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September 1995

US Army Corps
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Waterways Experiment
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Geophysical Investigation of Cluster 13, Edgewood Area, Aberdeen Proving Ground, Maryland

by Michael K. Sharp, Landris T. Lee, Jr.

WES

Prepared for U.S. Army Aberdeen Proving Ground

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3909 Halls Ferry Road
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Final report

Prepared for U.S. Army Aberdeen Proving Ground
Installation Restoration Program
Directorate of Safety, Health, and Environment
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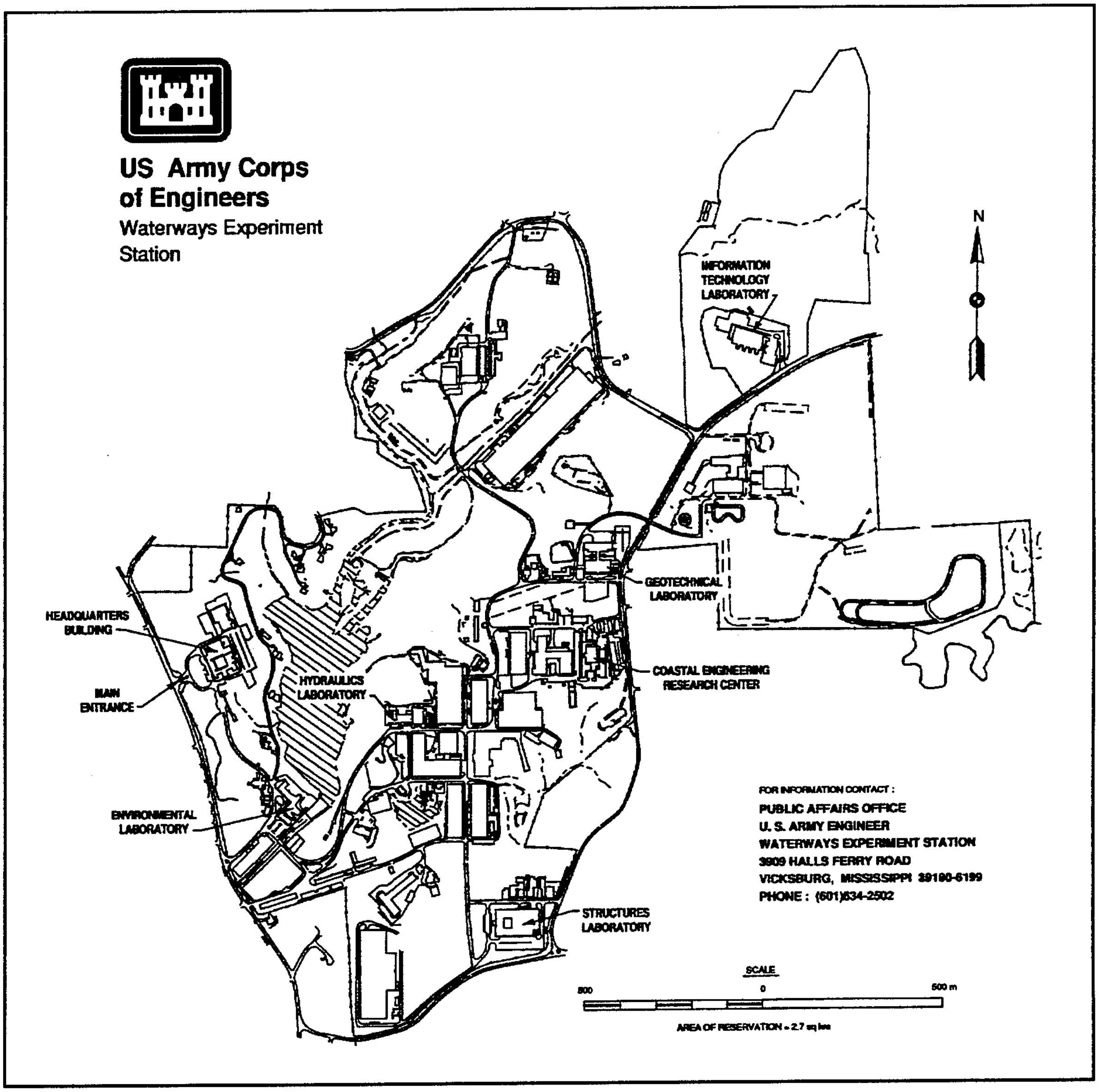

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Contents

Preface

A geophysical investigation was conducted at the Cluster 13 site, Edgewood Area, Aberdeen Proving Ground (APG), Maryland, by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), between 11 and 13 October 1994. The investigation was conducted for the Installation Restoration Program, Directorate of Safety, Health, and Environment, Aberdeen Proving Ground (APG). The Technical Monitor was Mr. Jerry Burgess. Mr. Don Green was the APG Area Manager.

This report was prepared by Mr. Michael K. Sharp, Earthquake Engineering and Geosciences Division (EEGD). The work was performed under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch. The work was performed under the general supervision of Drs. A. G. Franklin, Chief, EEGD, and William F. Marcuson III, Director, GL. Field work and data analysis were performed by Messrs. Sharp and Lee.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
gamma	1.0	nanotesla
inches	2.54	centimeters
millimhos per foot	3.28	millisiemens per meter
yards	0.9144	meters

1 Introduction

Background

A geophysical investigation was conducted on a portion of the Cluster 13 study area at Aberdeen Proving Ground (APG), Edgewood Area (EA), Maryland. This area of investigation consists of three sites suspected to have once contained buildings and related structures which have since been razed. These areas are shown in Figure 1 and for the purpose of this investigation were identified as sites 1-3.

Approach and Scope of Work

The objective of the geophysical investigation was to delineate anomalies indicative of underground structures (such as tanks, barrels, etc.). Three geophysical methods were used in this investigation; electromagnetic (EM), magnetic, and ground penetrating radar (GPR).

The success of using geophysical surveying methods for delineating targets of interest is based on there being a sufficient contrast in material properties, i.e., electrical, magnetic, chemical, etc. between the target and its surrounding materials. In this case it is expected that there is enough contrast between the natural materials and possible fill materials. Other factors affecting the ability to detect a target using geophysical methods are the size, depth and orientation of the target.

To accomplish the objectives of the investigation, a plan was devised to fully survey the areas of interest. The areas surveyed for this investigation are shown in Figure 1. Each site was fully investigated utilizing the magnetic and EM techniques. In areas where these surveys indicated anomalous conditions, the site was further investigated with the GPR.

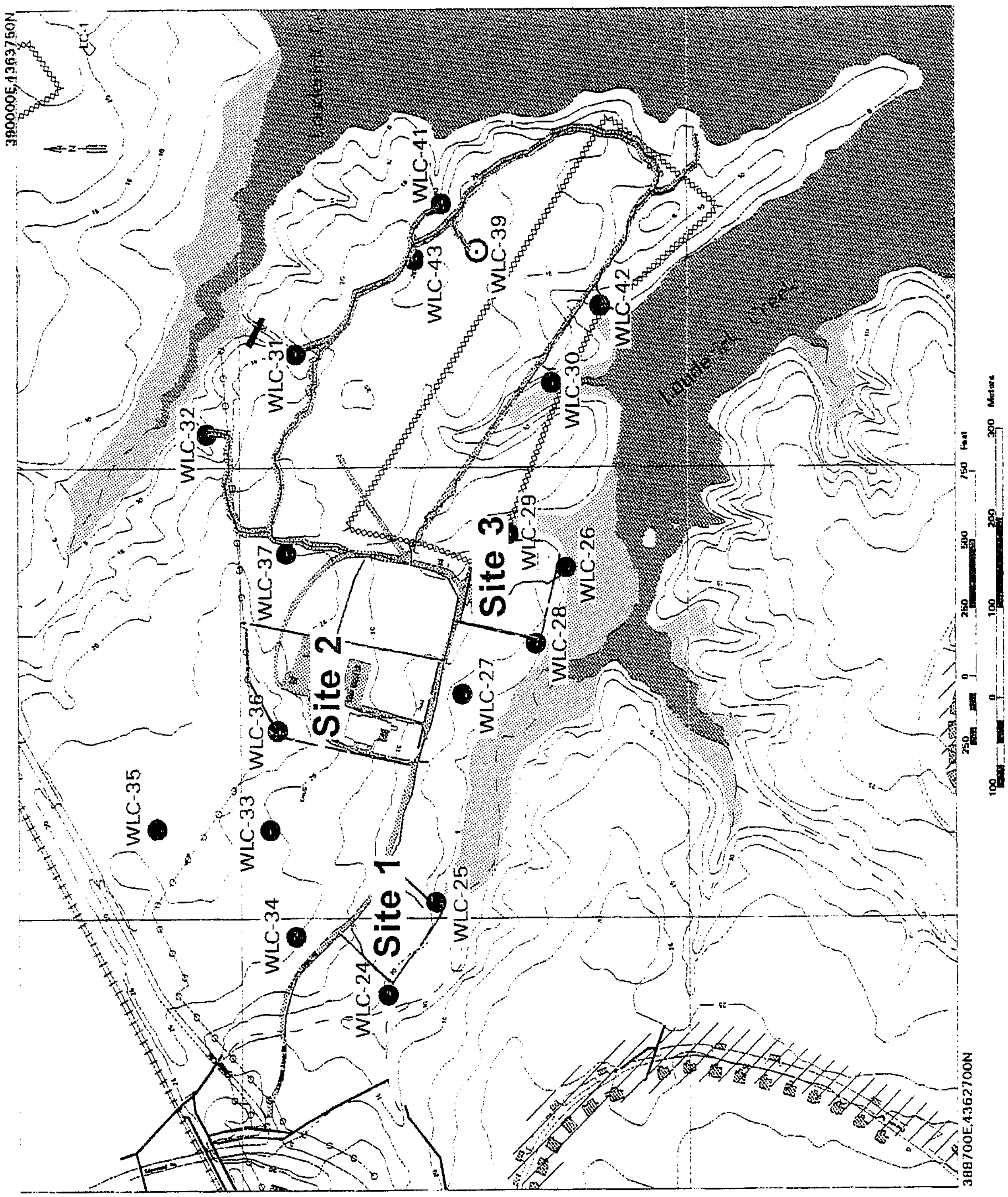

Figure 1. Aberdeen Proving Ground Cluster 13 area investigation sites 1 - 3

2 Site Geology

Cluster 13 lies southeast of the Fall Line in the Atlantic Coastal Plain physiographic province of Maryland. The Coastal Plain here is underlain by gently southeast dipping crystalline basement. Depth to basement in this area is likely to be around 152 m below mean sea level (MSL). The underlying Coastal Plain sediments consist of the Cretaceous Patapsco Formation of the Potomoc Group and the Pleistocene Talbot Formation (Owens, 1969; Thurmond, 1994).

The locations of monitoring wells and borings in the Lauderick Creek area are shown in Figures 1 and 2. Figure 2 is a map of the groundwater surface contours for the area derived from the eighteen monitoring wells placed throughout the region. From the shallow monitoring wells, two fence diagrams (Figures 3 and 4) have been derived showing the lithology of the upper 50 ft. The stratigraphic units have been simplified to reveal a near surface silt and clay water bearing unit overlying a sand and gravel unit overlying a clay layer interpreted as possibly Cretaceous.

A geologic cross section through the area, in a northeast to southwest orientation, is shown in Figure 5. The section is based on borings LC-1 (top right of Figure 2) and TH-2 (bottom center of Figure 2) in addition to monitoring wells WLC-31, WLC-29 and WLC-26. This section reveals some of the deeper lithology, 50 to 150 ft, of the Lauderick Creek area. The shallow lithology is as interpreted in Figures 3 and 4, with the deeper lithology revealing a thick clay layer overlying silt and clay.

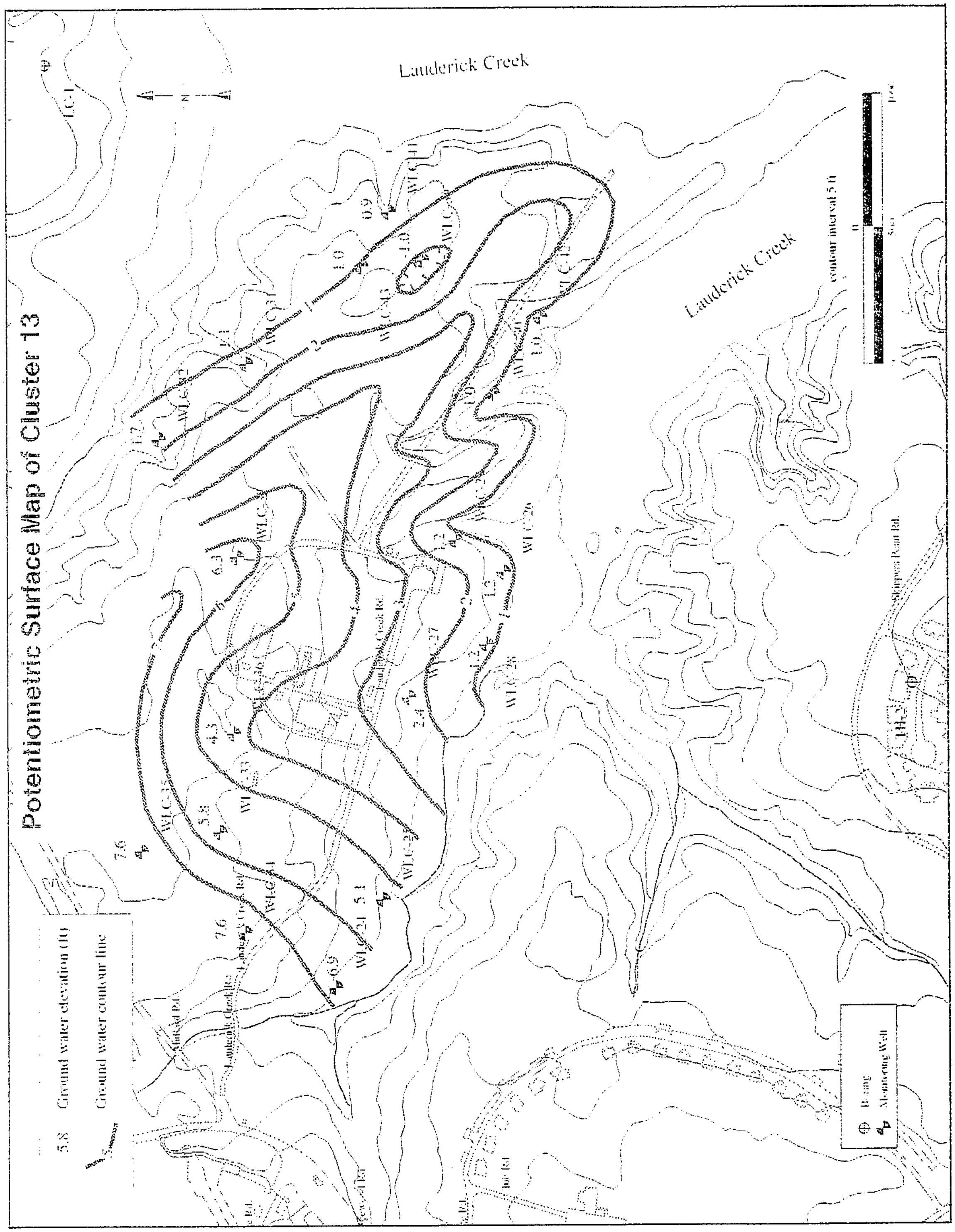

Figure 2. Cluster 13 groundwater surface contour map

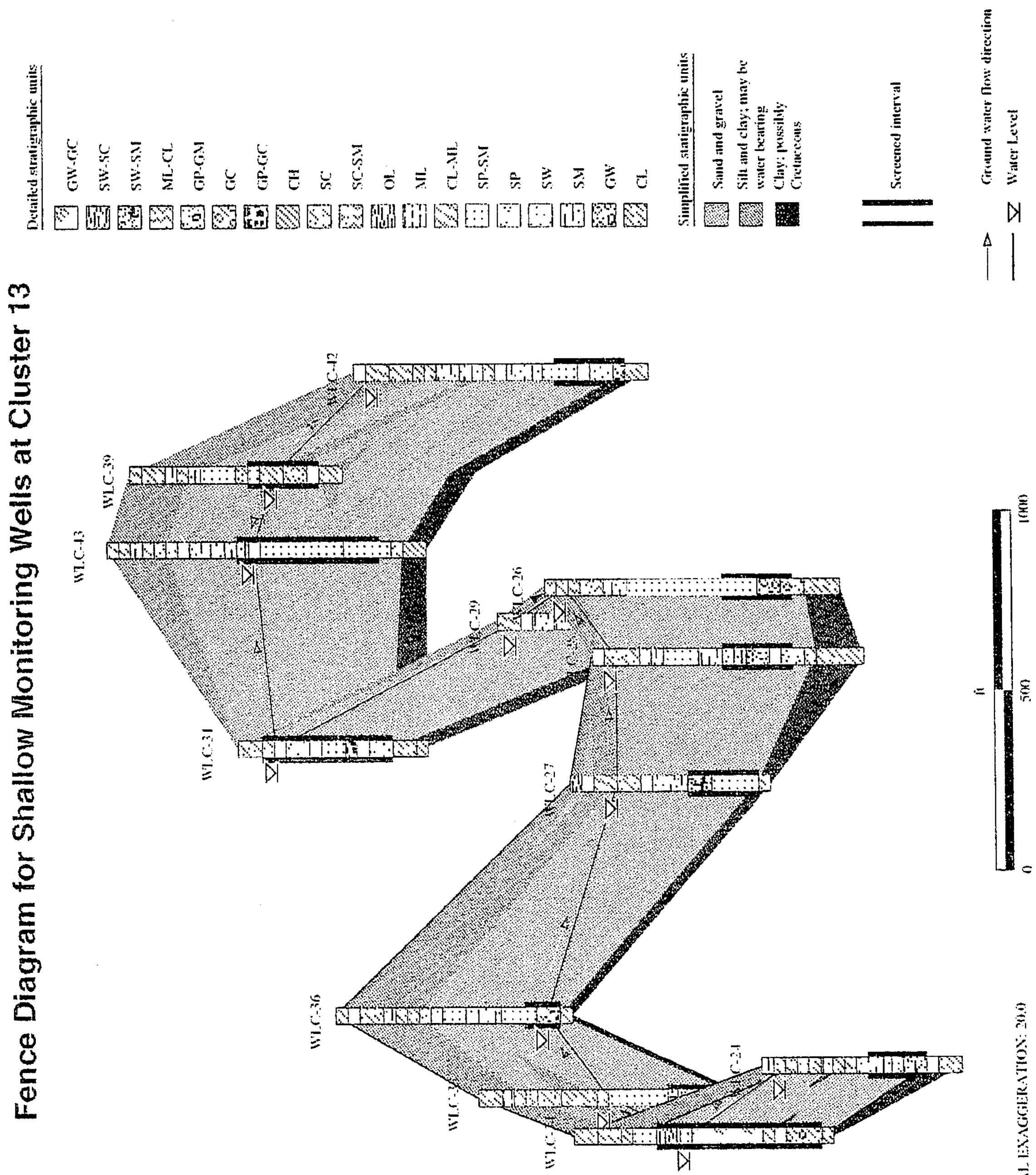

Figure 3. Cluster 13 shallow monitoring well fence diagram

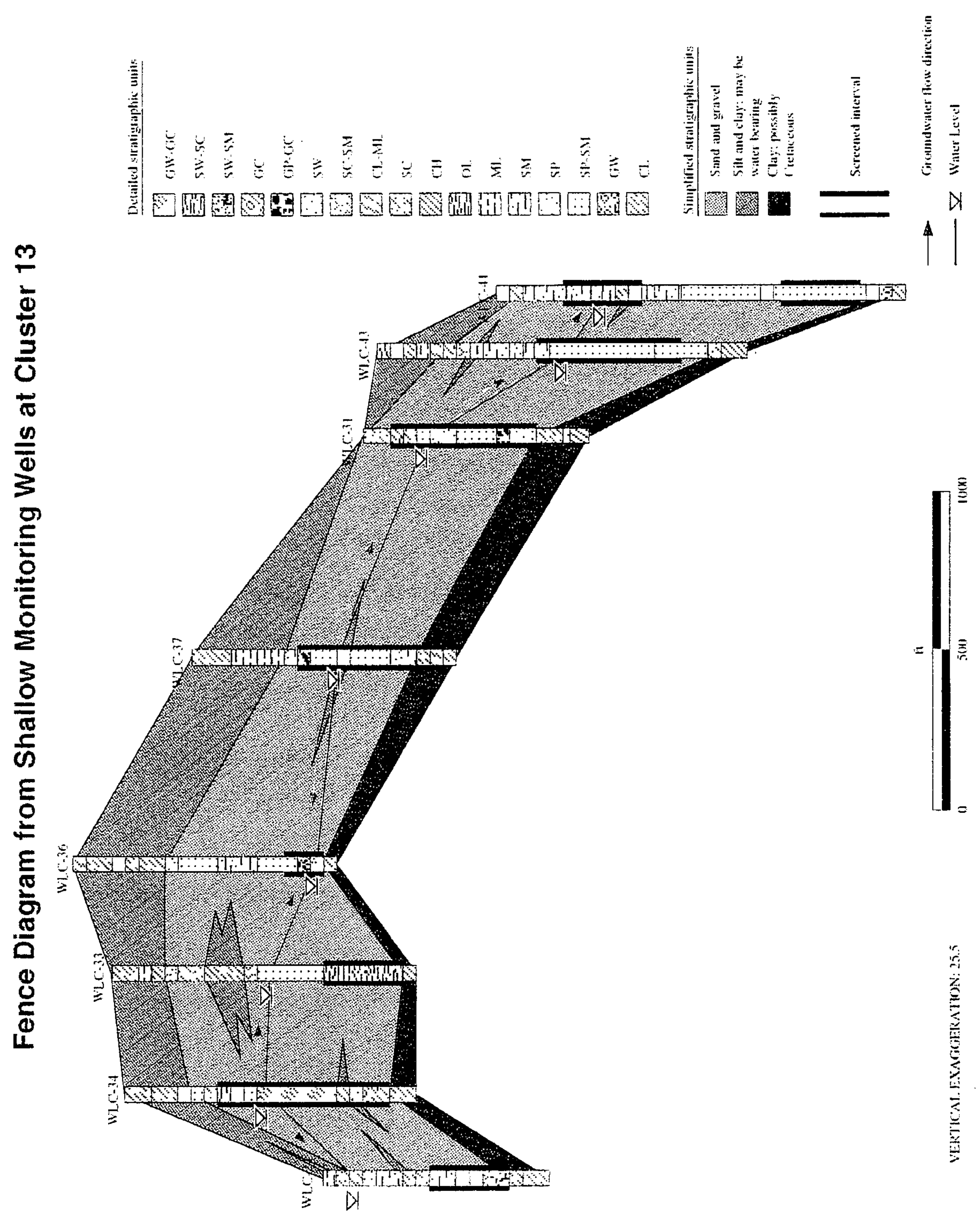

Figure 4. Cluster 13 shallow monitoring well fence diagram

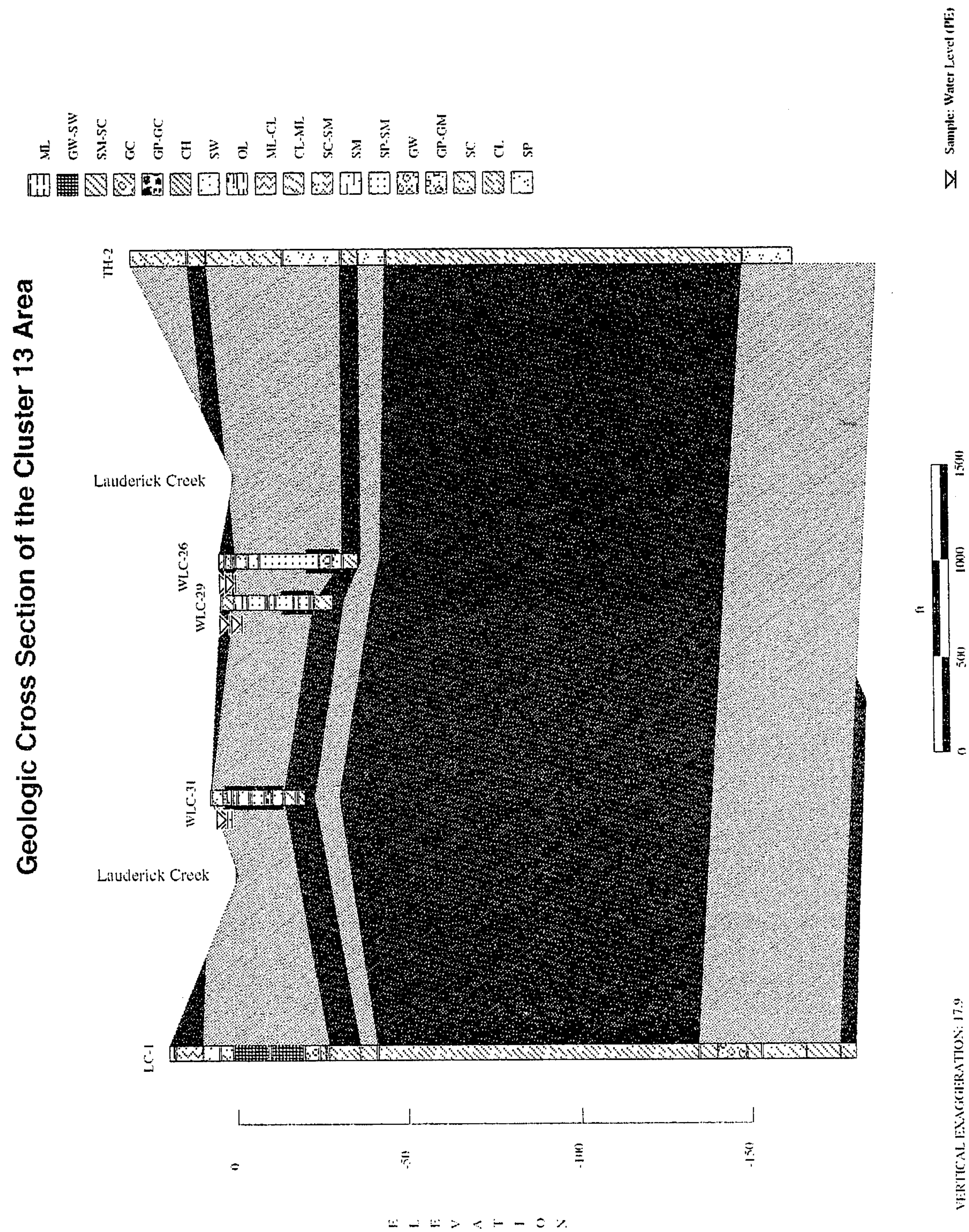

Figure 5. Cluster 13 geology cross section

3 Geophysical Test Principles and Field Procedures

Geophysical Test Principles

Electromagnetic Surveys

The frequency domain electromagnetic (EM) technique is used to measure differences in terrain conductivity. Like electrical resistivity, conductivity is affected by differences in soil porosity, water content, chemical nature of the ground water and soil, and the physical nature of the soil. In fact, for a homogeneous earth, the true conductivity is the reciprocal of the true resistivity. Some advantages of using the EM over the electrical resistivity technique are (a) less sensitivity to localized resistivity inhomogeneities, (b) no direct contact with the ground required, thus no current injection problems, (c) smaller crew size required, and (d) rapid measurements (McNeil 1980).

The EM equipment used in this survey consists of a transmitter and receiver coil set a fixed distance apart. The transmitter coil is energized with an alternating current at an audio frequency (kHz range) to produce a time-varying magnetic field which in turn induces small eddy currents in the ground. These currents then generate secondary magnetic fields which are sensed together with the primary field by the receiver coil. The units of conductivity are millimhos per meter (mmho/m) which are equivalent to units of millisiemens per meter (mS/m). The EM data are then presented in profile plots or as isoconductivity contours, if data are obtained in a grid form. A more thorough discussion on EM theory and field procedures is given by Butler (1986), Telford et al. (1976) and Nabighian (1988).

There are two components of the induced magnetic field measured by the EM equipment. The first is the quadrature phase component, which gives the ground conductivity measurement. The second is the inphase component, which is used primarily for calibration purposes. However, the inphase component is significantly more sensitive to large metallic objects and hence very useful when looking for buried metal containers (Geonics 1984). When measuring the inphase component, the true zero level is not known since the reference level is arbitrarily set by the operator. Therefore, measurements collected in this mode are relative to a reference level and have arbitrary units of parts per thousand (ppt).

Geonics model EM-31 ground conductivity meter was used to survey the site. The EM-31 has an intercoil spacing of 3.66 m and an effective depth of exploration of about 6 m (Geonics 1984). The EM-31 meter reading is a weighted average of the earth's conductivity as a function of depth. A thorough investigation to a depth of 4.6 m is usually possible, but below that depth the effect of conductive anomalies becomes more difficult to distinguish. The EM-31, when carried at a usual height of approximately 1 m, is most sensitive to features at a depth of about 0.3 m. Half of the instrument's readings result from features shallower than about 2.7 m, and the remaining half from below that depth (Bevan 1983). The instrument can be operated in both a horizontal and vertical dipole orientation with correspondingly different effective depths of exploration. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and co-planar) which gives the maximum depth of penetration. The instrument can be operated in a continuous or a discrete mode.

Magnetic Surveys

The magnetic method of surveying is based on the ability to measure local disturbances of the earth's magnetic field. Magnetic anomalies are caused by two different types of magnetism: induced and remanent magnetization. Remanent magnetization is a permanent magnetic moment per unit volume whereas induced magnetization is temporary magnetization that disappears if the material is removed from a magnetic field. Generally, the induced magnetization is parallel with and proportional to the inducing field (Barrows and Rocchio 1990). The remanent magnetism of a material depends on the thermal and magnetic history of the body and is independent of the field in which it is measured (Breiner 1973).

A GEM Systems GSM-19 'walking' magnetometer was used to measure the total field intensity of the local magnetic field. The magnetic unit of measurement is the nanotesla (nT) or gamma. One nanotesla is equivalent to one gamma. The local magnetic field is the vector sum of the field of the local magnetized materials (local disturbance) and the ambient (undisturbed) magnetic field.

The magnetometer was used with dual sensors thereby allowing the vertical gradient of the total magnetic field (TMF) to be measured. The gradient is taken by measuring the total field at a survey point using two sensors which are fixed a small vertical distance apart (for this survey 56 cm). The difference in values between the two sensors divided by their separation approximates the gradient measured at the midpoint of the sensor spacing. Two advantages of using the magnetic gradient are that (1) the regional magnetic gradient is filtered out thus local anomalies are better defined and (2) since the two readings are taken simultaneously, magnetic storm effects and diurnal magnetic variations are essentially removed (Breiner 1973). The magnetometers used in this survey have an absolute accuracy of approximately ± 1 gamma. For reference, the earth's magnetic field varies from approximately 60,000 gammas at the poles to 30,000 gammas at the equator (the nominal field strength at the site is approximately 53,000 gammas).

A magnetic anomaly represents a local disturbance in the earth's magnetic field which arises from a localized change in magnetization, or magnetization contrast. The observed anomaly expresses the net effect of the induced and remanent magnetization and the earth's ambient magnetic field. Depth of detection of a localized subsurface feature depends on its mass, magnetization, shape and orientation, and state of deterioration.

Ground Penetrating Radar Surveys

Ground penetrating radar (GPR) is a geophysical subsurface exploration method using high frequency EM waves. The GPR system consists of a transmitting and a receiving antenna. The transmitting electronics generate a very short duration high voltage EM pulse which is radiated into the ground by the transmitting antenna. The signal is reflected by materials having contrasting electrical properties back to the receiving antenna. The magnitude of the received signal as a function of time after the transmitter has been initiated is measured. The signals are then amplified, processed and recorded to provide a 'continuous' profile of the subsurface.

The transmitted EM waves respond to changes in soil and rock conditions having sufficiently different electrical properties such as those caused by clay content, soil moisture or ground water, water salinity, cementation, man-made objects, voids, etc. The depth of exploration is determined by the electrical properties of the soil or rock as well as by the frequency and power of the transmitting antenna. The primary disadvantage to GPR is its extremely site specific applicability; the presence of high-clay content soils in the shallow subsurface will generally defeat the application of GPR (Olhoeft 1984). High water contents in the shallow subsurface and shallow water tables can also limit the applicability of GPR at some sites. A general rule is that GPR should not be applied to projects in which the mapping objective is greater than 15 m in depth. For shallow mapping applications at sites with low clay content soils, GPR will generally have the best vertical and horizontal resolution of any geophysical method (Butler and Llopis, 1990).

A Sensors and Software Inc. Pulse Echo IV (pulseEKKO) GPR system with a center frequency antenna of 100 MHz was used to conduct the GPR surveys. The pulseEKKO antennas are resistively damped dipolar antennas. The antenna radiation patterns are the pattern of a half wavelength dipole. When the ground conditions are suitable, the great majority of the radiated signal is transmitted into the ground (typically 90%). Each antenna pair is designed to have a bandwidth to center frequency ratio of one, which implies that the antennas have useable energy over the frequency range of 50 to 150 MHZ. The transmitter has a peak voltage of 400 volts with a rise time of 2.5 ns. The power radiated is very dependent on the soil conditions around the radiating antenna. From a specification point of view, the 400V transmitter delivers a peak power of 3.2 kilowatts into a 50 ohm load. The receiver electronics module digitizes the voltage at the receiver antenna connector to 16-bit resolution. The receiver electronics clip the incoming voltage at a 50 mV level. The receiver noise level is nominally around 200 microvolts for a single stack. The present receiver resolution for a single bit after analog to digital (A/D) conversion is 1.5 microvolt. The received signal was displayed on a laptop computer screen during the survey to allow the operator to check data quality. The received signal was also recorded on the computer's hard disk for future processing. By recording a vertical intensity modulated scan for every 0.3 m of antenna travel, a nearly continuous profile is developed showing reflections from subsurface strata and anomalies within the strata. A near-horizontal geologic interface, for example, will appear as a near horizontal line or band on the GPR record. A small localized object, such as a buried metallic object will appear as a hyperbolic-shaped event centered over the object's location.

Field Procedures

The portion of the Cluster 13 area to be investigated was divided into three sites, previously shown in Figure 1. Site 1 was the partially wooded area just south of the access road. The site was 320 ft wide and 250 ft long at the largest dimensions. This site is bounded to the north by the access road, to the south by a small creek, to the east by the access road leading to well WLC-25, and to the west by the access road leading to well WLC-24. The grid used to survey Site 1 is shown in Figure 6. The grid was established with plastic (PVC) stakes placed on 20 ft centers, throughout the area, with measurements taken on 10 ft centers. Site 2 was the area around the only current above-ground structures at the site. The area is 320 ft wide and 800 ft long. This area is bounded to the north by the base boundary fence, to the south by a small creek, to the east and west by limits established by APG/EA personnel. A grid (Figure 7) was placed at this site using the same technique as discussed for Site 1. Site 3 was a partially wooded area located near wells WLC-28, WLC-26 and WLC-29. The area is 350 ft wide and 250 ft long. This site was bounded to the north by the site access road, to the south by a marsh, to the east by a marsh and to the west by the access road to well WLC-28. The grid for this site is shown in Figure 8.

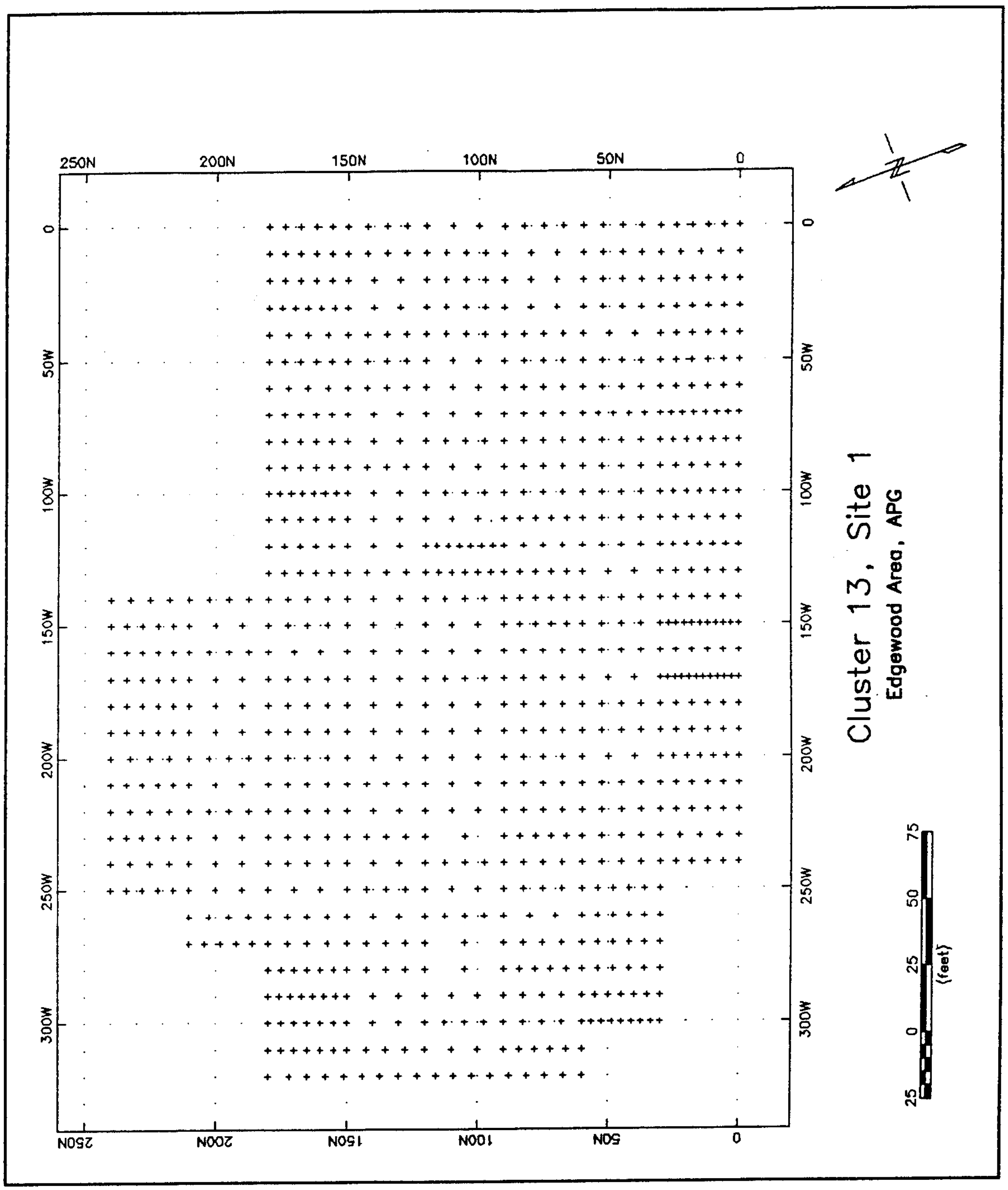

Figure 6. Layout of survey grid for Site 1

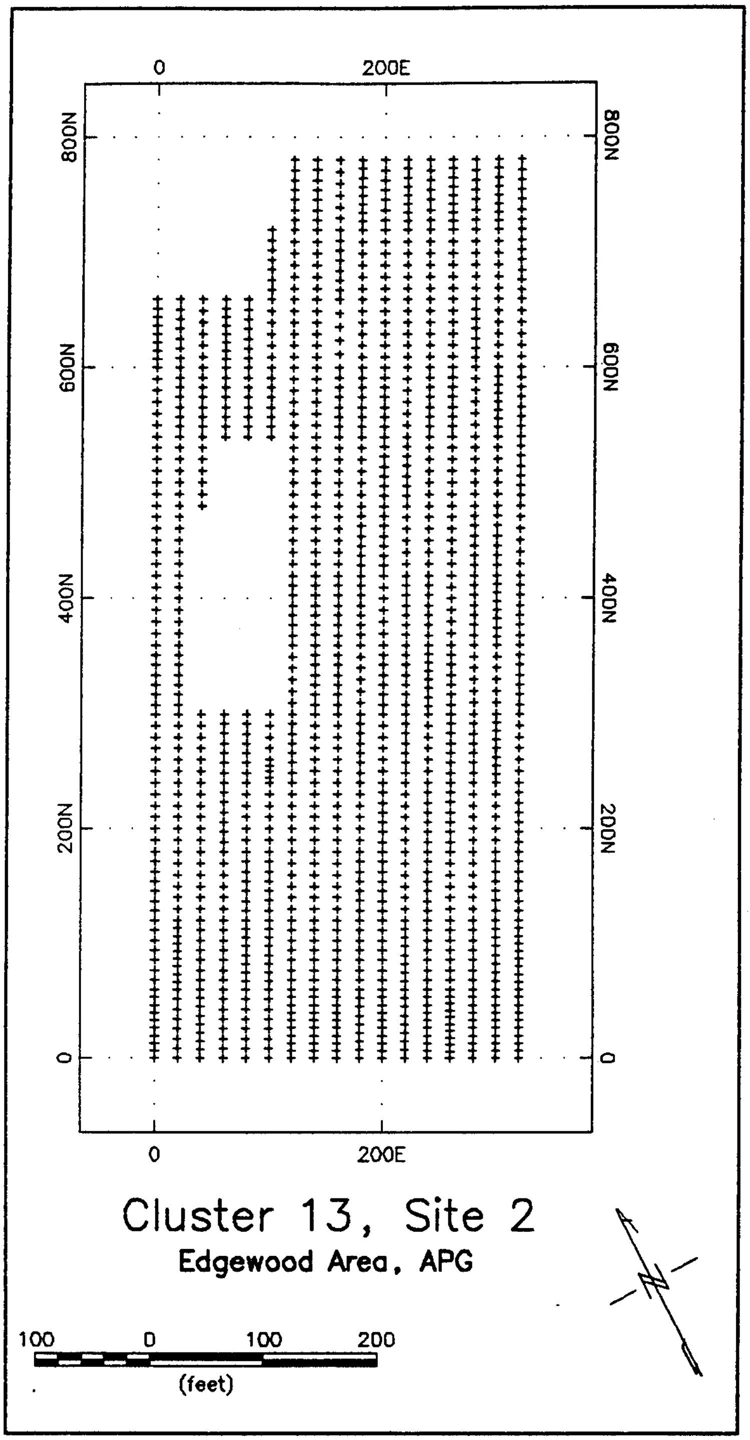

Figure 7. Layout of survey grid for Site 2

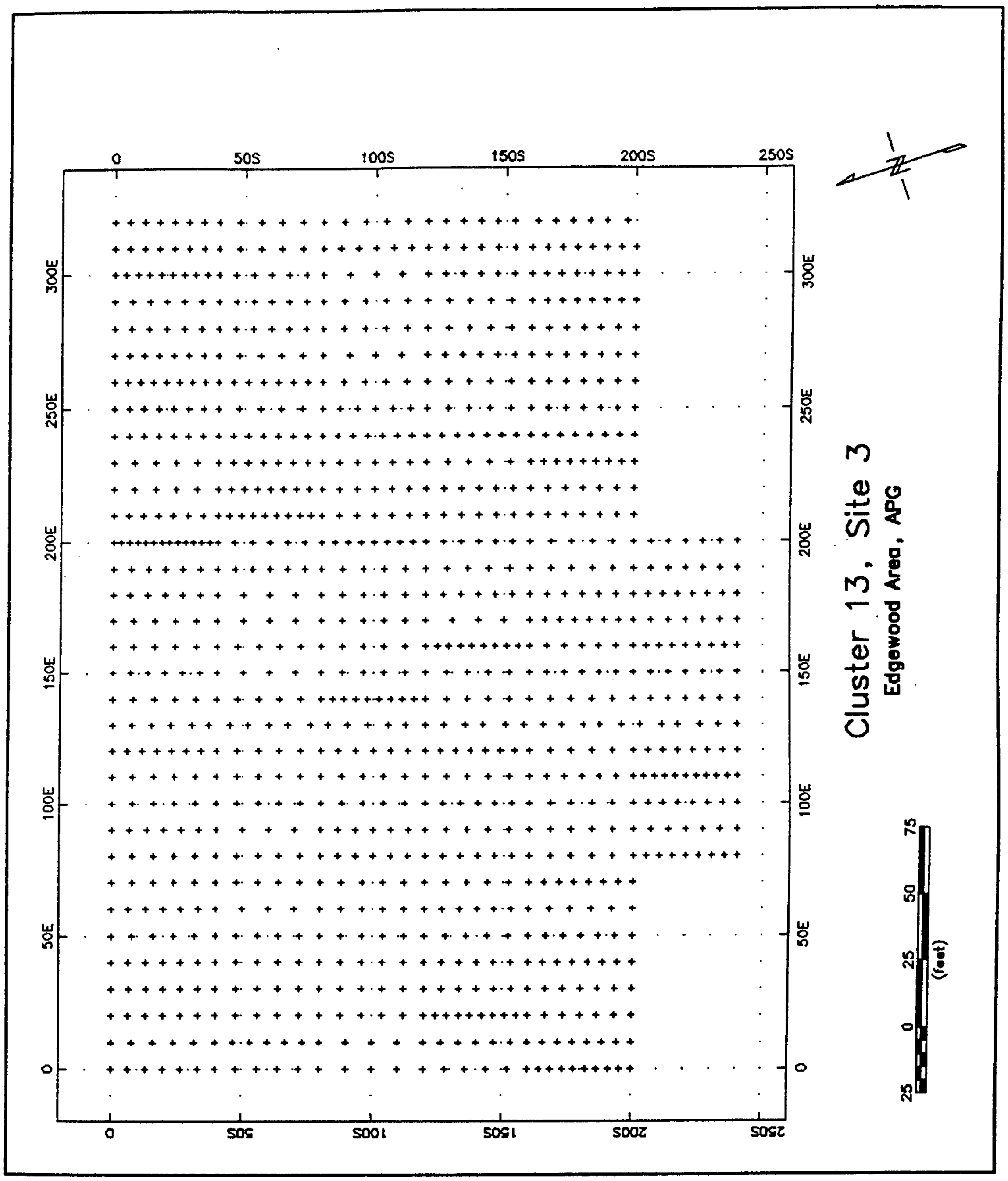

Figure 8. Layout of survey grid for Site 3

4 Test Results and Interpretation

In deciding what constitutes significant anomalies for a particular site several factors must be weighed. Anomaly detection is limited by instrument accuracy and local "noise" or variations in the measurements caused by factors not associated with the anomalies of interest such as fences, power lines, steel rails, etc. (cultural noise). For the anomaly to be significant, the measurement due to the anomaly must have a response greater than that caused by to the interfering cultural noise. Since the anomaly amplitude, spatial extent, and wavelength are the keys to detection, the size and depth of the feature causing the anomaly are important factors in determining detectability and resolution. The intensity of the anomaly is also a function of the degree of contrast in material properties between the anomalous feature and the surrounding material.

The results of the TMF, magnetic gradient, EM-31 conductivity and EM-31 in-phase data collected for the sites are presented as contour maps of the measured parameter. The color coded contour maps show a two-dimensional representation of the data with hot colors (reds) indicating areas with relatively high values and cold colors (blues) showing areas with relatively low values. The color coded legend on each EM-31 map is based on a nonlinear scale for the purpose of more clearly identifying anomaly locations. The color coded legend on each magnetic contour map is based on a linear scale. The GPR data are presented as depth sections for each line surveyed. The actual data are recorded as time sections and later converted to depth sections based on a knowledge of the subsurface velocities.

Site 1 Results

The portion of Cluster 13 designated as Site 1 is shown in Figure 1 with the corresponding survey grid shown in Figure 6. The results of the EM-31 survey are shown in Figures 9 and 10. Figure 9 is the results of the conductivity survey, with data nominally contoured every 1 mmho/m. Typical background values for this area are 2 to 6 mmho/m. Areas that are considered as anomalous would have values that deviate significantly from the background, either high or low, and are not associated with known surface features. There is an obvious high area in the eastern section of the grid which is associated with the access road to well WLC-25. The anomalies near location 100W,180N are associated with a metal trailer and construction equipment. There is also a small anomaly at location 60W,60N. The results of the inphase survey are shown in Figure 10. The data are contoured every 0.5 ppt with background values of 0.5 to 1.5 ppt. From this survey, the same areas appear anomalous as did those from the conductivity survey. In addition, effects from the access road to well WLC-24 can be seen at locations 320W,180N and 260W,220N.

The results of the magnetometer survey are shown in Figures 11 and 12. Figure 11 is the results of the total field survey, with contours spaced every 200 gammas. Typical background values for this area are approximately 54,200 gammas. Normally, magnetic anomalies from metallic objects will have a high and associated low that align in the direction of true magnetic north. There are no anomalies of this type in the data. However, several small areas do appear in the data. The area in the eastern portion of the grid at location 0W,70N is caused by a stack of drums close to the site. The area at location 60W,40N is prodced by an unknown source. The anomalies in the western portion of the plot are produced by surface metal as is the anomaly at location 240W,60N. Anomalies produced by the metal structures can be seen in the data at location 100W,180N. The results from the magnetic gradient survey are shown in Figure 12, with contours nominally every 200 gammas/m. Background values are -200 to 200 gammas/m. The same areas as discussed previously are apparent in these data also.

Based on the findings and interpretation from the surveys conducted in this area, all of the anomalies detected are associated with known surface features with the exception of that at location 60W,60N. The anomalies detected at this area are summarized in Table 1.

Table 1. Anomalies detected at Site 1

Anomaly	Location	Type	Cause
1	60W,60N	conductive,magnetic	unknown
2	100W,180N	conductive,magnetic	surface metal
3	320W,170N	conductive,magnetic	access road
4	50W,0N-0W,150N	conductive,magnetic	access road
5	320W,90N 320W,130N 240W,60N	magnetic	surface metal

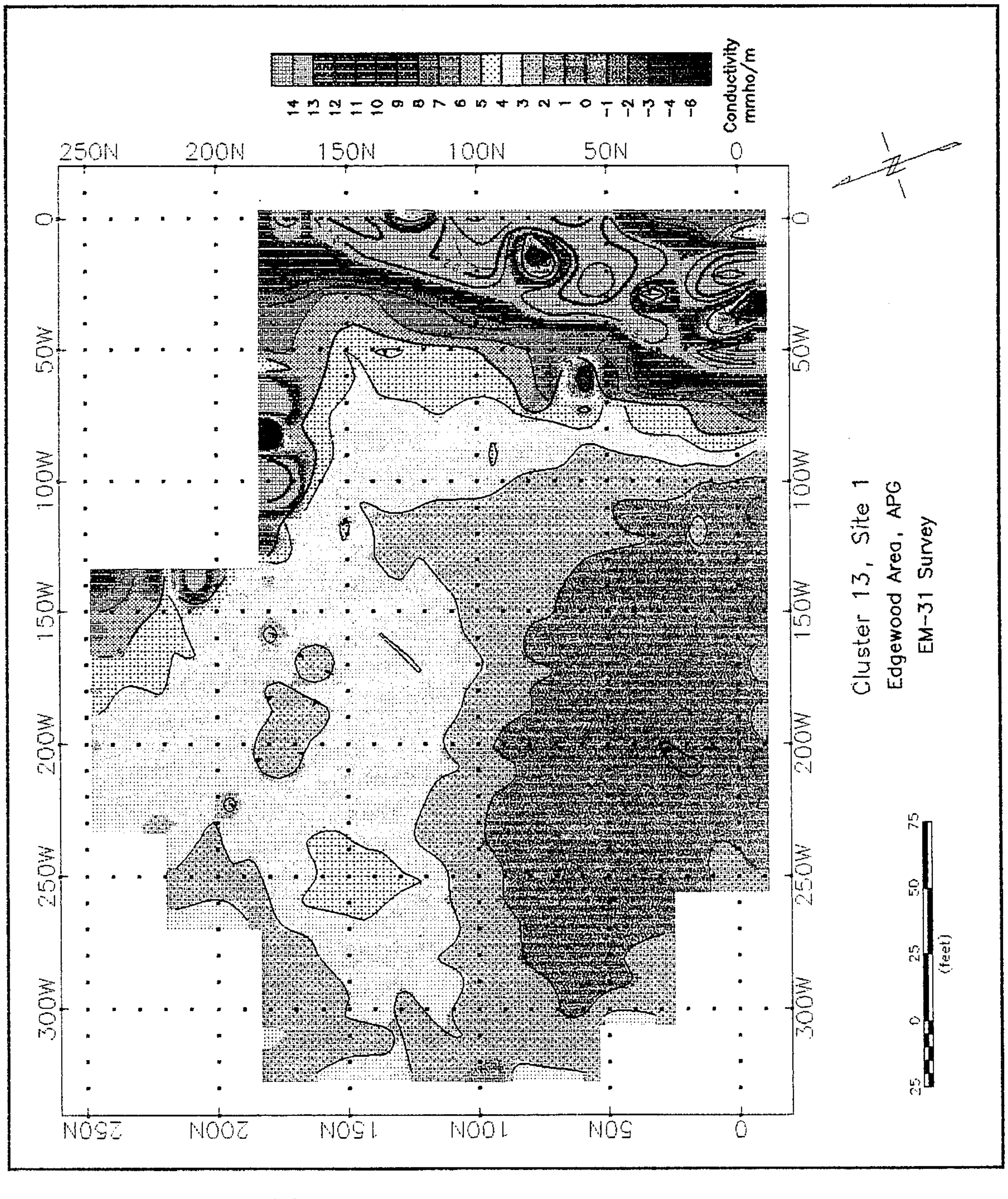

Figure 9. Site 1 conductivity survey

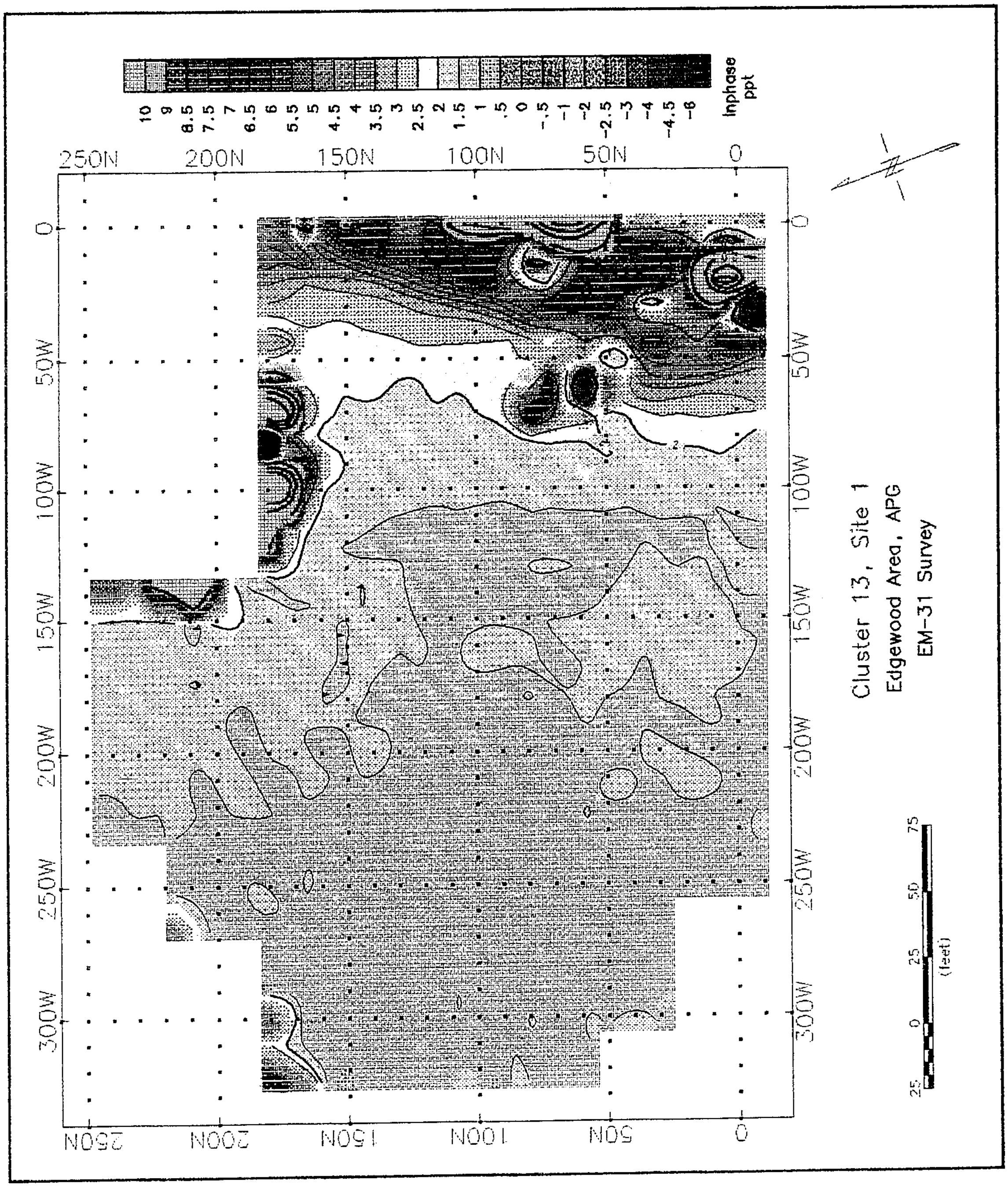

Figure 10. Site 1 inphase survey

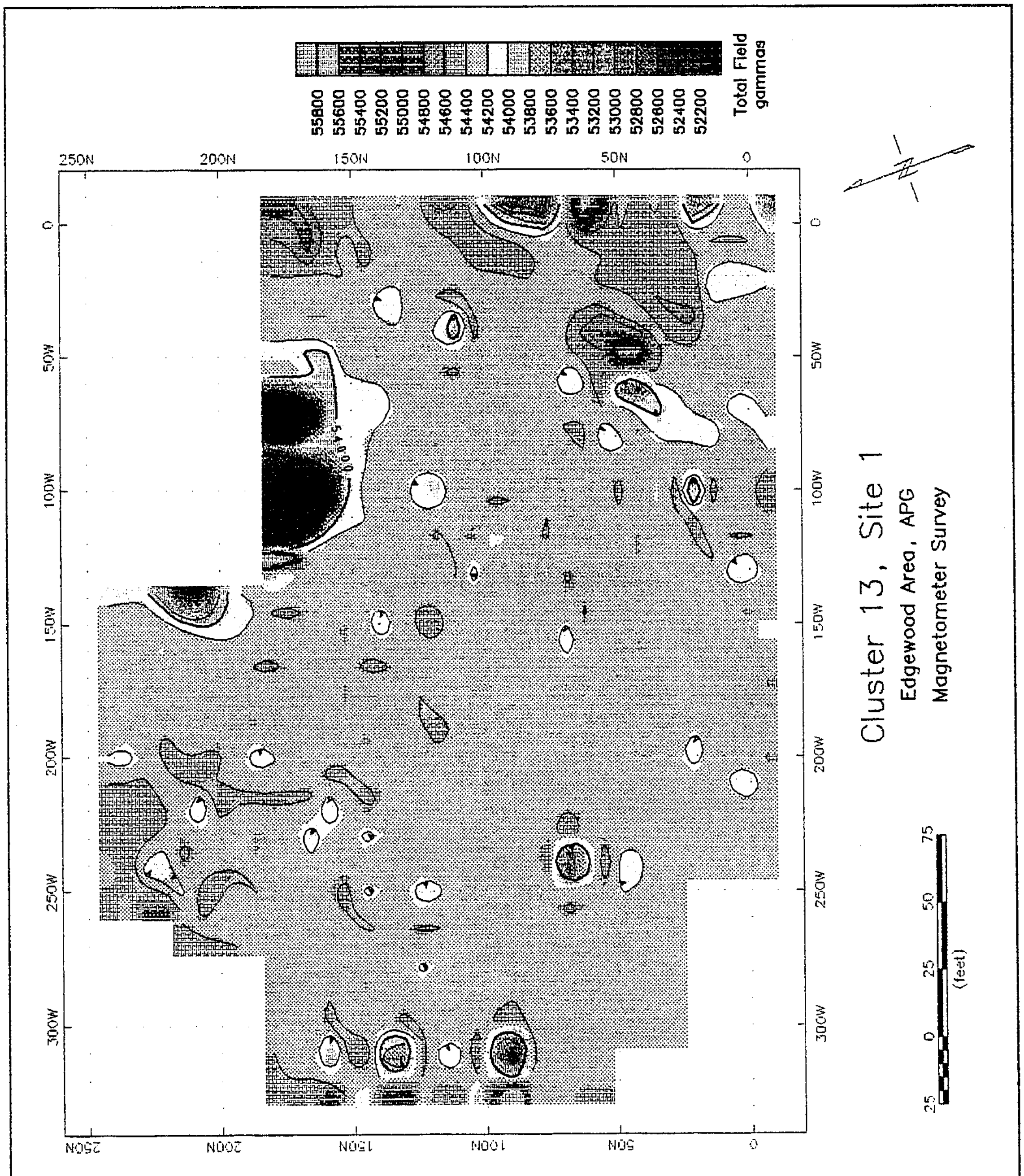

Figure 11. Site 1 total magnetic field survey

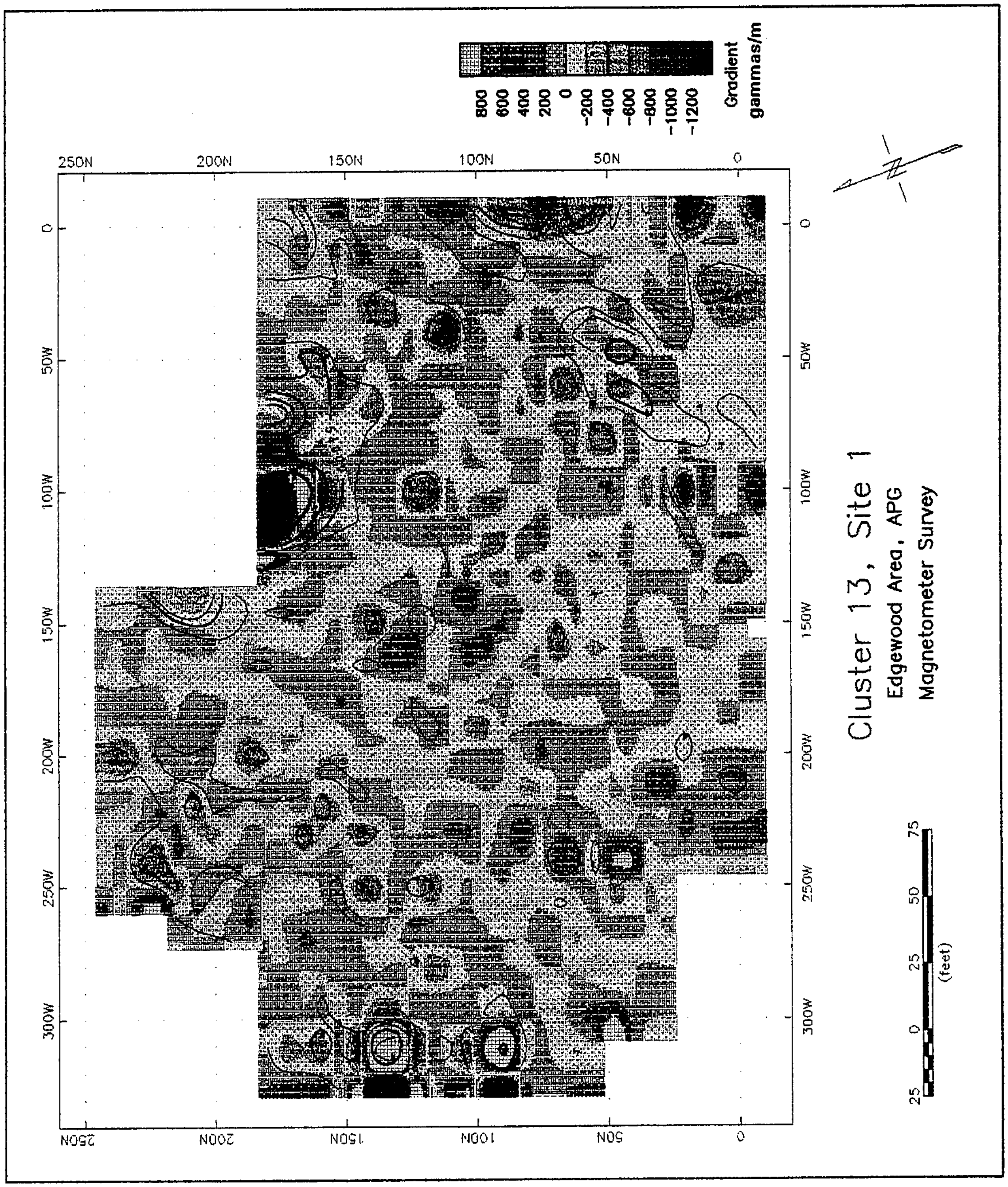

Figure 12. Site 1 magnetic gradient survey

Site 2 Results

The portion of Cluster 13 designated as Site 2 was shown in Figure 1 with the corresponding survey grid shown in Figure 7. The results of the EM-31 survey are shown in Figures 13 and 14. Figure 13 shows the results of the conductivity survey, with contours nominally spaced every 2.5 mmho/m. Typical background values for this area are 0 to 5 mmho/m. The 'blanked' area in the grid corresponds to the location of the buildings and related structures onsite. In addition, the entire area along line 180E from 200N to 700N had temporary metal storage structures intermittently spaced. The effects of these structures can be clearly seen in the data. Along line 200N, the effects of an underground water line are apparent due to the linear trend of the anomaly. The remaining anomalies are all related to surface features except for a faint anomaly at location 220E,440N. This anomaly is associated with an underground storage tank. The results of the inphase survey are shown in Figure 14, with contours nominally spaced every 1 ppt and background values of -3 to 0 ppt. The results are exactly as stated for the conductivity survey. The underground storage tank at location 220E, 440N is more visible in this data set.

The results of the magnetometer survey are shown in Figures 15 and 16. Figure 15 is the results of the total field survey, with contours every 500 gammas. Typical background values for this area range around 54,000 gammas. The same anomalies as previously discussed are apparent, with the absence of the underground pipeline at location 200N. Similar results can be seen in the magnetic gradient plot shown in Figure 16.

To determine the depth and size of the underground tank at location 220E,440N several GPR survey lines were conducted. Figure 17 shows the GPR survey over the tank in a north-south direction. The tank is clearly visible (large hyperbola) at position 10 m on the profile. The tank is shallow, with a depth to the top of 1 m. Subsequent to this line, four GPR survey lines were conducted on the north, south, east and west sides of the tank respectively. These surveys are shown in Figures 18-21 and were located 10 ft from the tank center in the east/west directions and 5 ft from the tank center in the north/south directions. These survey lines did not reveal the tank. Based on the survey line locations and the GPR data, the tank is estimated to be no larger than 10 ft by 5 ft with the long dimension oriented east/west and the short dimension oriented north/south.

Based on the interpretation of findings from all the surveys conducted in this area, all of the detected anomalies are from known surface and subsurface features. The underground storage tank at location 220E,440N was detected and subsequently sized by GPR. An anomaly table was not prepared for this site.

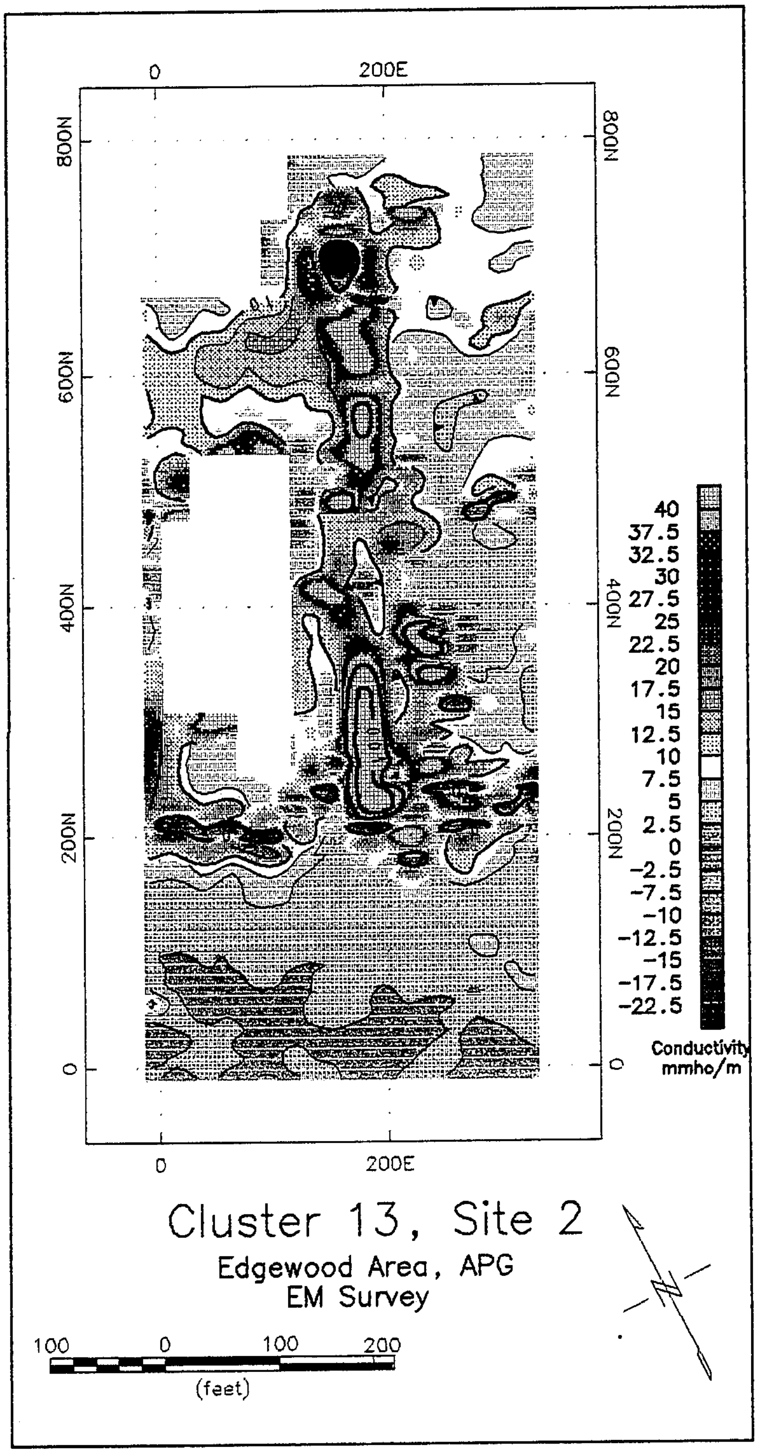

Figure 13. Site 2 conductivity survey

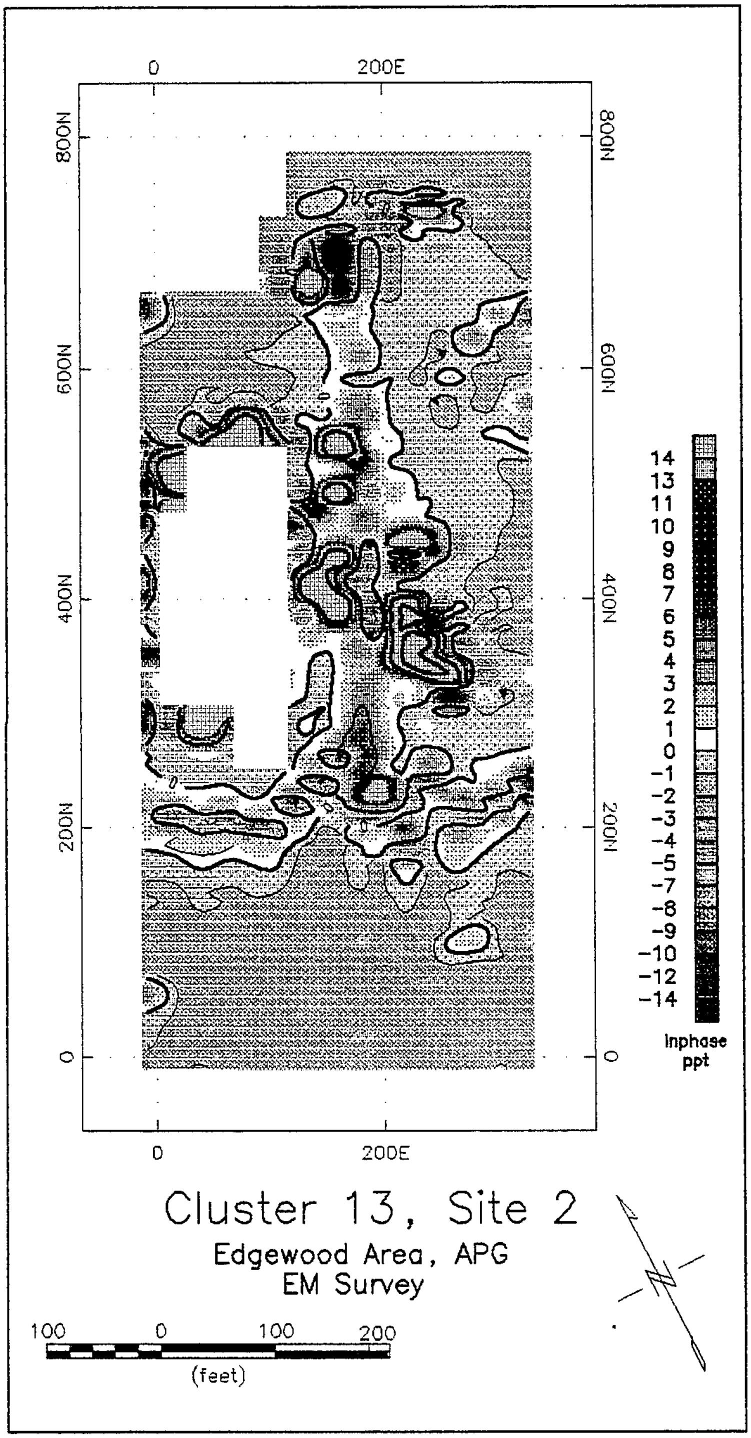

Figure 14. Site 2 inphase survey

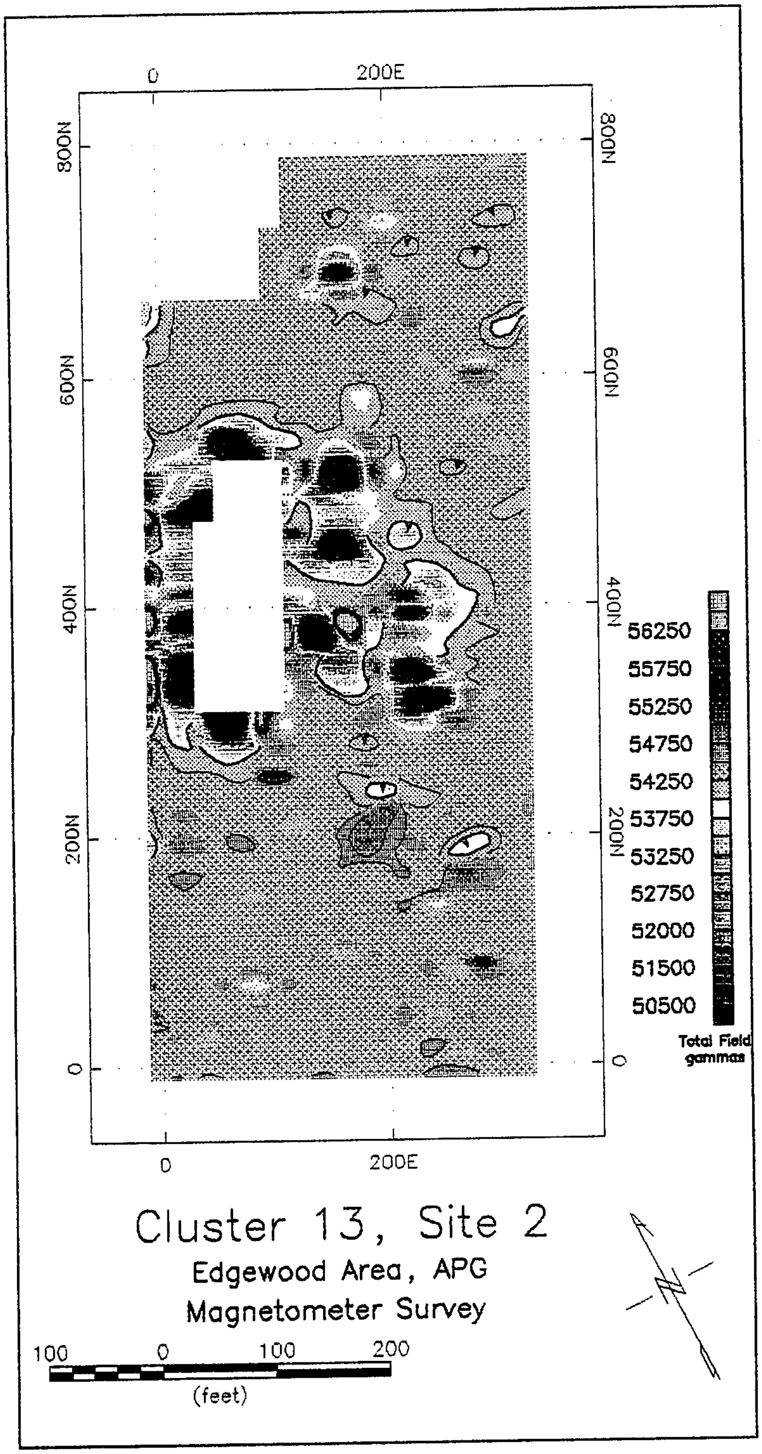

Figure 15. Site 2 magnetic total field survey

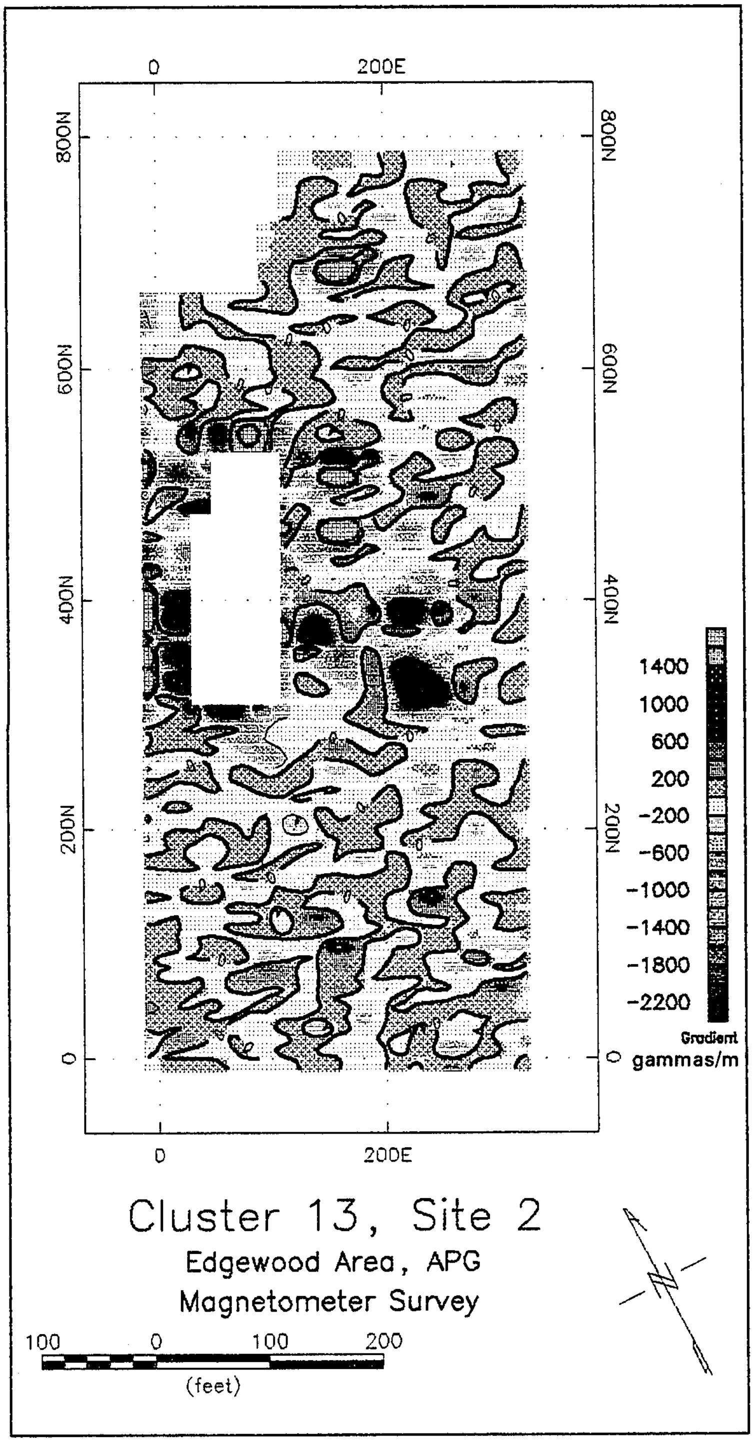

Figure 16. Site 2 magnetic gradient survey

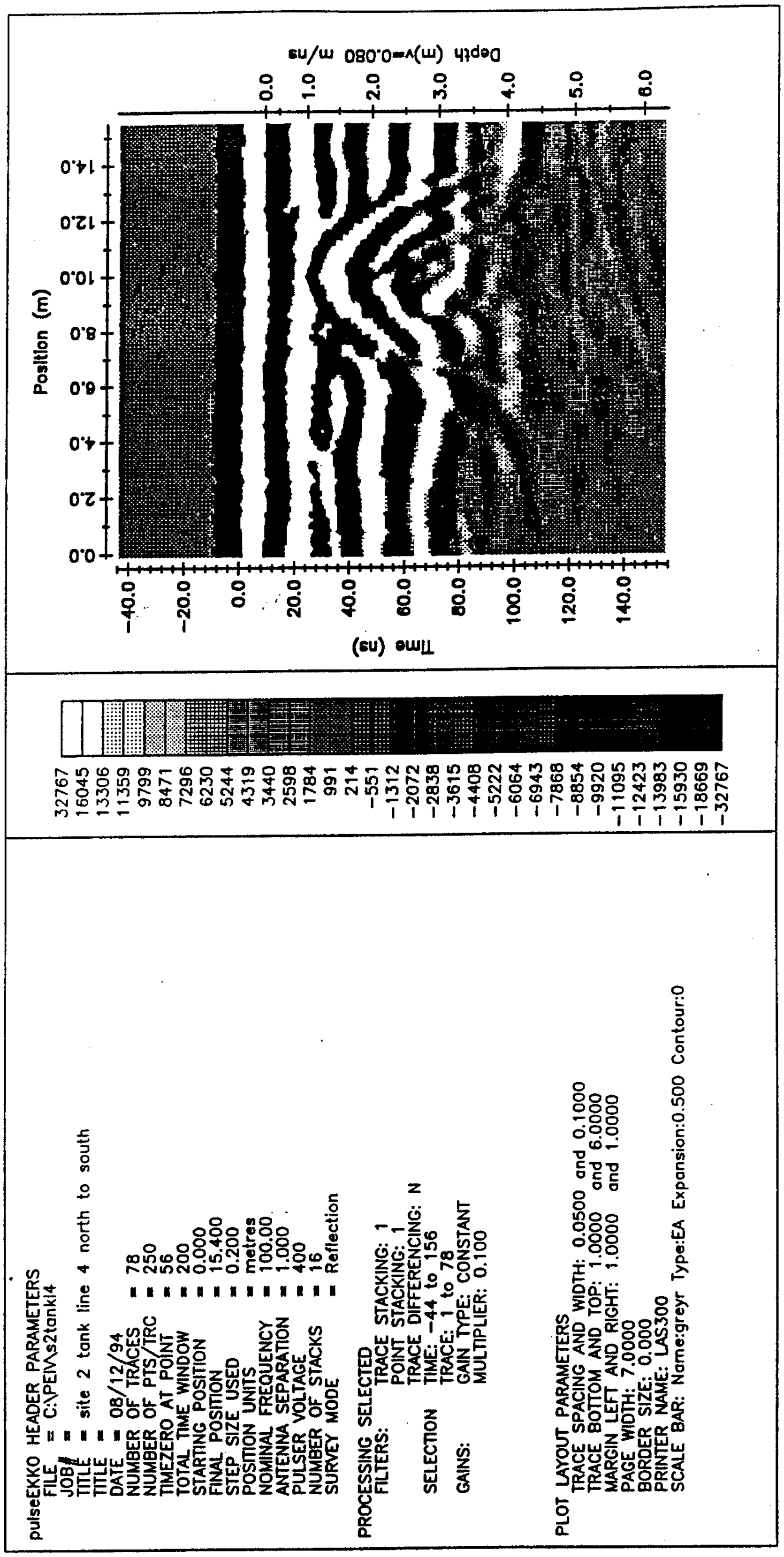

Figure 17. Site 2 GPR survey line over underground tank

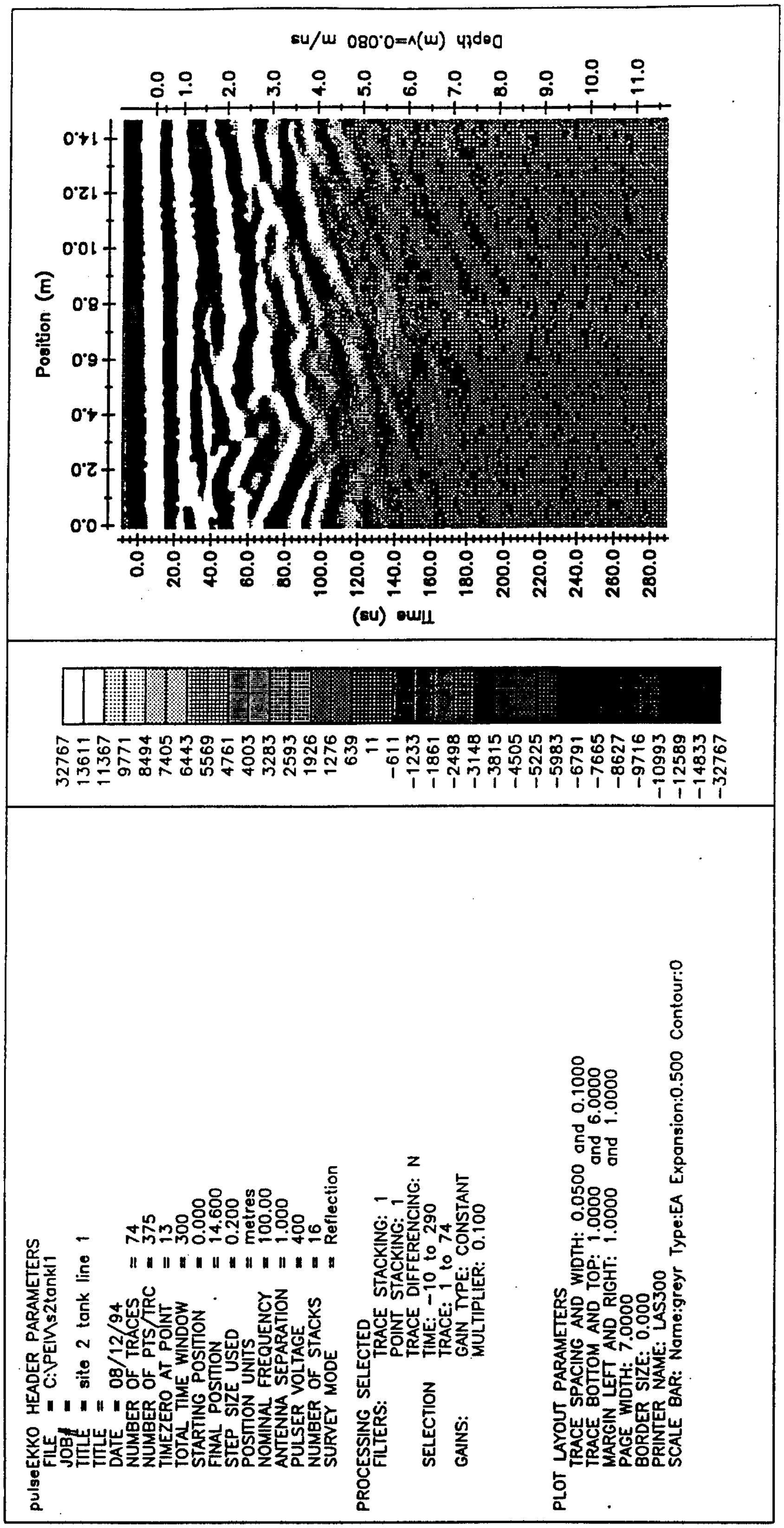

Figure 18. Site 2 GPR survey line north of underground tank

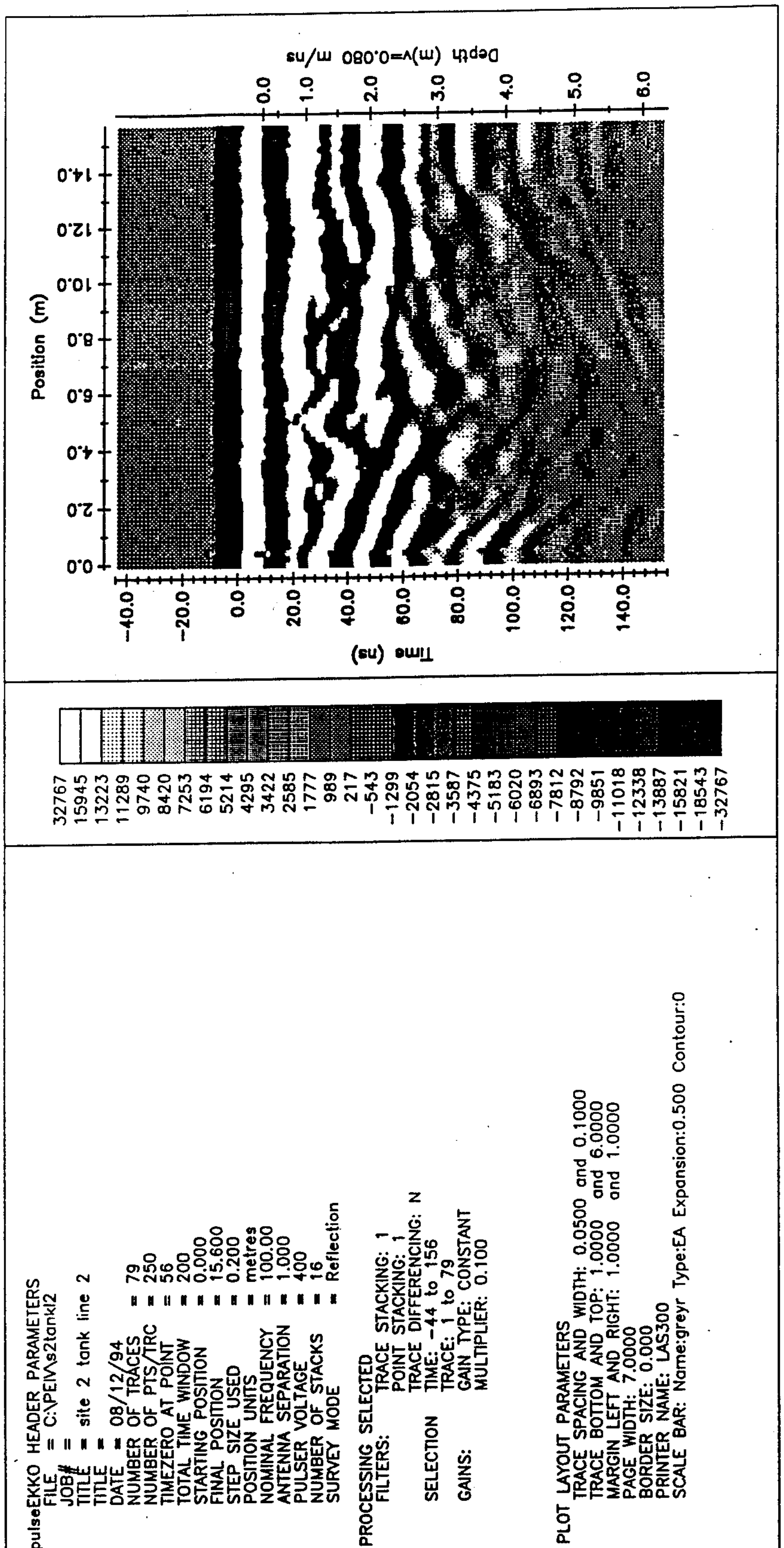

Figure 19. Site 2 GPR survey line south of underground tank

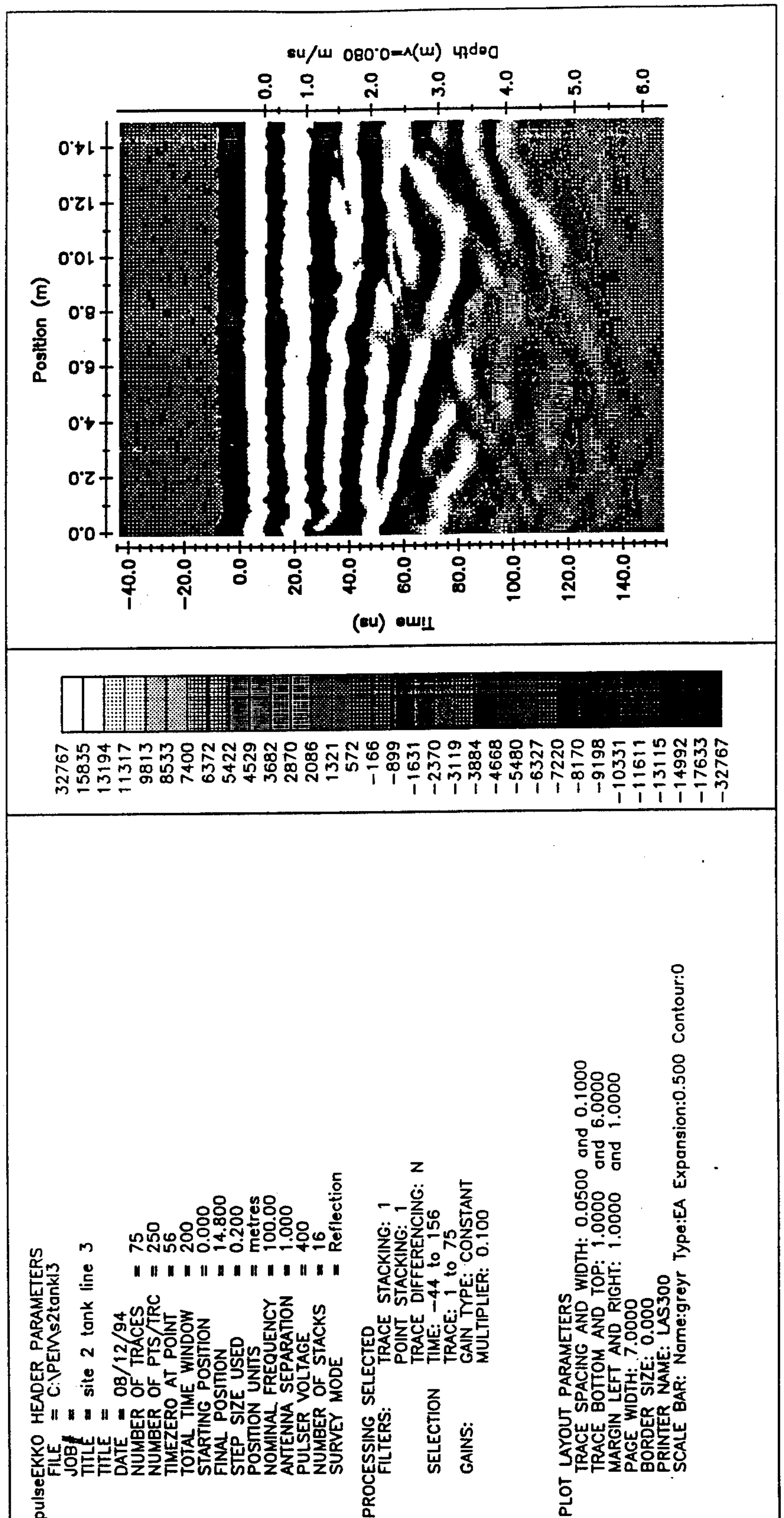

Figure 20. Site 2 GPR survey line east of underground tank

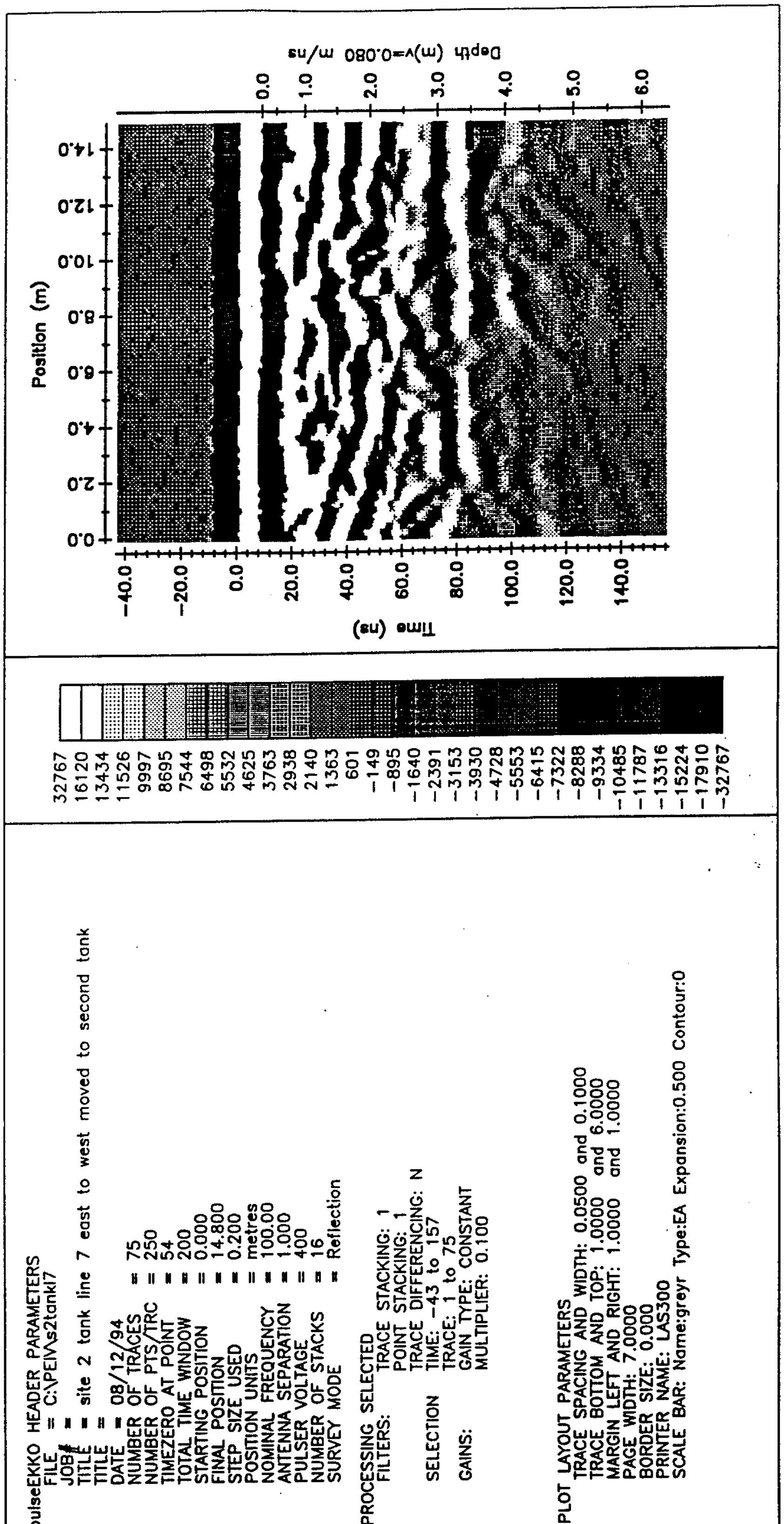

Figure 21. Site 2 GPR survey line west of underground tank

Site 3 Results

The portion of Cluster 13 designated as Site 3 was shown in Figure 1, with the corresponding survey grid layout shown in Figure 8. The results of the EM-31 survey are shown in Figures 22 and 23. Figure 22 shows the results of the conductivity survey, with contours nominally spaced every 2 mmho/m and background values of 2-6 mmho/m. The anomalies at location 120E,0S and 210E,0S are both associated with construction equipment. The anomaly at 330E,25S is associated with well WLC-29. The anomalies at locations 230E,140S and 270E,160S are associated with construction material. The only other anomaly located at 310E,170S is associated with surface metal. The results of the inphase survey are shown in Figure 23, with contours nominally spaced every 1 ppt and background readings of -2 to -1 ppt. The same anomalies as previously discussed are apparent, in addition to the access road leading to well WLC-26.

The results of the magnetometer survey are shown in Figures 24 and 25. Figure 24 is a plot of results from the total field survey, with contours every 200 gammas. Background readings for this area are approximately 54,300 gammas. The plot reveals the same anomalies as discovered from the EM survey. The results of the magnetic gradient survey are shown in Figure 25, with contours every 100 gammas/m. Here again the significant anomalies are the same as discussed for the total field survey.

Based on the survey results, it is interpreted that the anomalies detected at the site are from known surface features. The anomalies detected at this area are listed in Table 2.

Table 2. Anomalies detected at Site Three

Anomaly	Location	Type	Cause
1	120E,0S	conductive,magnetic	construction equipment
2	210E,0S	conductive,magnetic	construction equipment
3	330E,25S	conductive,magnetic	monitoring well
4	230E,160S	conductive,magnetic	construction equipment
5	270E,140S	conductive,magnetic	construction equipment
6	310E,130S	conductive,magnetic	surface metal

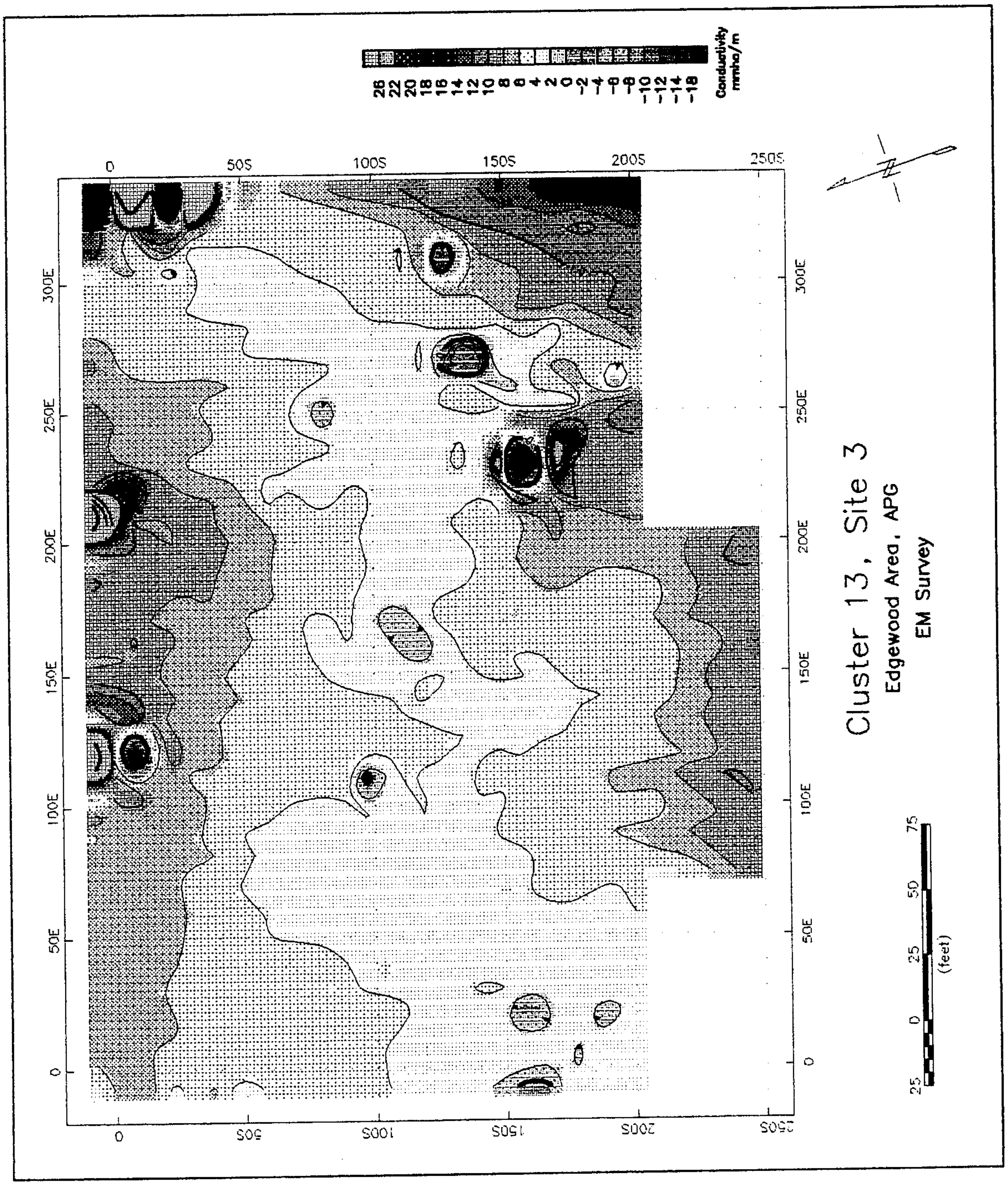

Figure 22. Site 3 conductivity survey

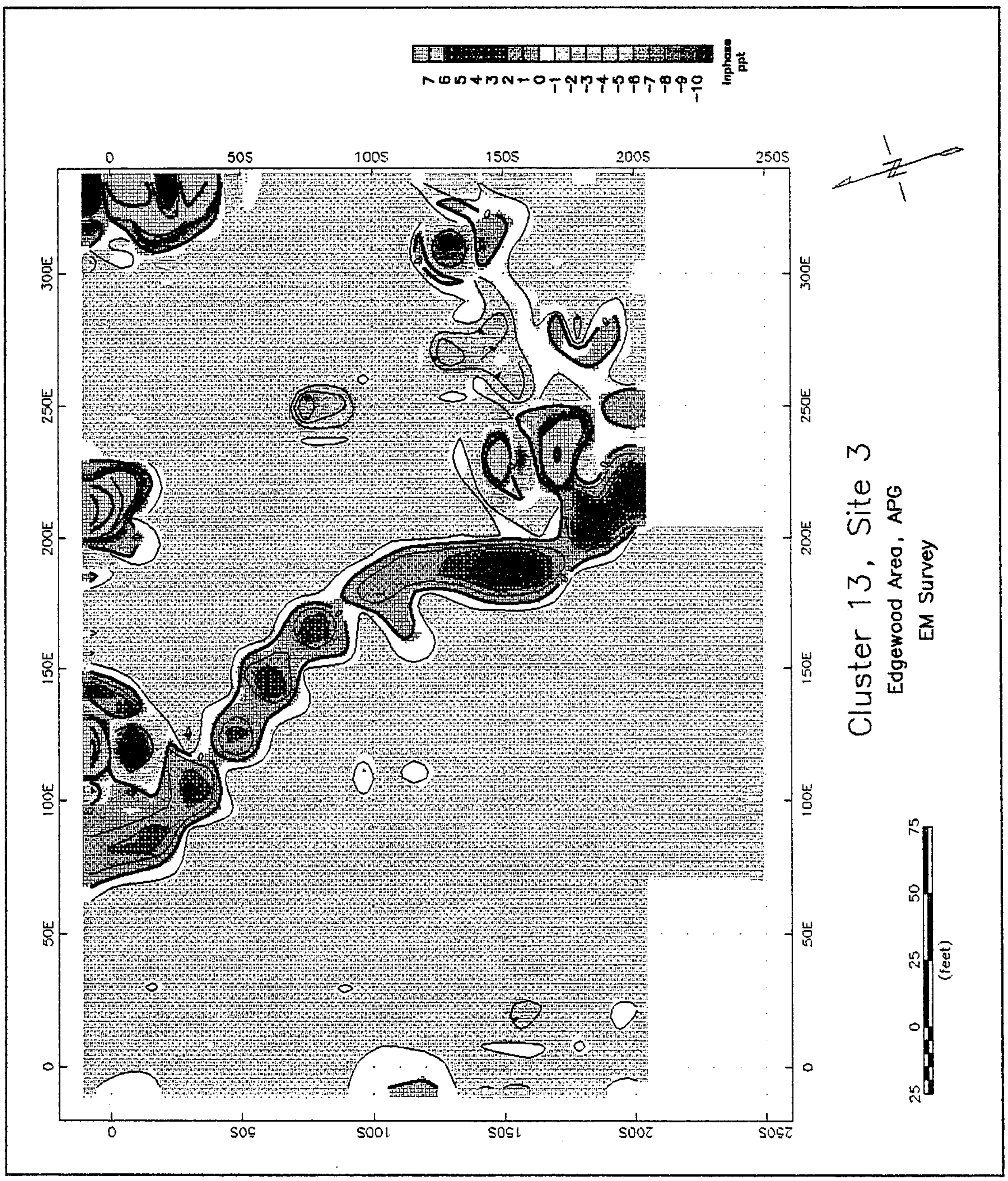

Figure 23. Site 3 inphase survey

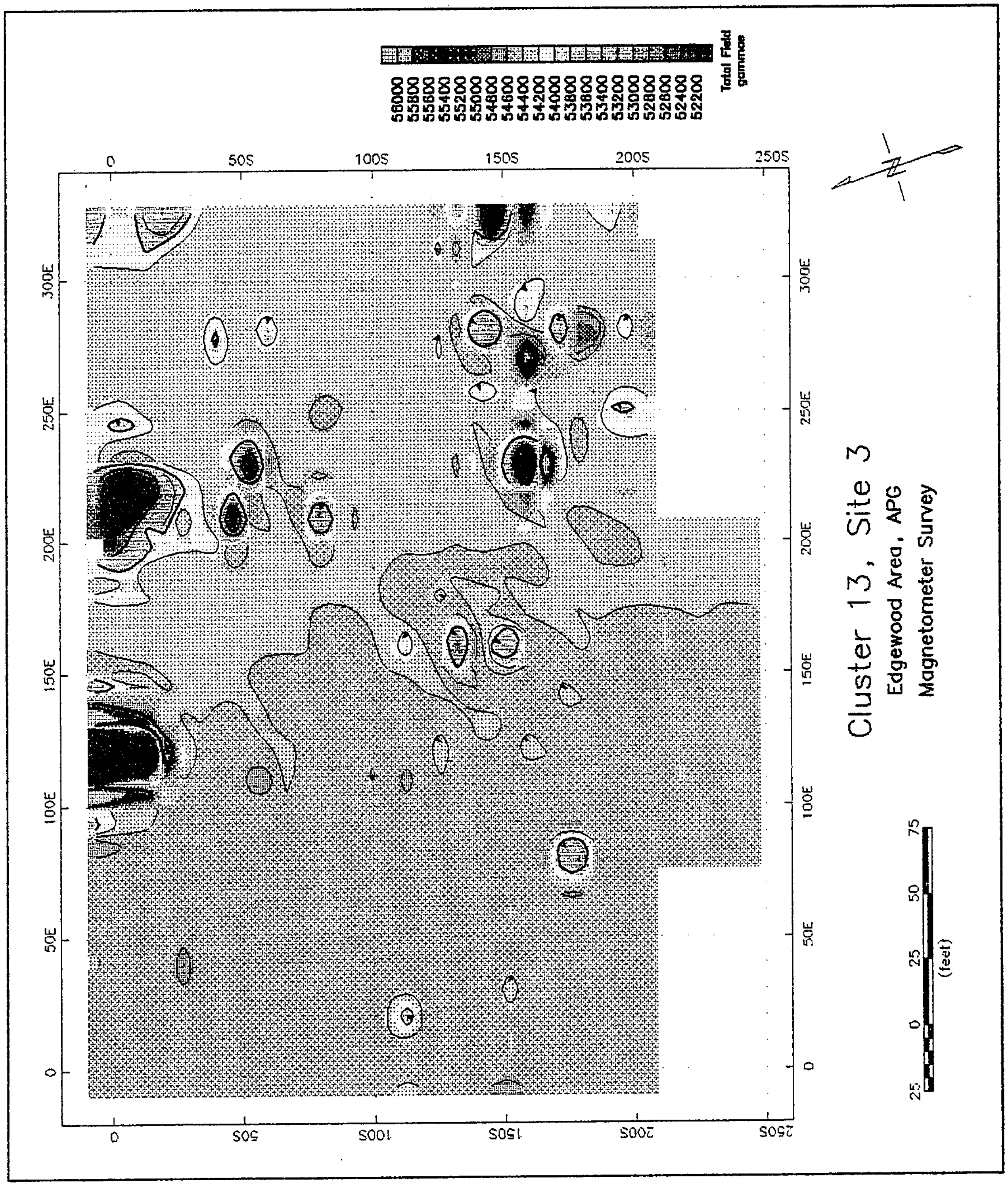

Figure 24. Site 3 magnetic total field survey

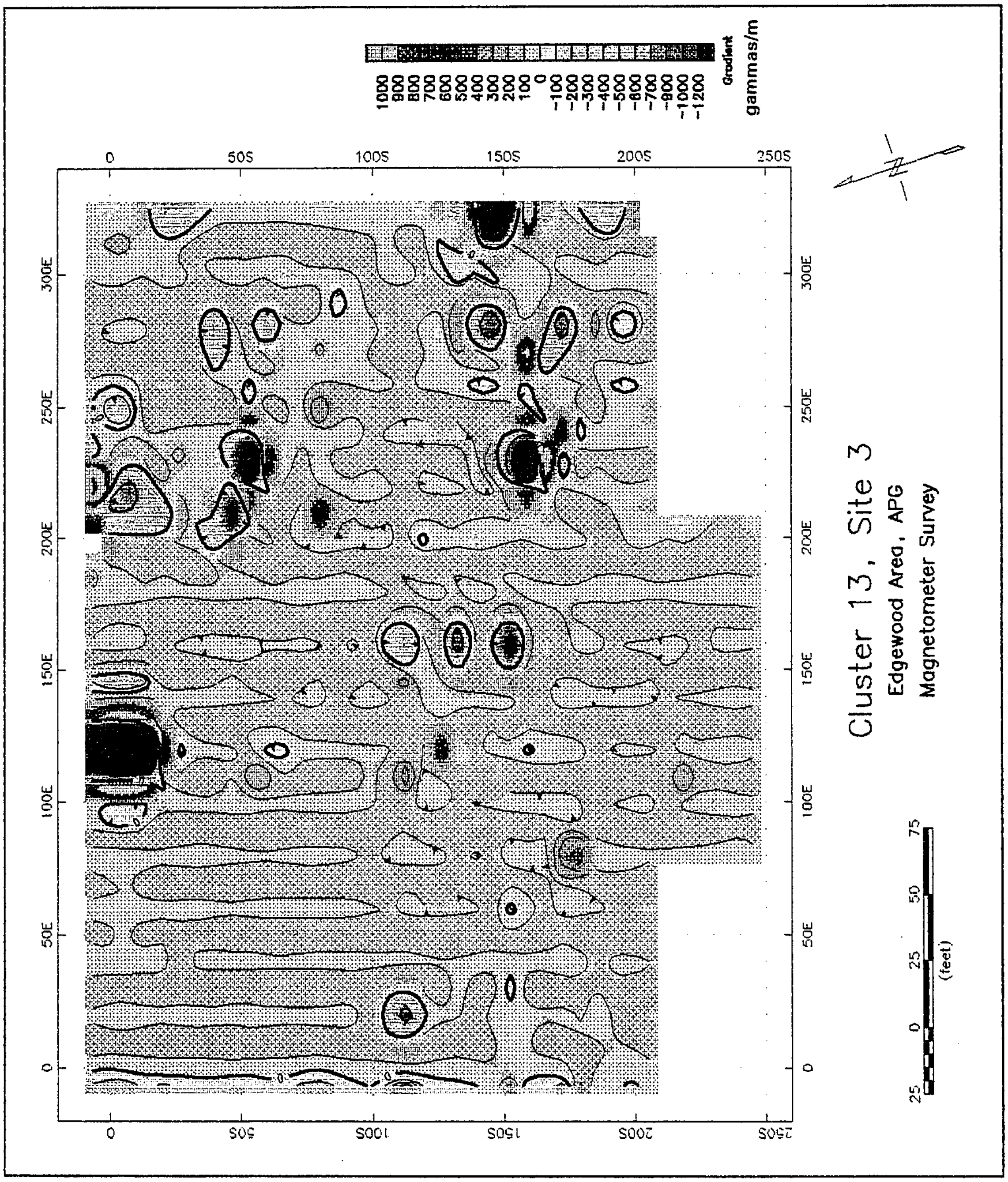

Figure 25. Site 3 magnetic gradient survey

5 Conclusions

During October 1994 a geophysical investigation was conducted on a portion of the Cluster 13 study area at APG/EA by WES personnel. The objective of the investigation was to delineate anomalies indicative of burial activities (such as tanks, barrels, etc.). Three geophysical methods were used in this investigation; EM, magnetic, and GPR surveys.

Based on the tests conducted at each site the following conclusions can be drawn. All of the anomalies at the sites, with the exception of one, are from known surface or subsurface objects. The only unknown anomaly was located in Site 1 at location 60W,60N. The underground storage tank located in Site 2 was detected. From the GPR surveys performed over and around the tank, it is estimated that the tank is buried 1m deep and is no larger than 10 ft long by 5 ft wide with the long axis oriented east/west.

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13. ABSTRACT *(Maximum 200 words)*

A geophysical investigation consisting of electromagnetic, magnetic, and ground penetrating radar methods was conducted at the Cluster 13 site located in the Edgewood Area of the Aberdeen Proving Ground, Maryland. The purpose of the investigation was to locate underground structures such as barrels and tanks. The results indicated the presence of an unknown underground anomaly at one site and its location was mapped.

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