



**WORK PLAN FOR
SUPPLEMENTAL
SITE INVESTIGATION**

PREPARED FOR:

FILE COPY

 *HERCULES, INC.*

CHEMICAL SPECIALTIES

HATTIESBURG, MISSISSIPPI

APRIL, 2003

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AVERY

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1.0 INTRODUCTION

Eco-Systems, Inc. (Eco-Systems) has been retained by Hercules Incorporated (Hercules) to conduct supplemental site investigation at the Hercules facility in Hattiesburg, Mississippi. The site location is shown on Figure 1. The supplemental site investigation is being conducted in response to a request from the Mississippi Department of Environmental Quality (MDEQ) in a letter dated February 3, 2003. The February 3, 2003 letter from MDEQ was sent after review by the MDEQ of the *Interim Groundwater Monitoring Report* (Eco-Systems, January 2003). The *Interim Groundwater Monitoring Report* was submitted voluntarily by Hercules after receipt of groundwater analytical results for groundwater monitoring conducted in accordance with the *Hercules' Site Investigation Work Plan* (Eco-Systems, February 1999) and additional comments of the MDEQ approval letter dated April 5, 1999.

1.1 BACKGROUND

Work conducted under the previous *Hercules Site Investigation Work Plan* centered on efforts to determine whether the miticide, Dioxathion, was present in site soil and groundwater. The work plan included installation of 5 groundwater monitoring wells (MW-7, MW-8, MW-9, MW-10, and MW-11) to add to the 6 existing groundwater monitoring wells installed at the site during prior investigations. Monitoring wells MW-7, MW-8, MW-9, MW-10 and MW-11 were installed to provide groundwater quality information near the former Dioxathion production area and near former wastewater sludge pits. The work also included installation of 14 temporary piezometers and 4 staff gauges. The piezometers and staff gauges were installed to provide hydrogeologic information in the uppermost saturated interval and to establish the relationship, if any, of the uppermost saturated interval to Green's Creek. Monitoring wells, piezometers, stream gauges, and other sampling locations installed or implemented during the previous site investigation are shown on Figure 2. Field activities for the previous site investigations were conducted between April 1999 and March 2003. The results of the site investigations are discussed in the *Interim Groundwater Monitoring Report* (Eco-Systems, January 2003) and the *Hercules Site Investigation Report* (Eco-Systems, April 2003).

The findings of the site investigations that are discussed in the *Interim Groundwater Monitoring Report* and the *Hercules Site Investigation Report* included the detection of volatile organic compounds (VOCs) at concentrations above Target Remediation Goals (TRGs) identified in the MDEQ Brownfields program in groundwater samples collected from monitoring wells MW-4, MW-8, MW-9, and MW-11. The highest concentrations of VOCs were detected in the groundwater sample collected from monitoring well MW-8. Monitoring well MW-8 is located near the former dioxathion production area.

The February 3, 2003 letter from MDEQ requested that Hercules submit this supplemental site assessment work plan to delineate the vertical and horizontal extent of VOCs detected in shallow groundwater at the facility. The letter from MDEQ also requested that Hercules conduct a geophysical investigation to delineate the lateral limits of the closed landfill on the site and to locate accumulations of buried metal within the landfill. The MDEQ letter requested the

location of buried drums; however, geophysics will allow for the identification of magnetic anomalies in subsurface soils that may be interpreted as accumulations of buried metallic objects.

1.2 PURPOSE AND SCOPE

The purpose of this supplemental site investigation will be to investigate the lateral and vertical extent of the VOCs that were detected in the groundwater samples collected from monitoring wells MW-4, MW-8, MW-9, and MW-11. The supplemental site investigation will also include a geophysical investigation to delineate the lateral limits of the landfill and, if possible, locate accumulations of buried metal.

The scope of this investigation will include the following:

- Mobilize a hydraulic probing unit to the site,
- Install probe borings and temporary monitoring wells, as necessary,
- Collect groundwater samples and have those samples analyzed for constituents of concern,
- Collect hydrogeologic information from probe borings and temporary monitoring wells,
- Evaluate the lateral limits of the constituents of concern in groundwater and the effectiveness of the existing monitoring well system,
- Conduct single well response tests and analyze the test data to provide hydraulic conductivity estimates,
- Conduct a geophysical survey to delineate the lateral boundaries of the waste in the former landfill area and locate accumulations of buried metal within the landfill area, and
- Prepare a supplemental site characterization report.

2.0 SITE SETTING

2.1 FACILITY LOCATION AND SITE DESCRIPTION

The Hercules facility is located on approximately 200 acres of land north of West Seventh Street in Hattiesburg, Forrest County, Mississippi. More specifically, the Site is located in Sections 4 and 5, Township 4 North, Range 13 West, just north of Hattiesburg, Mississippi (Figure 1). The facility has been in operation since 1923. The facility is bordered to the north by Highway 43 and Illinois-Central & Gulf Railroad, along with various residential and commercial properties. The southern property boundary is bordered by 7th Avenue; and by a cemetery and Zeon Chemical Company to the southwest. Across from these locations are residential areas. The eastern and western boundaries are bordered by sparsely populated residential areas.

The facility's historical operations consisted of wood grinding, shredding extraction, fractionation, refining, distillation, and processing of rosin from pine tree stumps. Historically, over 250 products were produced from the above-referenced operations and included: modified resins, polyamides, ketene dimer, crude tall oil wax emulsions, and Delnav, an agricultural miticide. Structures at the facility include offices, a laboratory, a powerhouse, production buildings, a wastewater treatment plant, settling ponds, a landfill, and central loading and packaging areas.

2.2 TOPOGRAPHY AND SURFACE DRAINAGE

Surface water drainage patterns at the Site conform generally to the topography which slopes toward Green's Creek on either side (Figure 2). Topography slopes generally to the south in the Wastewater Sludge Disposal Area, and to the north/northwest in the Former Industrial Landfill Area and the Former Delnav Production Area. A topographic divide located south/southwest of the Former Delnav Production Area separates north flowing surface water drainage to more east/southeast-trending drainage. The east-trending, perennial stream Green's Creek and its natural and man-made tributaries are the main surface drainage features in the area. Green's Creek leaves the Site at its northeast corner and subsequently runs into Bowie River, located approximately one (1) mile to the north/northeast.

2.3 SITE GEOLOGY AND HYDROGEOLOGY

The Site is located within the Pine Hills physiographic region of the Coastal Plain physiographic province. The topography of the region is characterized by a maturely dissected plain which slopes generally toward the southeast. The topography is dominated by the valleys of the Bowie and Leaf Rivers coupled with the nearly flat or gently rolling bordering terrace uplands.

The geologic formations beneath the Site are as follows (in descending order): Pleistocene alluvial and terrace deposits, the Miocene-aged Hattiesburg and Catahoula Sandstone formations, the Oligocene-aged Baynes Hammock Sand and Chickasawhay Limestone formations, and the Oligocene-aged Bucatunna Clay member of the Byron formation of the Vicksburg group. A conceptual cross section of the regional geology is shown on Figure 3.

The recent-aged alluvial and terrace deposits consist of flood plains and gravel, silts, and clays. The thicknesses of the alluvial and terrace deposits are variable due to erosion. Based upon drillers logs of wells located in the vicinity of the Site, thickness of the alluvial and terrace deposits is estimated to be approximately 50 feet.

Beneath the alluvial and terrace deposits lies the Hattiesburg formation, which is comprised predominantly of clay. Regionally, beneath Forrest County, the formation contains at least two (2) prominent sand beds from which a viable water supply is obtained. Logs from area wells indicate that the Hattiesburg formation ranges from approximately 130 feet to 260 feet in thickness.

The Catahoula sandstone underlies the Hattiesburg formation. It is not exposed near the facility, but is penetrated by numerous wells in the area. A drillers log of a municipal well approximately 1.25 miles northwest of the facility indicated that approximately 770 feet of Catahoula sandstone was encountered.

Near the Site, the Catahoula sandstone overlies the Chickasawhay limestone. Neither the Chickasawhay limestone nor the Bucatunna formation are considered to be very viable aquifers. The Bucatunna formation is comprised of clay and effectively act as a confining layer for the underlying Oligocene aquifer.

The Miocene aquifer is comprised of both the Hattiesburg and Catahoula sandstone formations. The aquifer system is composed of numerous interbedded layers of sand and clay. Because of their interbedded nature, the Hattiesburg and Catahoula sandstone cannot be reliably separated. The formations dip southeastward approximately 30 feet to 100 feet per mile. While this dip steepens near the coast, the formations thicken. The shallowest portions of the aquifer system are unconfined with the surficial water table ranging from a few inches to greater than six (6) feet below land surface. Deeper portions of the aquifer are confined, with artesian conditions common.

3.0 TECHNICAL APPROACH

The supplemental site investigation will be conducted in one mobilization. During the mobilization a Geoprobe® will be used to investigate site conditions and define the lateral extent and vertical extent of the VOCs detected in groundwater samples collected from MW-4, MW-8, MW-9, and MW-11. A geophysical survey will also be conducted during this mobilization. The geophysical survey will involve data collection with non-intrusive instrumentation to delineate the lateral limits of the landfill area and to locate accumulations of buried metal within the waste matrix.

3.1 GROUNDWATER INVESTIGATION

Groundwater samples will be collected in the vicinity of wells where VOCs have been previously identified in groundwater samples to delineate the lateral extent of the constituents of concern in the uppermost saturated interval. Previous investigation indicates that the uppermost saturated interval occurs within approximately 10 feet to 12 feet of ground surface. Initially, groundwater samples will be collected in close proximity to monitoring well MW-8, where samples containing the highest concentrations of VOCs have been detected during previous investigations. The initial samples will be analyzed for VOCs as quickly as possible by Bonner Analytical and Testing Company (BATCO) located in Hattiesburg, Mississippi. If VOCs are detected in the initial groundwater samples, additional groundwater samples will be collected from locations surrounding the initial locations. The additional groundwater samples will also be analyzed by BATCO, and the analytical results from the additional groundwater samples will be used to site other sampling locations. The investigation will continue using this iterative process until the lateral extent of the constituents of concern in the uppermost saturated interval is defined. It is estimated that up to 15 groundwater samples may be collected, depending on site conditions.

Groundwater samples collected during the Geoprobe® investigation will be collected from temporary monitoring wells installed using the Geoprobe®. The temporary monitoring wells will be screened across the uppermost saturated interval. After sample collection, the temporary monitoring wells will be left in place until they can be surveyed.

Groundwater conditions at the site will be evaluated based on geologic, groundwater quality, and groundwater flow information obtained during the Geoprobe® investigation and previous investigations.

3.2 GEOPHYSICAL INVESTIGATION

A former landfill is located north of the active plant area. The landfill was reported to have operated from approximately 1950 to approximately the early 1970's. The landfill was reportedly used to dispose of boiler ash, miscellaneous trash and debris, and other metallic objects such as empty drums. The practice at the plant at that time was to burn any organic

waste materials containing fuel value in the industrial boiler. The approximate boundaries of the former landfill can be topographically identified. A previous geophysical investigation was conducted in 1993 by Black and Veatch Waste Science and Technology Corporation (Black and Veatch) for the U.S. Environmental Protection Agency. The results of the previous geophysical investigation were discussed the *Site Inspection Report*. The landfill area investigated was reported to have the approximate dimensions of 150 by 250 feet in the Black and Veatch report. A copy of the relevant portions of the Black and Veatch report is included as Appendix A.

A combination of ground conductivity and magnetic intensity methods will be used to delineate the boundaries of the former landfill area and to locate accumulations of buried metal within the landfill area. For this survey, data will be collected at ten-foot intervals along lines spaced ten feet apart. This spacing should provide sufficient overlap to adequately delineate the lateral limits of the fill materials and identify most accumulations of buried metal.

Electrical conductivities of subsurface materials will be measured using a Geonics, Ltd., Model EM31. The EM31 is useful in detecting buried metal, inorganic groundwater plumes, and landfill cells. Magnetic intensity enhances data interpretation for subsurface magnetic materials such as buried metallic objects and will be measured using a Geometrics, Inc., Model G-858 cesium vapor magnetometer. Details of the geophysical survey methods and procedures are described in Section 4.8.

4.0 METHODS AND PROCEDURES

Unless otherwise stated, field activities will be conducted in accordance with the Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EPA Region IV, November, 2001), (EISOPQAM).

4.1 BORING ADVANCEMENT

During the first mobilization, borings will be advanced using a direct-push technology, hydraulic probing apparatus (Geoprobe® or similar) equipped with a soil coring device (MacroCore® or similar). The MacroCore® device will be driven to the target depth by the Geoprobe, opened to allow soil to enter the device, and driven across the desired sample interval. A four-foot long soil core, collected from a precise interval, will then be retrieved from the boring. Each boring will be cored continuously from the surface to the total depth of the boring.

4.2 SOIL SAMPLE COLLECTION

During soil sample collection using the Geoprobe® with MacroCore®, 2.5-inch diameter, 4-foot long soil coring device, each soil sample will be collected in a new, disposable, plastic liner tube. Soil core lithology will be described based on visual characteristics, and the core will be screened in the field using a photo-ionization detector (PID).

4.3 GROUNDWATER SAMPLING

Groundwater samples will be obtained through the installation of temporary monitoring wells. Immediately following the completion of borehole advancement a temporary monitoring well will be installed into the open borehole. Temporary monitoring wells will be completed by installing a one-inch (I.D.) PVC screen and riser into the uppermost water-bearing interval. A filter sock will be applied and secured to the screened interval prior to installation into the borehole. 20/40 silica sand will be added around the screen to a depth of approximately two feet above the top of the screen. A two-foot thick bentonite seal will be placed above the sand, and the remaining portion of the open hole will be filled with a high solids bentonite seal, which will prevent surface water from entering the boring. After collection of groundwater samples and hydrogeologic information, temporary monitoring wells will be removed and the open borehole will be pressure sealed to the surface with a cement/bentonite grout.

4.3.1 Well Development

Temporary monitoring wells will be developed by pumping until the discharge from the well is relatively free and clear of suspended sediment.

4.3.2 Groundwater Sample Collection

Prior to collecting a groundwater sample, the temporary monitoring wells may be purged using either *low-flow/low-stress* or traditional volume-based bailer, or similar, techniques. The *low flow/low stress* technique will consist of slowly lowering dedicated tubing connected to a peristaltic pump (or similar device) into a region of adequate permeability within the water-bearing zone. If possible, the suction end of the tubing will be placed at the midpoint of the well screen for sampling. Purging will begin with withdrawal of water at a rate that creates an equilibrium with recharge (e.g., stabilized water table). Equilibrium is dependent upon the stabilization of temperature, pH, specific conductance, turbidity and dissolved oxygen.

As only a thin vertical slice of the water-bearing zone is affected, field parameters typically stabilize immediately and turbidity is quickly reduced. If the yield of each well is insufficient to support the application of the *low flow/low stress*, traditional volume-based purging using either disposable Teflon bailers or a peristaltic pump will be employed. However, the introduction and removal of the bailer will be conducted in a manner to minimize the disturbance to the screened portion of the well. Purging will be continued until at least three (3) volumes of water and/or representative water quality criteria (above-referenced not including turbidity) have been met. The water quality field parameters will be measured with calibrated instruments and recorded in the field book along with the cumulative amount of water evacuated and time of batch parameter testing.

Once field parameters have stabilized (regardless of the purge method), groundwater to be collected for analysis will be sampled simply by collecting water from the discharge stream (tubing or bailer) directly into the Teflon-lined sample containers for subsequent laboratory analysis. In the event that field replicates are collected for Quality Assurance/Quality Control (QA/QC) concerns, field personnel will exercise care in assuring that alternating aliquots are placed in each replicate bottle until each bottle is filled.

Subsequent to sampling, sample containers will be placed and sealed on ice and shipped to the designated offsite laboratory for analysis. Chain-of-custody documentation will accompany all coolers. Personnel involved in sampling will wear clean, disposable gloves, which will be changed between each sample collection. All non-disposable sampling equipment will be decontaminated as outlined in Section 4.5.

4.4 ANALYTICAL METHODS

Groundwater samples will be analyzed by BATCO for volatile organic compounds (VOC) according U.S. EPA SW-846 methodology. Specifically, the samples will be analyzed for VOCs according to Method 8260B.

4.5 DECONTAMINATION

Probe equipment used to collect subsurface soil and groundwater samples (rods and samplers, temporary downhole casings, screens points) and other equipment used in sample collection will be accomplished by the following procedure:

- 1) Phosphate-free detergent wash.
- 2) Potable water rinse.
- 3) Deionized water rinse.
- 4) Isopropanol rinse.
- 5) Organic-free water rinse or air dry.
- 6) Individual tin foil wrap.

For boring activities, separate decontaminated samplers will be used between sample intervals within the same boring, thereby requiring decontamination between boring locations only.

4.6 QA/QC PROCEDURES

To attain Site QA/QC objectives in terms of accuracy, precision, completeness, comparability, and representativeness, QA/QC samples will be collected and sent to the analytical laboratory for analysis. QA/QC samples collected in the field will consist of field duplicates, splits, and equipment rinsate and trip blanks.

Field split samples of groundwater will be collected by alternating groundwater aliquots into an additional container from which the normal sample is collected. Split samples will also be collected in this manner for regulatory oversight and independent laboratory analysis, if required. Split samples are used to evaluate data reproducibility and, during this investigation, will be collected at a frequency of one (1) per ten (10) samples per matrix. Equipment rinsate blanks will be collected at a frequency of one (1) per twenty (20) samples per matrix. Equipment rinsate samples will be collected immediately following sampling equipment decontamination by running deionized water through decontaminated sampling equipment and collecting this water in sample containers. Trip blanks are supplied by the designated laboratory and consist of deionized water in a 40-ml vial. The trip blank will remain in the sample ice chest along with the investigation samples, and will be analyzed for target volatile compounds only.

4.7 DERIVED WASTE MANAGEMENT

Investigative-derived waste (IDW), (e.g., soil cuttings, plastic sampling tubes, decontamination water, well purge water, personal protective equipment, etc.) will be containerized immediately following generation and staged in a readily-accessible area to facilitate subsequent management. Containers generated during investigative activities will be identified and documented in the log book to facilitate subsequent management actions. Best Management Practices (BMPs), as outlined in the EISOPQAM, will be followed to minimize waste volumes and minimize client

liability. These BMPs will be based on review of historical analytical data and qualitative and quantitative field screening results and may allow for onsite spreading of non-impacted soils and/or water. Containerized waste containing constituents of concern will be reviewed for hazardous waste characteristics and transported and disposed of accordingly in an approved landfill within 14 days of receipt of all characterization data. Waste characterization review may include historical data, site sampling data, and applicable Toxicity Characteristic Leaching Procedure (TCLP) testing, if necessary.

4.8 GEOPHYSICAL SURVEY

4.8.1 Electromagnetic Terrain Conductivity

Ground conductivity is a non-intrusive method of measuring lateral variation in the electrical conductivity of subsurface materials. Measurements of electrical conductivity will be made with an EM31 Meter. The device is manufactured by Geonics Limited, of Mississauga, Ontario. The EM31 is simple in form, consisting of a magnetic field transmitting coil, a magnetic field receiving coil, and associated electronics. The coils of the instrument are held co-planar, at a fixed inter-coil spacing of twelve (12) feet. The transmitter coil is energized with an audio frequency alternating current. The resulting primary magnetic field (H_p) induces small electrical currents in the ground. These currents induce secondary magnetic fields (H_s) which, together with the primary field, are sensed by the receiver coil. Electrical conductivities of subsurface materials are deduced from the ratios of secondary to primary fields.

The EM31 is constructed in such a way that the secondary to primary magnetic field ratio (H_s/H_p) is proportional to ground conductivity. The phase of the secondary field lags that of the primary by at least 90° , due to inductive coupling between the transmitter coil and the target conductive material. Additional lag is determined by the properties of the conductor as an electrical circuit. For very poor conductors, the additional lag is close to zero. For very good conductors, it is close to 90° . Generally, the secondary field is somewhere between 90° and 180° out of phase with the primary. That portion of H_s which is only 90° out of phase is called the quadrature component. The EM31 is calibrated to provide quadrature values directly in standard conductivity units of milliSiemens per meter (mS/m). The fraction of H_s which is fully 180° out of phase with H_p is called the inphase component. Inphase values are provided in parts per thousand (ppt) of the primary field.

Both quadrature and inphase values will be simultaneously recorded by an automatic data logger for each survey point in the subject area. Both are influenced by the broad range of subsurface conductivities resulting from minute dissolution of soil particles, inorganic groundwater plumes, fill materials and buried metals. Being generally more sensitive to variations in relatively poor conductors, quadrature readings are used to interpret such features as relative inorganic groundwater concentrations. Being generally more sensitive to good conductors, on the other hand, inphase readings are the primary indicators of subsurface metal. Both quadrature and inphase values will be recorded during this survey.

The secondary field signal received and processed by the EM31 does not represent ground conductivity at a particular depth. Instead, it represents an integration of conductivities through thicknesses of tens of feet. Eighty (80%) percent of the instrument reading, for example, is due to materials lying at depths shallower than about thirty (30) feet. The thirty (30) foot level may be considered an "effective" exploration depth for detection of significant groundwater plumes. The maximum depth for detection of metallics is a function of the type and amount of buried material. Tightly packed accumulations low-grade steel can be found at depths of over 20 feet.

The EM31 will be calibrated according to manufacturer instructions, at the beginning of each survey session. Calibrations will be carried out at a fixed location within the survey area. Both quadrature and inphase values will be recorded. After data collection, the device will be taken back to the calibration point. Quadrature and inphase values will, again, be recorded. The differences in the two data sets will be used to determine and correct for "machine drift".

Additional information regarding the operation of terrain conductivity meters is included in Appendix B.

4.8.2 Magnetic Intensity

Total magnetic field intensity will be measured with a Geometrics, model G858 cesium vapor magnetometer. The device measures total field intensities by detecting a self-oscillating split-beam cesium vapor mechanism. The G-858 will be rigged with one sensor at waist height of the operator. The device has a data logging capability that will be used to record total magnetic field intensity at each survey location. A series of manual readings will also be collected at a fixed location at approximately one-hour intervals. The intensity versus time curves generated from the manual readings will be used to correct the G-858 survey data for diurnal variations of the earth's magnetic field. The data set produced will reflect the anomalous fields produced by buried magnetic material. The effective exploration depth of the device is a function of the amount of underlying metal. A manual summarizing the theory and operation of magnetometers is provided by the manufacturer (Breiner, 1973).

Additional information regarding collection and utility of magnetic intensity methods is included in Appendix C.

4.9 HEALTH AND SAFETY CONSIDERATIONS

Eco-Systems and all subcontractors of Eco-Systems will comply with a site-specific Health and Safety (H&S) Plan to be prepared in accordance with OSHA (29 CFR 1910.120) regulations. All individuals working at the site will have successfully completed an approved 40-hour safety training course and yearly 8-hour refresher courses, as necessary. All individuals working at the site will also receive Hercules' health and safety training for contractors provided at the facility or work under the direct supervision of personnel who have received the training from Hercules.

Prior to performing field activities associated with this Work Plan, all personnel will be required to sign a compliance agreement certifying that they have read, understand, and will abide by all provisions of the H&S Plan.

4.10 OTHER PROCEDURES

Procedures for soil boring and well installation, sample collection, sample containerization and packing, sample shipment, cross-contamination control, drummed material disposal, field documentation, chain-of-custody, data review, and other work items not specifically covered in this document will be conducted in accordance with the EISOPQAM.

5.0 REPORTING

Following receipt of the analytical results, a report documenting the field activities and the analytical results will be prepared. The report will include, at a minimum, the following:

- 1) a summary of investigative approach and field activities conducted,
- 2) field methods and procedures,
- 3) narrative of the investigative results with tabular and graphical presentation of the geochemical and/or geotechnical data,
- 4) iso-concentration maps may be generated for appropriate constituents of concern in groundwater to aid in visualizing the extent of impact,
- 5) analytical laboratory data sheets,
- 6) results of the QA/QC data review,
- 7) a summary of the findings, and
- 8) recommendations for further actions or management measures, if appropriate.

Field logs and construction diagrams will be included in appropriate appendices of the report.

6.0 IMPLEMENTATION SCHEDULE

Field activities will be implemented promptly following approval of this work plan by the MDEQ. Field work is anticipated to be completed within 50 days of project initiation, and the report of the field investigation results is anticipated to be submitted to the MDEQ within 120 days of project initiation following the authorization to proceed.

The schedule assumes that one mobilization for field work will be needed. The report will be prepared following receipt and review of complete laboratory data. The estimated schedule for project activities anticipated to complete this field investigation is shown below.

Activity	Days from Start
Procurement and Initiation of Field Activities	30
Completion of Field Activities	50
Receipt and Review of Laboratory Data	85
Report Preparation and Submittal to MDEQ	120



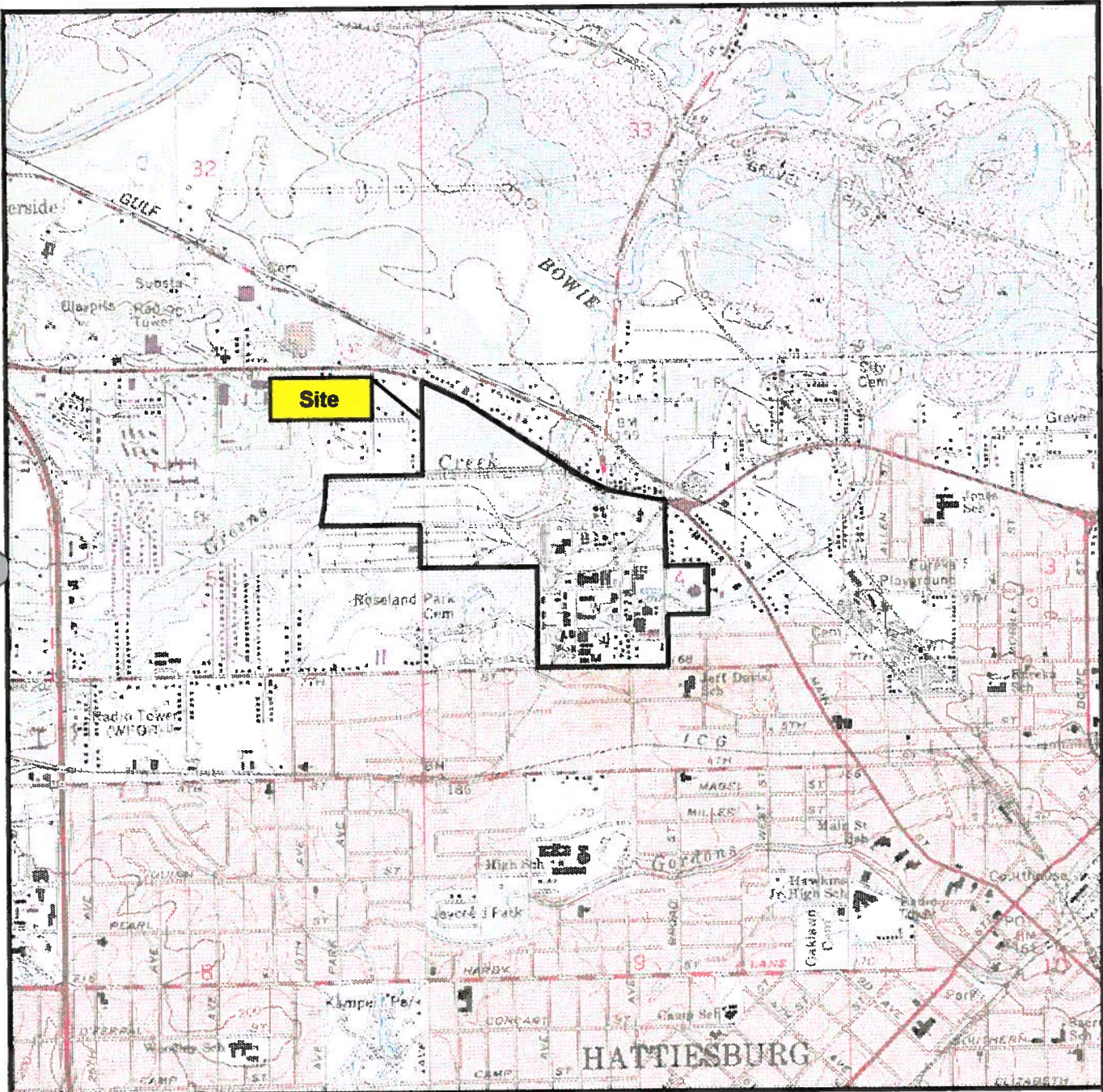
WAVERY

FIGURES

FIGURE 1
SITE LOCATION MAP



**SITE LOCATION MAP
HERCULES, INC.
HATTIESBURG, MS**



Source: Hattiesburg, Miss U.S.G.S. 7.5' Topographic Map

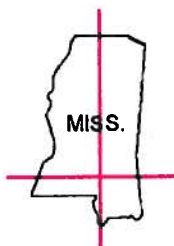


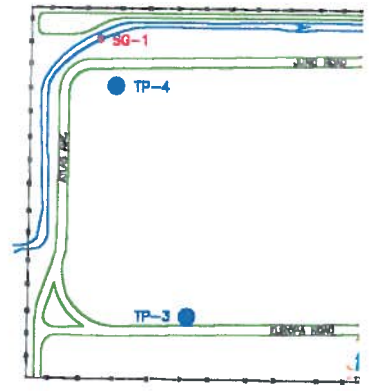
FIGURE 2

SITE PLAN SHOWING DATA POINT LOCATIONS

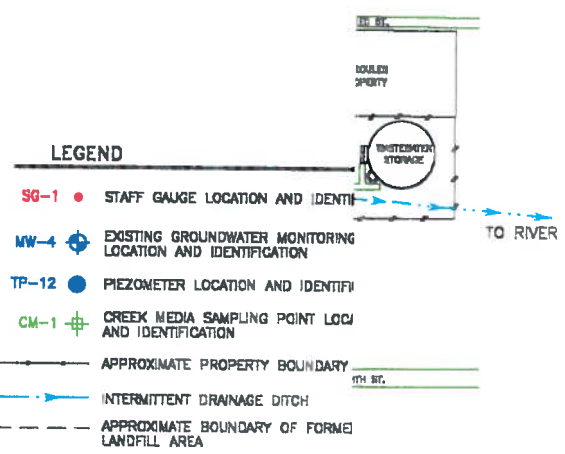


RESIDENTIAL/COMMERCIAL

GF



ZEON CHEMICAL CORPORATION



NOTES
 1. BASE MAP PROVIDED BY HERCULES, INCORPORATED

J:\S. 03\17\03 S:\PROJECTS\HER22173\DWGS\HER22173-DATA.dwg


	SITE PLAN SHOWING DATA POINT LOCATIONS	PROJECT NO. HER22173
	HERCULES CHEMICAL CO. HATTIESBERG, MISSISSIPPI	CAD FILE HER22173-DATA.dwg FIGURE 2

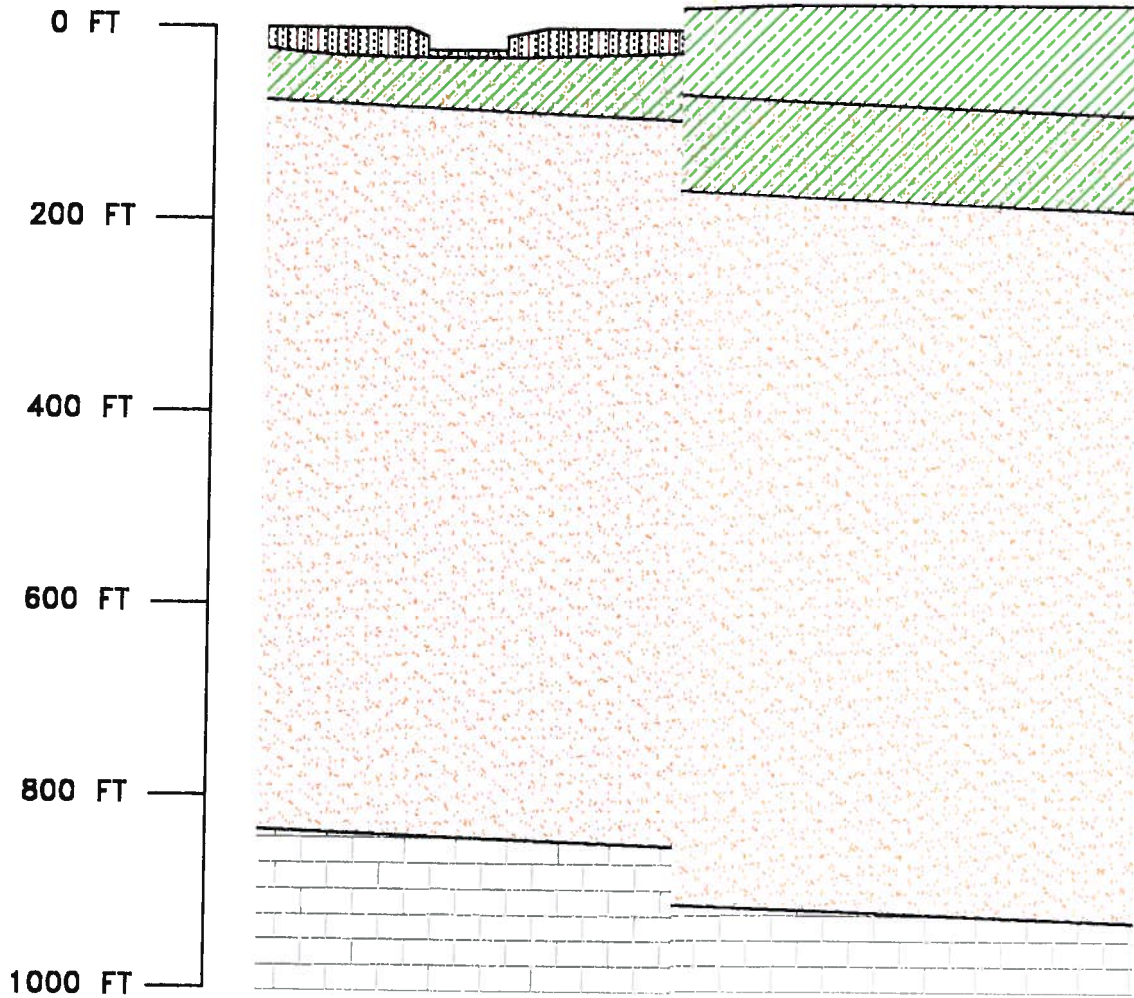
FIGURE 3
CONCEPTUAL REGIONAL CROSS SECTION

NORTH

SOUTH

Bowle River

rdy Street



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HERCULES CHEMICAL CO.
HATTIESBERG, MISSISSIPPI

PROJECT NO.
HER22173
CAD FILE
HER22173-XSECTION.dwg

CONCEPTUAL REGIONAL
GEOLOGIC CROSS SECTION

FIGURE
3

APPENDICES



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APPENDIX A
SITE INSPECTION REPORT

**SITE INSPECTION
REPORT**

Hercules, Inc.
Hattiesburg, Forrest County, Mississippi
EPA ID N° MSD008182081
WasteLAN N° 02297

EPA Work Assignment N° 11
EPA Contract N° 68-W9-0055

Prepared for
WASTE MANAGEMENT DIVISION
U.S. Environmental Protection Agency


Prepared by
B&V Waste Science and Technology Corp
BVWST Project N° 52011.040

April 29, 1993

Prepared by:


Carter Helm
Carter Helm
Site Manager

Reviewed by:


Ron Wilde
Ron Wilde
Technical Reviewer

Approved by:


Hubert Wieland
Hubert Wieland
Project Manager

Executive Summary

The Hercules, Inc. facility is located on West Seventh Street in Hattiesburg, which is situated in the northern portion of Forrest County, Mississippi. Since 1923, this 200 acre facility has manufactured over 250 different products through a chemical operation which involves wood grinding, shredding extraction, fractionation, refining, rosin processing and distillation. A state preliminary assessment was completed in December 1989.

Two source areas were detected on Hercules property: 37.7 acres of contaminated soil and 895,600 cubic feet of surface impoundments. The contaminated soil includes such contaminants as cadmium, cobalt, lead, mercury, toluene, MEK, benzene, PCB's, and acetone. Contaminants present in the surface impoundment include arsenic, heavy metals, toluene, MEK, and benzene.

The Hercules plant is located within the Pine Hills physiographic district of the Coastal Plain physiographic province. Groundwater occurs in the alluvial and terrace deposits as well as the Hattiesburg formation. The nearest private well is located 0.3 miles north of the site. The nearest municipal well is 0.7 miles northwest of the facility. The groundwater pathway is a great concern due to the release of contaminants and the large nearby population which utilizes groundwater.

The surface water pathway is also a concern at Hercules, Inc.. A release of contaminants has been noted within Greens Creek which is attributable to source areas on Hercules property. The presence of endangered or threatened species plus recreational fishing and swimming render this site a concern and threat to populations and environments.

The soil and air pathways are also a concern at the Hercules site. A large population surrounds the facility and many endangered and threatened species are found in close proximity to the site.

Due to releases of contaminants into the environment and the many targets potentially affected, further action should be planned under CERCLA authority for Hercules, Inc.

Site Inspection
Hercules, Inc.
Hattiesburg, Forrest County, Mississippi
EPA ID N° MSD008182081
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Site Inspection
Hercules, Inc.
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1.0 Introduction

Under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA), the U. S. Environmental Protection Agency (EPA), Waste Management Division of Region IV contracted B&V Waste Science and Technology Corp. to perform a site inspection (SI) and geophysical survey at the Hercules, Inc. site in Hattiesburg, Forrest County, Mississippi. The primary purpose of the investigation was to collect data and information regarding potentially hazardous environmental conditions at the site. The investigation included a review of readily available site-specific historical file documentation, collection and chemical analysis of readily identified wastes and potentially impacted media at the site, evaluation of preliminary assessment (PA) hypotheses, preparation of Hazard Ranking System (HRS) factor values and scores, collection of additional information relating to site conditions at the time of the investigation, and interview sources with knowledge related to the site and site activities in the past and present processes.

The objectives of the inspection were to evaluate the presence, of contaminants and to evaluate the potential for adverse impact on the environment. Additionally, the work effort will examine the potential pathways the contaminants could travel and the populations and environs the contaminants could potentially impact. Through these objectives, a recommendation was formulated regarding the necessity for additional work and the disposition of the site.

Background information pertaining to the site was collected from the State of Mississippi Department of Environmental Quality, U. S. EPA files, and Mr. Charles

Jordan, Environmental Supervisor for Hercules, Inc.. Additionally, information relating to the municipal water systems, the number of connections, and distribution patterns were obtained. A potable well survey was performed in the vicinity of the site to estimate the location and lateral distances from the site. The information collected is presented on a detailed map showing the approximate locations of field sampling activities and activities related to the geophysical surveys performed at the facility.

2.0 Site Description

2.1 Site Location

The Hercules, Inc. facility is located on West Seventh Street in Hattiesburg, which is situated in the northern portion of Forrest County, Mississippi. More specifically, the facility is located in Township 4 North, Range 13 West, within Sections 4 and 5 -just north of Hattiesburg, Mississippi (Appendix A). The geographic coordinates of the facility are 31° 20' 20" north latitude and 89° 18' 25" west longitude (Appendix A). Land use in the vicinity of the site is industrial/residential. The site location is detailed in Figure 1.

Climate in the Forrest County area is characterized by long, hot, humid summers because moist tropical air from the Gulf of Mexico persistently covers the area (Ref. 1, p. 1). Winters are cool and fairly short. Occasionally a rare cold wave occurs that dissipates in 1 or 2 days (Ref. 1, p.1). Precipitation is fairly heavy throughout the year (Ref. 1, p. 1). In the winter, the average temperature is 51° F, while during the summer the average temperature is 81° F (Ref. 1, p. 1). The average annual precipitation for the Hattiesburg area is 60 inches, with a mean annual lake pan evaporation of 46 inches, yielding a net annual precipitation of 14.0 inches (Ref. 2, pp. 43, 63). The 2-year, 24 hour rainfall is 5.0 inches (Ref. 3, p. 95). The elevation of Hercules, Inc. is approximately 170 feet above mean sea level (amsl). Estimated elevations within a four-mile radius of the facility range from 120 to 350 feet amsl (Appendix A).



BASE MAP IS A PORTION OF THE USGS 7.5 MINUTE QUAD. OF HATTIESBURG, MISS. 1964.



SITE LOCATION MAP
 HERCULES, INC.
 HATTIESBURG, FORREST COUNTY, MISSISSIPPI

FIGURE
 1

2.2 Site Description

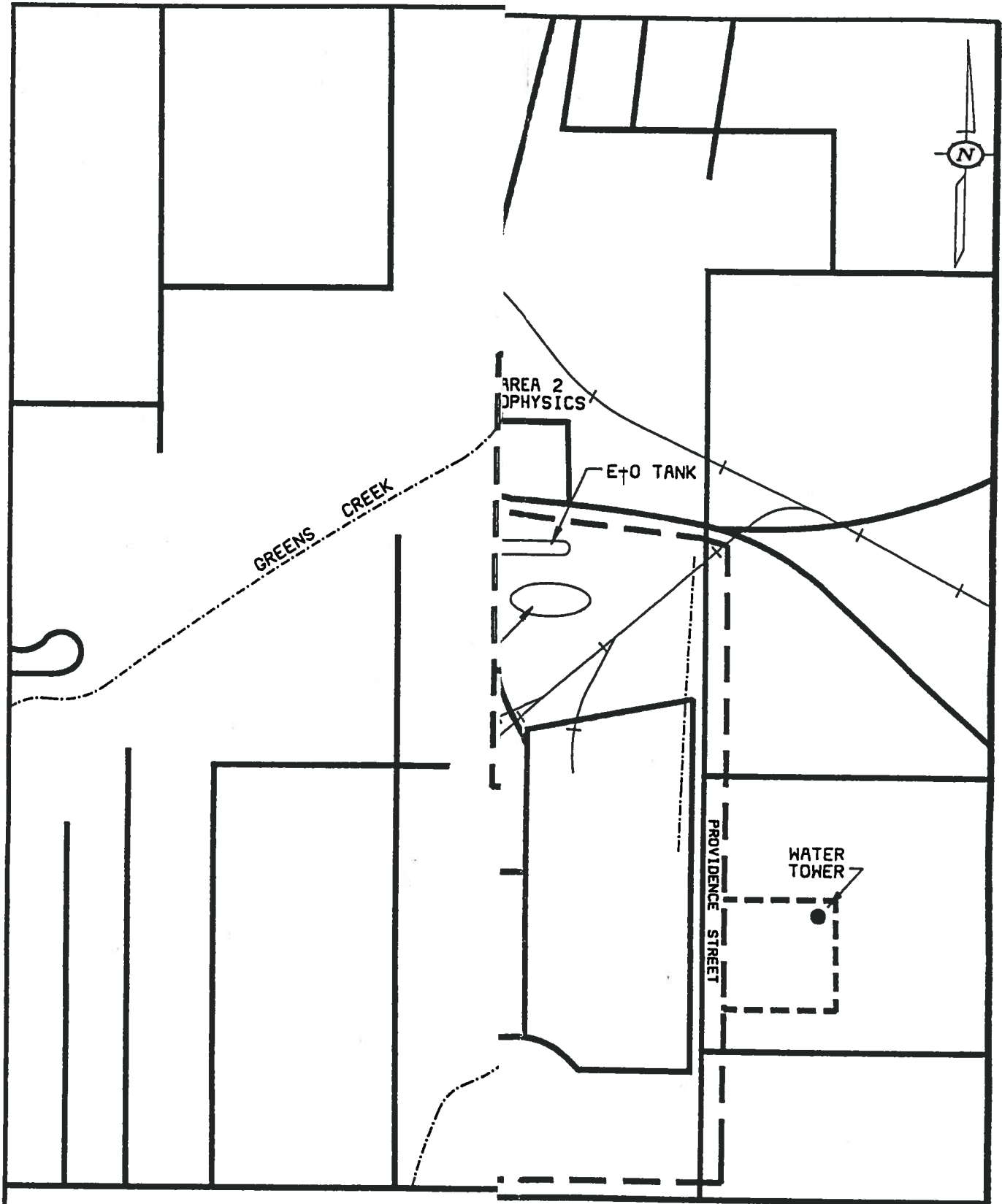
The Hercules facility is approximately 200 acres in size. The facility consists of a complex chemical operation that involves wood grinding, shredding extraction, fractionation, refining, distillation, and processing of rosin from pine tree stumps. Some of the products manufactured at the facility are modified resins, polyamides, ketene dimer, crude tall oil wax emulsions, synthetic rubber, and delnav, an agricultural pesticide (Ref. 4). Over 250 products are produced at the facility. The facility began operations in 1923 and is presently active in production (Ref. 5). Structures at the facility include the offices, laboratories, shops, powerhouses, a wastewater treatment plant, settling ponds, landfills, central loading and packaging facilities, and the railroad (Refs. 4;6).

The entire facility is fenced in and is not accessible to non-employees. This facility is surrounded by residential and industrial areas and the Rose Hill Cemetery (Ref.6, Appendix A). The site location map is shown as Figure 1, and a site layout map is displayed as Figure 2. The Hercules facility as well as specific site components have been documented with photographs and is displayed as Appendix B.

2.3 Operational History and Waste Characteristics

An area located on the north portion of facility property, is referred to as the "back forty," and has been used in the past for disposal of various wastes, including process wastes, boiler ash and waste treatment sludge from plant activities (Refs. 5, 6, 7). The type of disposal of the process wastes has been primarily by landfill, but sludge has also been disposed of in open shallow pits (surface impoundments). The boiler ash has been disposed of by landfill and waste piles (Refs. 6, 7, 8).

In 1980, pursuant to RCRA, Hercules filed notification for on-site generation, treatment and storage of spent sulfuric acid from a rosin polymerization operation (Refs. 8, 9). In 1983, the Mississippi Bureau of Pollution Control (BPC) determined that the spent sulfuric acid was exempt from the RCRA hazardous waste regulations, because it was being reused in the wastewater treatment system for elementary neutralization (Ref. 10). As a result of the determination, interim status for storage and treatment of the spent sulfuric acid in tanks and in a surface impoundment was



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SITE MISSISSIPPI

FIGURE 2

withdrawn and Hercules reverted to the status of an occasional generator (Ref. 10). The wastewater treatment system treats contaminated water from all sources throughout the plant. Hercules currently has a NPDES permit for discharge of the treated wastewater in the Bowie River (Ref. 11).

Prior to 1980, in response to a congressional subcommittee request for information from major chemical companies concerning waste disposal, Hercules voluntarily completed a survey form in which they identified disposal of various wastes from their process operations in a landfill on site. The landfill was referred to as the "back forty" landfill. This voluntary survey form later served as notification under the CERCLA program for on-site disposal of potentially hazardous substances. This landfill is not regulated under the RCRA program (Ref. 7, 8, 9).

3.0 Field Investigation

3.1 Geophysical Investigation

According to file material obtained through the U.S. EPA, Region IV, and the Mississippi Department of Environmental Quality, Hercules, Inc., landfilled, land applied and buried in pits: drums, sludge, boiler ash, and other process wastes in an area referred to as the "back forty" as well as a landfill area south of the back forty for an unknown period of time (Refs. 6, 7). Therefore, a surface geophysical survey program was developed to evaluate areas of specific concern within the northern portion of site property. The use of these instruments was intended to aid in the selection of sampling locations. Realizing the limitations of the methods and the equipment used, this activity was performed as a screening method. It should be understood that data gained from these surveys indicate a response of magnetic correlative change within the surficial soils, which may be attributable to subsurface burial or naturally occurring lithologic conditions. Information containing a detailed explanation and applications of these methods is contained in Appendix C.

The scope of surface geophysical surveys include the following activities:

- Conduct an electromagnetic (EM) survey in the "back forty" portion of the facility (evaluate subsurface conductivity).
- Conduct a regional magnetic (MAG) survey within the limits the facility boundaries (evaluate the earth's magnetic field intensity).
- Generate the following maps for each surveyed area:
 - Geophysical Base Map
 - Conductivity Contour Map
 - Conductivity Surface Anomaly Map
 - Magnetic Intensity Contour Map
 - Magnetic Intensity Surface Anomaly Map

3.1.1 Geophysical Survey Methodology

The two geophysical instruments used in the subsurface study were a ground proton precession magnetometer (Geonics-856) and an electromagnetic non-contacting ground conductivity meter (EM-31). At the beginning of field activities fresh batteries were installed and both instruments were put through their respective calibration and pre-operational procedures according to the manufacturers' specifications. Details of the calibration responses for both instruments are contained within the field logbook (Ref. 6).

A background base station was established in the far northwest corner of facility property, where undisturbed field conditions were believed to be present (Ref. 6). The base station locations were marked with wooden stakes, and measurements were taken with both instruments at the stations prior to the surveys and upon completion of the surveys. Field conditions at each area of concern and base station instrument readings were recorded in the Hercules BVWST logbook (Ref. 6). The field measurements collected from the actual grid locations were recorded on EM or MAG data sheets which are considered to be an extension of the BVWST logbook (Ref. 6).

At the background base station, five positions were established. A center position with four locations radiating outward and terminating 10 feet from the center positioned in the north, east, south, and west directions. At each position of the base station, three readings were collected with the magnetometer and the EM-31, respectively. The average background magnetic intensity response at the onset of magnetometer readings was 50,835.2 nanotesla. At the end of the day, the same background location readings indicated an average response of 50,838.9 nanotesla (Ref. 6). The 3.7 nanotesla variation is typical of ambient diurnal fluctuations, and indicates stable magnetic field conditions for the time interval during which the other magnetic field measurements were collected (Appendix C).

The electromagnetic non-contacting ground conductivity meter (EM-31) was used in one of its two operative modes, the "comp" mode also known as the in-phase component mode. The in-phase component mode is used to evaluate metal detection. Background values documented for the EM in comp mode registered between 38 to 42 mmhos/meter (Ref. 6). All EM readings were collected with two orientations at each station location: north-south and east-west.

Two areas on the Hercules site were selected to further evaluate subsurface conditions with surface geophysical methods. The two areas are detailed on Figure 2. As noted on Figure 2, the areas have been designated as "Area 1 Geophysics" and "Area 2 Geophysics." Area 1 is located within the north back forty, approximately 200 feet northwest of the sludge pits (Ref. 6, Figure 2). Area 1 measures 700 square feet, contains 10 foot intervals, and is situated approximately 150 feet east of the Moose Lodge (Ref. 6). The north-south baseline extends 70 feet and the west-east baseline measures 100 feet (Ref. 6). Refer to Figure 3 for the Geophysical Base Map for Area 1. A cartesian coordinate-oriented grid was laid out in both areas, using a Brunton compass and a right angle prism in addition to surveying techniques (stadia & levels). In Area 2, north-south and east-west oriented survey lines were spaced at 25 foot intervals. The north-south baseline extended 150 feet, while the east-west baseline was 250 feet, resulting in a total area of 37,500 square feet (Ref. 6). Figure 4 illustrates the Geophysical Base Map for Area 2.

The X (north) and Y (east) axes (baselines) were marked by wooded stakes in both areas. The other station locations within the coordinate system were marked by

labelled wire flags. The grids for both Areas 1 and 2 were tied into fixed points at each area of concern to ensure replication.

3.1.2 Geophysical Survey Results

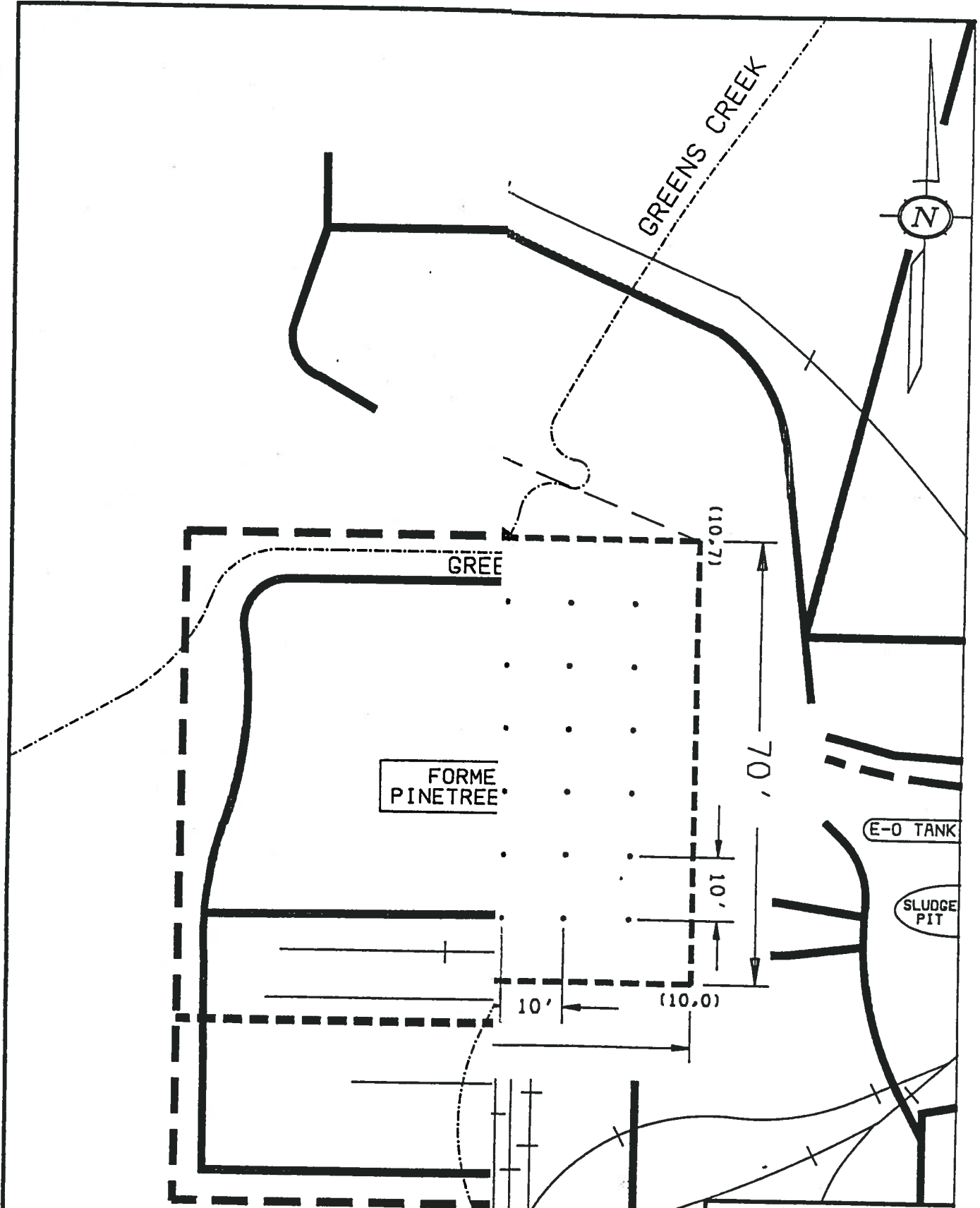
3.1.2.1 The Magnetic Field Intensity Survey. A Geonics-856 proton precession magnetometer was utilized to check and record the intensity of the earth's magnetic field at all station locations. Variations (anomalies) may be caused by the natural distribution of iron oxides or by the presence of buried iron or steel objects. The G-856 was calibrated and put through pre-operational checks according to manufacturer's recommendations. Magnetic intensity contour and anomaly maps were generated using Golden Graphics Surfer Software.

3.1.2.2 The In-phase Conductivity Survey. An electromagnetic (EM) non-contacting ground conductivity meter, the EM-31 was utilized to check and record subsurface conductivity measurements at each station location. The EM-31 was calibrated and put through pre-operational checks according to manufacturer recommendations.

Electrical conductivity is a function of soil type, rock type, porosity, and permeability. Metal objects and landfilled or buried materials with significant metallic properties may cause variations in subsurface conductivity and create "anomalies" or differences in background conditions.

Conductivity contour and anomaly maps were generated using Surfer Software (version 3.0).

3.1.2.3 Geophysical Results. The geophysical results from Area 1 using the Geonics-856 magnetometer depicts two distinctive anomalies. This area contains no surficial interference (Ref. 6). The area of interest extends from $X = 4$ to $X = 8$ and $Y = 1$ to $Y = 5$. Figure 5 is the contour map of magnetic intensities for Area 1. The two focal points are (6,4) and (6, 2). This area of interest measures 40 feet by 40 feet and is located beneath immature forest growth. Indications of subsurface geophysical anomalies, possibly buried metals are observable on the contour map (Figure 5) as closed contours (both hatchured and non-hatchured). Two hundred

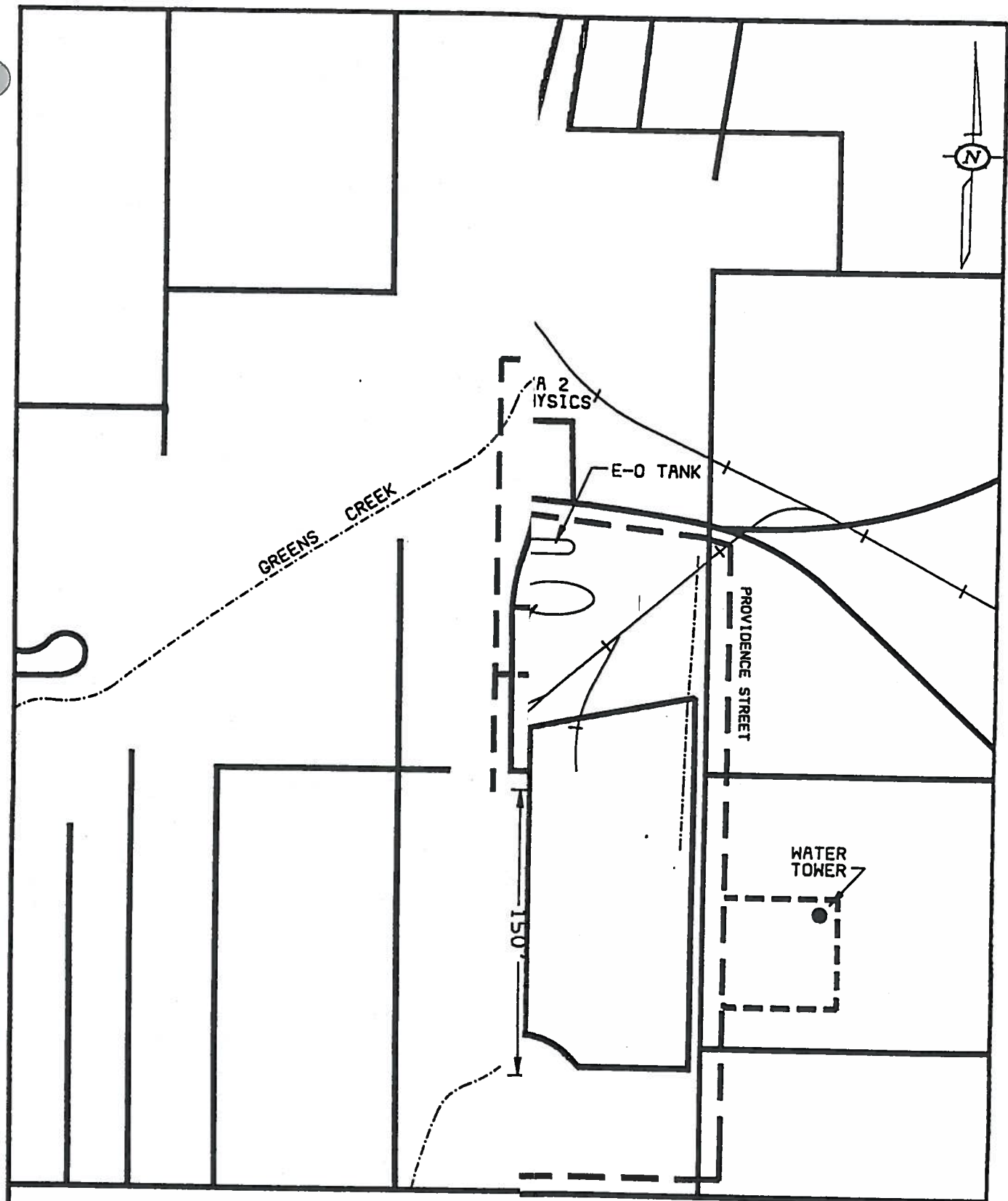


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GEORGETOWN, MISSISSIPPI

FIGURE 3



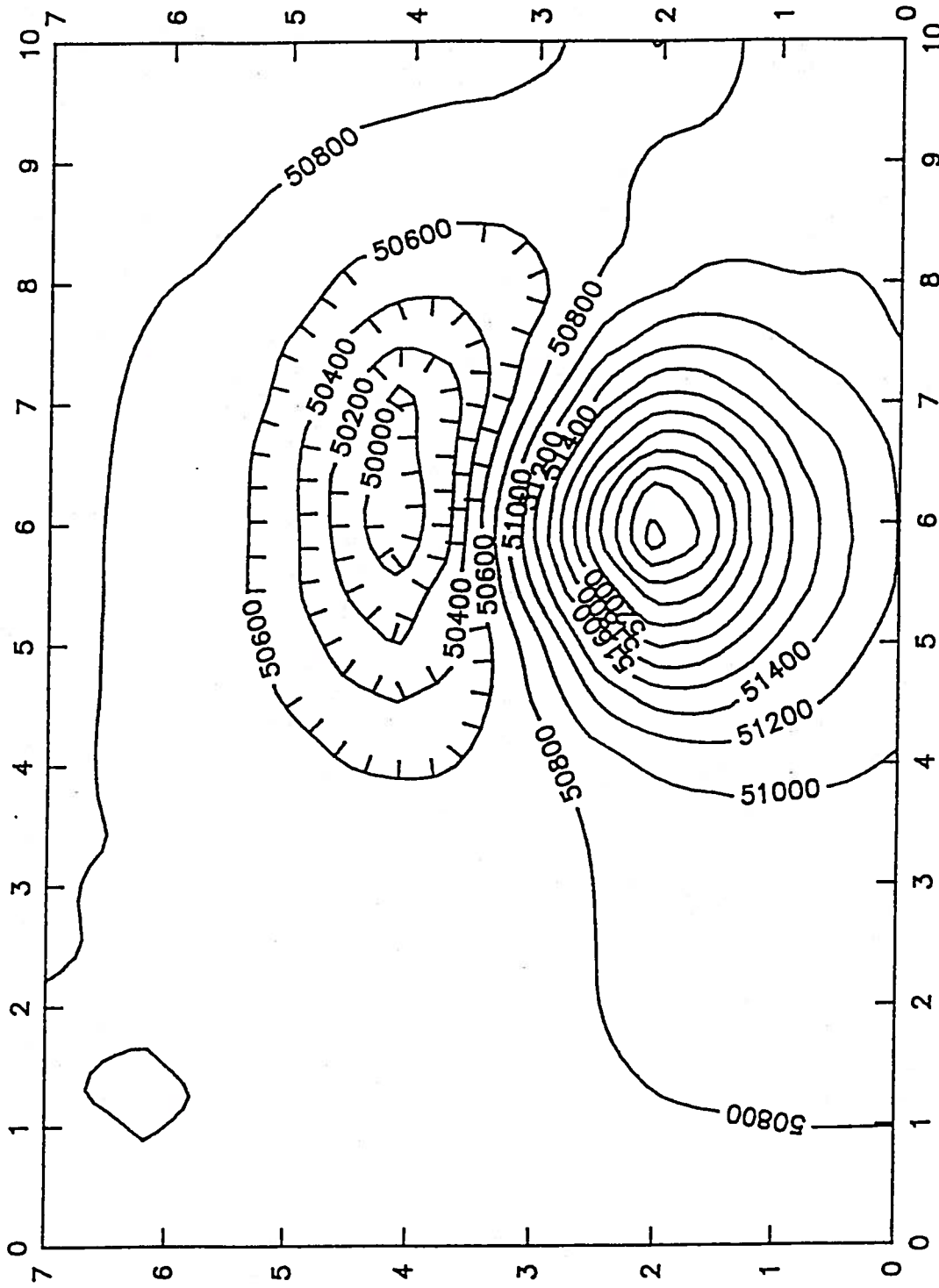
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GEOPHISPI

FIGURE 4

AREA 1 MAGNETIC INTENSITY CONTOUR MAP (NANOTESLA)



nanotesla contour line intervals are used in Figure 5. Measurements that differ from background magnetic intensities are considered anomalous and are indicated as closed contours. Magnetic readings that exceed background levels are shown with non-hatched contour lines ("peaks"), while measurements that fall below background intensities are similarly suspicious or anomalous and are indicated with hatched contouring ("valleys").

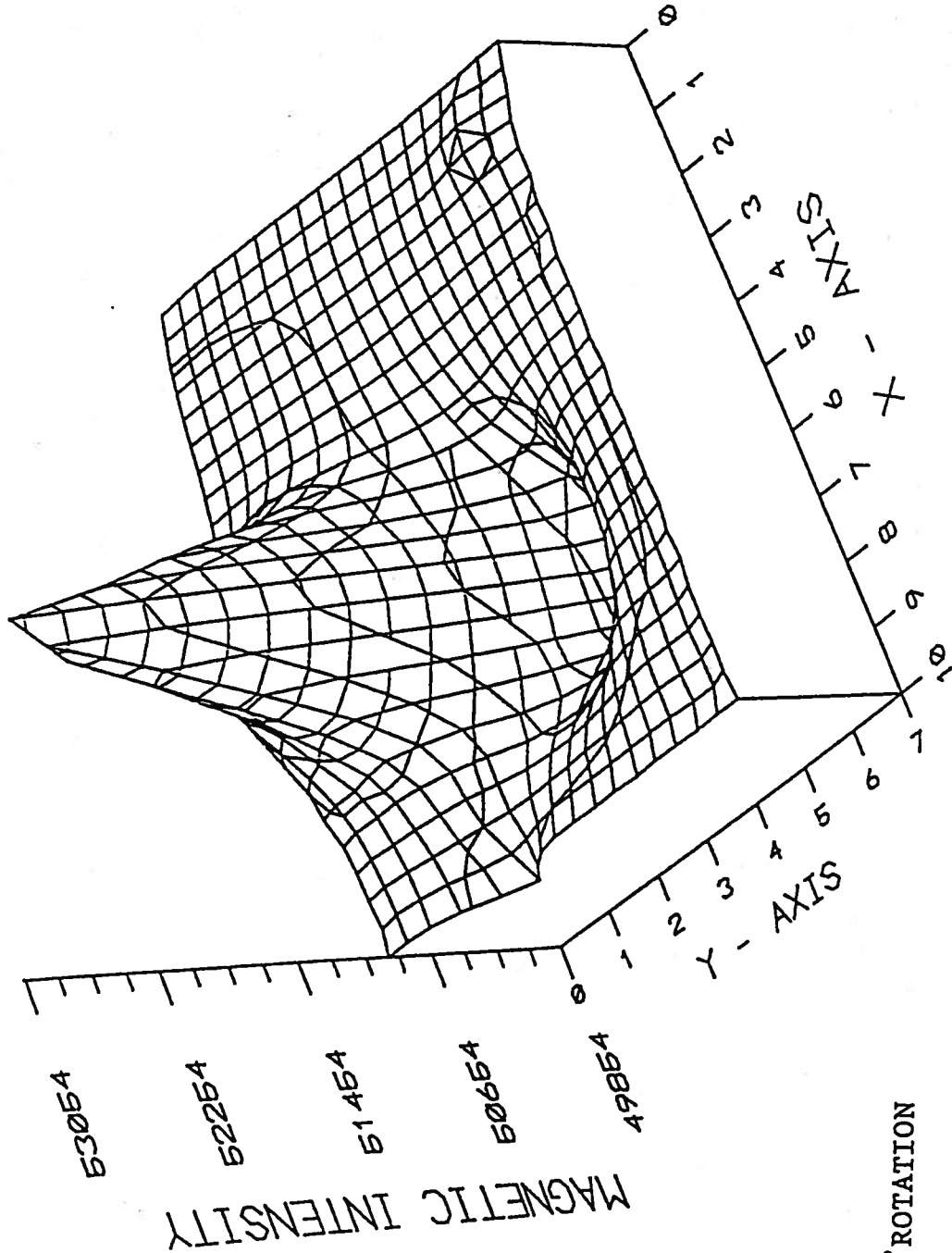
The highest magnetic intensity reading occurs at station (6, 2) and measures 53,387 nanotesla (Ref. 6). The lowest magnetic intensity reading occurs at station (6, 4) and measures 49,720 nanotesla (Ref. 6).

A surface map (3-dimensional) of isomagnetic intensities occurring in geophysical area 1 is included as Figure 6. The graphical representation of Area 1 on Figure 6 is rotated 180° to aid the viewer in seeing the anomalous "valley" surrounding station (6,4). An extreme "high" or "mountain" anomalous area occurs near station (6,2) on Figure 6.

Results from the EM-31 non-contacting terrain conductivity meter in the "comp" or "in-phase" mode yields data that show three anomalous areas in Area 1. Figure 7, a subsurface conductivity contour map, shows two high anomalies and one low anomaly. The contour interval for Figure 7 is 5 mmhos/meter. The subsurface conductivity surface map (3-dimensional), Figure 8, has not been rotated since the anomalous "valleys" are close to the origin (0,0) and therefore easily viewed by the reader. An extremely high ground conductivity reading of 115 mmhos/m was observed at station (7,7). The lowest conductivity reading (0 mmhos/m) occurred at stations: (6,2), (7,3), (6,3), and (6,4). This area of low anomalies form a triangle of concern centered around station (6,3) within geophysical Area 1.

Geophysical Area 2 indicates magnetic intensity anomalies in the northwest quadrant of the large study area as Figure 9 illustrates. The area of interest extends from $X = 0$ to $X = 4$ and $Y = 2$ to $Y = 6$ (Figure 9). Figure 9 is the contour map of magnetic intensities for Area 2. Contour line intervals measure 2000 nanotesla. Two focal points that occur are at stations (1,3) and (3,6). The northwest corner of the Area 2 grid is an area of interest which measures 100 feet by 100 feet or 10,000 square feet.

AREA 1 ISOMAGNETIC SURFACE MAP (NANOTESLA)



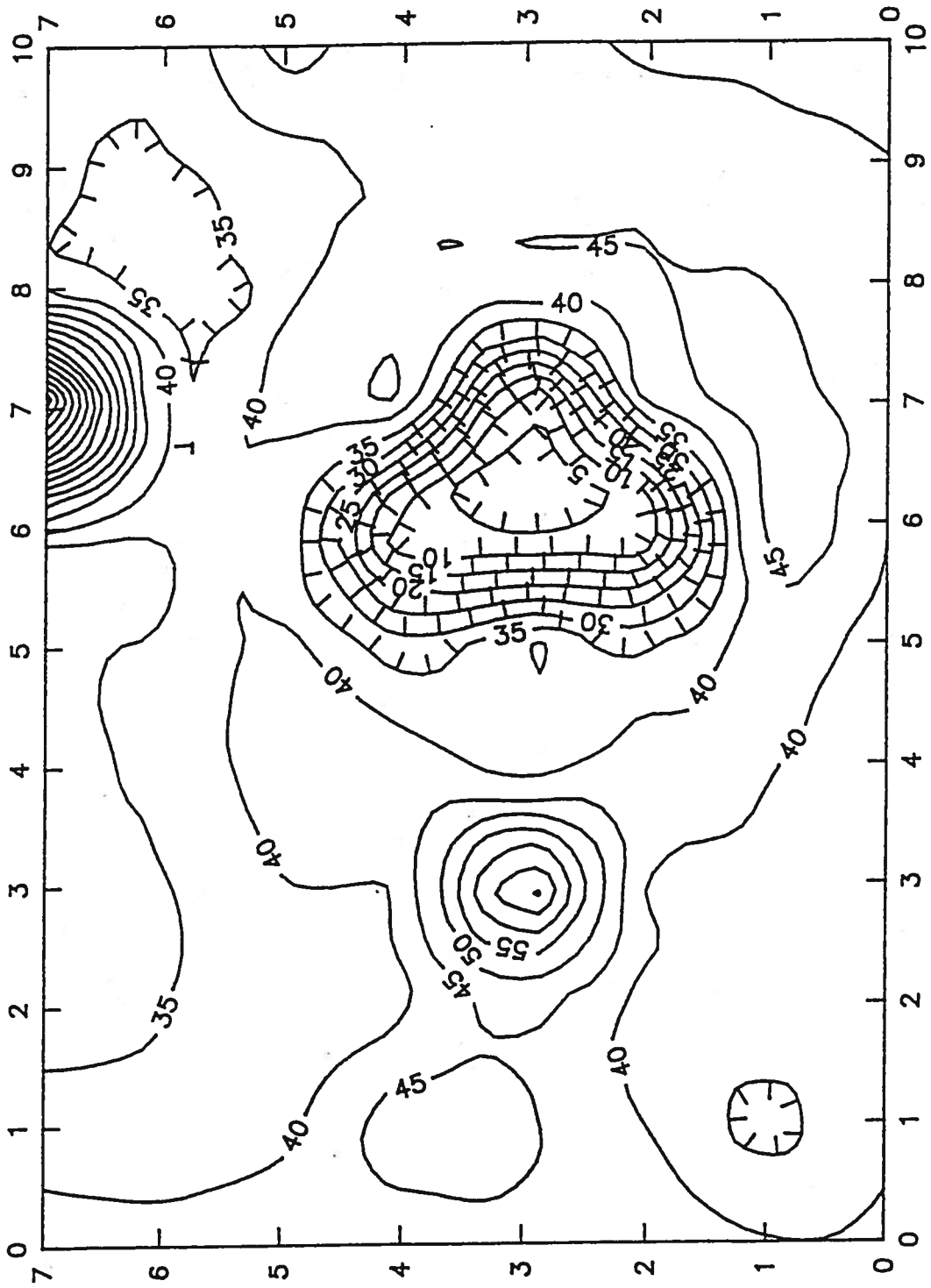
NOTE: 180° ROTATION



HATTIESBURG, FORREST COUNTY, MISSISSIPPI
HERCULES, INC.

FIGURE 6

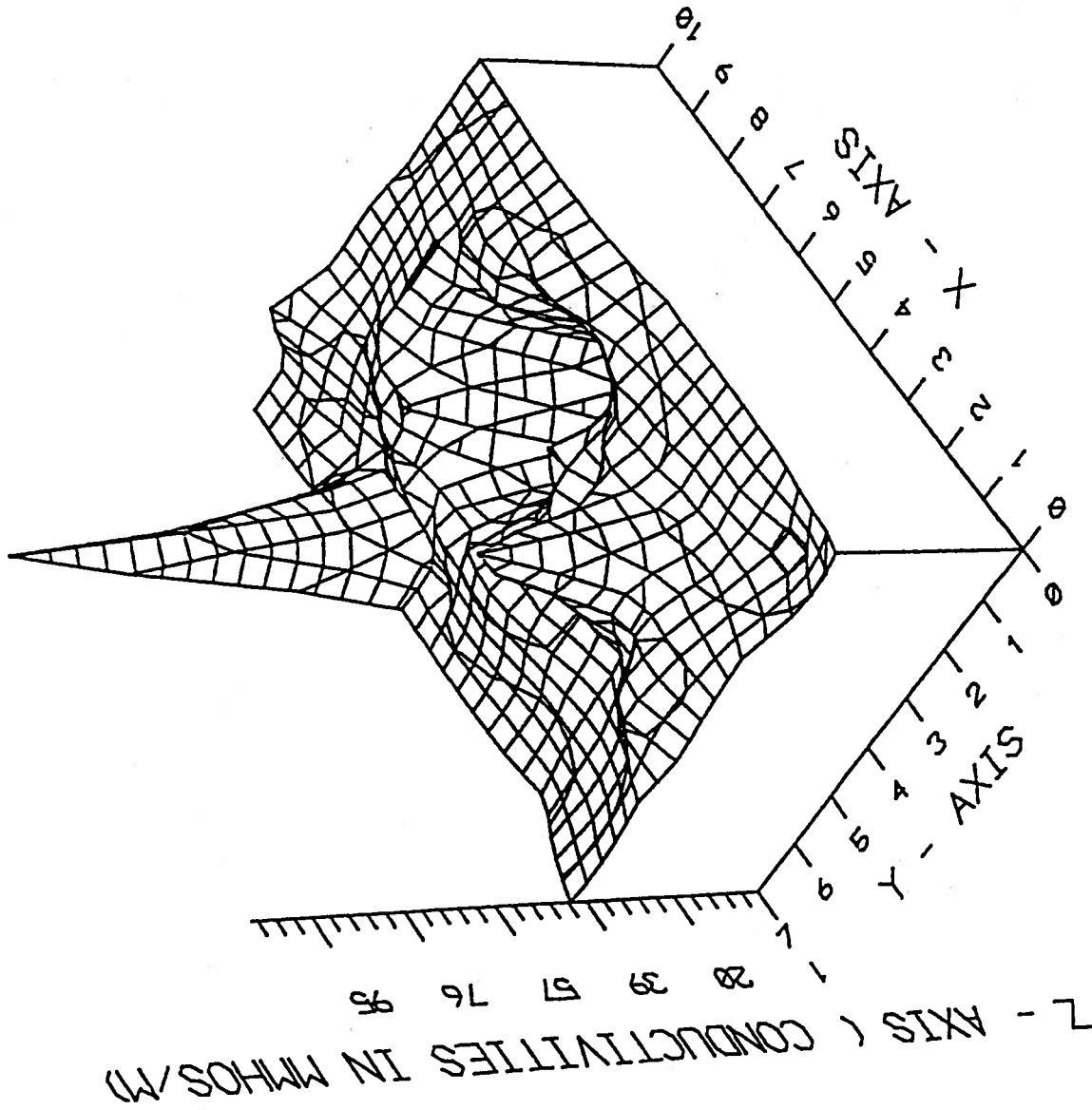
AREA 1 SUBSURFACE CONDUCTIVITY CONTOUR MAP MMHOS/M



HATTIESBURG, FORREST COUNTY, MISSISSIPPI

FIGURE 7

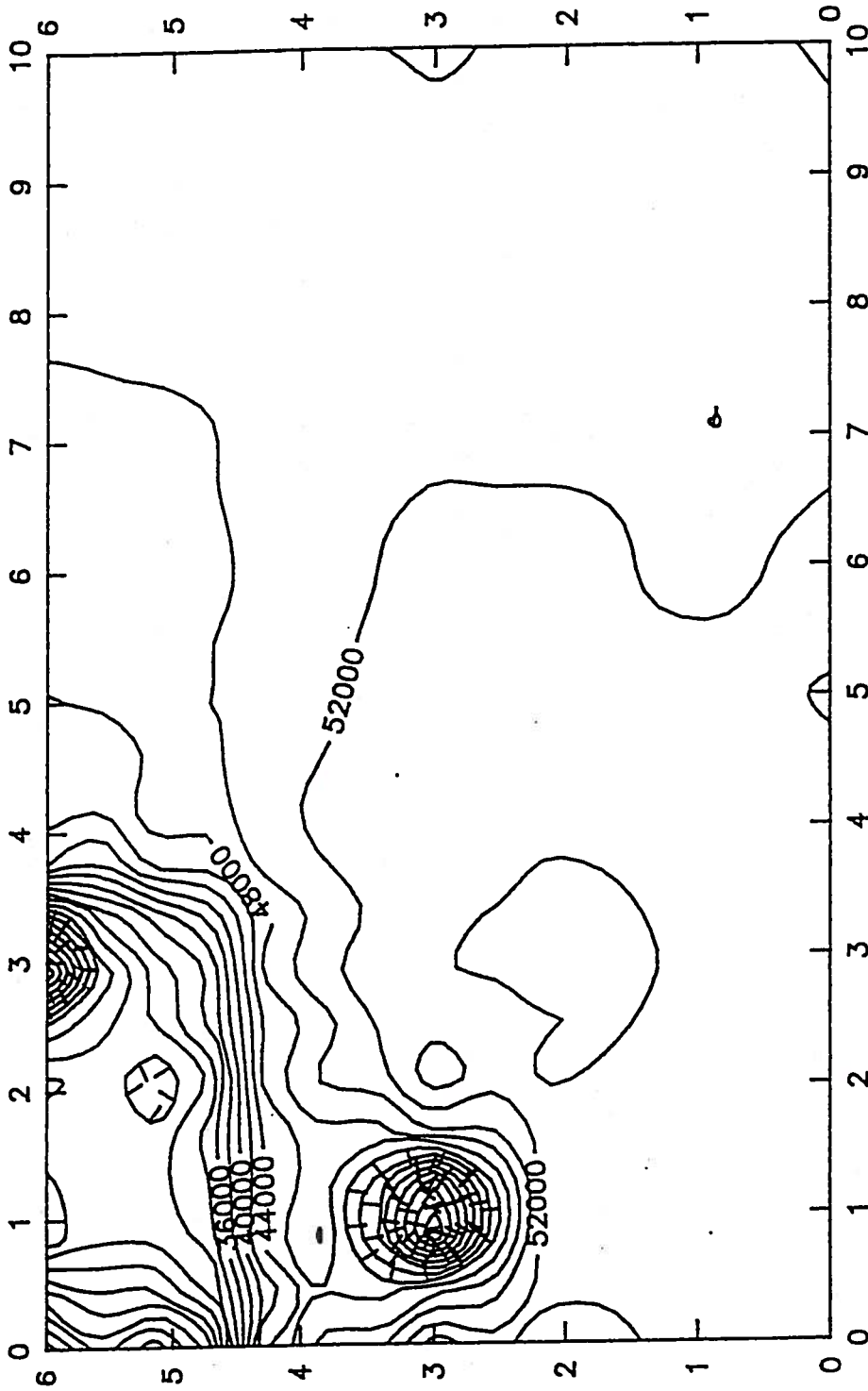
AREA 1 PLOT OF SUBSURFACE CONDUCTIVITIES



HATTIESBURG, FORREST COUNTY, MISSISSIPPI
HERCULES, INC.

FIGURE 8

AREA 2 MAGNETIC INTENSITY MAP (NANOTESLA)



The lowest magnetic intensity occurs at station (3,6) and measures 11,539 nanotesla (Ref. 6). Another interesting anomaly occurs at station (1,3) and measures 23,606 nanotesla. In Figure 10, it becomes evident that the low magnetic intensity readings of the northwest quadrant becomes significant or anomalous whereas the anomalous highs seem to be normal background conditions (Ref. 6). Figures 9 and 10 exemplify the low, anomalous magnetic reading characterizing Area 2. Figure 10 is the isomagnetic surface map (3-dimensional) which has been rotated 90° to help distinguish these anomalous "valleys."

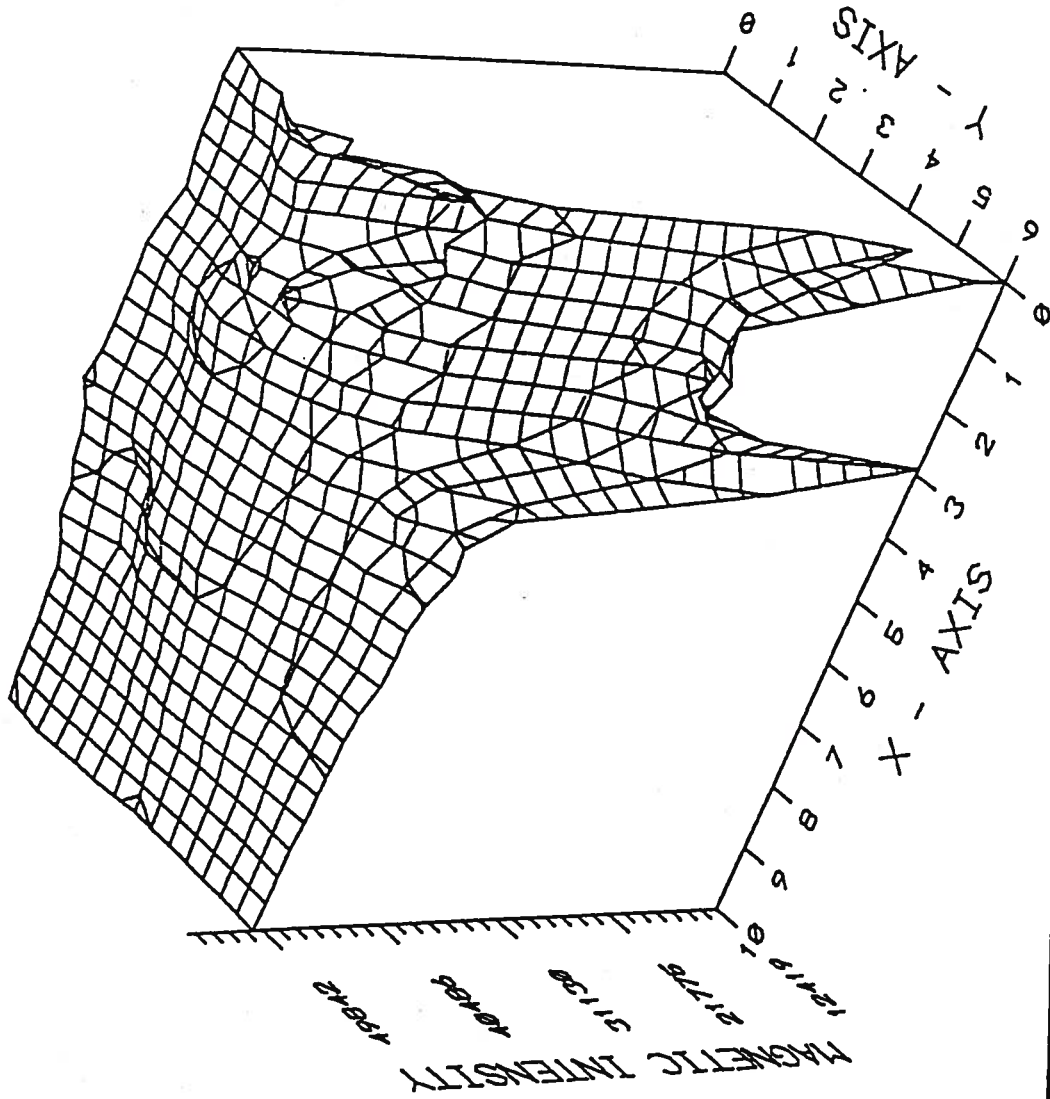
Results from the EM-31 conductivity meter, in the "comp" (in-phase) mode yields data which illustrates a low of 0 mmhos/m at station (1,4) and a conductive high of 210 mmhos/m at station (3,4) (Ref. 6). Figure 11 is the subsurface conductivity contour map for Area 2. The contour interval is 10 mmhos/m. Figure 12 is a 3rd dimensional reflection of conductivities at Area 2 are shown on Figure 12. No rotation was necessary in Figure 12.

3.1.3 Geophysical Conclusions

Both the magnetic intensity survey (Figure 5) and the in-phase conductivity survey (Figure 7) outline the same area of interest in Area 1. this area is centered around the following station locations: (6,2) and (6,4). The magnetic intensity maps (Figures 5 and 6) do not indicate any other area of anomalous readings. The conductivity maps (Figures 7 and 8) do, however, show other potential areas of subsurface inconsistencies, particularly near stations (3,3) and (7,7). After evaluating all geophysical data for Area 1, the most anomalous area is determined to be between station coordinates (6,2) and (6,4). Natural subsurface conditions do not appear to exist in this area. Subsequently, soil and groundwater samples (HI-SS-05, HI-SB-05, and HI-TW-05) were collected between those two station locations.

Area 2 as depicted by Figures 9 through 12 also illustrates a common area of anomalous readings, i.e., the northwestern quadrant of the grid. Of particular interest are the station locations (1,3) and (1,4). In fact, there is a 54 percent difference in station (1,3) magnetic intensity readings compared to background magnetic intensity readings. Conductivity readings at station (1,4) differ greatly from background readings (a span of 40 mmhos/meter).

AREA 2 ISOMAGNETIC SURFACE MAP (NANOTESLA)



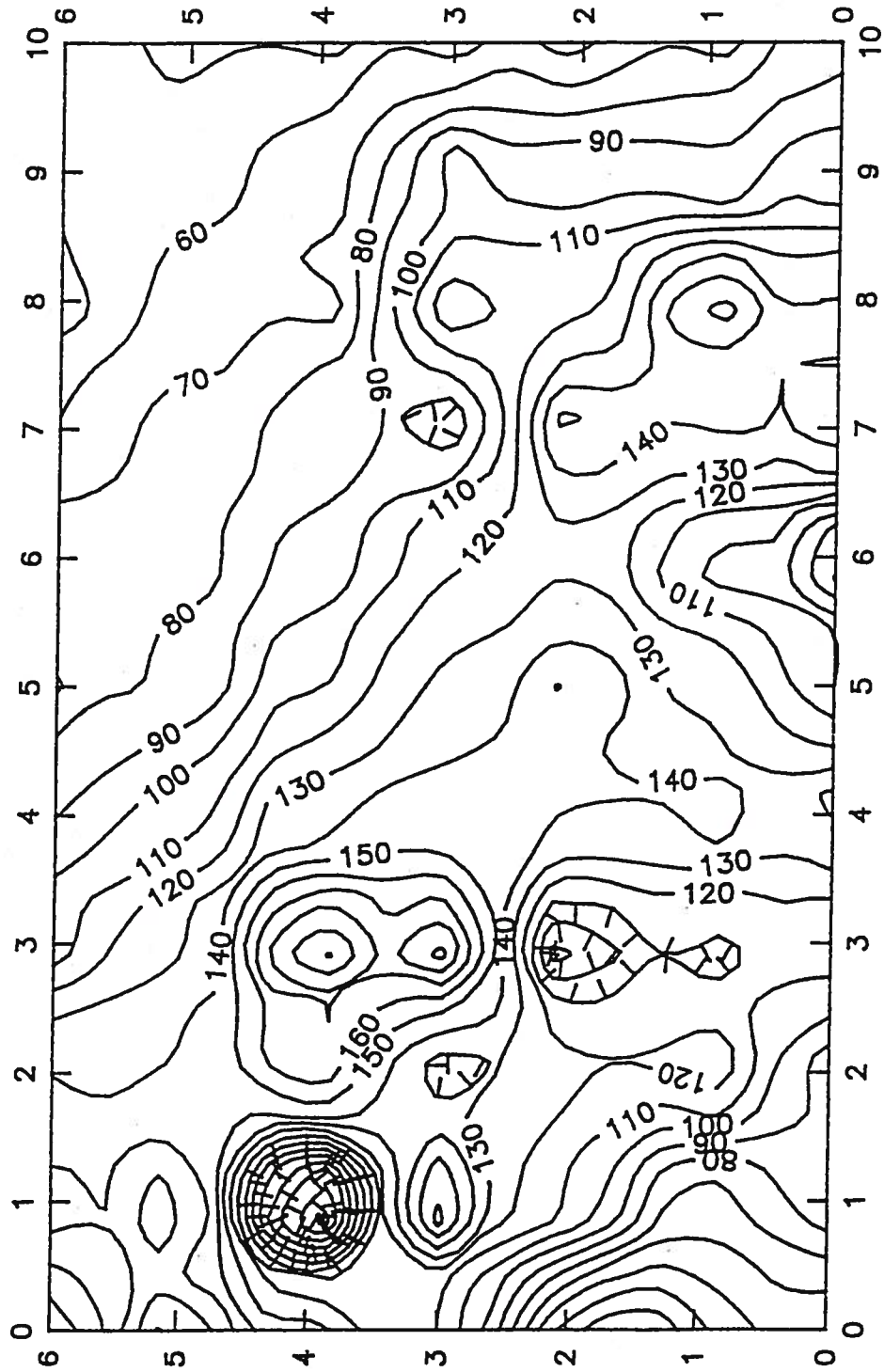
NOTE: 90° ROTATION



HATTIESBURG, FORREST COUNTY, MISSISSIPPI
HERCULES, INC.

FIGURE 10

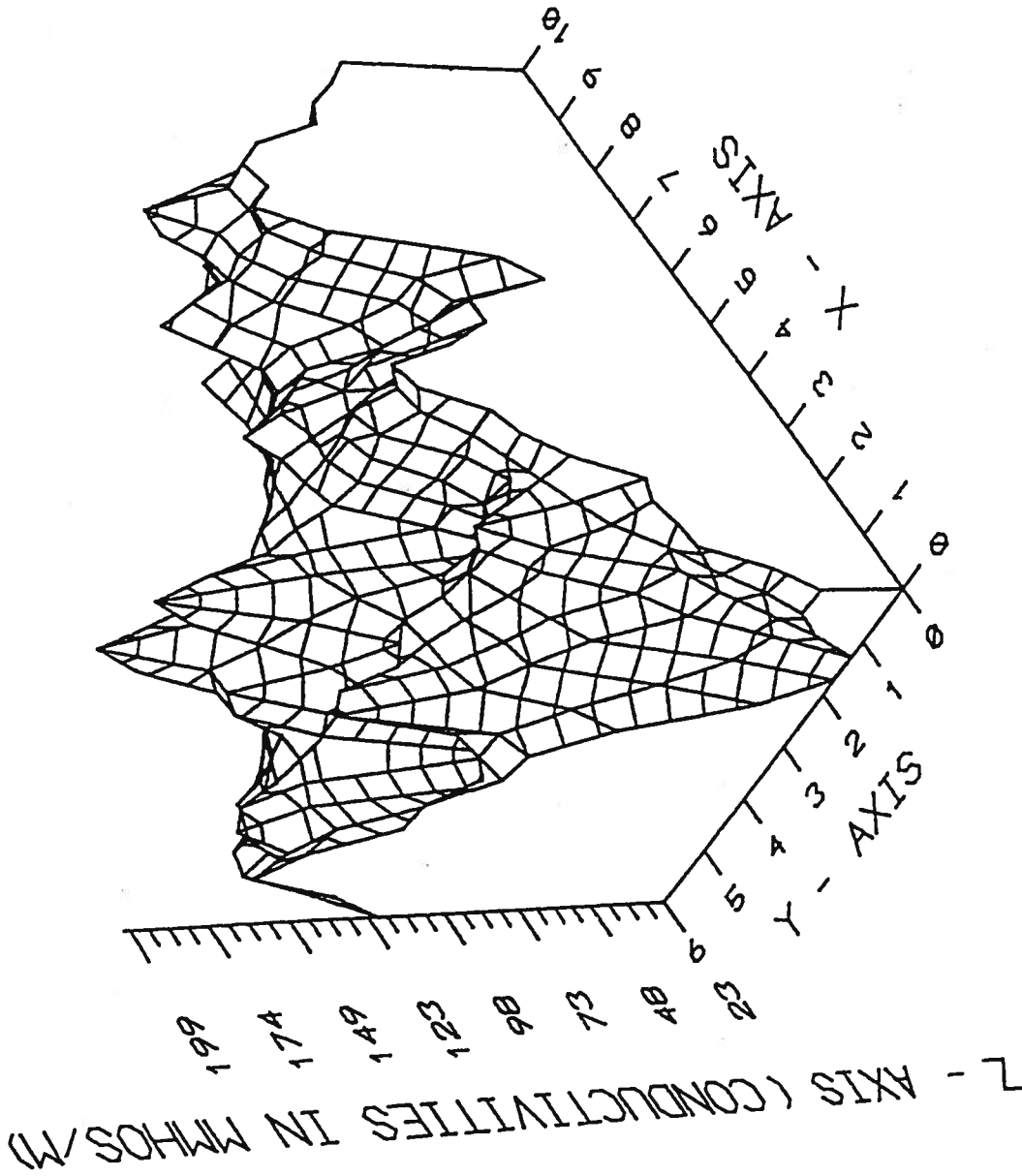
AREA 2 SUBSURFACE CONDUCTIVITY CONTOUR MAP MMHOS/M



HATTIESBURG, FORREST COUNTY, MISSISSIPPI

FIGURE 11

AREA 2 PLOT OF SUBSURFACE CONDUCTIVITIES



HATTIESBURG, FORREST COUNTY, MISSISSIPPI

Subsurface conductivity values show their greatest variation in the western third of the grid area.

After careful consideration, the BVWST geophysical team had determined that soil sampling between station locations (1,3) and (1,4) would best characterize Area 2. Subsequently, sample HI-SS-04 was collected from this area.

3.2 Sample Collection

During the field investigation, conducted during the weeks of June 22 and August 17, 1992, B&V Waste Science and Technology Corp. attempted to identify and characterize contaminants which may be present in the environment as a result of activities that were conducted at the Hercules site. To accomplish this, BVWST collected environmental sediment, surface water, surface soil, subsurface soil, and groundwater samples from a number of strategic locations. These locations were selected based on historical information, hydrological data for the region and site area, and direct observation at the site.

3.2.1 Sample Collection Methodology

All sample collection, sample preservation, and chain-of-custody procedures used during this inspection were in accordance with the standard operating procedures as specified in Sections 3 and 4 of the Environmental Compliance Branch's Standard Operating Procedures and Quality Assurance Manual, United States Environmental Protection Agency, Region IV, Environmental Services Division, February 1, 1991, and with the Field Study Plan prepared by BVWST on June 12, 1992. Deviations from the study plan include the following:

- Only two of the 6 proposed temporary wells were installed. Auger refusal occurred due to metal debris and/or numerous roots encountered.
- Only one of the two on-site monitoring wells was sampled. The integrity of the second well was questioned by the sampling crew due to a well obstruction and no locking cap.



REVERA

APPENDIX B
TERRAIN CONDUCTIVITY METHODS

Peterson

TWO PAPERS ON ELECTROMAGNETIC SURVEYING

**ELECTROMAGNETIC RESISTIVITY MAPPING
OF CONTAMINANT PLUMES**

J.D. McNeill,
Geonics Limited

And

**USE OF NDT METHODS TO DETECT
BURIED CONTAINERS IN SATURATED
SILTY CLAY SOIL**

Robert M. Koerner, et al
Drexel University

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on Management of Uncontrolled Hazardous Waste Sites
may be obtained from HMCRI, 9300 Columbia Blvd.,
Silver Spring, MD 20910

ELECTROMAGNETIC RESISTIVITY MAPPING OF CONTAMINANT PLUMES

J.D. McNEILL
Geonics Limited
Toronto, Ontario

FACTORS AFFECTING SOIL RESISTIVITY

The electrical resistivity of a soil is a measure of the relative difficulty encountered in causing an electrical current to flow in it; the more resistive the soil, the smaller the current flow for a given voltage. Surprisingly, most physical constituents of a soil are electrical insulators of such high resistivity that no appreciable current flows through them. What does allow significant current to flow is the relatively conductive soil moisture; it is this parameter which often controls the soil bulk resistivity.

An electrical model of soil where it is considered to consist of a large number of insulating particles immersed in a conductive fluid is shown in Fig. 1. The mixture resistivity should be affected both by the resistivity of the conductive soil moisture and also by the fact that the insulating particles act to impede the current flow. Empirically it has been established that Archie's Law often gives the correct behavior of soil resistivity:^{1,2}

$$\rho_{\text{sample}} = \rho_{\text{moisture}} \times \frac{1}{(\text{soil porosity})^3} \quad (1)$$

and, as expected, there is a linear relationship between soil resistivity and the resistivity of the included water. Now the water resistivity is determined mainly by the ionic content since it is the movement of ions that carries the electrical current. For a given voltage more ions permit greater current flow, i.e. reduced resistivity; it is on this principle that the use of resistivity surveys to outline contaminated areas is based.

However, other factors also affect the measured soil resistivity. For example, it is evident from Eq. 1 that soil porosity has a somewhat greater effect on soil resistivity than the soil moisture, so that variations in soil type, which result in changes in porosity can cause incorrect interpretation of resistivity surveys carried out to map contaminants. Clay content (and the type of clay) can additionally affect soil resistivity because of a "surface conduction"

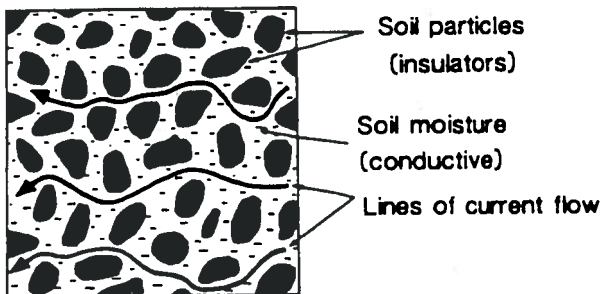


Figure 1.
Electric model of soil sample

phenomenon which occurs in clay. Furthermore since resistivity measurements are influenced by the vertical distribution of resistivity, which is in turn influenced by the vertical distribution of soil moisture, variations in the moisture profile (such as changes in the level of the water table) will affect survey results.

Since geological and hydrogeological factors can affect soil resistivity, surveys intended to delineate a contaminant area must include a sufficient density of measurements both over the suspect region and also beyond into the surrounding area so that the possible influence of any of the above factors can be determined. Furthermore, the survey interpreter must always bear in mind the various factors other than soil water resistivity that can influence the survey results.

CONVENTIONAL RESISTIVITY SURVEY TECHNIQUES

Conventional resistivity surveys are carried out by inserting four metal electrodes in the ground in one of a number of arrays. The theory of such techniques is well covered in the literature.³

In general, a voltage applied across two of the electrodes causes a current to flow in the soil, and the resulting voltage measured across the two other electrodes is a measure of the soil resistivity. The Wenner array, commonly used for geotechnical surveys, is shown in Fig. 2. The depth to which resistivity is sensed is determined essentially by the inter-electrode spacing, and for the Wen-

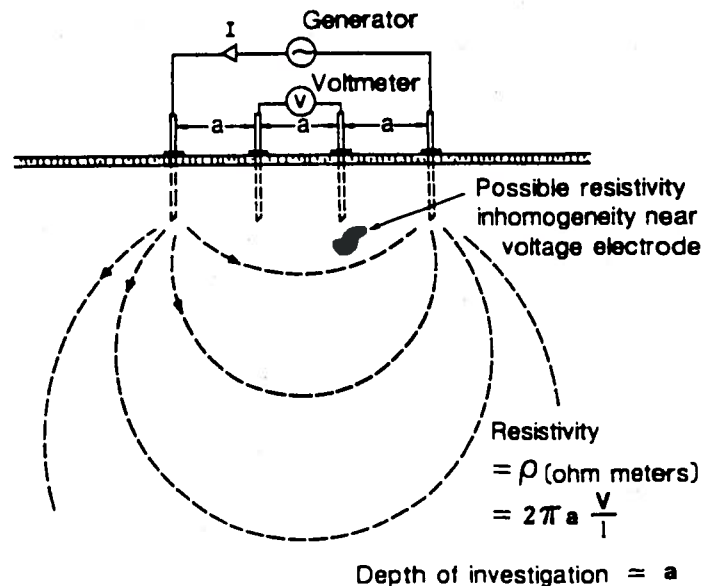


Figure 2.
Conventional resistivity (Wenner array)

schematically in Fig. 4, would be approximated by the engineer/geologist as a three-layer geometry also indicated in Fig. 4.

Suppose further, that in a certain region the groundwater may be sufficiently contaminated to double the groundwater conductivity, that is, through Eq. 1 to double the conductivity of the intermediate layer of Fig. 4. The question arises: "With a conventional resistivity array of fixed interelectrode spacing 'a' or an electromagnetic system with fixed intercoil spacing 's' how is the instrumental response calculated over such 'layered earths' so that the difference in response between the contaminated and uncontaminated areas can be determined?"

If the earth resistivity was uniform with depth, Eq. 2 shows that the Wenner array, for a given current I, would give an inner electrode voltage V_u related to the resistivity by:

$$V_u = \frac{\rho I}{2\pi a} \quad (4)$$

If now the earth is layered, as indicated in Fig. 4, a different value of voltage V_x will be measured for the same current I and inter-electrode spacing a, and an apparent resistivity can be defined by:

$$\rho_a = 2\pi a \frac{V_x}{I} \quad (5)$$

For a layered earth the apparent resistivity so defined will reflect the influence of the various resistivities at the different depths.

To return to the contaminant problem, the question can now be rephrased as "for a given fixed inter-electrode spacing how does the apparent resistivity vary in going from the uncontaminated to the contaminated region?" Unfortunately, for conventional resistivity techniques, such a calculation requires a reasonably complicated computer program (although it can now be performed on the most advanced programmable pocket calculators). The calculation for an arbitrarily layered earth cannot be performed by hand.

For electromagnetic measurement of terrain conductivity at low induction number, the concept of apparent conductivity is entirely analogous. Equation (3) is inverted to yield:

$$\sigma_a = \frac{4}{2\pi f \mu s^2} \frac{H_s}{H_p} \quad (6)$$

which, for the case of a uniform earth gives the correct terrain conductivity, and for the case of a layered earth gives an apparent conductivity which also depends on the layering.

A major difference between the conventional and the electromagnetic survey techniques is that for the latter it is a simple matter to calculate the apparent conductivity (by hand) for any type of layering. The reason for this difference is that for conventional resistivity measurements, the current distribution at any point in the layered earth is a complicated function of the parameters of all of the layers. In the case of the electromagnetic surveys, the local current flow is determined by the local conductivity—changed in any given layer do not affect (to the low induction-number approximation) the current flow in other layers.

It is thus possible to generate the curve in Fig. 5 which shows, for

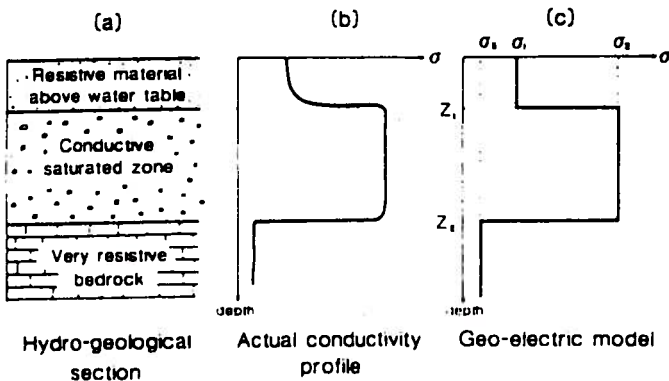


Figure 4. Typical ground conductivity profile

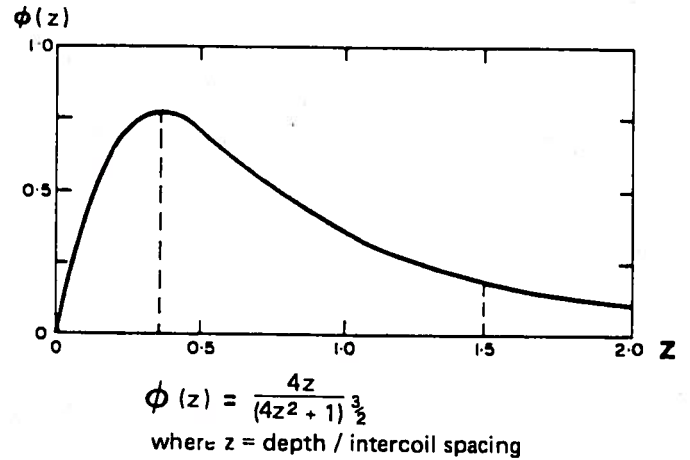
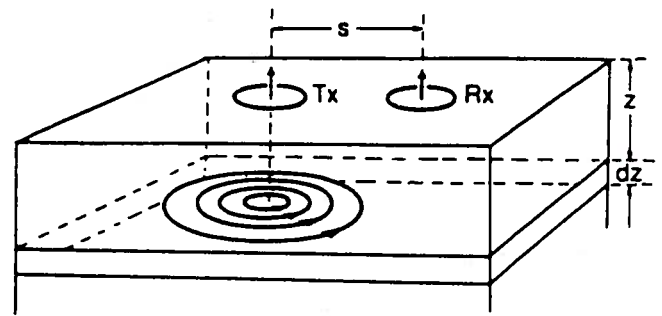


Figure 5. Relative sensitivity to ground at various depths

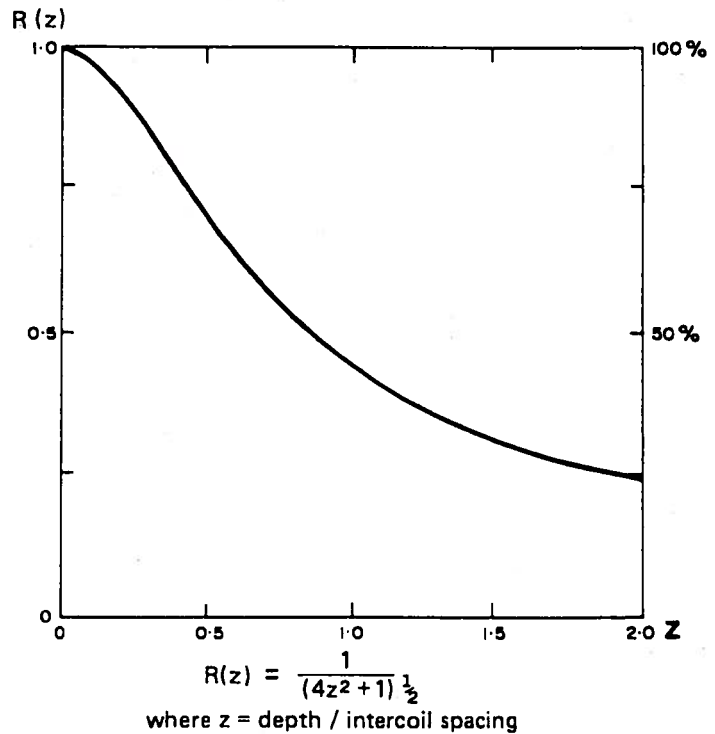


Figure 6. Cumulative sensitivity to ground at various depths

a uniform earth, the relative contribution to the meter reading from a thin horizontal layer of thickness dz at any depth z, (where z is the real depth normalized with respect to the intercoil spacing). The figure shows that this relative response is very small near the surface, that it increases with depth, becoming a maximum at 0.4 intercoil spacings (i.e. at 4 m if the intercoil spacing is 10 m) and then gradually decreases again. There is still appreciable response at 1.5

in a manner completely analogous to that for conventional resistivity equipment, i.e. measurement is made over a wide range of intercoil spacings. Technical problems associated with the dynamic range of the received signal make this difficult and expensive to do, and currently available instrumentation has a maximum of three switch-selectable intercoil spacings of 10, 20 and 40 m.

In summary, inductive electromagnetic techniques are most suited to rapid reconnaissance-type surveys, where the relatively high initial cost of the equipment can be offset by the speed and low cost with which surveys can be carried out, and where the resolution in conductivity, whereby small variations can be accurately mapped, is a prime consideration in the survey objectives.

For those situations where very high or very low conductivities are to be mapped, or where an accurate profile of the vertical distribution of resistivity is the objective, conventional resistivity techniques will still be required.

SURVEY INSTRUMENTS

Instrument design conforming to the condition of operation at low values of induction number, forms the basis of the patented Geonics EM31, EM34-3 and EM38 terrain conductivity meters. The EM31, a one-man portable instrument with a fixed intercoil spacing of 3.7 m and a depth of exploration of about 6.0 m is shown in Fig. 7. Basically designed as a rapid reconnaissance instrument the EM 31 can be effectively used with a chart recorder to provide continuous profiles of ground conductivity. In addition this instrument is very effective in detecting and mapping the location of buried metallic drums.⁹ Finally, by laying the instrument on the ground and making two measurements, one with the device in

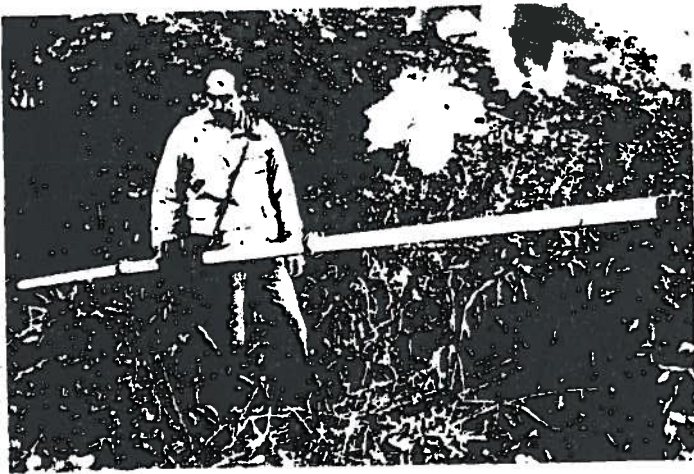


Figure 7.
EM 31

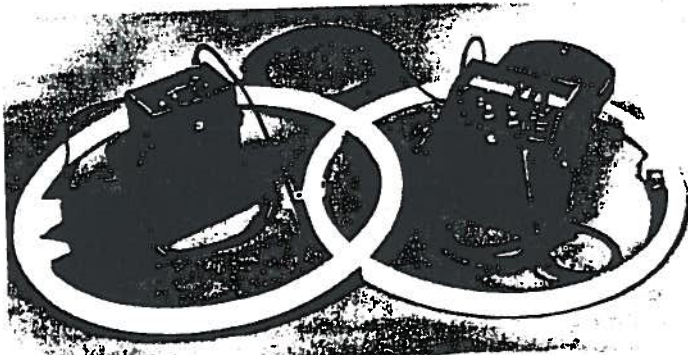


Figure 8.
EM 34-3

normal position and a second on its side (vertical and horizontal dipole modes), it is possible to detect a two-layered earth and to ascertain whether the more conductive material is near surface or at depth.¹

The EM34-3 (Fig. 8) is a two-man instrument with switch-selectable intercoil spacings of 10, 20, or 40 m to permit maximum depths of 15, 30 and 60 m. It too can be operated in either the vertical or horizontal dipole mode to vary the instrumental sensitivity with depth. The two coils are connected by a flexible cable: the receiver console has two meters—one of which electronically indicates the intercoil spacing.

To make a measurement the transmitter operator stops at the survey mark: the receiver operator then moves his coil with respect to the transmitter until this meter indicates that the correct intercoil spacing has been achieved, whereupon he reads the terrain conductivity on the second meter. The whole procedure takes about 20 sec.

The EM 38 is a 1.0 m long instrument (depth about 1.5 m) designed for soil salinity measurements.

SURVEY CASE HISTORY

A case history⁴ will illustrate some of the features of surveys carried out using inductive electromagnetic techniques.

The survey area, shown in Fig. 9, is described by Greenhouse and Slaine⁴ as follows:

"A variety of waste chemicals from herbicide and pesticide manufacturing were deposited in lined lagoons situated on glacial overburden during the 1970s. One or more of the lagoon liners has leaked into an unconfined aquifer, producing ground-water conductivity anomalies proportional to total dissolved solids (primarily chloride and sodium). The contamination threatened a nearby creek but the pattern of movement was unknown. Geophysical surveys were requested to assist in locating a drilling program."

This is a typical application for a geophysical survey.

During the planning stages of a conductivity survey, Greenhouse and Slaine obtain all of the available hydrogeological data on the

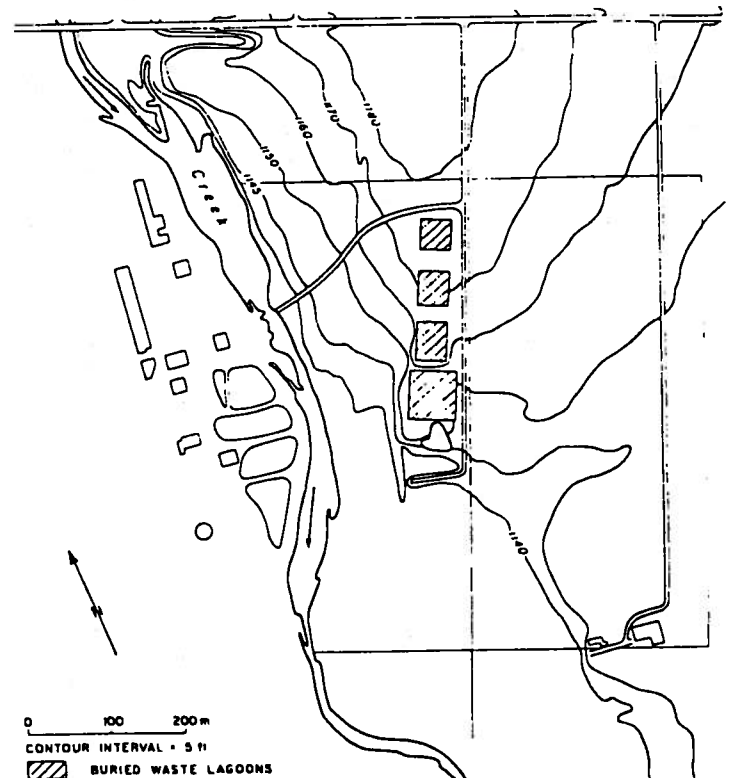


Figure 9.
Survey case history area

USE OF NDT METHODS TO DETECT BURIED CONTAINERS IN SATURATED SILTY CLAY SOIL

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INTRODUCTION

There are estimated to be 30,000 to 50,000 existing dump sites in the United States containing various amounts and types of hazardous materials. Furthermore, many new sites are discovered on a regular basis. One of the first pieces of information needed in the cleanup process is the physical extent of the dump site and the resulting polluted area. This is very difficult to do when hazardous materials (often in metal and plastic containers) are buried beneath the ground surface. Since traditional methods of core borings and excavation of test pits are dangerous, discontinuous, and expensive, the use of non-destructive testing (NDT) methods is often suggested. Many of these methods, including those of the authors,^{1,2} have been described in the literature.

In an earlier study,³ we evaluated use of the various NDT methods to locate buried metal and plastic containers in a uniform dry sandy soil. In that study, the metal and plastic containers were buried at known locations and depths in various patterns and seven NDT methods used for detection. The results indicated that the metal detector, very low frequency electromagnetic, magnetometer and ground probing radar techniques are of definite value in delineating the drums. Continuous wave microwave techniques were less successful, and seismic refraction and electrical resistivity were unsuccessful under those particular conditions.

Since the soil and the site of that study³ represented nearly ideal conditions, it was decided to repeat the entire project by burying the metal and plastic containers in a saturated fine grained soil which was eventually located in a construction contractor's storage yard.

Following this section is a description of the NDT techniques used, details of the site and specific results obtained.

DESCRIPTION OF EXPERIMENTAL METHODS

Since the continuous wave microwave technique was only marginally successful and seismic refraction and electrical resistivity techniques were unsuccessful on the previously described nearly ideal site,³ they were not attempted for this more difficult situation. Commercially available metal detector (MD), very low frequency electromagnetic (VLF-EM), magnetometer (MA) and ground probing radar (GPR) were used.⁴⁻¹⁰

The metal detector (sometimes called a pipe locator or eddy current method) and very low frequency electromagnetic methods operate on essentially the same principle. They will be discussed together. Both of the instruments used had two coils; many of the less expensive metal detectors are single coil/inductance change instruments. A transmit coil generated an electromagnetic field and a

receiving coil in the vicinity picks up the resulting field. Some of the field arrives via the air and some via the subsurface material. The field through the air is essentially constant for a given transmitter-to-receiver distance, but the field arriving from the subsurface materials depends on the subsurface electrical conductivity and magnetic permeability. If a conducting body is present in the subsurface material between the two coils, the total detected field is altered and the anomaly noted.

A magnetometer measures changes in the earth's magnetic field. Any magnetic object, e.g., an iron ore deposit or a buried steel object, will alter the earth's magnetic field locally and thus can potentially be detected. The most commonly used magnetometer employs proton nuclear magnetic resonance. The nuclear spin of the proton precesses at a frequency which is linearly proportional to the total magnetic field at the nucleus. If the total magnetic field changes because of an anomaly, the precession frequency change can be read accurately, and hence the magnetic field change can be determined precisely.

In the ground probing radar technique, a few cycles of electromagnetic radiation (100 MHz to 900 MHz) are sent into the ground from a highly damped antenna. A reflection occurs when a medium of different dielectric constant is encountered. The time it takes for the pulse to travel down and back gives an indication of the depth of the object. Lateral surveying gives an indication of the spatial extent of the objects.

SITE DETAILS

The containers were buried in a heavy construction contractor's storage yard in North Wales, Pa. The 150 ft by 120 ft area was bounded by trees and a drainage ditch to the north, a chain link fence to the east and south and miscellaneous forms, tanks and trailers to the west.

Disturbed and undisturbed samples indicated that the soil was a dense sandy silty clay of 128 lb/ft³ unit weight and 19% water content. This is equivalent to a 98% relative density (via standard Proctor compaction test) and 100% saturation. Other physical properties of the soil showed that the specific gravity was 2.54, the liquid limit was 32%, the plastic limit was 23% and the shrinkage limit was 11%. Regarding gradation characteristics, 21% was in the silt size range and 4% was the clay size range. Thus, the soil is classified as ML-CL by the Unified Soil Classification system. Being near the high point of the local topography, the soil was only about 4 ft to 6 ft thick above bedrock which was observed to be decomposed red shale, fractured at 4 ft but rapidly became sound at a depth of about 6 ft.

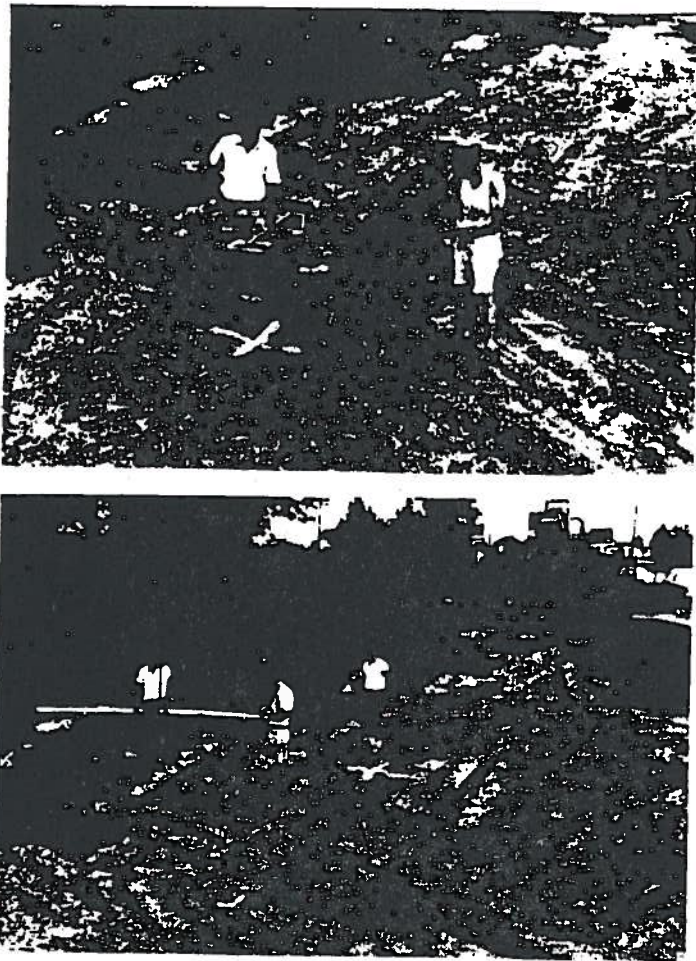


Figure 3.

Photographs of Site Showing Metal Detector (upper) and Very Low Frequency Electromagnetic (lower) Techniques for Detecting Buried Containers. Crosses Mark Locations Where Containers are Buried.

ground surface before the containers were buried. In the vicinity of the trailers and metal forms, the metal detector remained pinned continuously.

The results of the very low frequency electromagnetic device (commercially available from Geonics Ltd., Model No. EM-31) are given in Fig. 5. Similar to the previous results, the system accurately located all metal containers, but no plastic ones (Fig. 5). The possible exception was the plastic container buried 1 ft deep along scan line #4. Anomalous spots were also seen along scan lines where no containers were buried but, as described before, quite possibly for the same reason. At a few of these locations the MD and VLF-EM readings were in agreement, e.g., along scan line #5 at 90 ft west of the base line.

The magnetometer results (commercially available from EG and G Geo-Metrics, Model No. F-856) are shown in Fig. 6. The individual scan lines showing magnetic field data were interpreted and plotted for this figure. Correlation with actual containers locations was very poor for the steel drums (which was unexpected) and for the plastic drums (which was expected). The westerly portion of each scan line became swamped due to the heavy magnetic metal (i.e., steel) concentration of the tanks, forms and trailers on the ground surface.

Results from the ground probing radar (commercially available from Geophysical Survey Systems, Inc., Model No. SIR-7) scans are not shown in the same format as the preceding techniques because results were very negative. A typical GPR trace along scan line #2 is shown in Fig. 7. The trace was made over the four 30 gal steel drums buried at 1 ft, 4 ft, 2 ft and 3 ft, respectively, and then

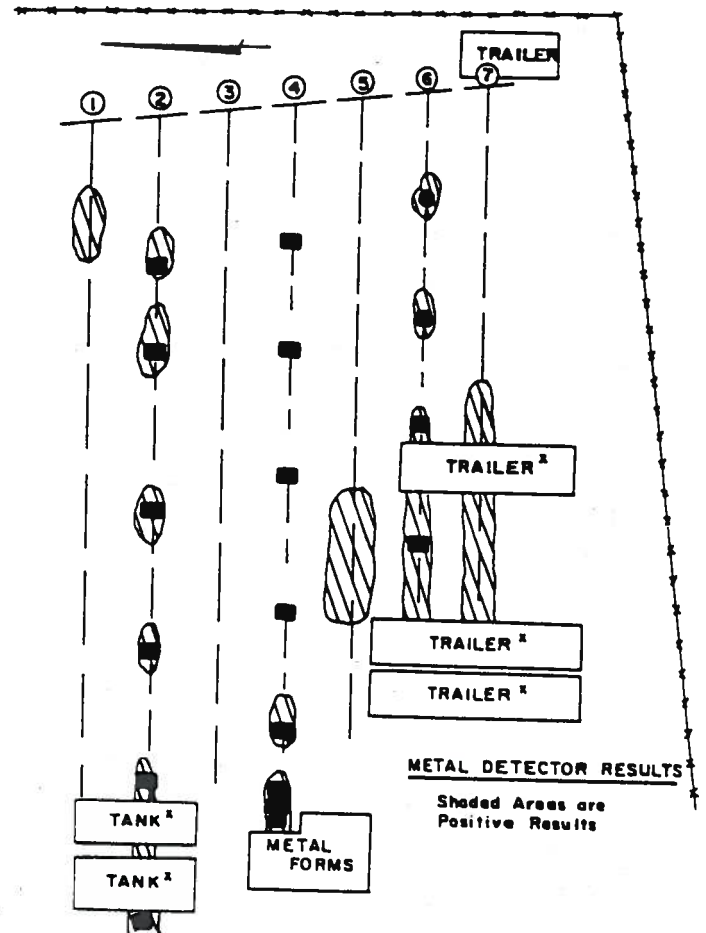


Figure 4.

Plan View of Site Showing Results of Metal Detector (MD) Survey. See Fig. 2 for Actual Container Identification.

over the 55 gal drum at a 3 ft depth. No discernible return signal was noted at the proper locations. This was typical of all GPR scans over the site.

Four separate scan trips were made to the site, one before drum placement and three afterwards. Perhaps a GPR system with signal enhancement capabilities would have shown the expected parabolic shapes indicating a curved object, but it was not obvious in this situation.

CONCLUSIONS AND RECOMMENDATION

In contrast to the earlier study of container detection in a dry sandy soil, most NDT techniques worked quite well; at this site conditions were much more formidable. The major differences between the sites were the:

- High clay content of the soil
- Complete saturation of the soil voice
- Closeness of the bedrock to the ground surface
- The fact that the bedrock surface was not abrupt but weathered from highly decomposed to very hard within a 2 ft thickness
- Relatively confined area where background noise is present.

In spite of the above difficulties, this is typical of a real site having buried containers.

For this situation, the metal detector and very low frequency electromagnetic methods worked equally well in locating metal containers. On the basis of equipment cost, the authors would favor the metal detector (\$600 versus \$8,000). The VLF-EM has a deeper penetration depth and lateral scan sensitivity as determined

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REFERENCES

1. Lord, A.E., Jr., Tyagi, S.D. and Koerner, R.M., "Nondestructive Testing (NDT) Methods Applied to Environmental Problems Involving Hazardous Material Spills," *Proc. of 1980 Conference on Control of Hazardous Material Spills*, May 13-15, 1980, Louisville, Ky. 174-179.
2. Lord, A.E., Jr., Koerner, R.M. and Freestone, F.J., "The Identification and Location of Buried Containers via Nondestructive Testing Methods," *Journal of Hazardous Materials*, 5, 1982, 221-233.
3. Lord, A.E., Jr., Tyagi, S., Koerner, R.M., Bowers, J.J., Sankey, J.E. and Cohen, S., "Use of Nondestructive Testing Methods to Detect and Locate Buried Containers Verified by Ground Truth Measurements," *Proc. 1982 Hazardous Materials Spills Conference*, April 19-22, 1982, Milwaukee, WI, 185-191.
4. Lord, A.E., Jr., Tyagi, S.D. and Koerner, R.M., "Use of Eddy Currents as a Potential NDT Method Applied to Hazardous Material Spill Problems," Report 2 to EPA on Cooperative Agreement CR80777710, January 6, 1981 (available on request).
5. Lord, A.E., Jr., Tyagi, S.D. and Koerner, R.M., "Use of Very Low Frequency-Electromagnetic (VLF-EM) Measurements as a Possible NDT Method Applied to Hazardous Material Spill Problems," Report 8 to EPA on Cooperative Agreement CR80777710, July 4, 1981 (available on request).
6. Lord, A.E., Jr., Tyagi, S.D. and Koerner, R.M., "Use of Proton Precession Magnetometer as a Potential NDT Method Applied to Hazardous Material Spill Problems," Report 4 to EPA on Cooperative Agreement CR80777710, February 20, 1981 (available on request).
7. Cook, J.C., "Ground Probing Radar," *Proc. of Symposium on Subsurface Exploration, Underground Excavation and Heavy Construction*, American Society of Civil Engineers, 1974, 172-174.
8. Morey, R.M., "Continuous Subsurface Profiling by Impulse Radar," *Proc. of Symposium on Subsurface Exploration for Underground Excavation and Heavy Construction*, American Society of Civil Engineers, 1874, 213-232.
9. Rosetta, J.V., "Detection of Subsurface Cavities by Ground Probing Radar," *Proc. of Symposium on Detection of Subsurface Cavities*, U.S. Army Waterways Experiment Station, Vicksburg, MS, 1977, 120-127.
10. Lord, A.E., Jr., Tyagi, S.D. and Koerner, R.M., "Use of Ground Probing Radar and CW Microwave Measurements as Possible NDT Methods Applied to Hazardous Material Spill Problems," Report 13 to EPA, Edison, New Jersey, on Cooperative Agreement CR80777710, October 1, 1981 (available on request).