

**United States  
Department of  
Agriculture**

**Natural Resources  
Conservation  
Service**

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**Subject:** ENG -- Electromagnetic Induction (EMI) Assistance

**Date:** 13 October 1998

**To:** Janet Oertly  
State Conservationist  
USDA-NRCS,  
Suite 340, One Credit Union Place  
Harrisburg, PA 17110-2993

**Purpose:**

The purpose of this investigation was to conduct an EMI survey of a contaminated well site in Union County, Pennsylvania.

**Participating Agencies:**

USDA-NRCS  
Pennsylvania Department of Environmental Protection (PDEP)  
Union County Conservation District

**Participants:**

Robert Boos, Nutrient Management Specialist, PDEP, Williamsport, PA  
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA  
Pamela Ritter, Chesapeake Bay Program Technician, Union County Conservation District, Lewisburg, PA  
Jeff Schmid, Nutrient Management Specialist, PDEP, Williamsport, PA  
John Zaginaylo, Area Engineer, USDA-NRCS, Bloomsburg, PA

**Activities:**

All field activities were completed on 10 October 1998.

**Equipment:**

The electromagnetic induction meter used is the EM31, manufactured by Geonics Limited\*. This meter is portable and requires one person to operate. Principles of operation have been described by McNeill (1980a). No ground contact is required with this meter. The meter provides limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. The observation depth is dependent upon intercoil spacing, transmission frequency, and coil orientation. The EM31 meter has a fixed intercoil spacing of about 3.86 meters. It operates at a frequency of 9.8 kHz. Changing coil orientation can vary observation depths. The EM31 meter has theoretical observation depths of about 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively.

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. All grids were smoothed using a cubic spline interpolation. In the enclosed plots, colors, shadings and filled contour lines have been used to help 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 colors or shades themselves.

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

### **Discussion:**

Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site investigations. Advantages of EMI are its portability, speed of operation, flexible observation depths (with commercially available systems from about 0.75 to 60 m), moderate resolution of subsurface features, and comprehensive coverage. Results of EMI surveys are interpretable in the field. This geophysical method can provide, in a relatively short time, the large number of observations needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and siting monitoring wells.

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 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.

Electromagnetic induction has been successfully used to investigate the migration of contaminants from waste sites (Brune and Doolittle, 1990; Drommerhausen et al., 1995; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988). Electromagnetic induction has been used to infer the relative concentration, extent, and movement of contaminants from animal-waste management systems. Electromagnetic induction does not provide a direct measurement of specific ions or compounds. However, measurements of apparent conductivity have been correlated with specific ions that are mobile in the soil and associated with animal wastes. Apparent conductivity has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in soils (Brune and Doolittle, 1990; Ranjan and Karthigesu, 1995; Eigenberg et al., 1998).

### **Study Site:**

A domestic well at the farm of Tom Hosterman near Laurelton is contaminated. The setting of the well is rather complex and it has been difficult to ascertain the source(s) of contamination. The well is located adjacent to the house. The well is down slope from a manure storage tank, milk house and a milk house drain line. The concrete manure storage tank was constructed in 1990 and is located up slope and to the north of the house. This waste-storage facility is about 120 feet from the well.

The site is located in areas of Calvin-Klinesville shaly silt loam, 3 to 8 and 15 to 25 percent slopes; and Watson silt loam, 3 to 8 percent slopes (Eckenrode, 1980). Calvin is a moderately deep, well drained soil. Klinesville is a shallow, somewhat excessively drained soil. These soils formed in residuum weathered from red, noncalcareous shale, siltstone, and sandstone. Calvin is a member of the loamy-skeletal, mixed, mesic Typic Dystrochrepts family. Klinesville is a member of the loamy-skeletal, mixed, mesic Lithic Dystrochrepts family. Watson is a very deep, moderately well drained soil that formed in till derived from shale, siltstone, and sandstone. Watson is a member of the fine-loamy, mixed, mesic Typic Fragiuults family.

The topography of the survey area has been simulated in the three-dimensional plot shown in Figure 1. Within the survey area, relief is about 18 feet. The location of the manure storage tank is shown in Figure 1. The house and well are located near the eastern border of the survey area. The surface slopes away from the manure storage tank and towards the south and east. A diversion, designed to intercept runoff, is located mid-slope below the manure storage tank. The center line of this feature is shown as a blue segmented line in Figure 1.

### **Survey Procedures:**

An irregularly shaped, 160 by 160-foot grid was established in the area located to the immediate north of the house and the contaminated well. The survey area did not include the contaminated well. The grid interval was about 20 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. This procedure provided sixty-three observation points. At each of the sixty-three observation points, the surface elevation was determined with a level

and stadia rod. Datum was the corner of a concrete pad located near the milk house. This point represented the 100 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.

#### Results:

Table 1 summarizes the apparent conductivity measurements. Values of apparent conductivity were highly variable across the survey area. The high variability was principally attributed to the presence of cultural features (structures and buried drainage and utility lines) within or near the site and animal wastes from the manure storage tank. In general, values of apparent conductivity increased and became less variable with increasing observation depths. This vertical trend could reflect increasing moisture and soluble salt contents, and the presence of shale or siltstone bedrock at lower soil depths.

The apparent conductivity of the upper 3 meters (measured with the EM31 meter in the horizontal dipole orientation) averaged 11.89 mS/m with a standard deviation of 30.78. One-half of the observations had values of apparent conductivity between 12.0 and 20.6 mS/m. The apparent conductivity of the upper 6 meters (measured with the EM31 meter in the vertical dipole orientation) averaged 21.61 mS/m with a standard deviation of 15.33. One-half of the observations had values of apparent conductivity between 15.2 and 22.4 mS/m.

**Table 1**  
**Basic Statistics**  
**EMI Survey**  
(All values are in mS/m)

Meter	Orientation	Minimum	Maximum	1st	Quartiles		Average
					Median	3rd	
EM31	Horizontal	-215.2	47.4	12.0	15.1	20.6	11.89
EM31	Vertical	9.0	100.6	15.2	17.9	22.4	21.61

Figure 2 contains two-dimensional plots of the data collected with an EM31 meter in the horizontal and vertical dipole orientations. These plots show the spatial distribution of apparent conductivity for the upper 3 (upper plot) and 6 meters (lower plot) of the soil profile. In each plot, the isoline interval is 10 mS/m. Areas with apparent conductivity of less than 20 mS/m are believed to represent "normal" soil conditions (relatively undisturbed or uncontaminated). In Figure 2, to assist interpretations, these areas have been colored green. Areas having apparent conductivity less than 0 mS/m or greater than 20 mS/m have been scaled in shades of light yellow to red. These negative or elevated apparent conductivity values are considered anomalous. Negative values of apparent conductivity are often attributed to the presence of metallic objects within the electromagnetic fields of the meter. Negative values are only evident in the measurements taken with the EM31 meter in the horizontal dipole orientation. Negative values can be seen adjacent to the milkhouse (lower left-hand corner of upper plot) and adjacent to the manure storage tank. The negative values near the manure storage tank are believed to have been caused by rebar in the tank's walls.

Elevated apparent conductivity values (>20 mS/m) can be produced by high concentration of moisture and/or soluble salts. In both of the plots appearing in Figure 2, values of apparent conductivity exceed 20 mS/m in the area surrounding the manure storage tank. This pattern is attributed to higher concentration of soluble salts and moisture emanating from the manure storage tank.

In Figure 2, the upper plot represents patterns existing near the soil surface. The spatial patterns are believed to principally reflect interference from near-by cultural features. At the scales of mapping shown in Figure 2, no significant "plume of contaminants" emanating from the manure storage tank is identifiable at shallow (0 to 3 meters) soil depths. In Figure 2, a band of slightly higher apparent conductivity values extends across the left-hand portion of the upper plot. This band approximates the location of the diversion channel and is believed to principally reflect higher soil moisture contents.

In Figure 2, the lower plot represents patterns existing at deeper soil depths. In the lower plot, a conspicuous plume-like pattern surrounds the manure storage structure and extends down slope towards the barns and milk house. It is possible,

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that this zone of slightly higher conductivity represents a subsurface plume that contains detectable levels of soluble salts. However, this is an assumption; verification is needed to confirm this interpretation.

Neither plot supports contamination of the well from the manure storage tank.

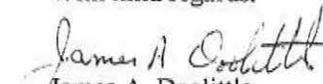
Plots contained in Figure 3 show the distribution of apparent conductivity measured with the EM31 meter in the horizontal (upper plot) and vertical (lower plot) dipole orientations. In each plot, a two-dimensional plot of apparent conductivity has been overlaid upon three-dimensional surface net diagram of the site. The isoline interval is 10 mS/m. These plots hopefully provide a better opportunity to visualize the data and to appreciate spatial patterns.

**Conclusions:**

1. Restrictive patterns of relatively higher apparent conductivity surround the manure storage tank. Although interference from the structure is probable, these patterns suggest that some seepage or other loss of wastes from the manure storage tank has occurred. Contamination of the well by the manure storage tank is not supported by the results of this investigation.
2. It is possible that other contaminant plumes exist within the site, but were too small or noncontrasting to be detected with the EM31 meter. Contaminant plumes can exist below the depths observed in this survey (6.0 meters).
3. The enclosed simulations provide basis tools for assessing site conditions and for designing sampling and monitoring schemes.
4. Results from these field studies do not replace the need for direct sampling, but rather guide in the placement of monitoring wells and provide supplemental information. Sampling is required to evaluate the type and concentration of contaminants.

It was my pleasure to assist you and your staff in this project.

With kind regards,

  
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cc:

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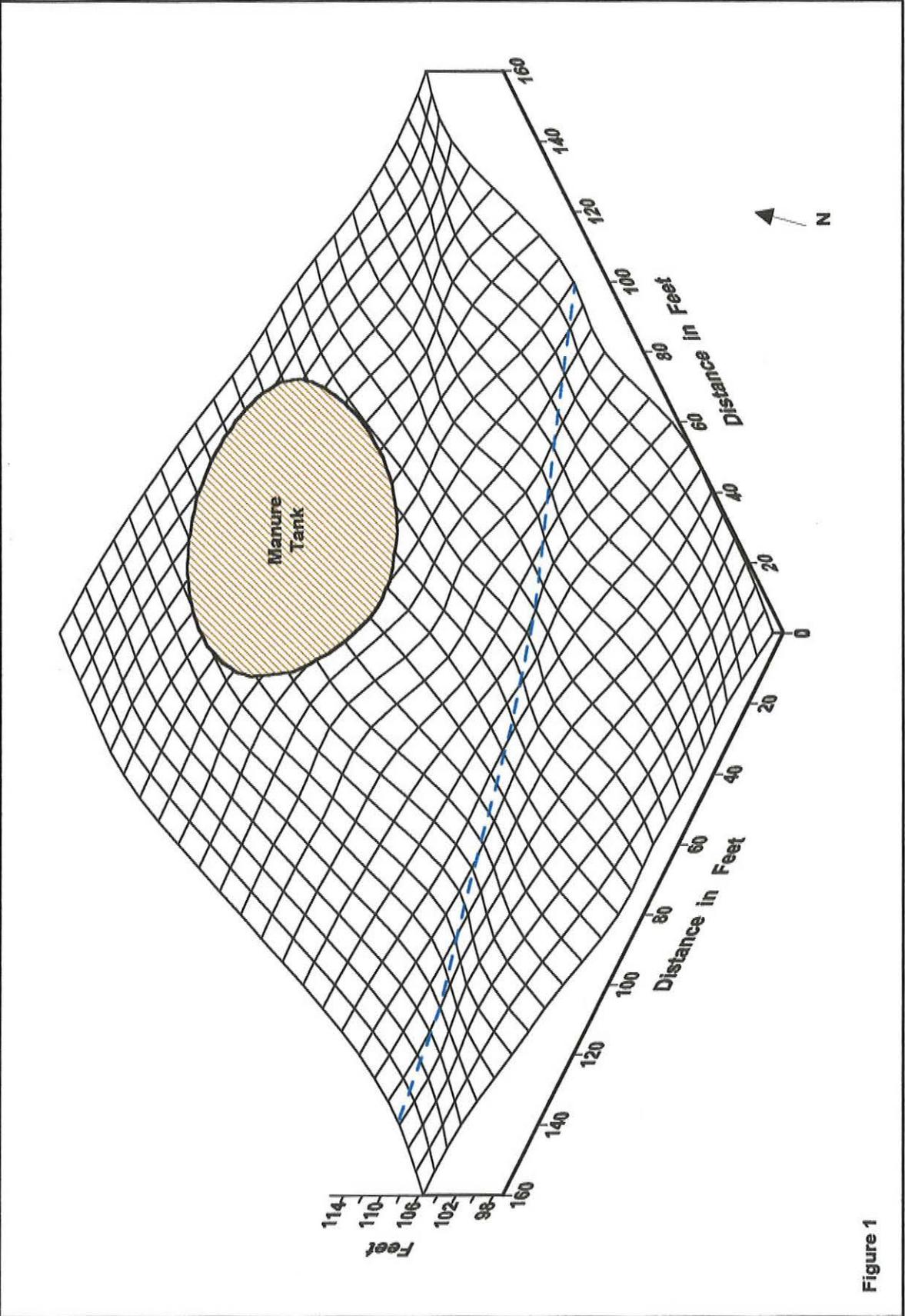
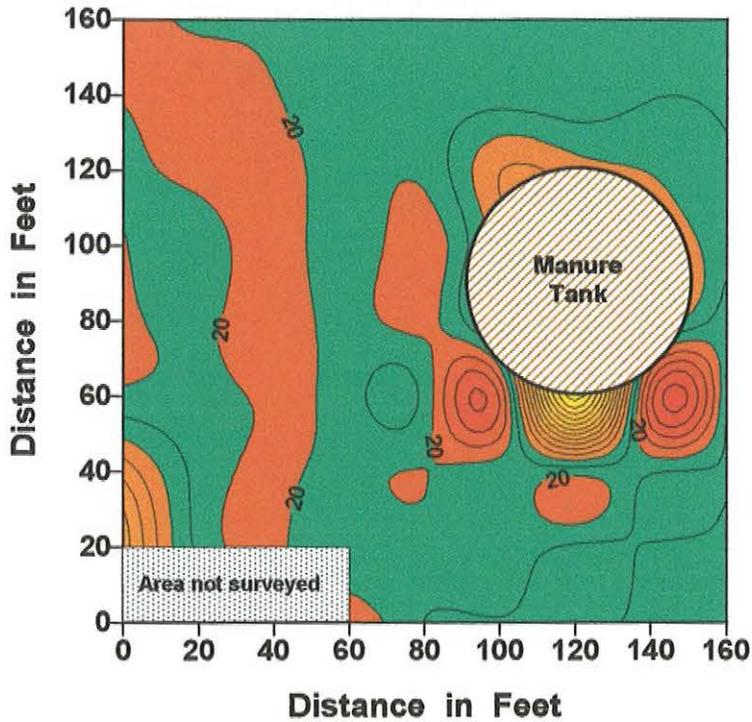


Figure 1

# EMI SURVEY TOM HOSTERMAN'S MANURE STORAGE FACILITY

0 to 3 Meters



0 to 6 Meters

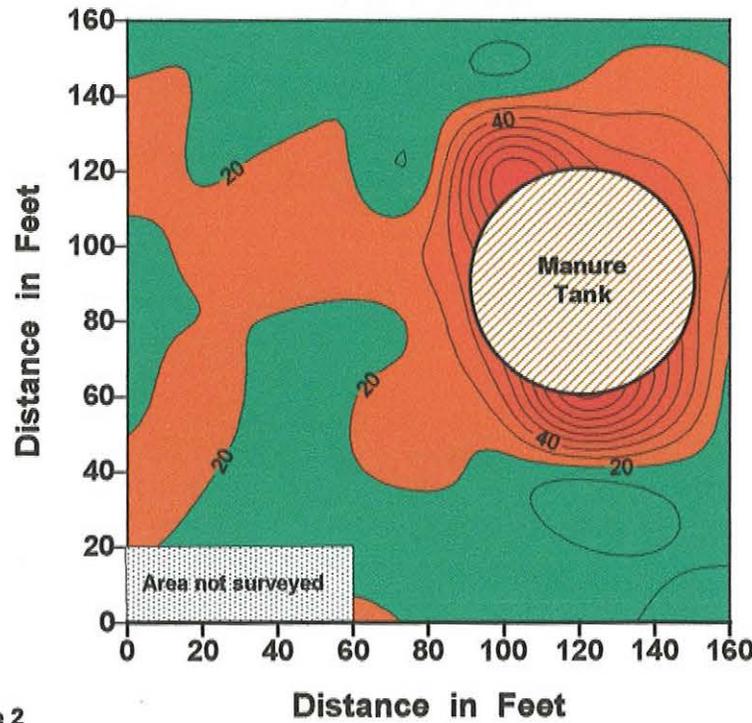
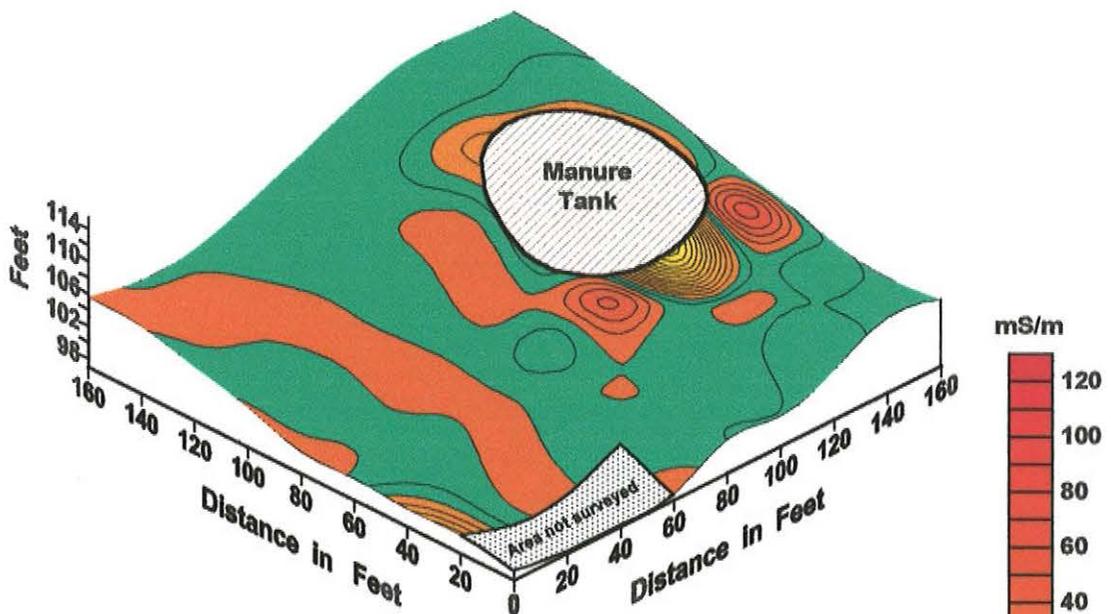


Figure 2

# EMI SURVEY TOM HOSTERMAN'S MANURE STORAGE FACILITY

0 to 3 Meters



0 to 6 Meters

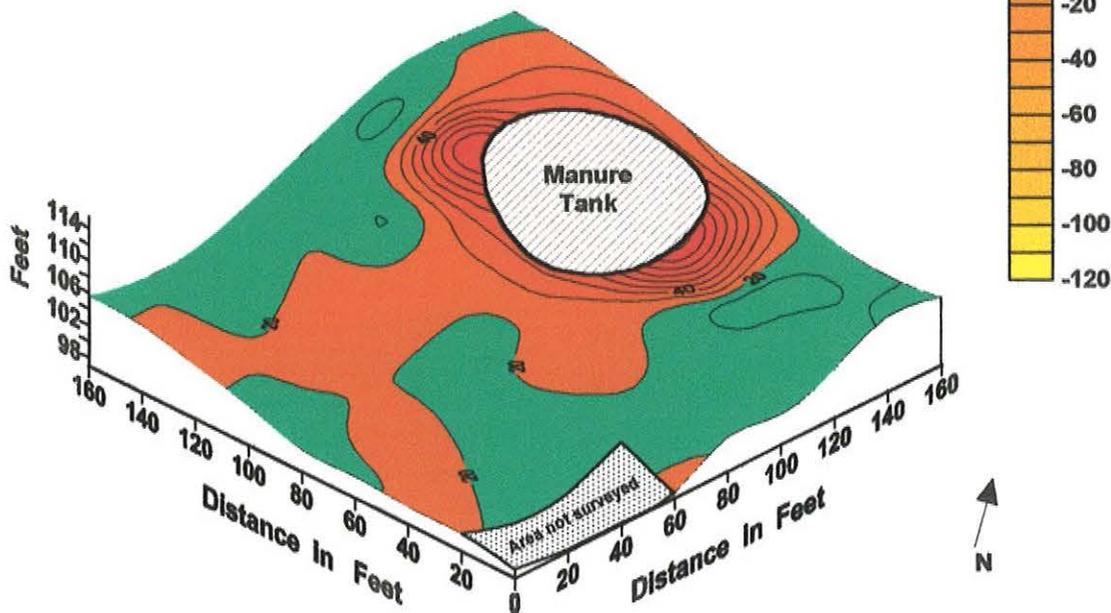


Figure 3