WORK PLAN FOR SUPPLEMENTAL SITE INVESTIGATION

PREPARED FOR:

HERCULES, INC.

CHEMICAL SPECIALTIES

HATTIESBURG, MISSISSIPPI

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1.0 INTRODUCTION

Eco-Systems, Inc. (Eco-Systems) has been retained by Hercules Incorporated (Hercules) to prepare this revised work plan for 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.

This revised work plan has been prepared in response to comments contained in a letter from the Mississippi Department of Environmental Quality (MDEQ) dated April 24, 2003, which discussed, among other issues, the original *Work Plan for Supplemental Site Investigation* (Eco-Systems, April 4, 2003). This revised work plan also includes changes based on comments contained in a letter from the MDEQ dated June 11, 2003, which discusses the meeting between Hercules and the MDEQ that took place on June 6, 2003.

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 a work plan for supplemental site assessment to delineate the vertical and horizontal extent of VOCs detected in shallow groundwater at the facility. That work plan was submitted to the MDEQ on April 4, 2003. 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. It should be noted that geophysical methods will only allow for the identification of magnetic anomalies in subsurface soils that may be interpreted as accumulations of buried metallic objects.

After review of the *Work Plan for Supplemental Site Assessment* (Eco-Systems, April 2003), the MDEQ sent a letter to Hercules dated April 24, 2003, which addressed 12 issues in the work plan and requested a revised work plan. Those issues were further discussed in a meeting between Hercules and the MDEQ on June 6, 2003, and in letter from the MDEQ to Hercules dated June 11, 2003. This revised *Work Plan for Supplemental Site Assessment* (Eco-Systems, June 2003) encompasses the revisions agreed upon between Hercules and the MDEQ.

1.2 Purpose and Scope

The original purpose of the supplemental site investigation was 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 original supplemental site investigation also included a geophysical investigation to delineate the lateral limits of the landfill and, if possible, locate accumulations of buried metal. In response to comments from the MDEQ, the supplemental site investigation has been revised to include additional analytical parameters, investigation of the surface water and stream sediments upstream from previously sampled locations, investigation of groundwater quality in the vicinity of piezometers, TP-1, TP-4, TP-5, and TP-11, and additional geophysical investigation in the area west of the landfill.

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 and vertical limits of the constituents of concern in groundwater and the effectiveness of the existing monitoring well system,
- Collect stream sediment and surface water samples from Green's Creek at locations upstream from previous stream sampling locations,

- 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 and other areas of the site, 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. The Geoprobe® will also be used to investigate groundwater quality in the vicinity of piezometers TP-1, TP-4, TP-5, and TP-11. Surface water and stream sediment samples will be collected from Green's Creek at locations up stream from previous sampling locations to investigate the upstream limits of the constituents detected in previous surface water and stream sediment locations.

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. The MDEQ has also requested that the geophysical survey also include an unspecified area of the site to locate another potential burial area.

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. Initial proposed sampling locations and possible secondary sampling locations are shown on Figure 4.

As requested by the MDEQ, groundwater samples collected during this investigation will also be analyzed for Dioxathion. However, the dioxathion analyses will be conducted on a typical turn around time of approximately 2 weeks.

As also requested by the MDEQ, groundwater samples will be collected in the vicinity of piezometers TP-1, TP-4, TP-5, and TP-11. Samples from these locations will be analyzed for VOCs, SVOCs and Dioxathion.

As requested by the Environmental Permits Division of the MDEQ, groundwater monitoring of monitoring wells MW-4, MW-10, and MW-11 will also be conducted during this mobilization. For quality control purposes groundwater monitoring of the upgradient monitoring well, MW-1, will be conducted during the same sampling event. Samples collected from the existing monitoring wells, MW-1, MW-4, MW-10 and MW-11, will be analyzed for VOCs and Dioxathion.

Except for the groundwater samples collected from existing monitoring wells, 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.

In order to investigate the vertical extent of the VOCs in groundwater, at least four of the Geoprobe® borings will be extended into the underlying clays of the Hattiesburg formation. Available information indicates that Geoprobe® refusal will occur in the Hattiesburg formation. If the depth from the water table to the top of the underlying clay is at least 20 feet, a second groundwater sample will be collected from the lower portion of the saturated interval.

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. The proposed geophysical survey area for this work plan is shown on Figure 5.

Ground conductivity and magnetic methods will also be used to investigate an unspecified area as requested by the MDEQ. For the unspecified area, a series of lines will be established to cover the area of interest with sufficient overlap to provide adequate data to describe any anomalies contained within the area. It is anticipated that a similar line spacing and data point spacing will be used in the unspecified area as describe above for the landfill area. However, should the size of the unspecified area, or time constraints, dictate, a wider data point and line spacing may be utilized for the unspecified survey area. In any event, data will be collected from grid locations spaced no more than 50 feet apart.

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 4.10.

3.3 Surface Water and Stream Sediment Investigation

As requested by the MDEQ, a surface water sample and a stream sediment sample will be collected from Green's Creek at the point where Green's Creek enters the Hercules property. A surface water sample will also be collected from the previous surface water sampling location CM-1. The surface water sample and the stream sediment sample collected from the Hercules property line will be analyzed for VOCs and Dioxathion. The surface water sample collected from the CM-1 location will be analyzed for VOCs.

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

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 installed to bracket the observed water table. Ideally, a 10-foot long well screen will be installed to a depth approximately 8-feet below the observed water table. However, if the clays of the Hattiesburg formation are encountered at depths less than 8-feet below the observed water table, the screen will be set at a shallower depth.

In at least four locations, the borings will be installed to the top of the Hattiesburg formation, which will be identified by the dense clay that marks the contact. If, at any of these four locations, the observed water table is 20 feet or greater above the top of the Hattiesburg formation, two temporary monitoring wells will be installed. The first will be installed using a screen, that is 5-feet in length, to the top of the clay unit to investigate groundwater quality in the lower portion of the alluvial aquifer. A second temporary monitoring well will then be installed in a boring placed within 5 feet, laterally, of the deeper boring. The second temporary monitoring well will be installed to bracket the observed water table, as described above.

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. The filter sock has a screen mesh of approximately 240 microns, which is sufficient to retain most fine sand and larger particles. 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 representative water quality criteria (referenced above) have been met or until five (5) well volumes of water have been purged. 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 VOC analysis will be sampled stopping the peristaltic pump, removing the influent tubing from the well, and allowing the groundwater contained in the influent tubing to drain into the sample containers. If a bailer is used for purging, the groundwater sample will be poured directly from the bailer into the containers. Groundwater collected for other analyses will be collected 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 Surface Water and Stream Sediment Sampling

Surface water will be collected from Green's Creek by submerging the sample container into the flow of the creek to a depth sufficient to fill the containers. Samples will be collected beginning downstream and working upstream to mitigate the potential for cross-contamination related to disturbed materials drifting downstream to subsequent sampling locations. To prevent disturbed particles from entering the sample containers, the samples will be collected upstream of the sampler. Surface water will be placed into containers provided by the laboratory and delivered to the laboratory for analysis.

Stream sediment will be sampled immediately after collecting the surface water sample from the same location. Sediments to be analyzed for Dioxathion will be collected using a stainless steel spade. The spade will be decontaminated prior to each use. Sediments to be analyzed for VOC will be collected using single-use, sampling syringes provided by BATCO. Sediments will be placed into containers provided by the laboratory and delivered to the laboratory for analysis.

4.5 Sample Identification

Each sample collected will be identified by a unique alpha-numeric code. The first three digits (HER) of each sample code will denote the Hercules site. This portion of the code will be following by a hyphen (-) and two letters designating the type of sample. Groundwater samples will be represented by "GW". Surface water samples will be represented by "SW". Stream sediment samples will be represented by "SD", and soil samples by the letters "SO". Equipment rinsate samples will be represented by the letters "RS", trip blank samples by the letters "TB", and blind duplicate samples by the letter "BD".

For groundwater samples, the code is followed by a hyphen and a four (4) or two (2) digit code indicating the temporary groundwater sampling point (e.g. GP1) or existing monitoring well number (03 for MW-3), respectively. This code is followed by a hyphen and a four-digit code indicating the month and year the sample was collected.

For soil samples, the code is followed by a hyphen and a three-digit code representing the soil probe identification (GP1). This code is then followed by sample depth in feet below ground surface.

For rinsate and trip blank samples, the code is followed by a two-digit sequential sample number representing the running total of this type of sample collected at the Site to date. For each sample type, the letter "D" will be added to the sequential sample number to specify a duplicate sample. Duplicate could also be presented to the laboratory as "blind" and these samples will be designated with a running total as "BD1". These types of QA/QC samples are discussed in Section 4.8.

Subsequent to sampling, a waterproof paper label will be attached to each sample container containing the following information:

- Project number,
- Site/project name,
- Sample identification code,
- Sampler's name,
- Date and time of sample collection,
- Preservative (if any), and
- Parameters for analysis.

4.6 Analytical Methods

Groundwater samples will be analyzed by BATCO for volatile organic compounds (VOC) according U.S. EPA SW-846 method 8260B and Dioxathion according to Hercules' *Sampling and Analysis Protocol for Determination of Dioxathion in Water*. Groundwater samples collected from locations adjacent to piezometers TP-1, TP-4, TP-5, and TP-11 will also be analyzed for semi-volatile organic compounds (SVOCs) according to U.S. EPA SW-846 method 8270.

Surface water and stream sediment samples will be analyzed for VOC according U.S. EPA SW-846 method 8260B and Dioxathion according to Hercules' *Sampling and Analysis Protocol for Determination of Dioxathion in Water*.

4.7 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.

4.8 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. As requested by the MDEQ, one (1) blind duplicate sample will be collected for each group of groundwater samples collected during the Geoprobe® investigation that are submitted to the laboratory for expedited analyses. It is estimated that one (1) blind duplicate sample will be submitted for every five (5) groundwater samples submitted. Since only the VOC analyses will be expedited, the blind duplicate samples will only be analyzed for VOC.

4.9 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.

4.10 GEOPHYSICAL SURVEY

4.10.1 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 (Hp) induces small electrical currents in the ground. These currents induce secondary magnetic fields (Hs) 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 (Hs/Hp) 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 Hs 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 Hs which is fully 180° out of phase with Hp 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.

4.10.2 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.

4.11 Health and Safety Considerations

Eco-Systems and all subcontractors of Eco-Systems will comply with a site-specific <u>Health and Safety (H&S) Plan</u> 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.

4.12 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

FIGURES

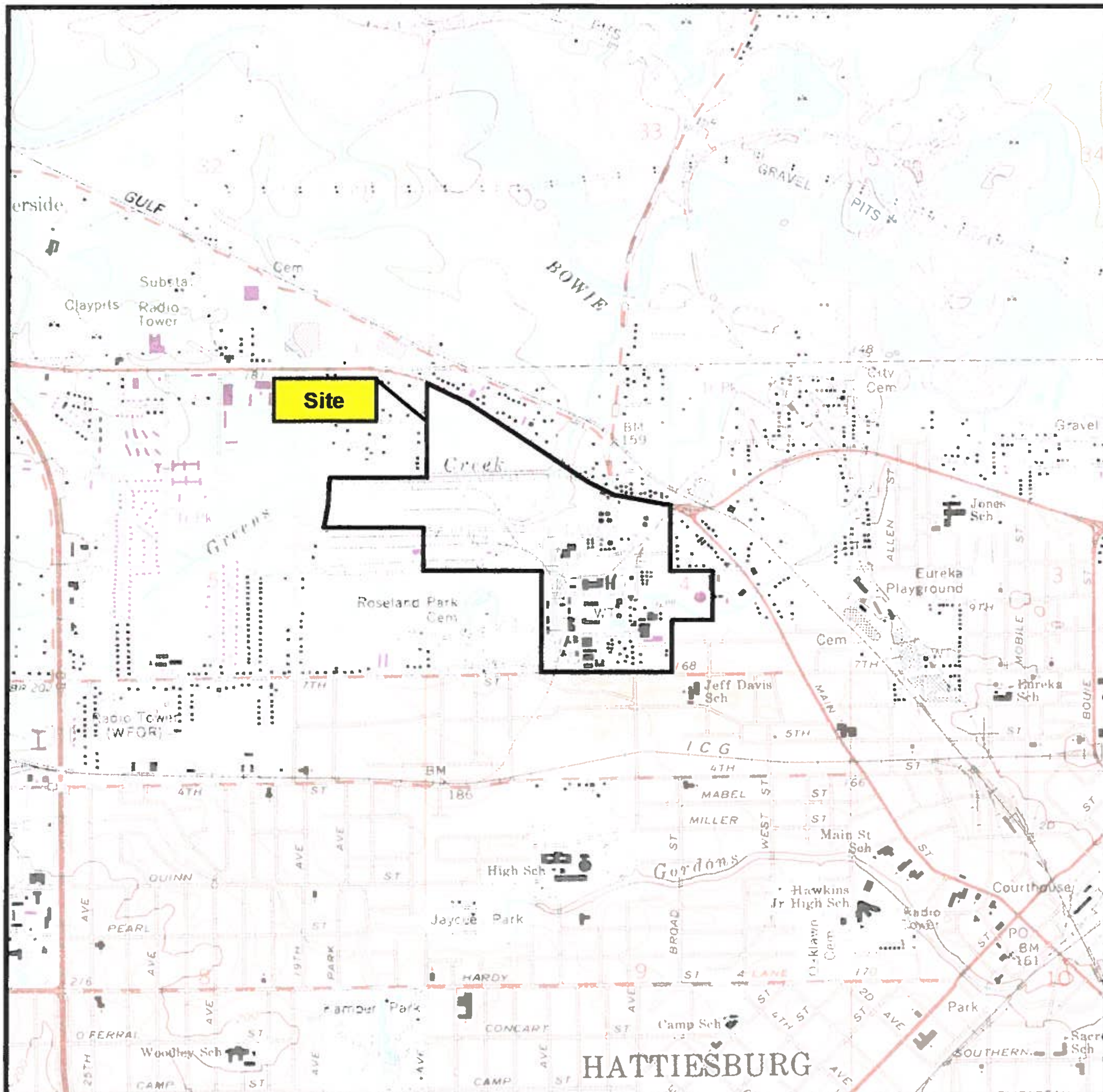
FIGURE 1

SITE LOCATION MAP

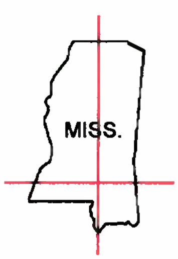
Eco-Systems, Inc.
Consultants, Engineers and Scientists

FIGURE 1

SITE LOCATION MAP
HERCULES, INC.
HATTIESBURG, MS



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



HER22173

HERCULES

FIGURE 2

SITE PLAN SHOWING DATA POINT LOCATIONS

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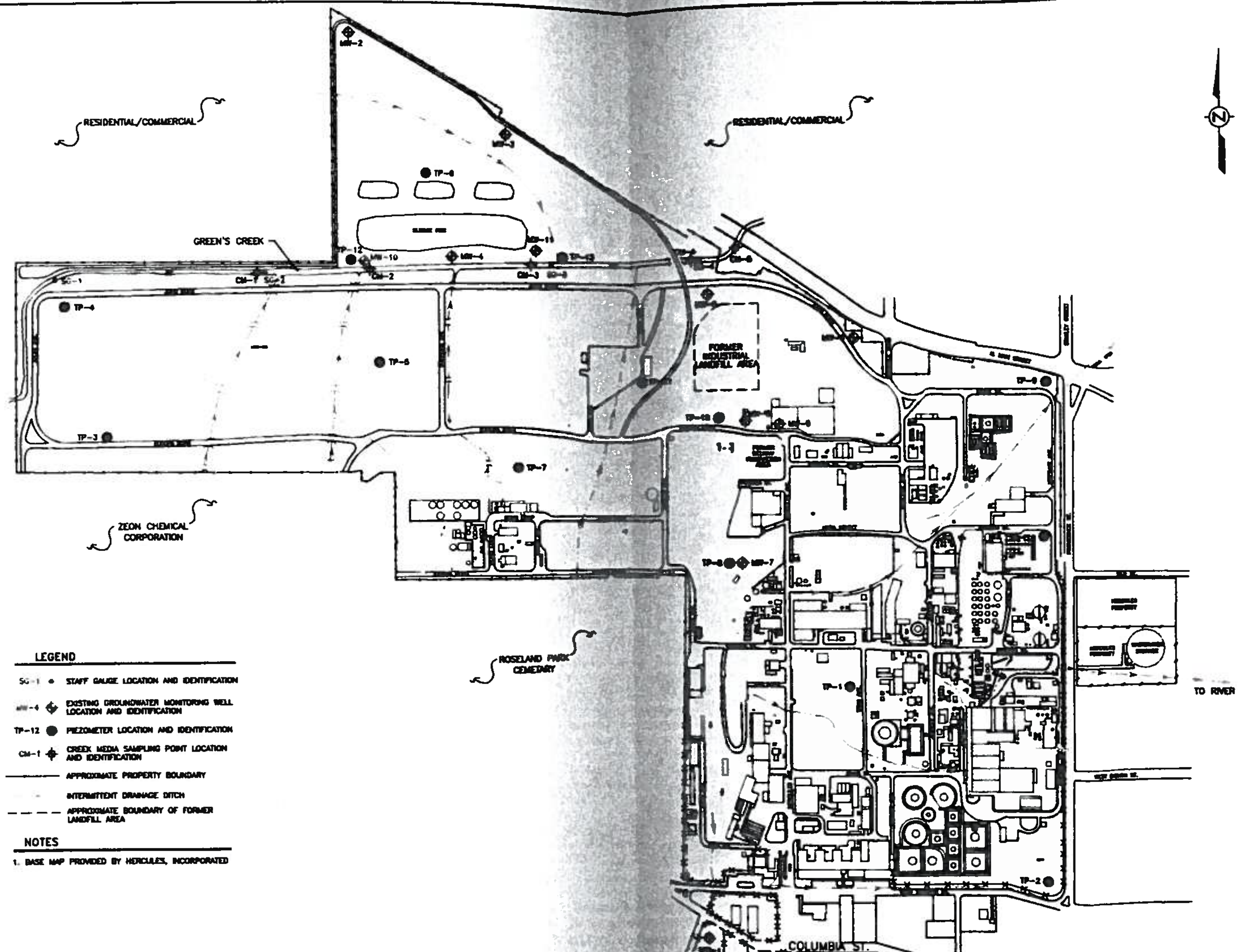

LEGEND

SG-1 ●	STAFF GAUGE LOCATION AND IDENTIFICATION
MW-4 ◈	EXISTING GROUNDWATER MONITORING WELL LOCATION AND IDENTIFICATION
TP-12 ●	PIEZOMETER LOCATION AND IDENTIFICATION
CM-1 ✦	CREEK MEDIA SAMPLING POINT LOCATION AND IDENTIFICATION
———	APPROXIMATE PROPERTY BOUNDARY
·····	INTERMITTENT DRAINAGE DITCH
— — —	APPROXIMATE BOUNDARY OF FORMER LANDFILL AREA

NOTES

1. BASE MAP PROVIDED BY HERCULES, INCORPORATED

HERCULES
CHEMICAL SPECIALTIES

DATE: 3/18/03
SCALE: 1"=450'
DRAWN: N. SISSON
CHECKED:
REVIEWED:
PROJECT MANAGER:

Eco·Systems, Inc.
Consultants, Engineers and Scientists

SITE PLAN SHOWING DATA POINT LOCATIONS

HERCULES CHEMICAL CO.
HATTIESBERG, MISSISSIPPI

PROJECT NO. HER22173
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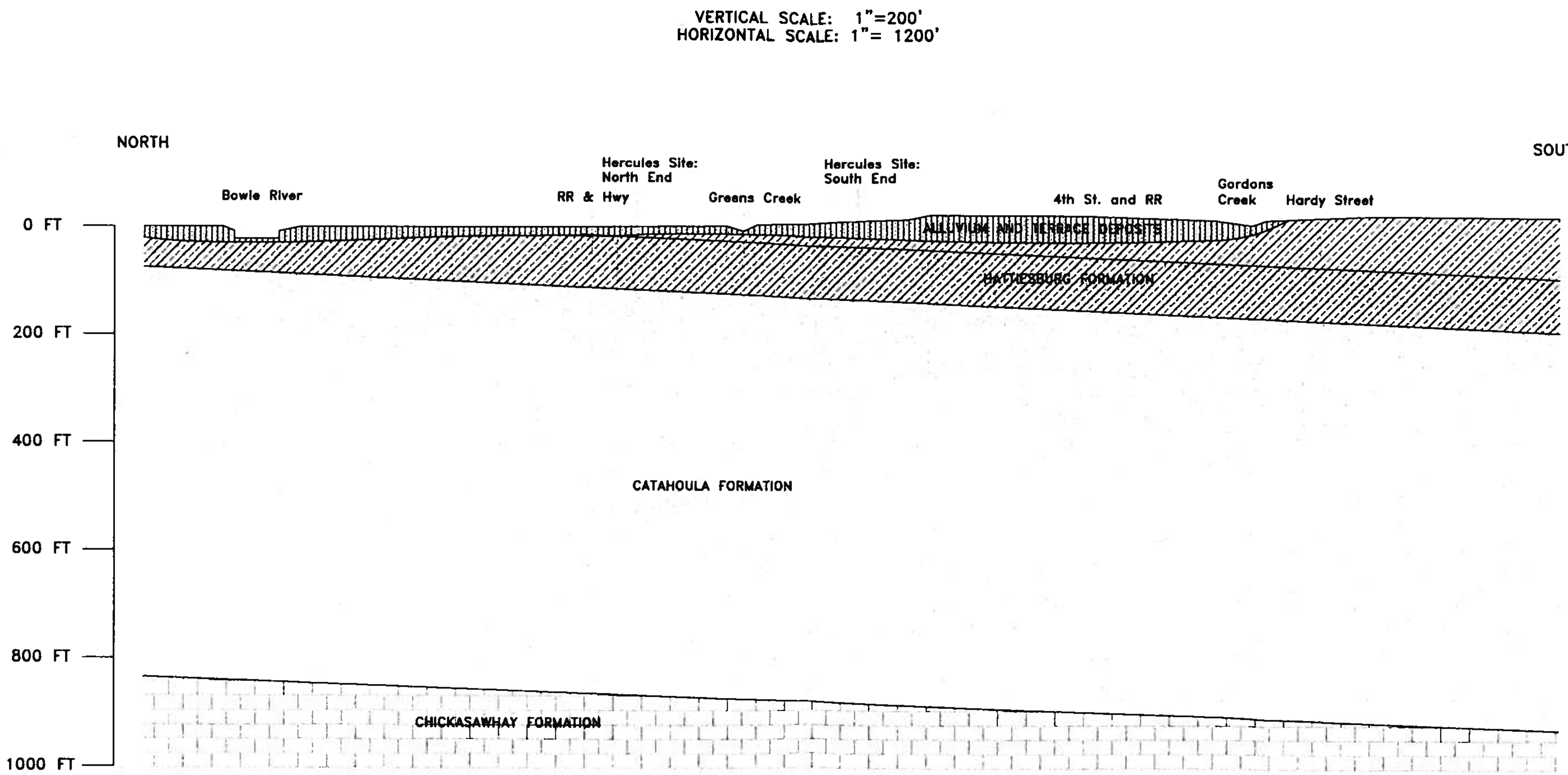
FIGURE 2

ESI

FIGURE 3

CONCEPTUAL REGIONAL CROSS SECTION



LEGEND

- SILTY SAND
- CLAY AND SILTY CLAY
- SAND, GRAVELY SAND, AND SILTY SAND
- LIMESTONE

HERCULES CHEMICAL SPECIALTIES

DATE: 4/1/03
SCALE: AS SHOWN
DRAWN: GALLOWAY
CHECKED:
REVIEWED:
PROJECT MANAGER:

Eco·Systems, Inc.
Consultants, Engineers and Scientists

HERCULES CHEMICAL CO.
HATTIESBERG, MISSISSIPPI

CONCEPTUAL REGIONAL GEOLOGIC CROSS SECTION

PROJECT NO. HER22173
CAD FILE HER22173-XSECTION.dwg
FIGURE 3

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FIGURE 4

SITE PLAN SHOWING PROPOSED SAMPLING LOCATIONS

APPENDIX A

SITE INSPECTION REPORT

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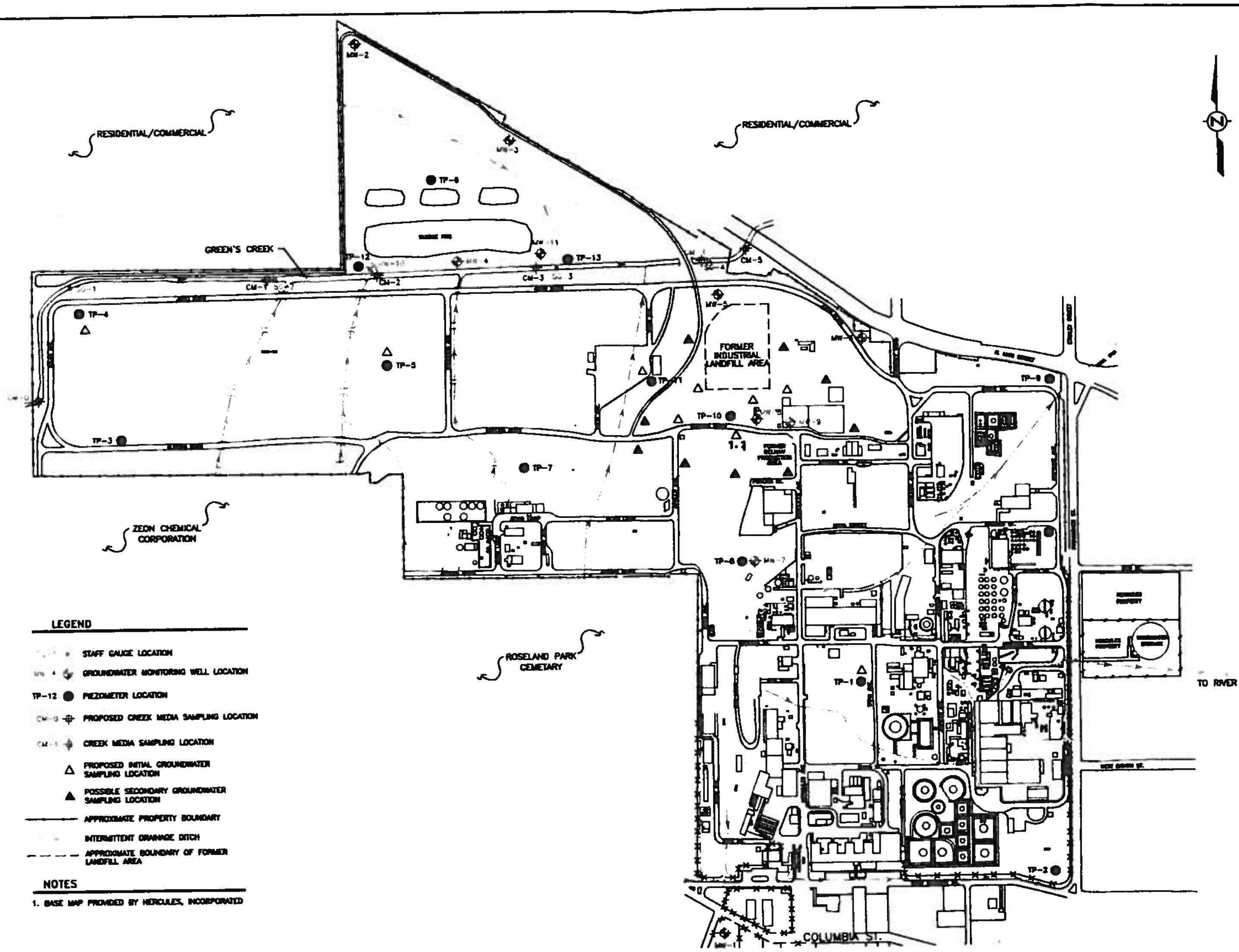

HERCULES CHEMICAL SPECIALTIES

DATE: 06/19/03
SCALE: 1"=450'
DRAWN: N. SISSON
CHECKED:
REVIEWED:
PROJECT MANAGER:

Eco-Systems, Inc.
Consultants, Engineers and Scientists

SITE PLAN SHOWING PROPOSED SAMPLING LOCATION

HERCULES CHEMICAL CO.
HATTIESBERG, MISSISSIPPI

PROJECT NO. HER23051
CAD FILE HER23051-SAMPLE.dwg
FIGURE 4

FIGURE 5

SITE PLAN SHOWING GEOPHYSICAL SURVEY AREA

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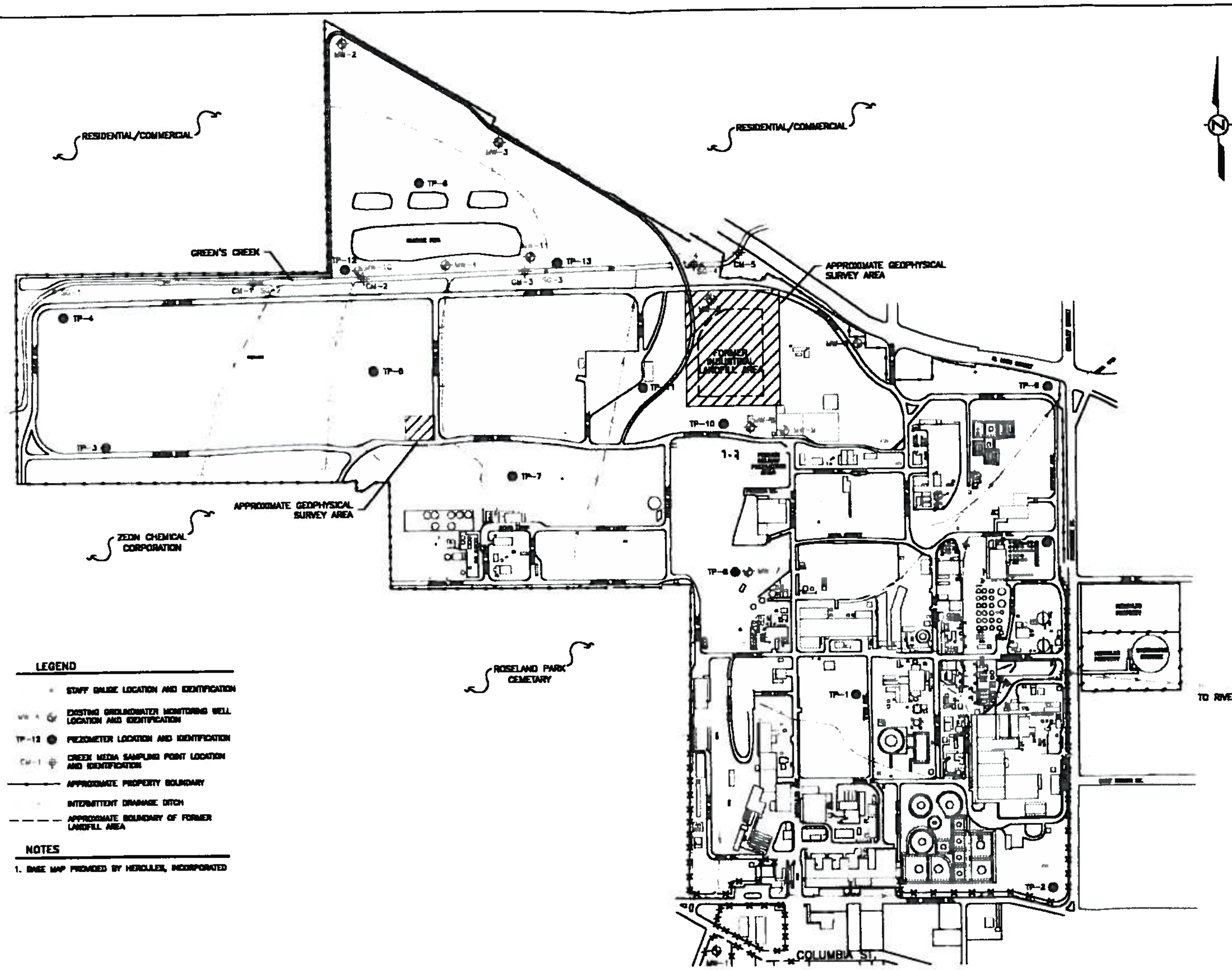

HERCULES CHEMICAL SPECIALTIES	DATE: 08/19/03 SCALE: 1"=450' DRAWN: N. SISSON CHECKED: REVIEWED: PROJECT MANAGER:	Eco·Systems, Inc. Consultants, Engineers and Scientists	SITE PLAN SHOWING GEOPHYSICAL SURVEY AREA HERCULES CHEMICAL CO. HATTIESBERG, MISSISSIPPI

PROJECT NO.	HER23051
CAD FILE	HER23051-GEOPHYS.dwg
FIGURE	5

ESI

APPENDICES

SITE INSPECTION REPORT

Hercules, Inc.

Hattiesburg, Forrest County, Mississippi

EPA ID № MSD008182081

WasteLAN № 02297

EPA Work Assignment № 11

EPA Contract № 68-W9-0055

Prepared for

WASTE MANAGEMENT DIVISION

U.S. Environmental Protection Agency

Prepared by

B&V Waste Science and Technology Corp

BVWST Project № 52011.040

April 29, 1993

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Ron Wilde
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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 contaminates 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 № MSD008182081
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Site Inspection
Hercules, Inc.
Hattiesburg, Forrest County, Mississippi
EPA ID № MSD008182081

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Site Inspection
Hercules, Inc.
Hattiesburg, Forrest County, Mississippi
EPA ID № MSD008182081

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

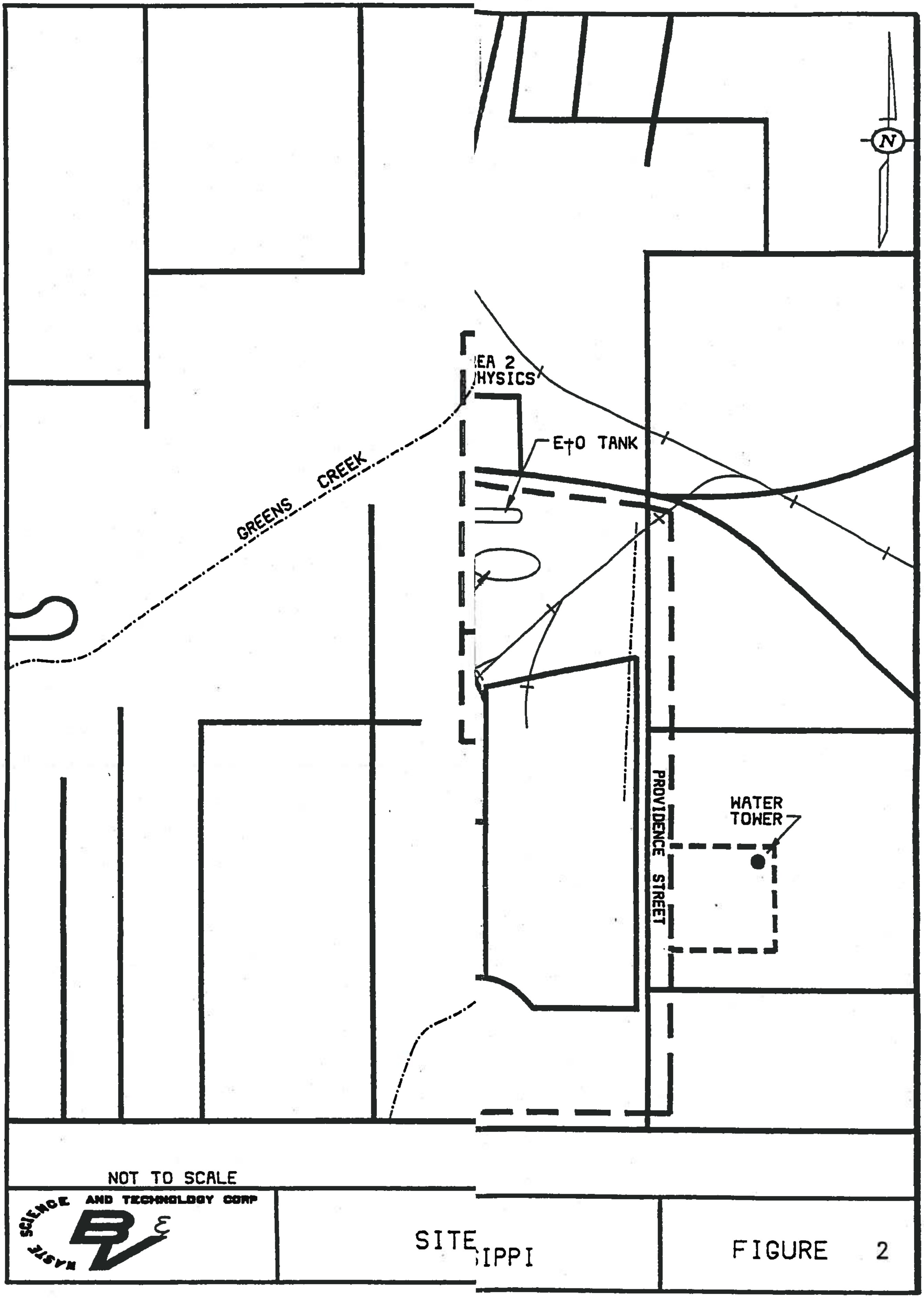
The Hercules facility is approximately 200 acres in size. The facility consists of a complex chemical operation that involves wood grinding, shredding extraction, fractionation, refining, distillation, and processing of rosin from pine tree stumps. Some of the products manufactured at the facility are 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


EA 2
HYSICS
E+O TANK
GREENS CREEK
PROVIDENCE STREET
WATER TOWER
NOT TO SCALE
SCIENCE AND TECHNOLOGY CORP
SITE
SIPPI
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 corresistive change within the surfical 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

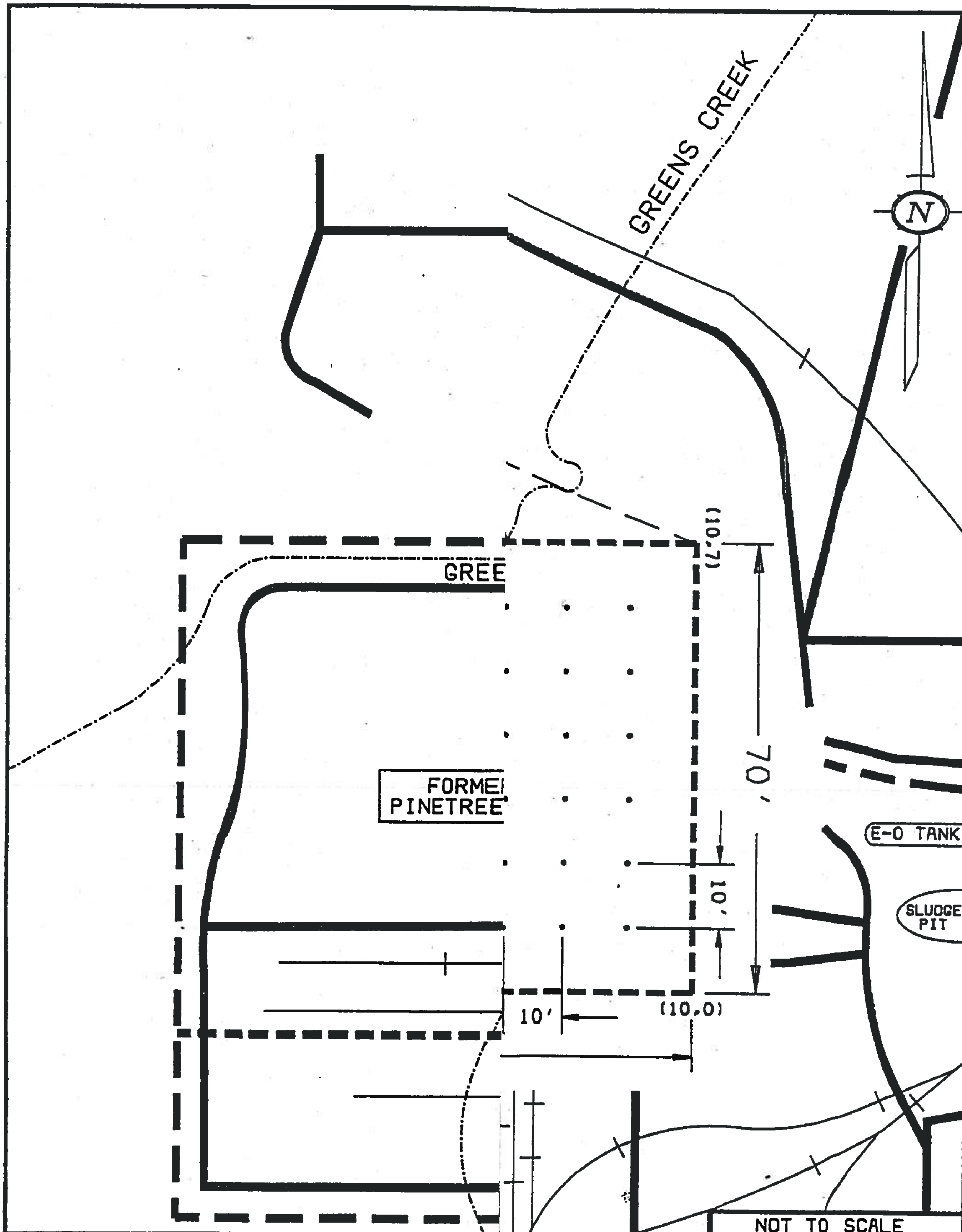
3.1.2.1 The Magnetic Field Intensity Survey. A Geonics-856 proton precession magnetometer was utilized to check and record the intensity of the earth's magnetic field at all station locations. Variations (anomalies) may be caused by the natural distribution of iron oxides or by the presence of buried 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).

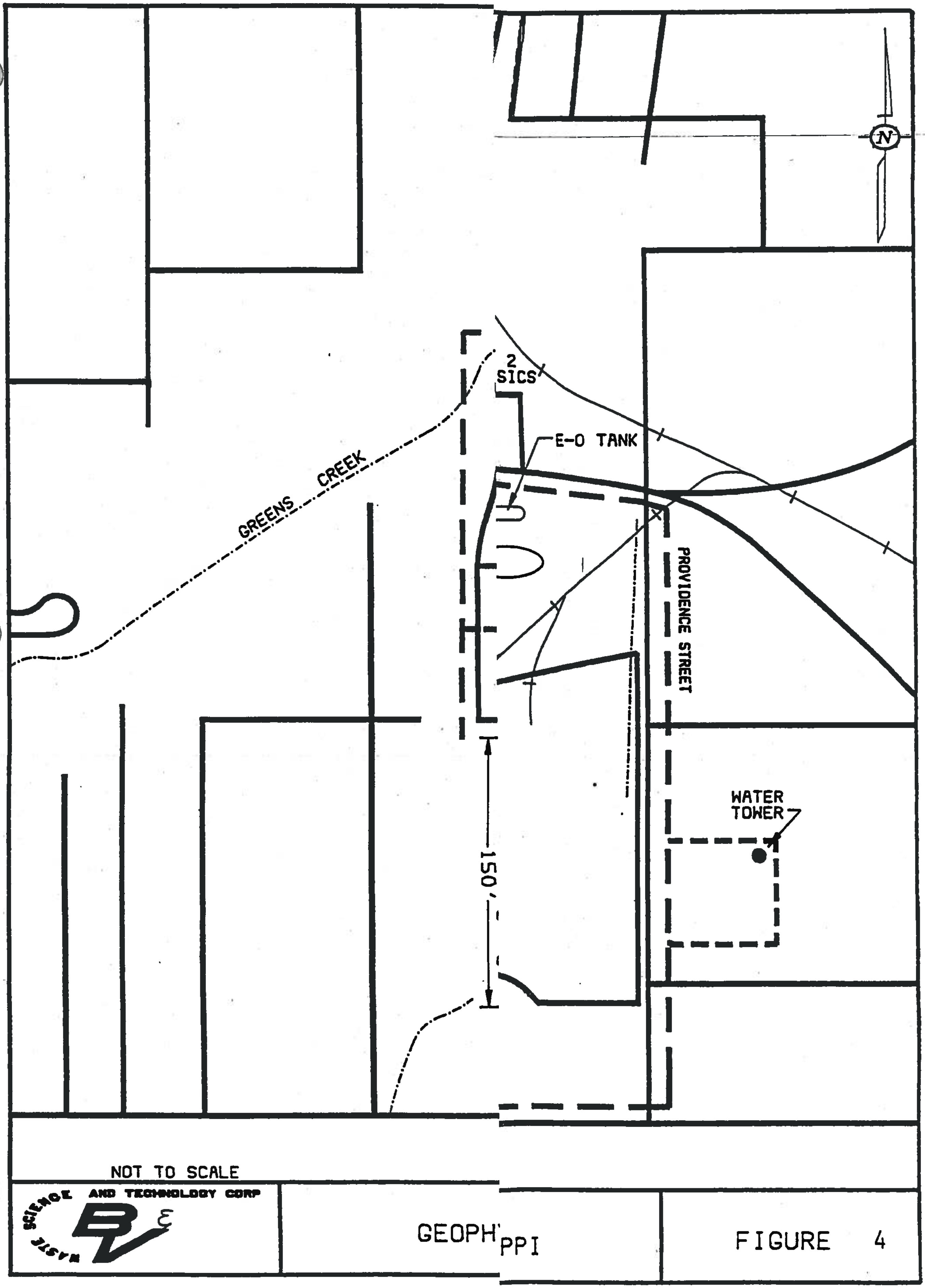
3.1.2.3 Geophysical Results. The geophysical results from Area 1 using the Geonics-856 magnetometer depicts two distinctive anomalies. This area contains no surficial interference (Ref. 6). The area of interest extends from X = 4 to X = 8 and Y = 1 to Y = 5. Figure 5 is the contour map of magnetic intensities 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



WASTE SCIENCE AND TECHNOLOGY CORP

GEOPI IPPI

FIGURE 3



2 SICS
E-O TANK
GREENS CREEK
PROVIDENCE STREET
WATER TOWER
150'
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SCIENCE AND TECHNOLOGY CORP
GEOPH' PPI
FIGURE 4

AREA 1 MAGNETIC INTENSITY CONTOUR MAP (NANOTESLA)

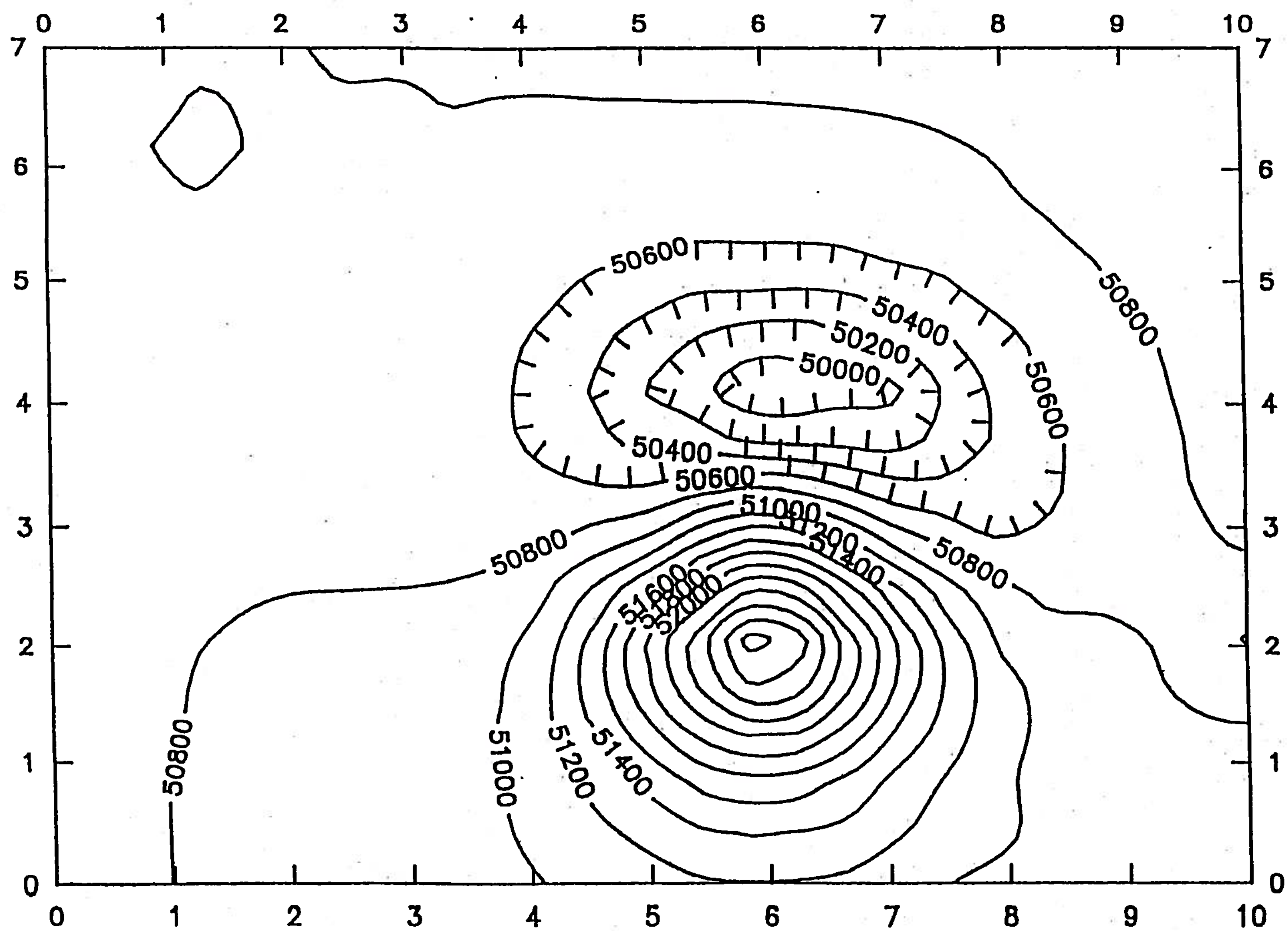

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FIGURE 5

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

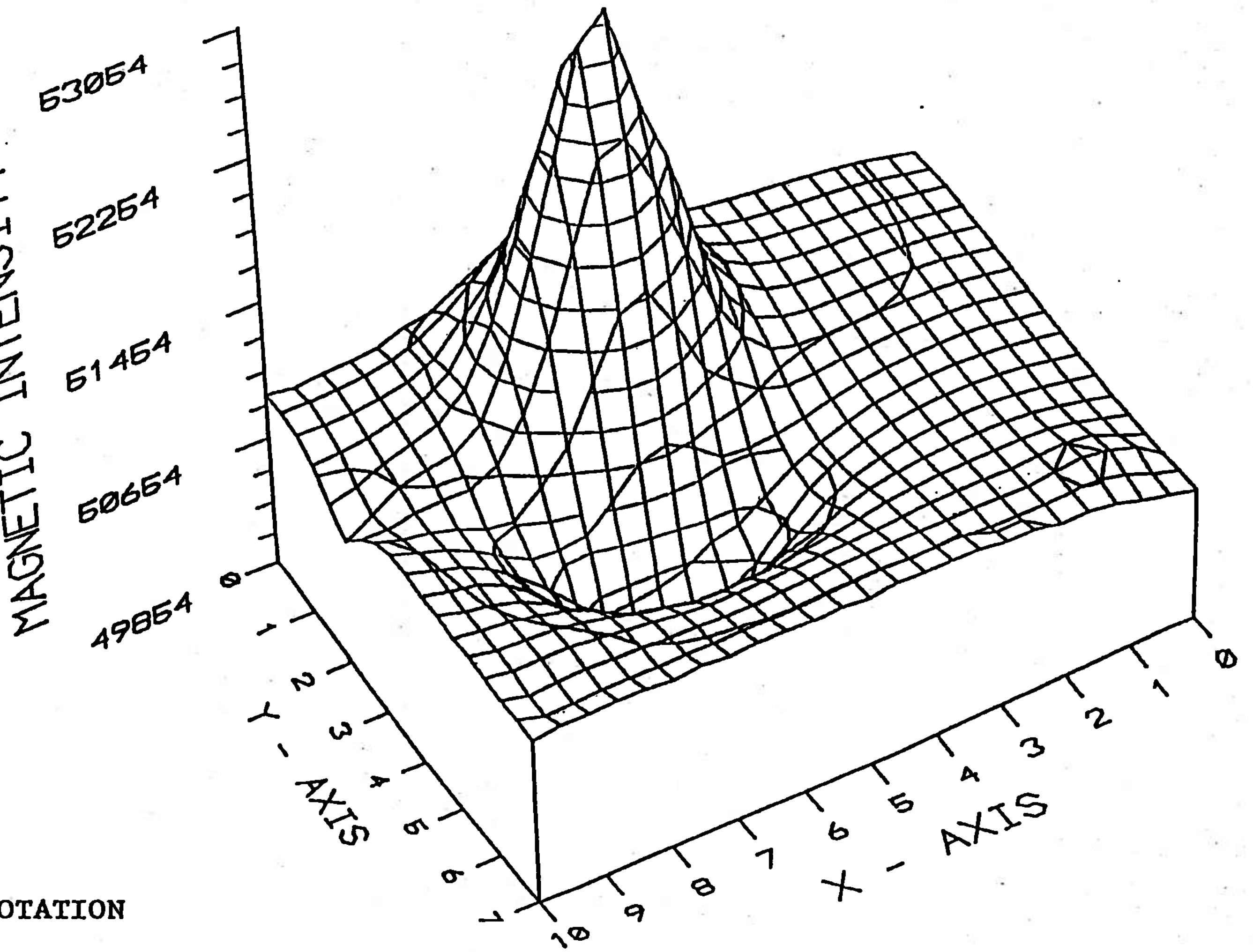
The highest magnetic intensity reading occurs at station (6, 2) and measures 53,387 nanotesla (Ref. 6). The lowest magnetic intensity reading occurs at station (6, 4) and measures 49,720 nanotesla (Ref. 6).

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" anomolous 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

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FIGURE 6

AREA 1 SUBSURFACE CONDUCTIVITY CONTOUR MAP MMHOS/M

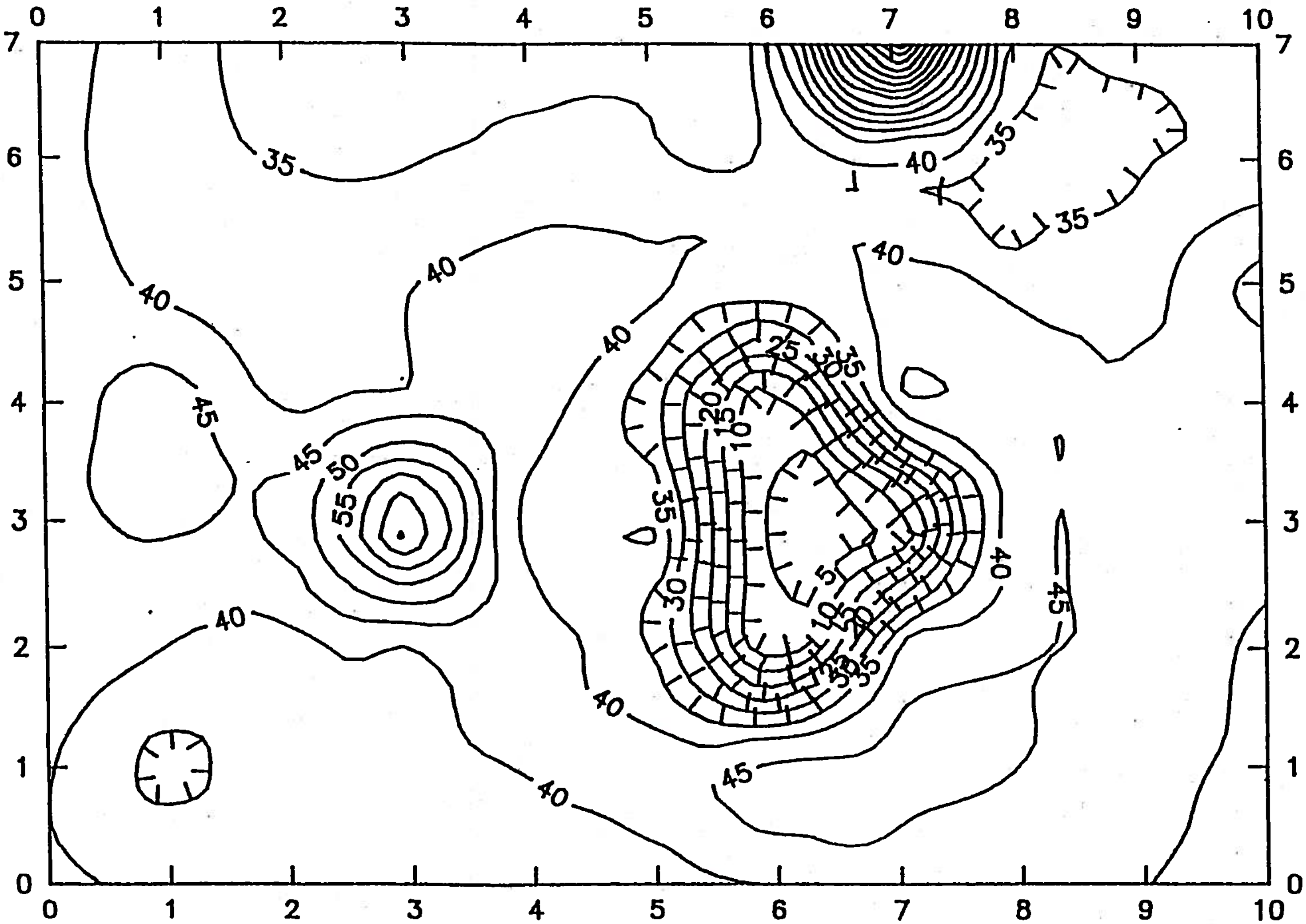

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FIGURE 7

AREA 1 PLOT OF SUBSURFACE CONDUCTIVITIES

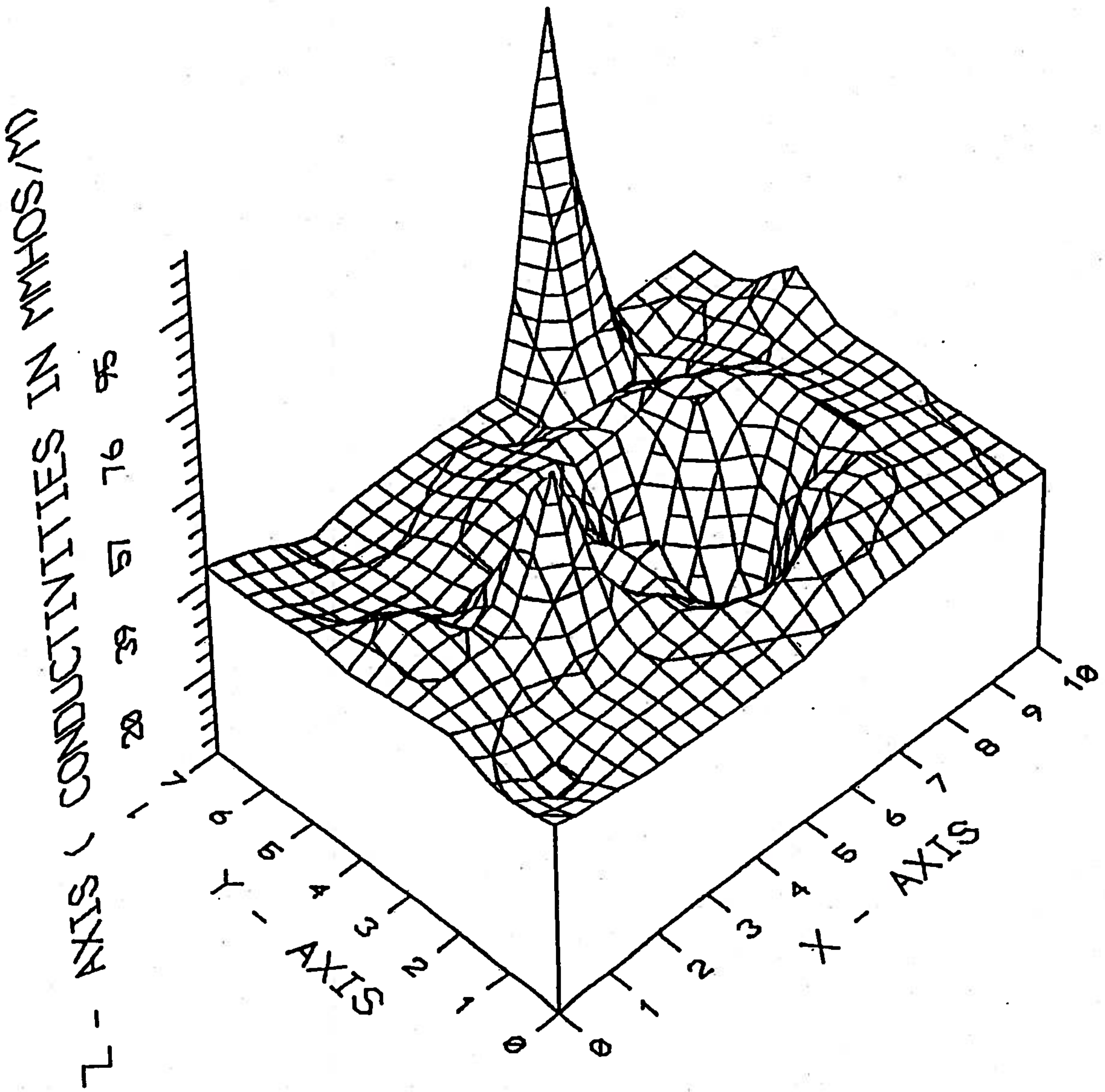

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FIGURE 8

AREA 2 MAGNETIC INTENSITY MAP (NANOTESLA)

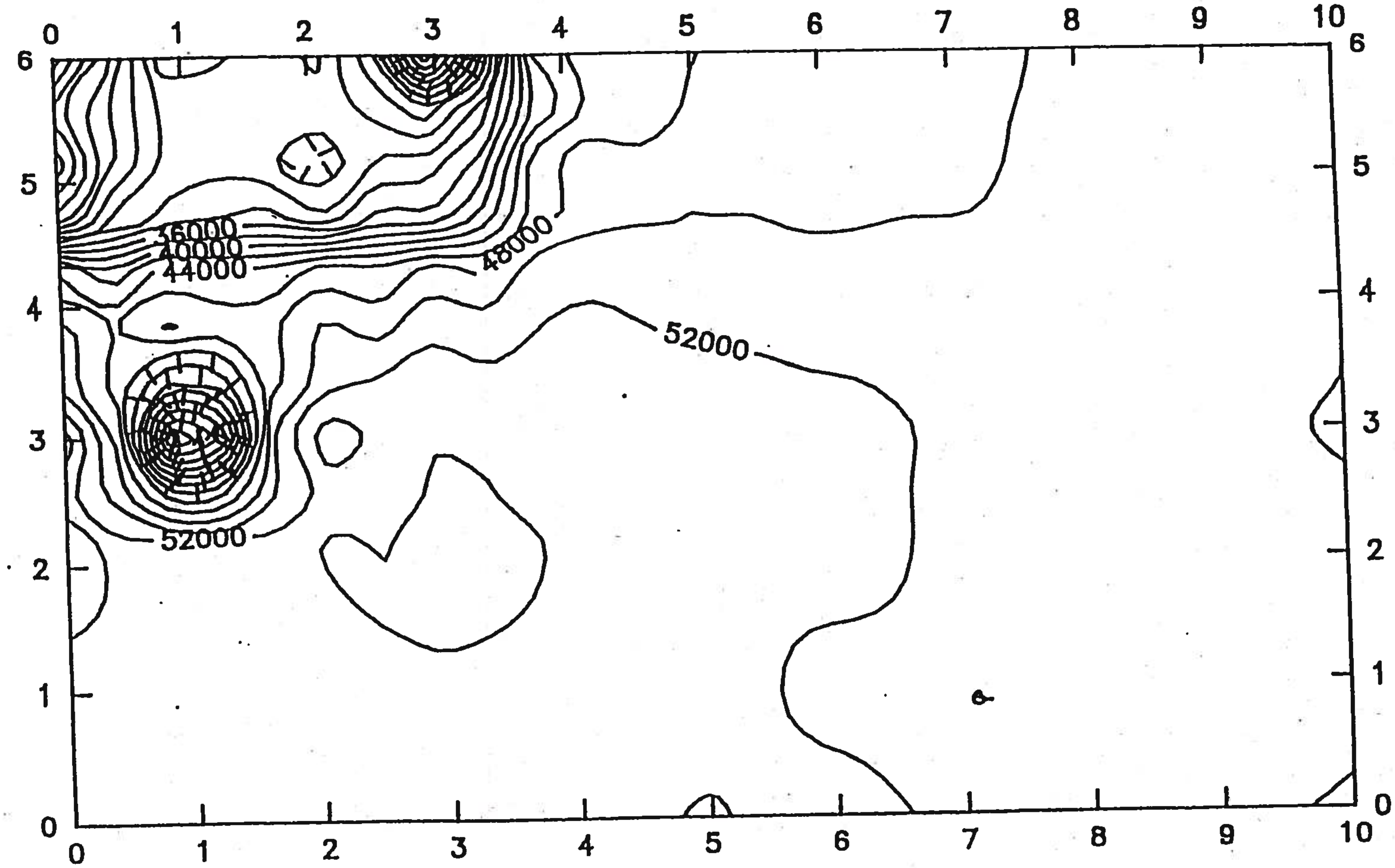

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FIGURE 9

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."

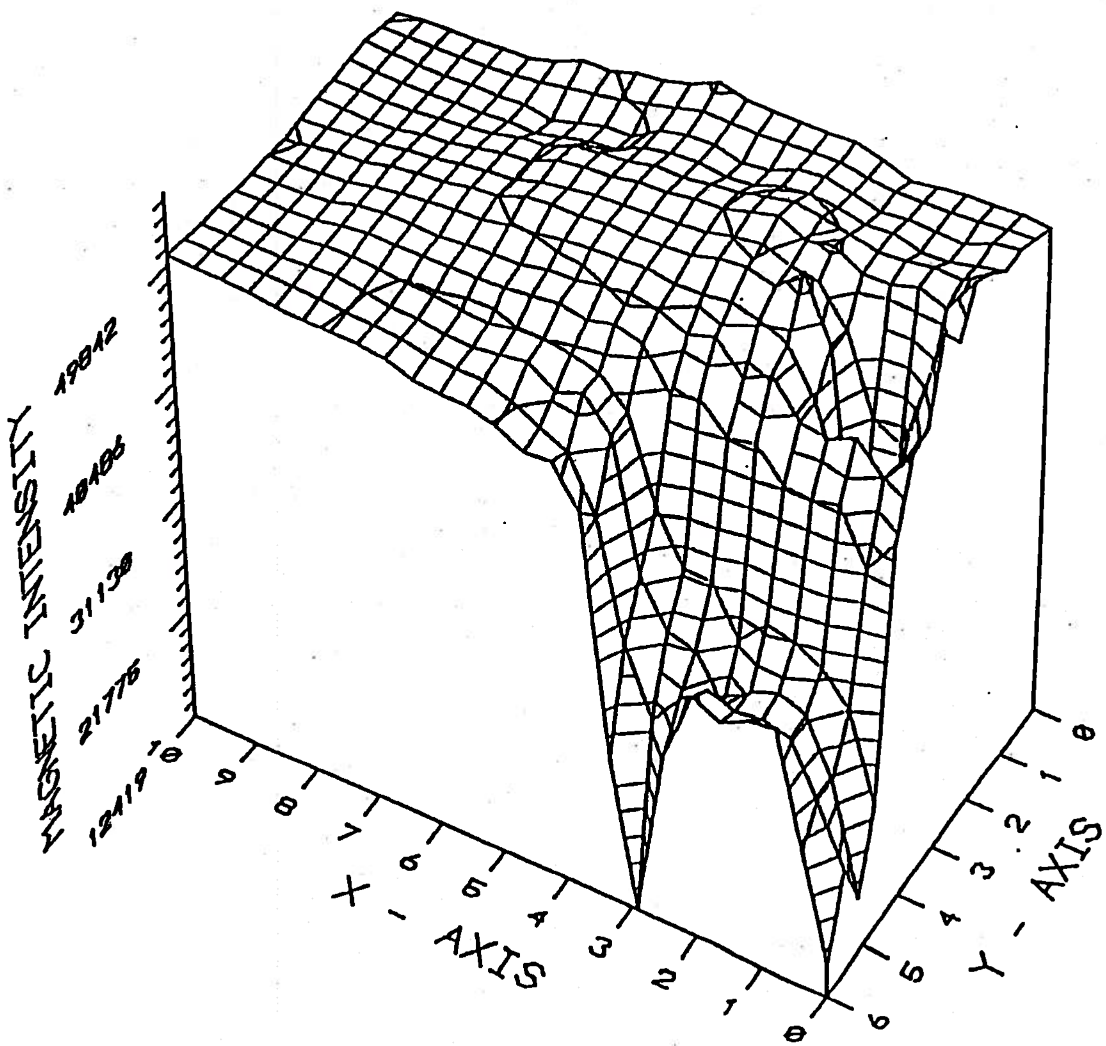
Results from the EM-31 conductivity meter, in the "comp" (in-phase) mode yields data which illustrates a low of 0 mmhos/m at station (1,4) and a conductive high of 210 mmhos/m at station (3,4) (Ref. 6). Figure 11 is the subsurface conductivity contour map for Area 2. The contour interval is 10 mmhos/m. Figure 12 is a 3rd dimensional reflection of conductivies 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 inconsistences, 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

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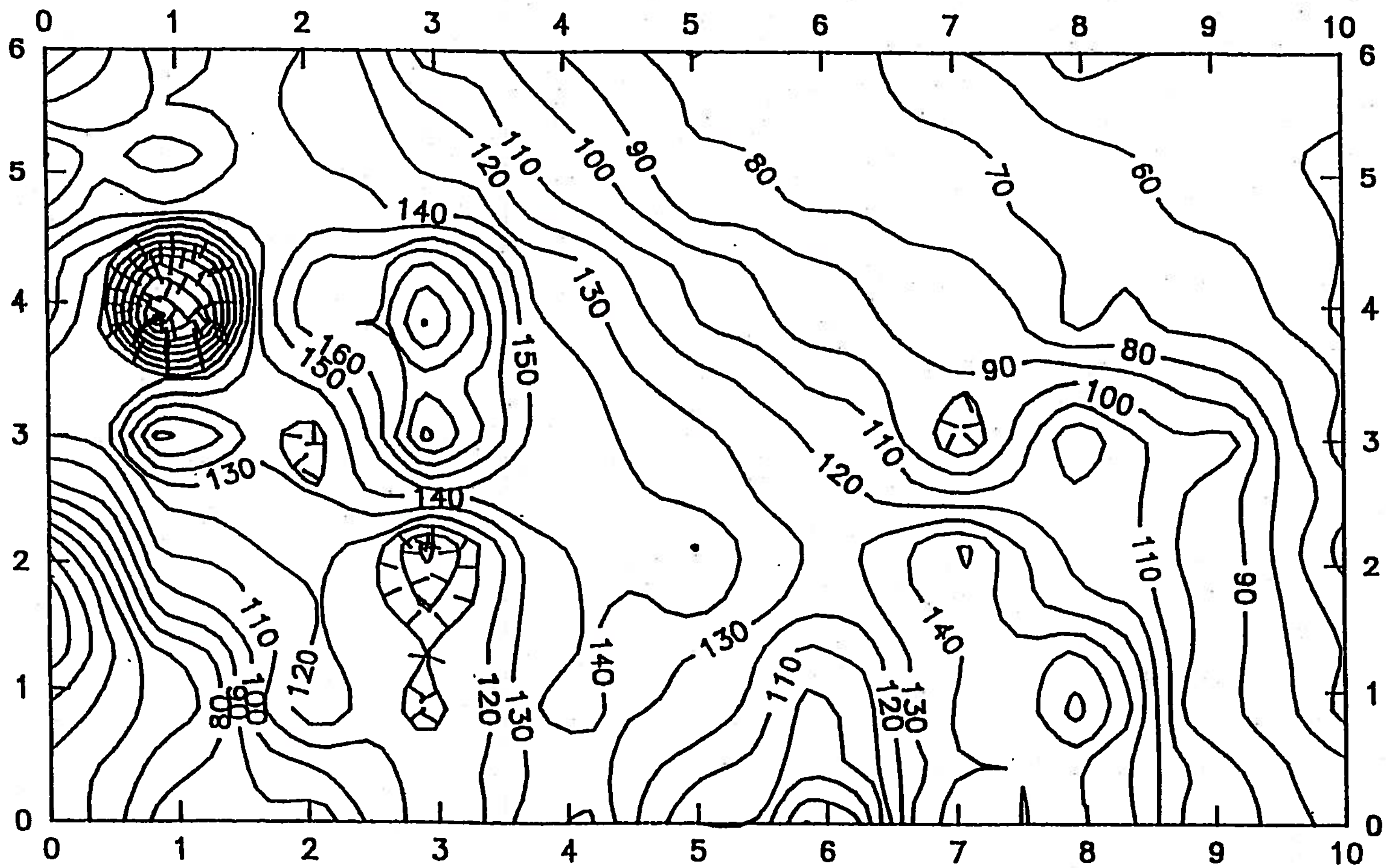
FIGURE. 10

AREA 2 SUBSURFACE CONDUCTIVITY CONTOUR MAP MMHOS/M



MASTIC SCIENCE AND TECHNOLOGY CORP

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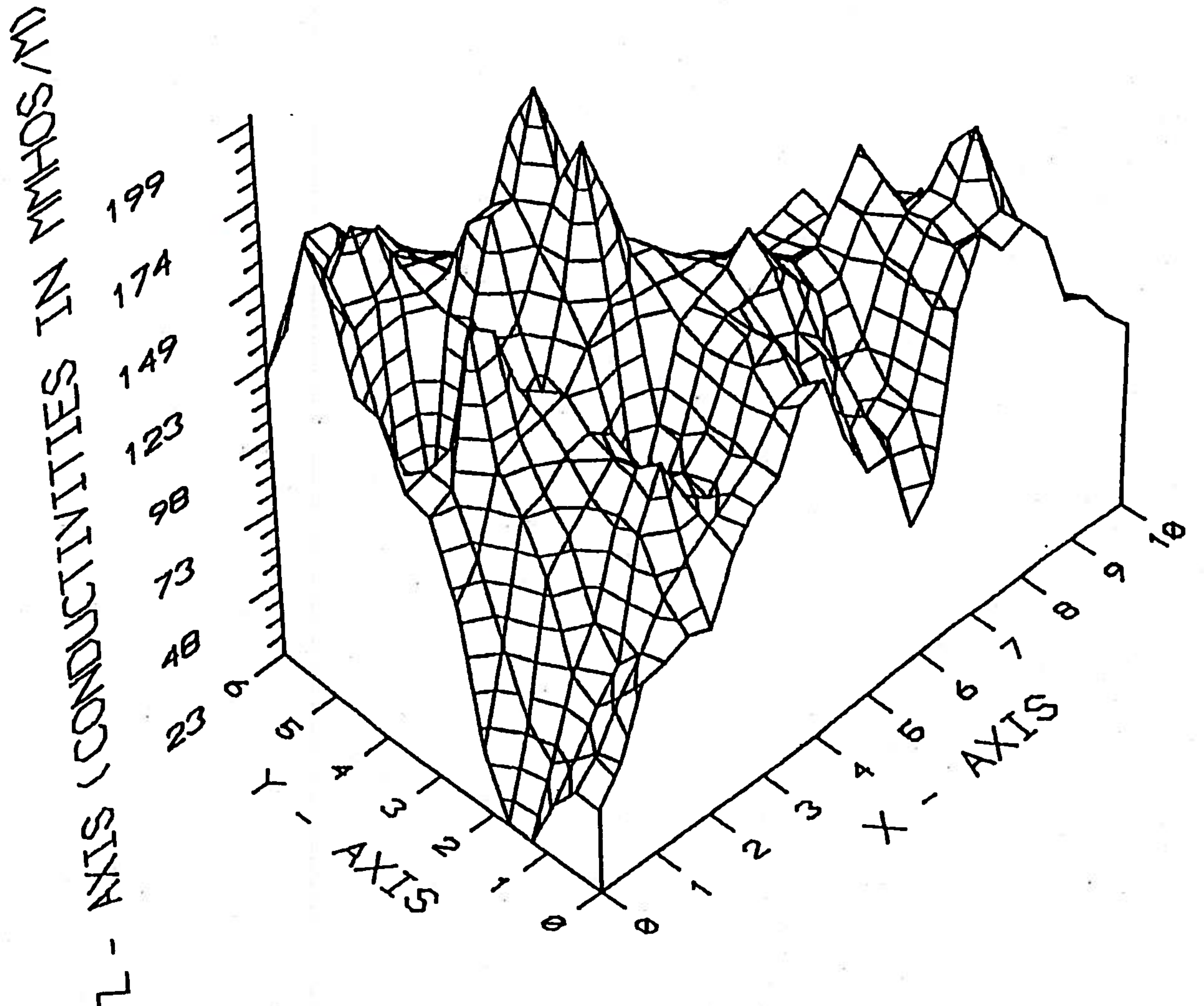
FIGURE 11

AREA 2 PLOT OF SUBSURFACE CONDUCTIVITIES



BASIC SCIENCE AND TECHNOLOGY CORP	HERCULES, INC. HATTIESBURG, FORREST COUNTY, MISSISSIPPI	FIGURE 12

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.

ESI

APPENDIX B

TERRAIN CONDUCTIVITY METHODS

Peterman

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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Complete Proceedings of the 1982 National Conference 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]

$$\rho \text{ sample} = \rho \text{ moisture} \times \frac{1}{\sqrt{(\text{soil porosity})^3}} \tag{1}$$

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" 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-

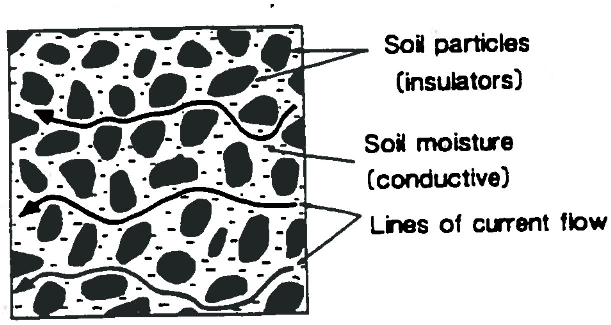


Figure 1.
Electric model of soil sample

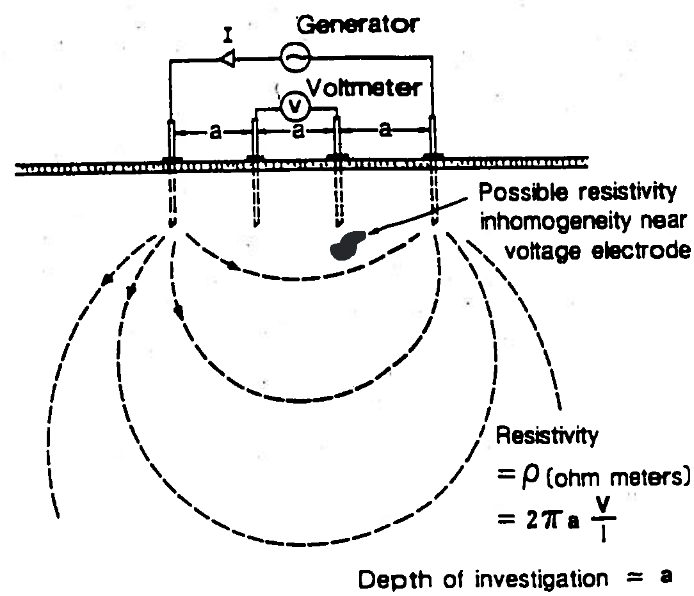


Figure 2.
Conventional resistivity (Wenner array)

ner array it is usually considered to be approximately a. The resistivity of the ground for the Wenner array is given as:

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

where ρ = resistivity (Ωm)
a = inter-electrode spacing (m)
I = current flowing through outer electrodes (amps)
V = voltage across inner electrodes (volts)

Although widely used for resistivity surveys, there are several disadvantages related to the use of electrodes:

- It may be difficult or impossible to drive electrodes into compact earth. It is impossible to survey in the winter when the ground is frozen.
- The presence of resistive inhomogeneities (for example, rocks) near the voltage electrodes can cause large measurement errors, even though the physical size of the inhomogeneity is much smaller than the anticipated depth of exploration. Reconnaissance surveys are usually carried out by making a series of measurements along the survey line at constant inter-electrode spacing to achieve essentially constant depth of exploration. The survey data are plotted as a profile of measured resistivity along the survey line. Such profiles can be quite "noisy" due to electrical inhomogeneities with the result that the presence of subtle changes in resistivity caused by a contaminant, might be missed by the interpreter.
- In order to make a measurement the four electrodes must be accurately spaced (Fig. 2) and a total length of wire equal to 4a must be connected between the electrodes and the instrumentation. Thus the process is laborious and progress is slow. Even for the most organized surveys the survey costs on a line-mile basis are high.

These high costs lead in turn to several important consequences:

- Within the presumed anomalous area, insufficient measurements may be carried out to accurately characterize the plume.
- Outside of the anomalous area, insufficient measurements may be carried out to accurately characterize the background against which the plume is to be contrasted or to determine the existence and nature of other anomalous regions which may exist and which may or may not be caused by contaminants.
- In areas of complex hydrogeology a time-consuming and expensive survey may be performed, to learn, at the conclusion, that the data are inconclusive. The contaminant may simply not be present in sufficient quantities to produce a marked and unambiguous anomaly over the survey geological noise. Since such cases do occur, the inclination to carry out further resistivity surveys can be greatly tempered by a few such failures, which is unfortunate since resistivity measurement is often the single most successful method in delineating contaminant plumes.

It was in recognition of the usefulness of resistivity and the high cost of the conventional methods that inspired the research staff at Geonics Limited to examine the application of electromagnetic techniques for making resistivity measurements.

ELECTROMAGNETIC SURVEY TECHNIQUES

Let a small transmitter coil be situated on or close to the earth, as indicated in Fig. 3. An alternating voltage, typically at an audio frequency, is applied to the terminals of this coil, causing a current to flow. This current generates an alternating magnetic field which, through Faraday's Law, causes electrical currents to be induced in the earth (no such current is induced in the air, which is effectively infinitely resistive).

The induced currents in the earth generate a secondary magnetic field. Both the primary and the secondary fields are detected by a receiver coil located near the transmitter coil, as shown in Fig. 3, and, in principle, measurement of the ratio of the secondary to the

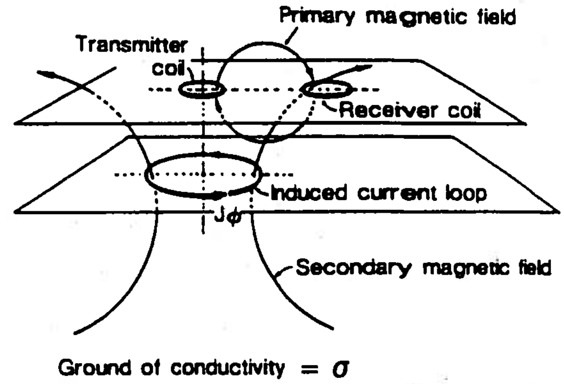


Figure 3.
Inductive electromagnetic fields

primary magnetic field strength can be used to determine the electrical resistivity of the earth. In general, however, this ratio is an extremely complicated function of the resistivity, the distance beween the transmitter and receiver coils, and the frequency of the transmitter current, so that interpretation of the results in terms of the resistivity is quite involved.[2,3] Furthermore, the depth of investigation is also a complicated function of the same three parameters.

Fortunately a substantial simplification in the response function results when the energizing frequency is chosen to be sufficiently low so that the condition known technically as "operation at low values of induction number" is fulfilled.[3] For the remainder of this paper all reference to the use of inductive electromagnetic techniques assumes that the condition of a low induction number has been met.

For example, for low values of induction number the ratio of the secondary to primary magnetic field at the receiver becomes simply:

$$\frac{H_s}{H_p} = \frac{i2\pi f\mu\sigma s^2}{4} = \frac{i\pi f\mu\sigma s^2}{2} \quad (3)$$

where f = operating frequency (Hz)
s = intercoil spacing (m)
σ = ground conductivity which is the reciprocal of resistivity (mho/m)
μ = permeability of free space (a constant)

and the quantity i ($=\sqrt{-1}$) indicates that the magnetic field arising from the induced currents in the ground is phase shifted by 90° with respect to the primary magnetic field, greatly simplifying measurement of the small ratio given by Eq. 3.

For the four-electrode resistivity measurement, Eq. 2 indicates that the ratio of the voltage across the inner two electrodes, divided by the current through the outer electrodes, is linearly proportional to the terrain resistivity. For the electromagnetic measurement, Eq. 3 shows that the magnetic field ratio is linearly proportional to the ground conductivity rather than resistivity, since, subject to the constraint of operation at low induction number, the more conductive the ground the larger the current flow in the ground, and the larger the resultant secondary field. Instruments based on this principle are therefore called ground conductivity meters.

There are further advantages and some disadvantages to measurement of terrain conductivity using the principles outlined. The advantages fall into two main groups; ease of calculation of system response to a layered earth and operational simplicity.

Calculation of Layered-Earth Response

In general, the resistivity or conductivity of the earth varies with depth; for example in a typical vertical profile the conductivity will initially increase with depth due to increasing soil moisture, becoming essentially constant at the water table due to saturation. If the underlying bedrock has very low porosity, the conductivity would now decrease. Such a continuous conductivity profile, shown 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:

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

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

$$\rho a = 2\pi a \frac{V_\ell}{I} \qquad (5)$$

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:

$$\sigma a = \frac{4}{2\pi f \mu s^2} \frac{H_s}{H_p} \qquad (6)$$

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

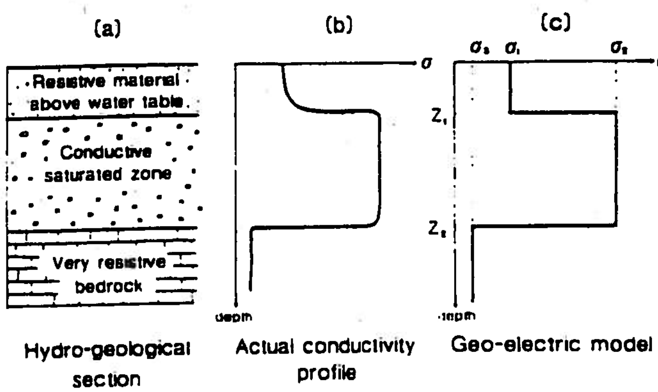
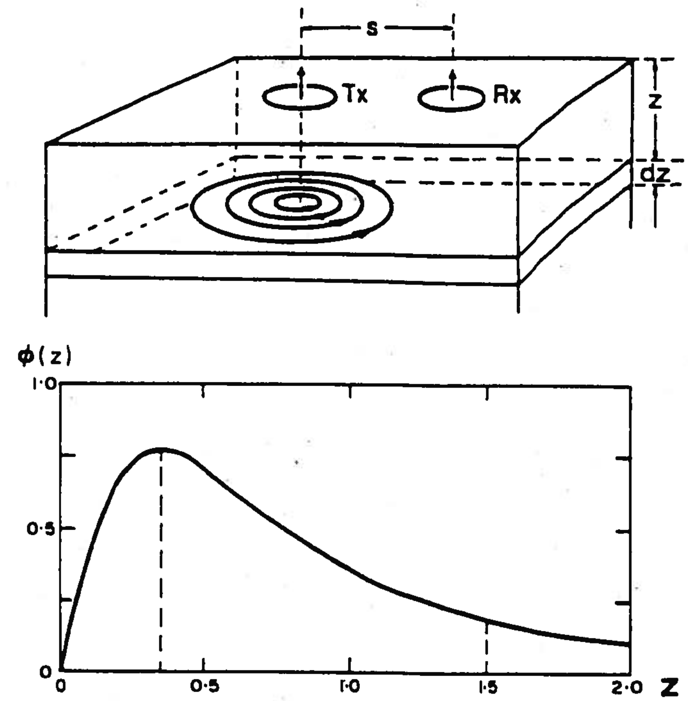


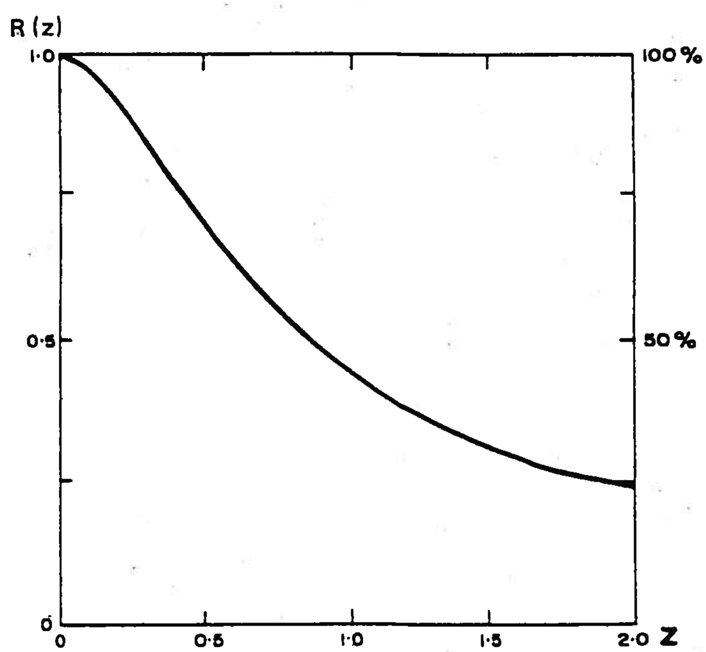
Figure 4.
Typical ground conductivity profile



$$\phi(z) = \frac{4z}{(4z^2+1)^{\frac{3}{2}}}$$

where z = depth / intercoil spacing

Figure 5.
Relative sensitivity to ground at various depths



$$R(z) = \frac{1}{(4z^2+1)^{\frac{1}{2}}}$$

where z = depth / intercoil spacing

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

intercoil spacings. To construct such a response curve for conventional resistivity techniques is not possible due to the interaction of current flow at different depths.

Knowing the relative response to material at any given depth, it is possible to generate from Fig. 5, the curve of Fig. 6 which gives the cumulative contribution to the meter reading from all material below any depth "z" (again normalized with respect to the intercoil spacing). This curve can be used to quickly calculate the apparent conductivity from a layered earth as follows,[3] using the data from Table 1.

Table 1.
Postulated Geoelectric Section (Fig. 4)

Uncontaminated Area		Contaminated Area	
ρ_1 = 200Ωm	σ_1 = 5 mmho/m	ρ_1 = 200Ωm	σ_1 = 5 mmho/m
t_1 = 5 m	z_1 = 5 m	t_1 = 5 m	z_1 = 5 m
ρ_2 = 50Ωm	σ_1 = 20 mmho/m	ρ_2 = 25Ωm	σ_2 = 40mmho/m
t_2 = 10 m	z_2 = 15 m	t_2 = 10 m	z_2 = 15 m
ρ_3 = 1000Ωm	σ_3 = 1 mmho/m	ρ_3 = 1000Ωm	σ_3 = 1 mmho/m

where σ (mmho/m) = 1000/ρ (Ωm)
and t_i is the thickness of the ith layer
and z_i is the distance from the surface to the bottom of the ith layer.

Assuming the intercoil spacing is 10 m, all of the material below 0 meters produces 100% of the instrumental response, all the material below 5 m produces 70% of the instrumental response and all below 15 m produces 31% of the response. Therefore, the material between 0 and 5 m produces 100-70 = 30% of the total response and the material between 5 and 15 m produces 70-31 = 39% of the response. Since each layer produces its own contribution independently of that from the other layers, regardless of their conductivity, to obtain the apparent conductivity one simply adds the relative contribution from each layer, weighted according to its own conductivity:

$$\sigma = \sigma_1 \times 0.30 + \sigma_2 \times 0.39 + \sigma_3 \times 0.31$$

or, more generally :

$$\sigma_a = \sigma_1 (1-R(z_1)) + \sigma_2 (R(z_1)-R(z_2)) + \sigma_3 (R(z_2)) \qquad (7)$$

where R(z) is the function given in Fig. 6.

For the uncontaminated area:

$$\begin{aligned}\sigma_a &= 5\,(1-0.70) + 20\,(0.70-0.31) + 1\,(0.31)\\ &= 1.50 + 7.80 + 0.31\\ &= 9.61 \text{ mmho/m}\end{aligned}$$

whereas for the contaminated area:

$$\begin{aligned}\sigma_a &= 5\,(1-0.70) + 40\,(0.70-0.31) + 1\,(0.31)\\ &= 1.50 + 15.60\\ &= 17.41 \text{ mmho/m}\end{aligned}$$

Because of the contributions from the first and third layers, the apparent conductivity has less than doubled.

The equation for R(z) is extremely simple (Fig. 6), so the calculation of the apparent conductivity for any number of layers can be carried out with the simplest pocket calculator or, using the graph, by hand. The contribution from each layer to the total is immediately apparent, and it is simple to calculate the variation caused by changes within any given layer.

In the example, a 2/1 change in the middle layer conductivity produced a 1.8/1 change in the overall apparent conductivity. If, however, the conductivity of the first layer increased from 5 to 25 mmho/m, for example, by encountering a region with high clay content, the contribution from this layer would increase from 1.5 to 7.5 mmho/m which could be confused as an increase in the contaminant in the second layer. The provision for quick and simple calculations of this type facilitates both the planning of surveys and estimating the probability of their success.

Operational Advantages of Electromagnetic Conductivity Measurement

- Resistivity inhomogeneities of a size much less than the anticipated depth of exploration would, if they were located near the voltage electrodes, produce an anomalous measurement which is truly "geological noise" since without further measurements it is not possible to determine the resistivity contrast, the physical location, or the size of the anomaly. In the case of the inductive conductivity technique it can be shown[4] that the current concentration in the ground is highest in the vicinity of the transmitter coil and one might anticipate that this technique would be especially sensitive to inhomogeneities in this location. However, these high amplitude current loops have a small radius and their effect on the relatively distant receiver is negligible. The net result is that in the inductive technique, once the intercoil spacing has been selected to be approximately equal to the desired depth of the exploration, the system is quite insensitive to small, local variations in conductivity, and an accurate measurement of the bulk conductivity is obtained. This is particularly important in studies for groundwater contamination where the changes in the apparent conductivity due to the presence of the contaminant may be rather small. Fortunately variations in the apparent conductivity of 20% are quickly and reliably measured.
- The presence of a highly resistive upper layer offers no barrier to measurements with inductive electromagnetic systems and surveys can be carried out when the upper layer is frozen, through desert sand, and even through concrete (assuming that there are no reinforcing bars).
- With the electromagnetic measurements, the effective depth of exploration is given approximately by one and a half times the intercoil spacing, whereas for conventional resistivity measurements the exploration depth is only one third the array length. There is no necessity to lay out lengths of wire on the ground which are much greater than the exploration depth and there is no requirement for electrodes.
- It is a simple matter to incorporate circuitry which automatically indicates the correct intercoil spacing, thus doing away with the requirement of physically measuring the distance.
- The equipment is lightweight and readily portable. A "two-man" instrument achieves an exploration depth of up to 60 m.

Instrumental Disadvantages of Electromagnetic Conductivity Measurement

The disadvantages of the inductive electomagnetic terrain conductivity meters are instrumental in nature:

- At levels of conductivity below about 1 mmho/m, there simply is not enough response from the small currents induced in the ground to obtain an accurate measurement. At high levels of conductivity, the "low induction number" approximation breaks down and the instrument response becomes increasingly non-linear with conductivity. This constraint also makes it difficult to design an instrument for large depths of exploration.
- The measured ratio of secondary to primary magnetic field is typically 0.3% and often less (Eq. 3). To achieve precision at these levels requires sophisticated electronic design, which results in instruments that are significantly more expensive to manufacture than conventional resistivity equipment.
- Ideally the instrument "zero" would be set by removing the instrument from the influence of all conductive material, including the earth. Obviously this is not possible and it is difficult to establish and maintain this zero to better than a few tenths of a mmho/m over the wide ranges of temperature, humidity, and mechanical shock to which geophysical equipment is routinely exposed. This feature further limits the accuracy in highly resistive ground.
- In principle conductivity sounding with depth can be carried out

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.[3] Finally, by laying the instrument on the ground and making two measurements, one with the device in 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.[3]

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 history[4] 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 Slaine[4] 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 groundwater 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

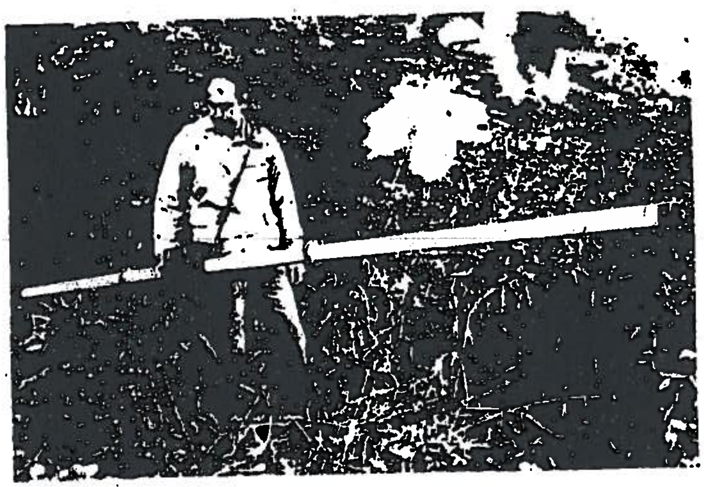


Figure 7.
EM 31

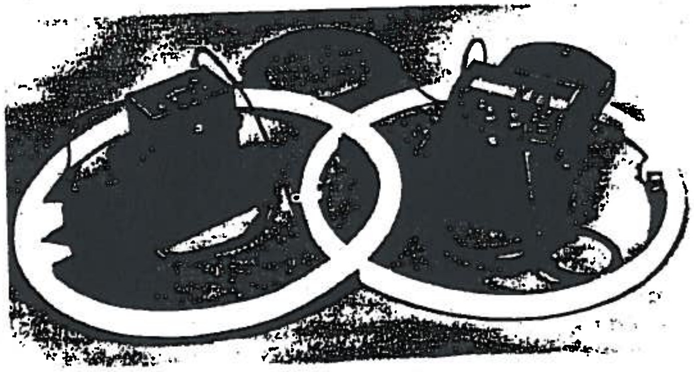


Figure 8.
EM 34-3

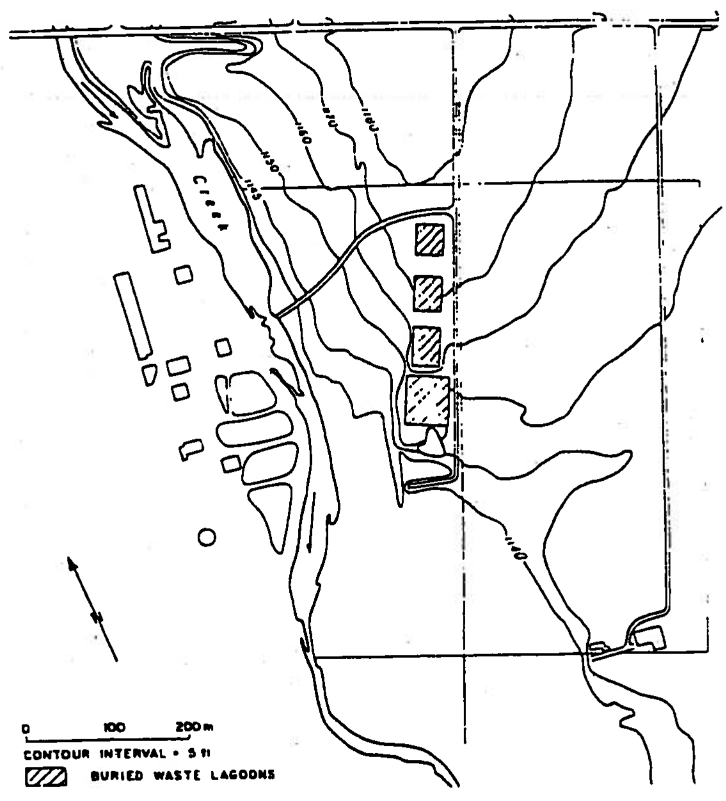


Figure 9.
Survey case history area

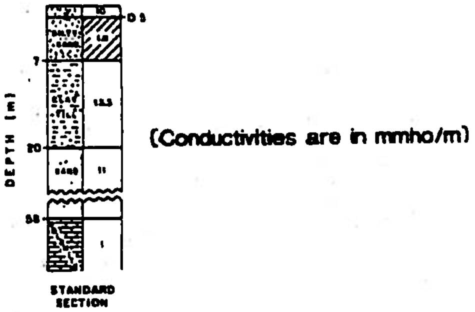


Figure 10.
Hydro-geological and geo-electric section

site. These data are used to construct a hydrogeological model such as that shown in Fig. 10. Alongside each geological unit an estimate is made (generally from previous survey experience) of the electrical conductivity of that unit in order to make a geo-electric section. Next those formations whose conductivity might change due to contamination are identified. For example, in Fig. 10 "the unconfined sand aquifer is apparently isolated from the lower regional sand aquifer by a clay till. Groundwater flow in the upper sand was expected to be horizontal and towards the creek."[6]

In order to determine which instrument, coil orientation, and intercoil spacing is most suitable for the survey, calculations of the type outlined above are performed to obtain the apparent conductivity measured by each instrument or spacing as the conductivity of the postulated contaminated section is allowed to increase. From such calculations the optimum instrument or spacing can be selected, and, furthermore, estimates made of the survey success, since as shown it is a simple matter to vary the conductivities in the geo-electric section (to account for possible errors in their estimated magnitude) and to determine whether these will mask the anticipated anomaly. For this survey site, such calculations suggested that for the EM31, any increase in conductivity of the silty sand formation of more than a factor of about 1.8 would produce a detectable anomaly over the usual background variations, and that for the EM34-3 (used in the horizontal dipole mode) this factor would be about 2.2, both of which would indicate a successful survey since a higher change in conductivity could be anticipated form the contaminant.

> "Measurements were made on a basic 50 m grid covering a 500 x 500 m area centered on the southernmost lagoon...The grid was refined to 25 m for much of the western half of the survey, for a total of 150 stations per instrument. Establishing the grid required 14 man hours; the...EM 31 and EM34 surveys required 10 and 20 man hours respectively."[6]

Greenhouse and Slaine chose a logarithmic base for their data presentation. More specifically, they plotted contours of decibels:

$$20 \log_{10} \frac{\sigma_a (x, y)}{\sigma_a \text{ (background average)}} \qquad (8)$$

where $\sigma_a (x, y)$ = measured values of σ_a over the survey area

σ_a (background average) = average background conductivity (i.e. average value measured off the anomaly).

Thus, the zero db contour outlines the background, and their contour interval of 4 db portrays successive factors of about 1.6 over the background. They suggest three advantages for this technique:

- Logarithmic contours do not cluster close to the course and thus do a better job of defining the plume
- Non-dimensional contour units with a zero background put all instruments on an equal basis
- The procedure is easily automated once σ_a (background average) is identified.

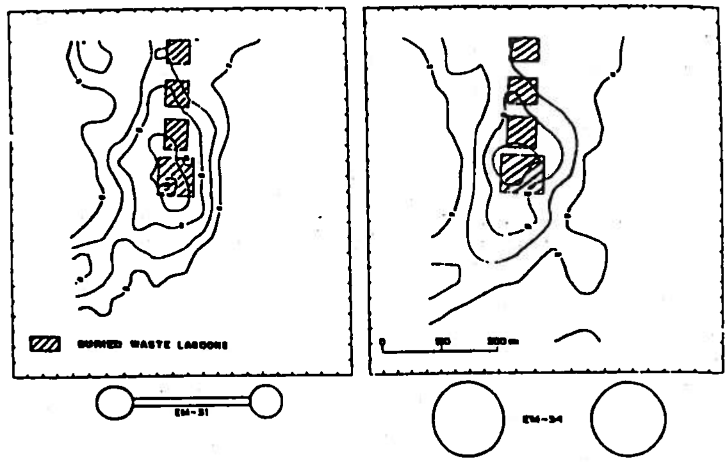


Figure 11.
Survey data

The survey data, shown in Fig. 11, clearly indicate a well-defined plume-like anomaly heading toward the creek from the two southern lagoons. As anticipated by the calculations, the anomaly is somewhat larger on the EM31 survey since it is situated more closely at the depth of maximum response for this instrument. Apparently the two northern lagoons were excavated and replaced with clear fill several years ago, explaining the lack of a conductive anomaly at their location. Unfortunately insufficient test well control is available to confirm that the conductivity plume is due to contaminant, as however, seems probable.

CONCLUSIONS

The case history illustrates the important features of the inductive electromagnetic technique viz.—the ease of estimating the survey response, the speed with which surveys can be carried out, and the ability to detect small changes in conductivity. Many conventional resistivity surveys fail to produce convincing results since the high cost usually results in too little data with inadequate resolution and an anomalous region that is not convincingly contrasted against the background. Inductive electromagnetic techniques, while also having disadvantages as discussed previously, do offer features which are particularly well suited to the rapid and accurate mapping of contaminant plume.

ACKNOWLEDGEMENT

Grateful appreciation is extended to J.P. Greenhouse and D.D. Slaine at the University of Waterloo for interesting discussions concerning survey data obtained using electromagnetic techniques.

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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 study[3] 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-received 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 processes at a frequency which is linearly porportional 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 given 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/ft^3 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.

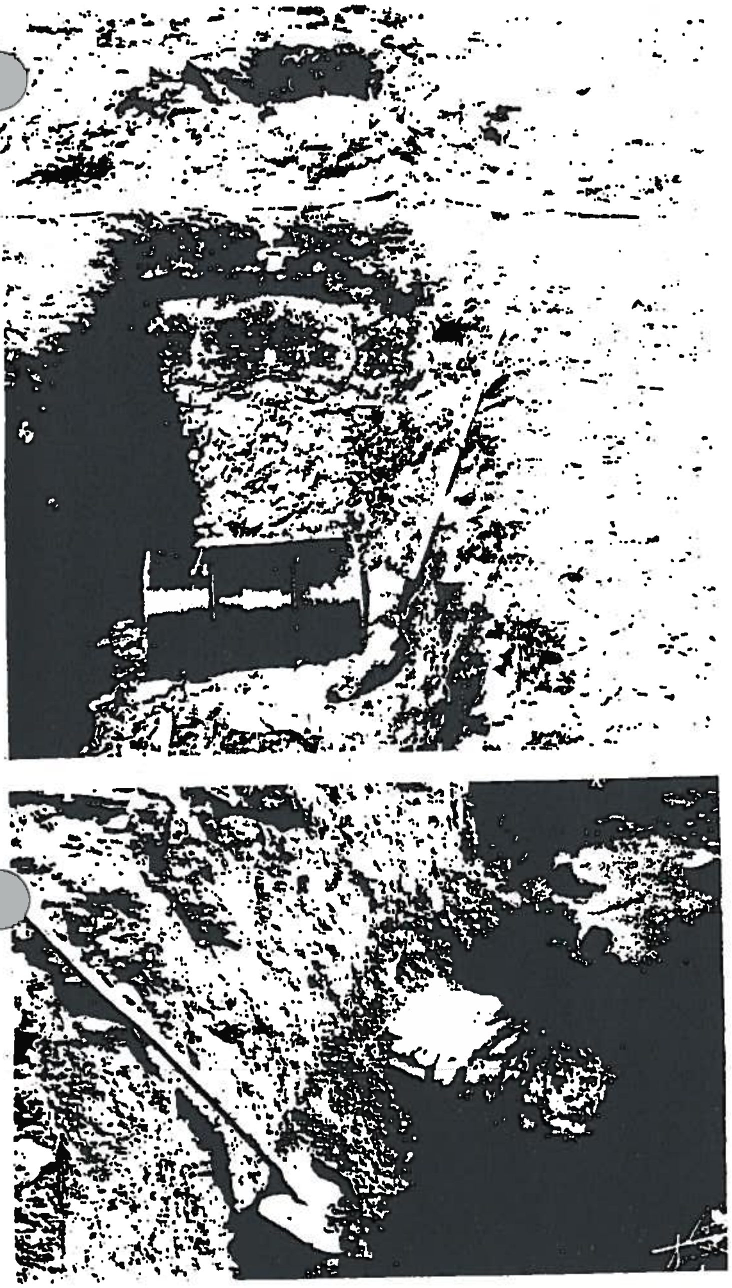

Figure 1.
Photographs of Containers After Placement and During Backfilling. Upper is a 30 Gallon Steel Drum; Lower is a 40 Gallon Plastic Drum.

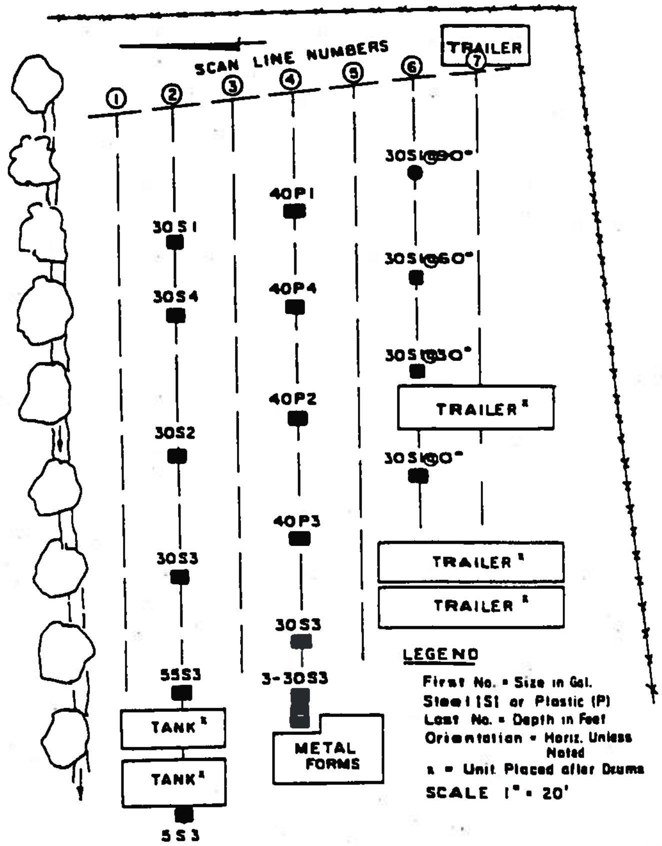

Figure 2.
Plan View of Site Boundaries and General Conditions, Buried Container Deployment and Survey Scan Lines for Various NDT Techniques.

Eighteen (18) steel and plastic containers were placed in backhoe excavated holes that varied from 2 ft to 6 ft deep (see Fig. 1). The soil cover over the containers varied from 1 ft to 4 ft. The container burial patterns were as follows:

- Four 30 gal steel containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Three steel containers (5 gal, 30 gal and 55 gal) buried at 3 ft of cover. (The 30 gal drum was included in the previous pattern.)
- Four 40 gal plastic containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Four 30 gal steel containers buried with 3 ft of cover. Three of the containers were adjacent to one another and the fourth was separated by 16 ft.
- Four 30 gal steel containers with 1 ft of cover were each oriented at 90°, 60°, 30° and 0° with the horizontal.

In general, all containers were cylindrical, placed with their long axis horizontal (except where noted), placed empty, placed approximately 25 ft from each other (except where noted) and backfilled with the same soil that was excavated at the particular location involved. After hand backfilling and tamping soil around the drums, the site was further backfilled and compacted by a heavy dozer, graded off to a level condition and allowed to stabilize for approximately four months. During this time period the contractor brought additional equipment onto the site which made the area more representative of conditions at an actual site. Fig. 2 is a plan of the site, the containers and other relevant items.

RESULTS

Each of the aforementioned NDT techniques were used at the site by making a series of seven parallel scans about 10 ft apart (see Fig. 2), with data being taken at 2 ft intervals along each scan. Fig. 3 contains photographs of two of the techniques during monitoring. Results were transferred from profiles along each scan (results not shown due to paper size limitations), to generalized plan views. These generalized results are presented in this paper.

The metal detector (commercially available from Fisher Company, Model M-Scope)* gave results shown in Fig. 4. The cross hatched areas along scan lines show where the device gave a positive indicate that each metal container was accurately located, but that none of the four plastic containers was located. Positive location of a buried object by the device is given by pinning of the dial. indicator and by an audible signal. Positive signals were observed on scan lines where no containers were purposely buried. This is understandable since the site had numerous metal objects (old cans, reinforcing bars, fencing, springs, etc.) very near to the

*Mention of trademarks or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency or Drexel University.

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.

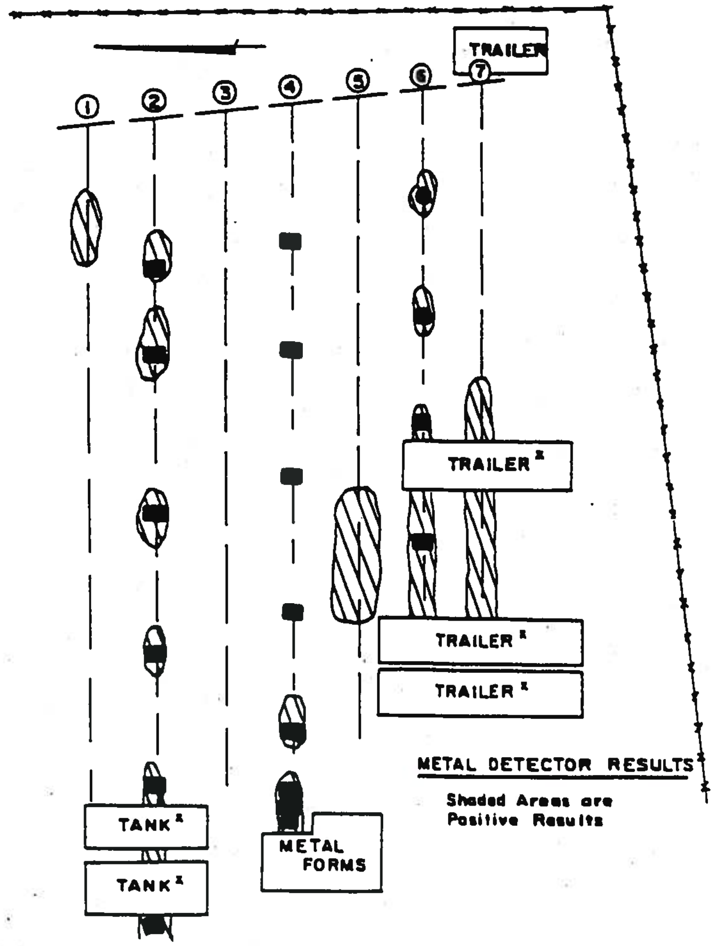

Figure 4.
Plan View of Site Showing Results of Metal Detector (MD) Survey. See Fig. 2 for Actual Container Identification.

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 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

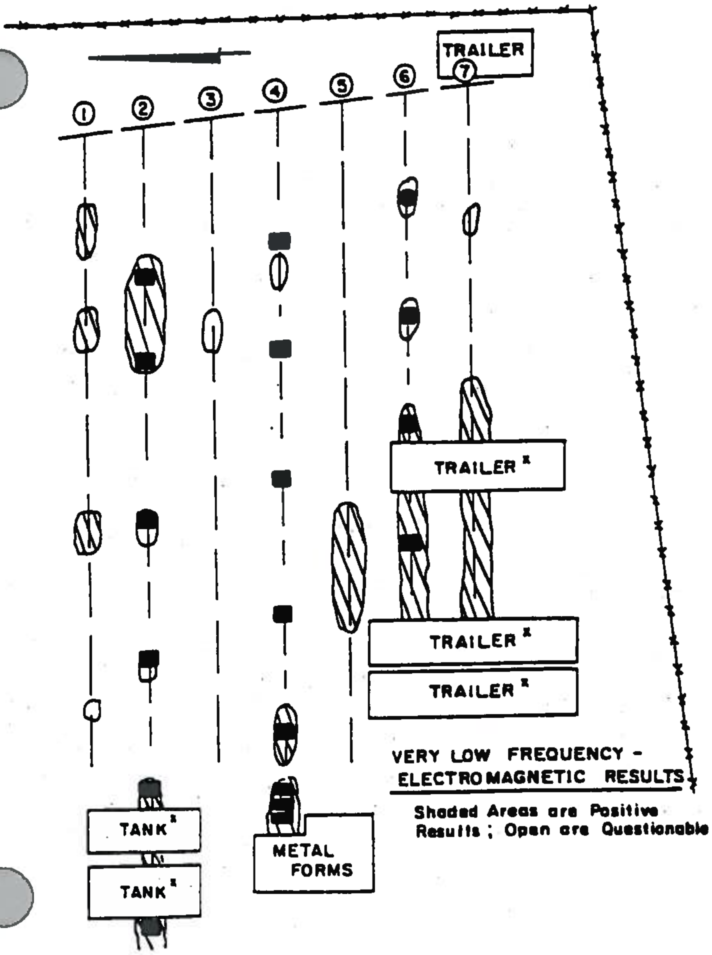

Figure 5.
Plan View of Site Showing Results of Very Low Frequency Electromagnetic (VLF-EM) Survey. See Fig. 2 for Actual Container Identification.

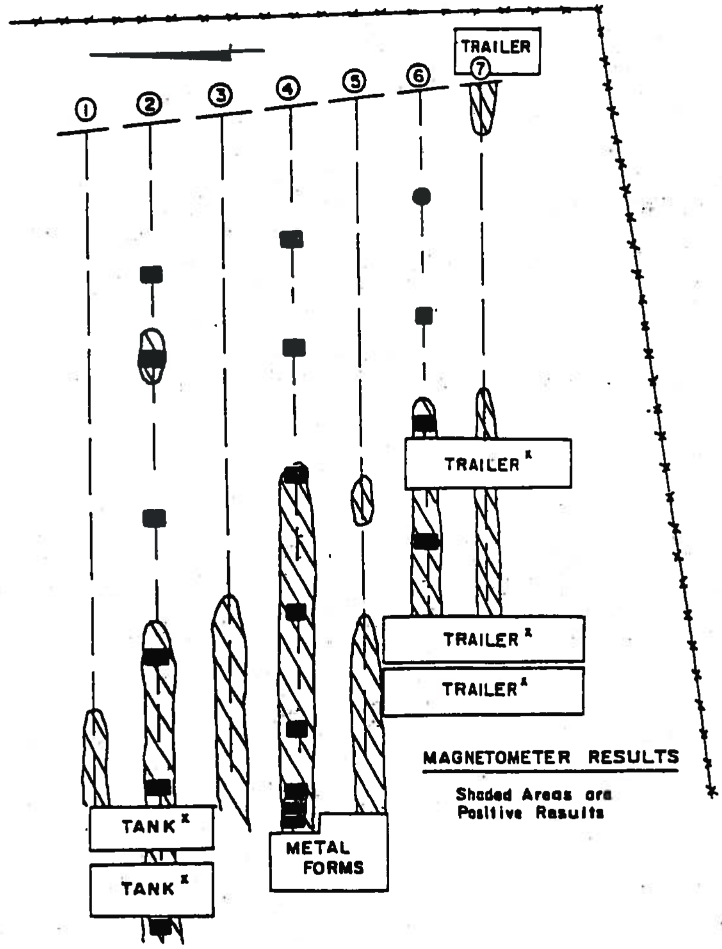

Figure 6.
Plan View of Site Showing Results of Magnetometer (MA) Survey. See Fig. 2 for Actual Container Identification.

from the earlier study.[3] However, neither the MD nor the VLF-EM will give the depth to the reflecting object.

The magnetometer was unsuccessful because of the abundance of buried metal objects. This conclusion was expected and confirmed by this work.

Somewhat surprising was the failure of the ground probing radar to detect even the shallow buried containers. Neither steel nor plastic could be located—a marked departure from the earlier study.[3] Probably the saturated clay soil attenuated the signal before any significant penetration occurred or the background conditions submerged the signal in noise. GPR is the preferred technique known to the authors to give a specific depth to a reflecting object, but in this case was simply not successful.

Other NDT techniques that were marginally successful or unsuccessful at the sandy soil site[3] were not deployed at this saturated clay soil site for the reasons stated earlier.

On the basis of these two studies (reference 3 in dry sandy soil and this one in saturated clay soils), the authors recommend that a high quality metal detector be the first NDT method to be used at a suspect site. Only metal objects, at relatively shallow burials, can be detected, but this is very often the actual situation. The device is inexpensive (about $600), can be obtained from a number of equipment manufacturers, is easy to use, gives both meter and audible inductions of a buried object and is instantaneous. It obviously has drawbacks. Such limitations as only being able to locate metal objects and poor penetration depth are the most pronounced, however, its use as the first method to be deployed is highly recommended.

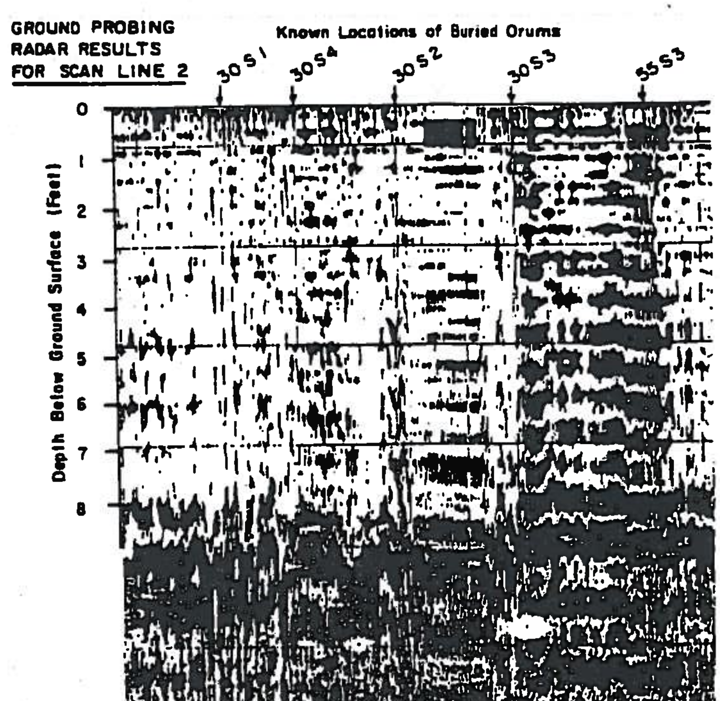

Figure 7.
Ground Probing Radar (GPR) Trace Over Scan Line #2 Showing Arrows Where Five Containers Are Actually Located.

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APPENDIX C

MAGNETIC INTENSITY METHODS