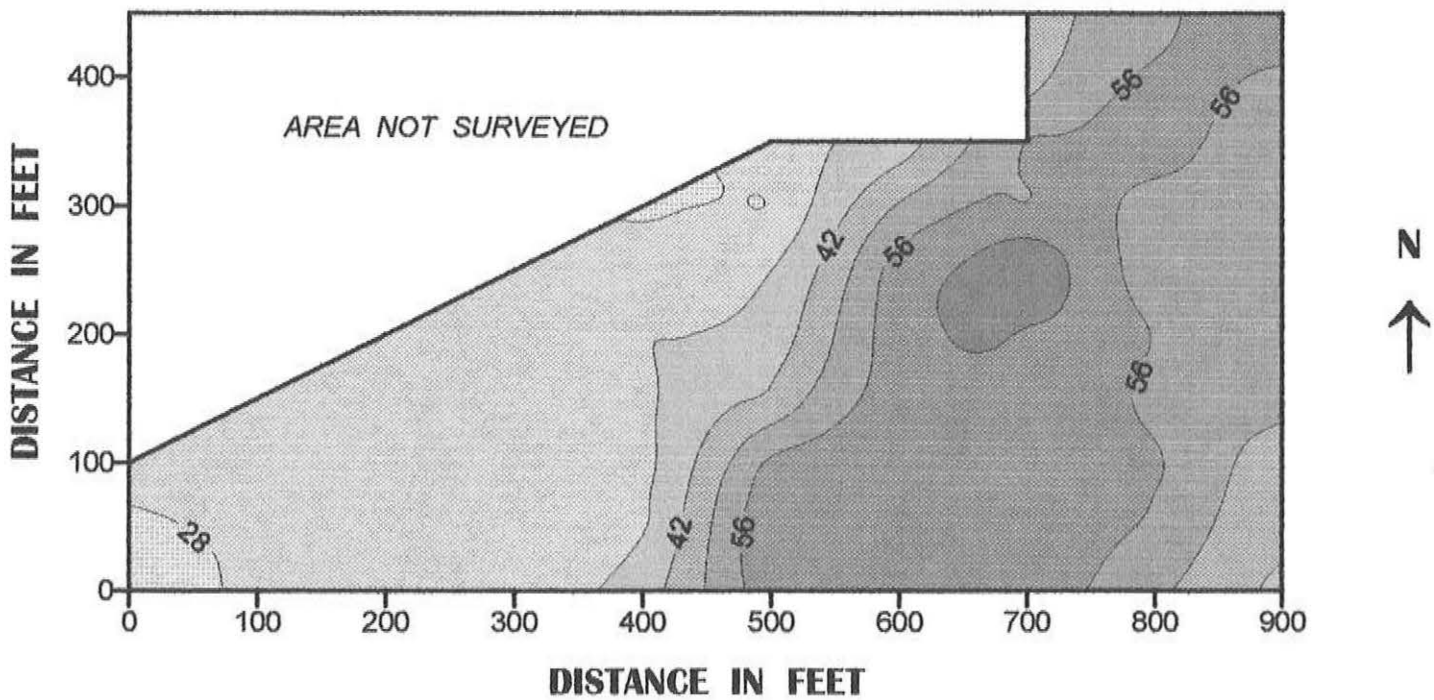


Figure 12

RELATIVE TOPOGRAPHY
WASTE-HODING FACILITY
HOLYOKE, COLORADO

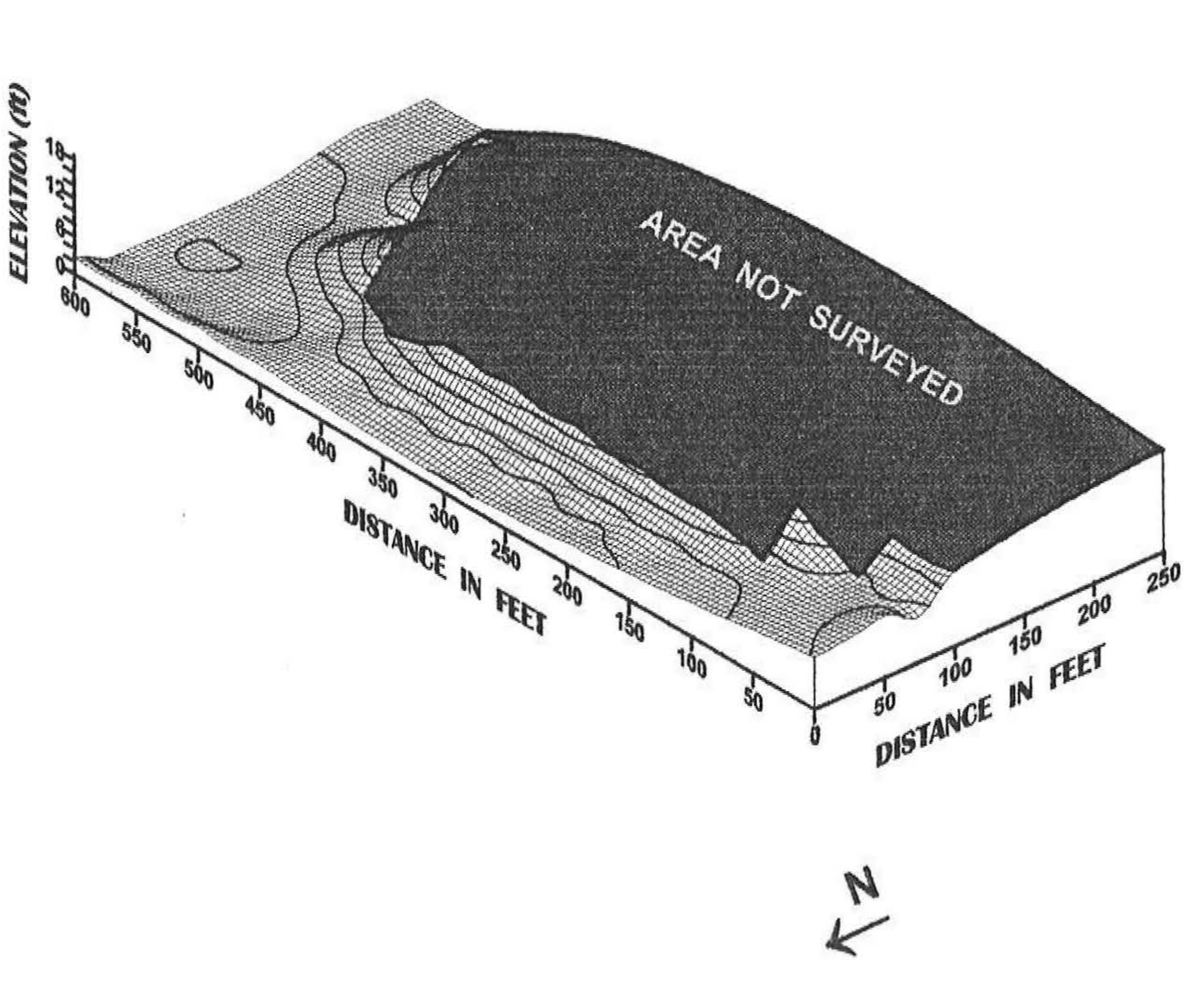


Figure 13

EM SURVEY
WASTE-HOLDING FACILITY
HOLYOKE, COLORADO

EM31 METER
HORIZONTAL DIPOLE ORIENTATION

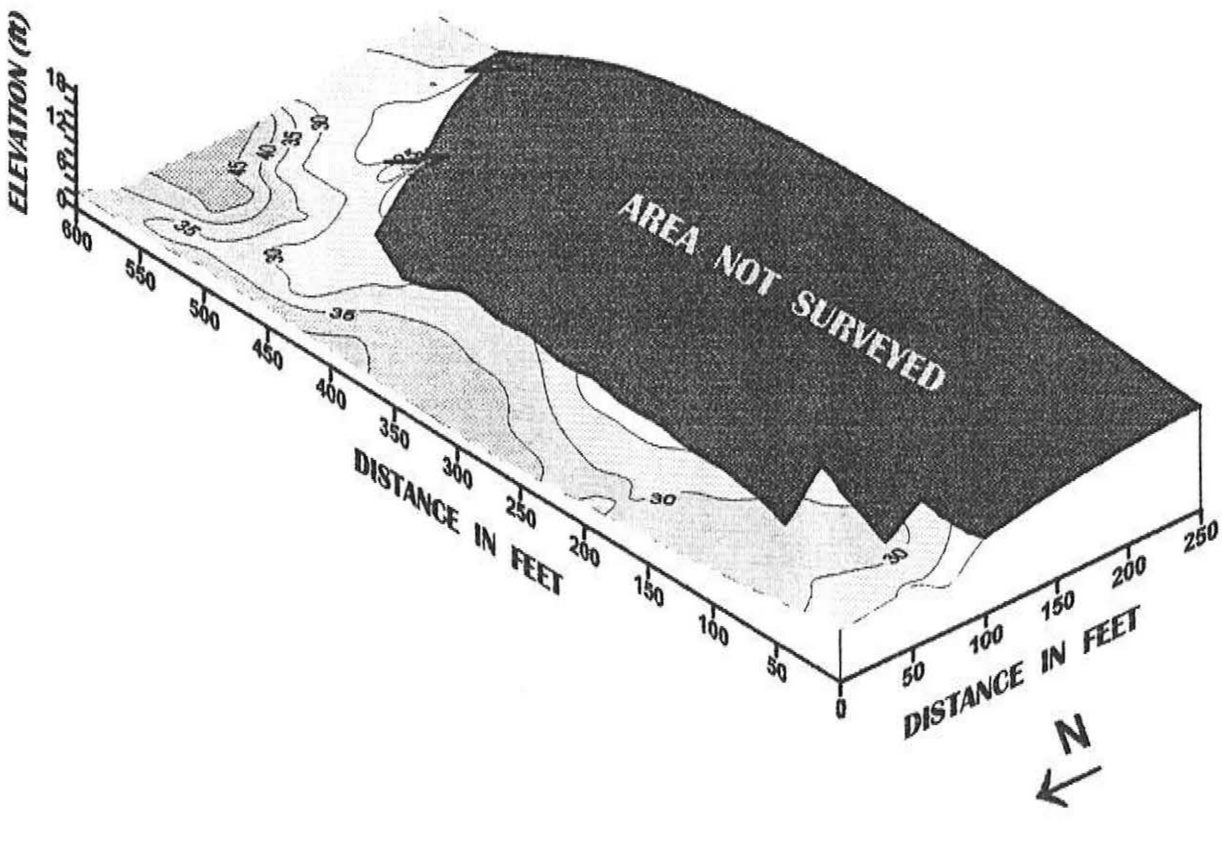


Figure 14

EM SURVEY
WASTE-HOLDING FACILITY
HOLYOKE, COLORADO

EM31 METER
VERTICAL DIPOLE ORIENTATION

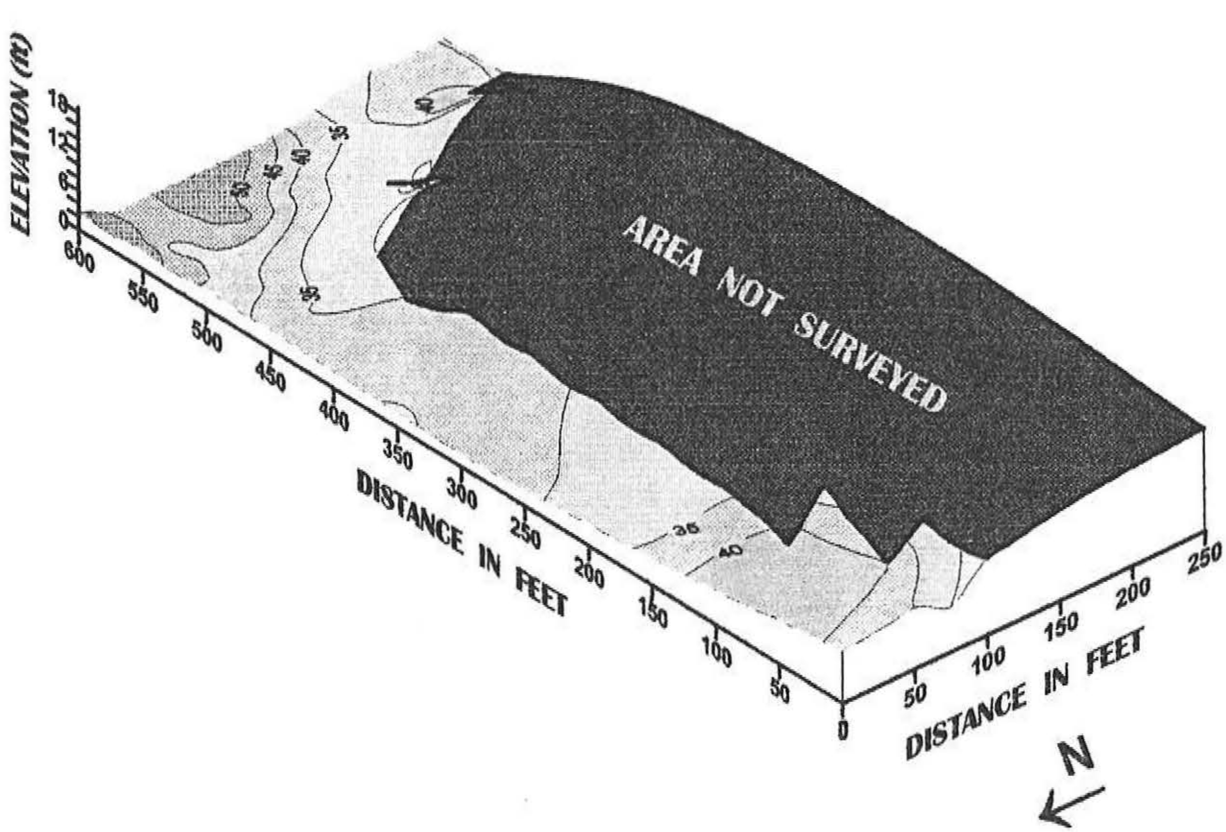
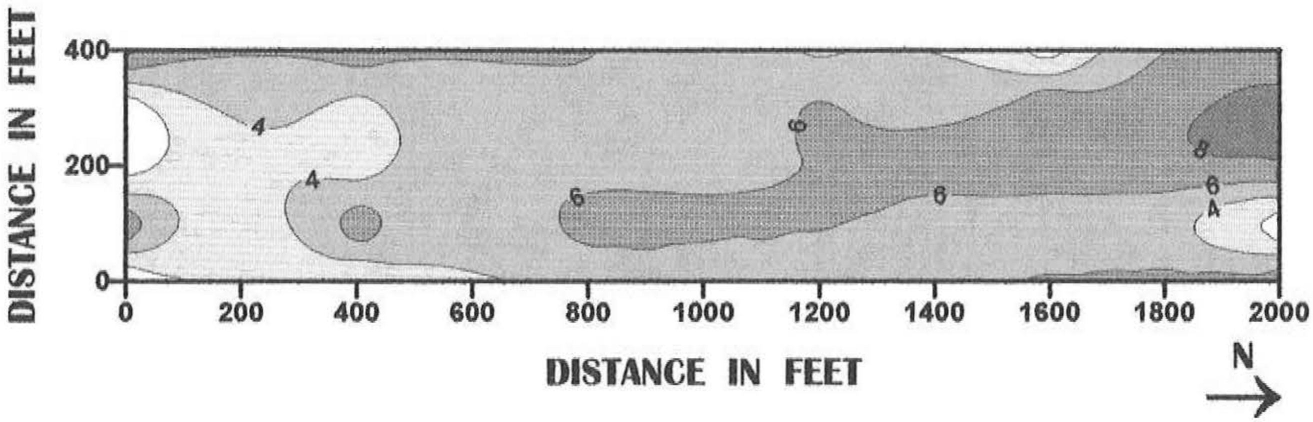


Figure 15

RELATIVE TOPOGRAPHY
IRRIGATED FIELD OF CORN
SEDGWICK, COLORADO



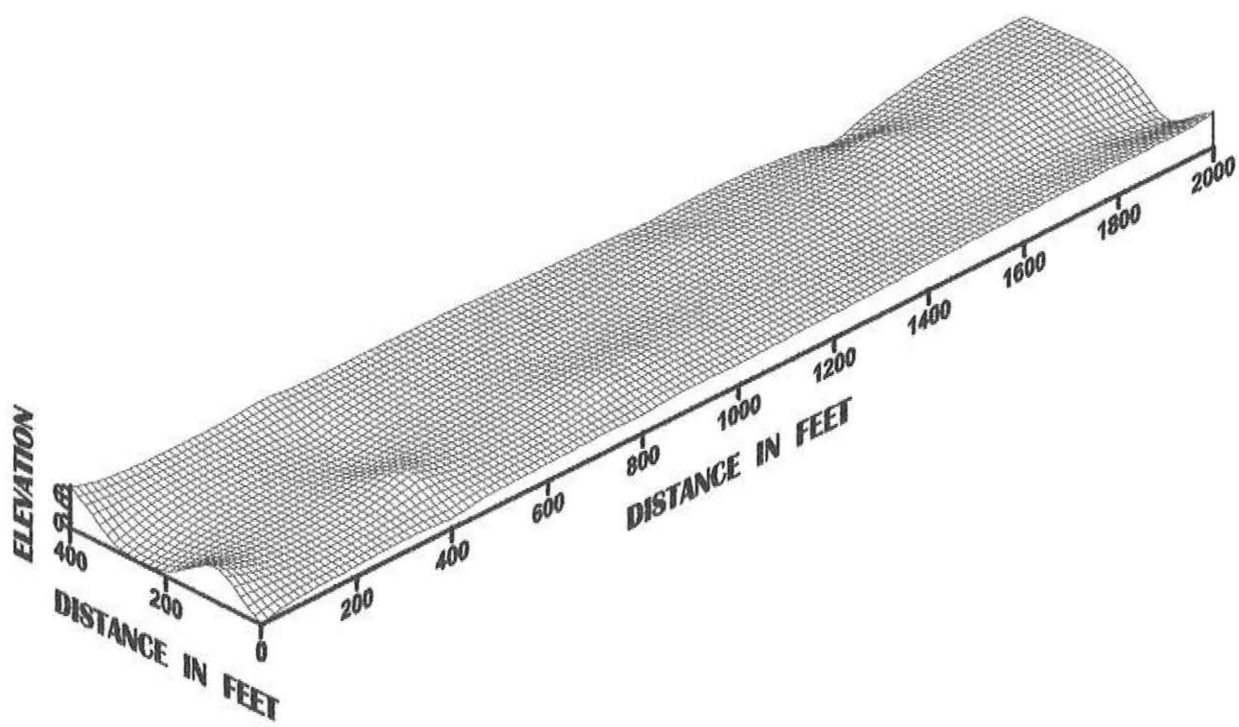
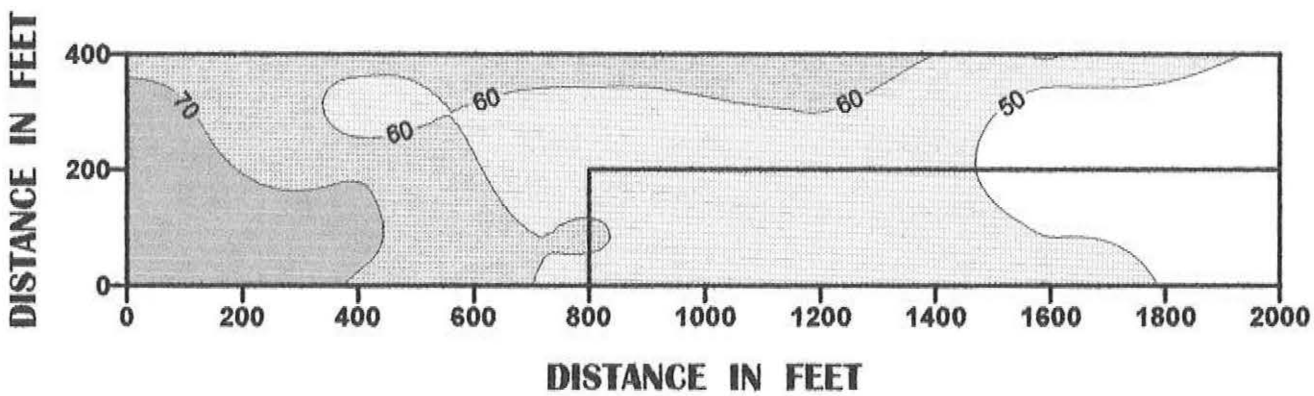


Figure 16

EM SURVEY
IRRIGATED FIELD OF CORN
SEDGWICK, COLORADO

EM38 METER
HORIZONTAL DIPOLE ORIENTAION



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VERTICAL DIPOLE ORIENTATION

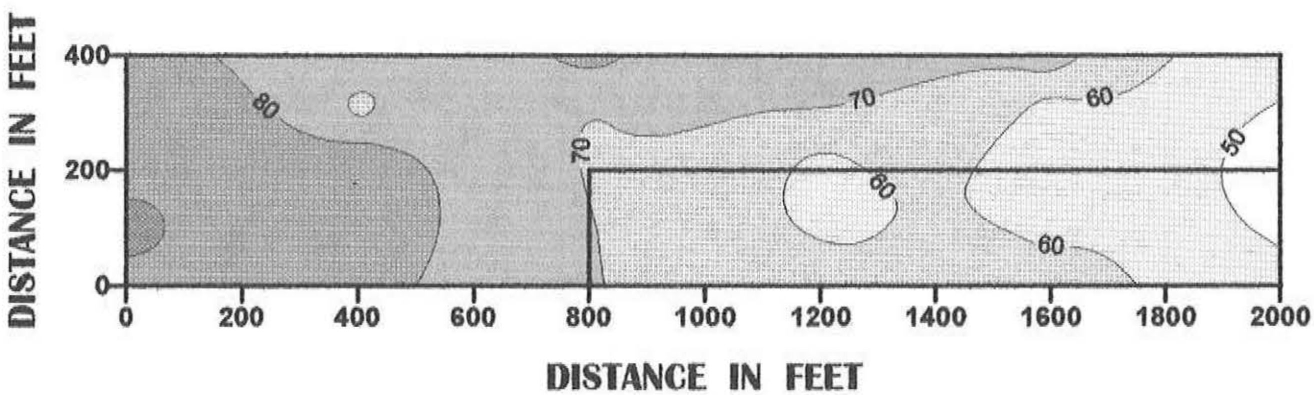


Figure 17

EM SURVEY
IRRIGATED FIELD OF CORN
SEDGWICK, COLORADO

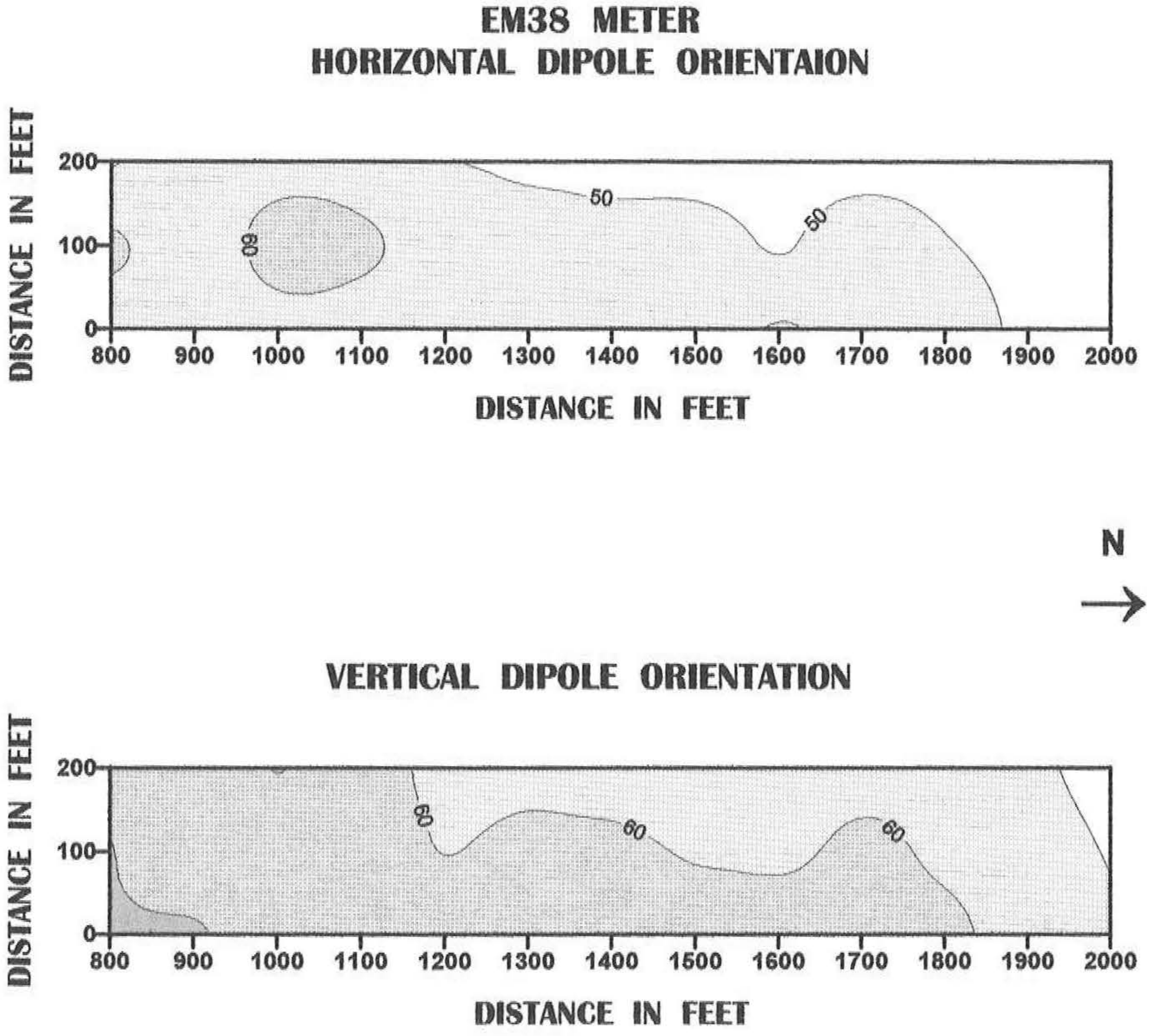
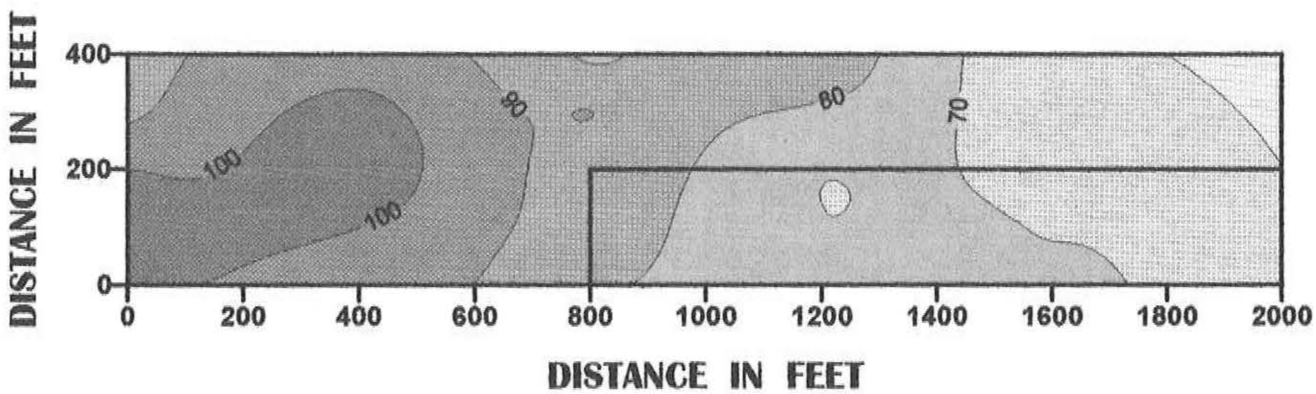


Figure 18

EM SURVEY
IRRIGATED FIELD OF CORN
SEDGWICK, COLORADO

EM31 METER
HORIZONTAL DIPOLE ORIENTAION



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VERTICAL DIPOLE ORIENTATION

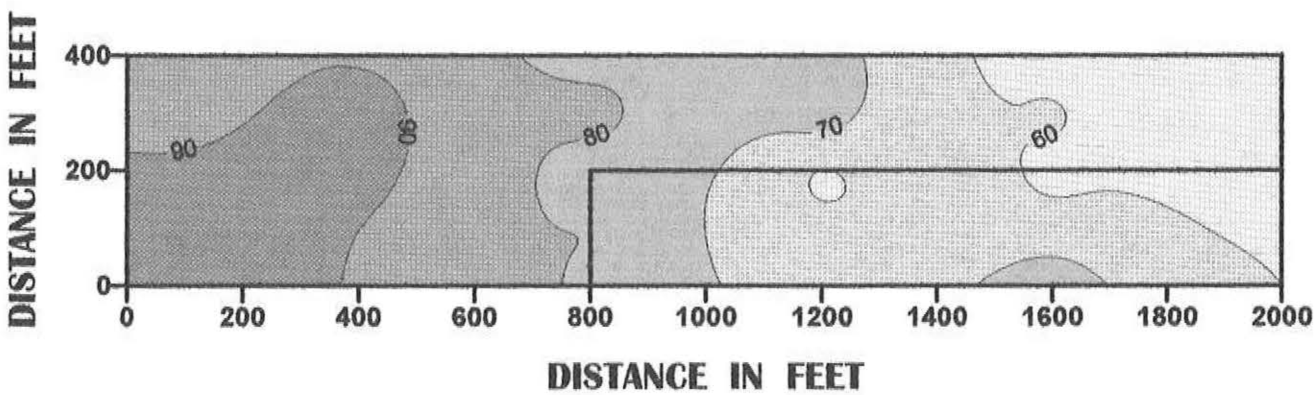
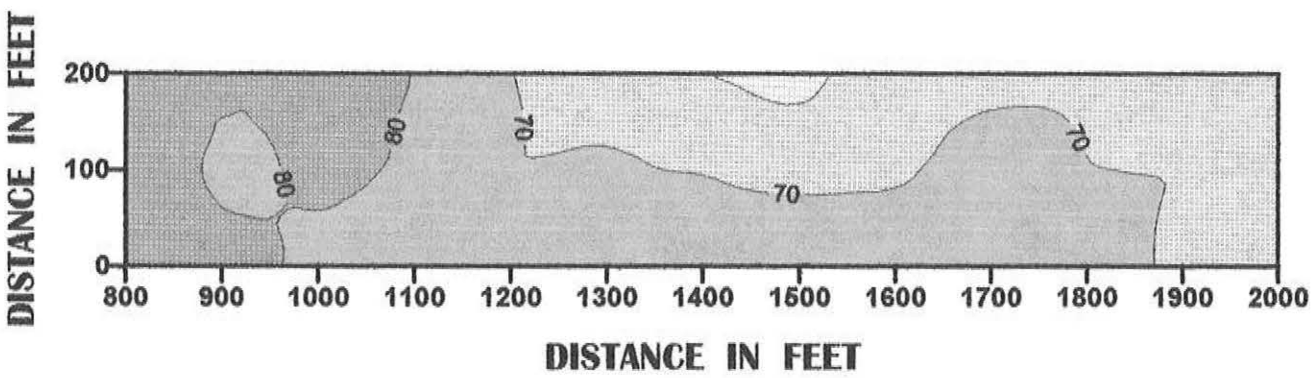


Figure 19

EM SURVEY
IRRIGATED FIELD OF CORN
SEDGWICK, COLORADO

EM31 METER
HORIZONTAL DIPOLE ORIENTAION



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VERTICAL DIPOLE ORIENTATION

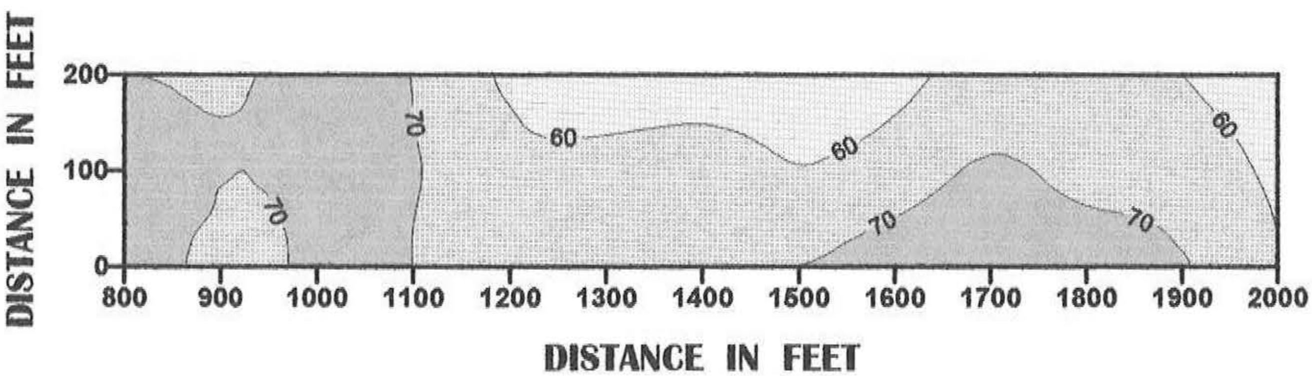

Figure 20