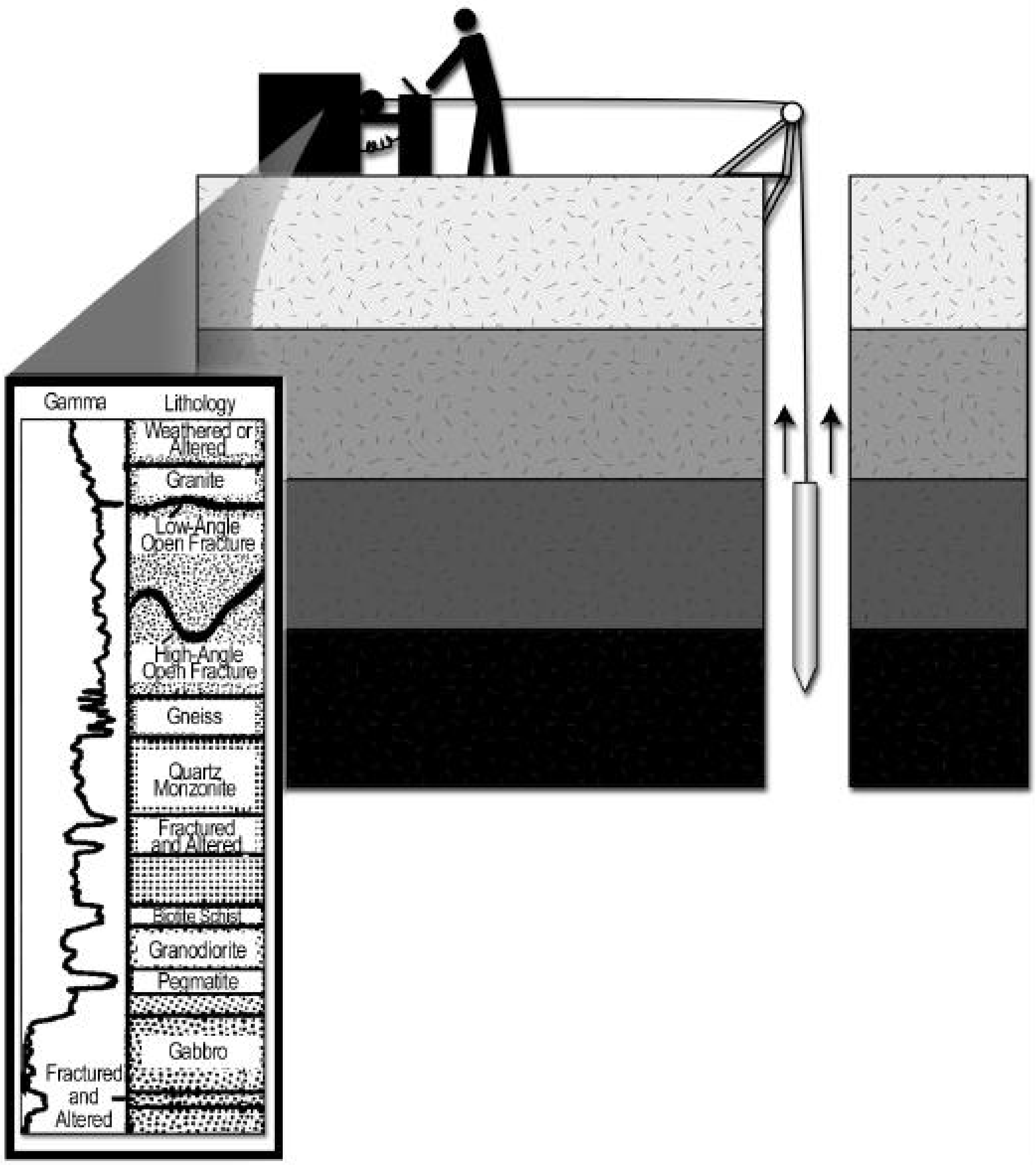
United States
Environmental Protection
Agency

Office of Solid Waste and
Emergency Response
(5102G)

EPA-542-R-00-003
August 2000
www.epa.gov/tio
cluin.org

EPA

Innovations in Site Characterization: Geophysical Investigation at Hazardous Waste Sites



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Comments or questions about this report may be directed to the United States Environmental Protection Agency, Technology Innovation Office (5102G), 401 M Street, SW, Washington, D.C. 20460; telephone (703) 603-9910.

Foreword

This document contains eleven case studies designed to provide performance information for innovative uses of geophysical technologies that support less costly screening for site characterization. The case studies and the technologies that they highlight are included in the following table:

Site Name	Geophysical Technology
Baker Woods Creosoting	Ground Penetrating Radar, Electromagnetometry
Ciba-Geigy Hamblet and Hayes	Ground Penetrating Radar
Crystal Oil Refinery	Ground Penetrating Radar, Electrical Resistivity
Kansas Underground Storage Tank	Electrical Conductivity
Kelly Air Force Base, Zone 4	Vertical Seismic Profiling
Marshalltown Former Manufactured Gas Plant	Electrical Conductivity
New Mexico State Highway and Transportation (NMSHTD) Underground Storage Tank Investigation	Magnetometry, Electromagnetometry, Natural Gamma Logging
New Hampshire Plating	Seismic Reflection Surveys, Ground Penetrating Radar, Natural Gamma, Electromagnetic Induction Logging
Tinker Air Force Base	Seismic Reflection
Trail Road Landfill	Natural Gamma Ray, Magnetometry, Electrical Conductivity, Temperature, Density
Wurtsmith Air Force Base	Ground Penetrating Radar, Electromagnetic Induction, Magnetometry

These case studies are part of a larger series of case studies that will include reports on new technologies as well as novel applications of familiar tools or processes. They are prepared to offer operational experience and to further disseminate information about ways to improve the efficiency of data collection at hazardous waste sites. The ultimate goal is enhancing the cost-effectiveness and providing flexible tools for characterizing hazardous waste sites.

Acknowledgments

This document was prepared for the United States Environmental Protection Agency's (EPA) Technology Innovation Office. Special acknowledgment is given to all of the Principal Investigators for their thoughtful suggestions and support in preparing these case studies.

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INTRODUCTION

Throughout the 1990s, the methods used to characterize hazardous waste sites have changed considerably. Site managers have found that the collection of a limited number of high-quality, high-cost, analytical data points that dominated site characterization in the early part of the decade resulted in a lack of broader understanding of site conditions. The earlier characterization practices also often required long time horizons for the compilation of sufficient data to support remedial decisions. The high costs, long time frames, and limited nature of the information associated with earlier practices have led to the emergence of a number of innovative techniques designed to speed the data collection process, increase the amount of information collected, and lower the overall cost of data collection. The various agencies and departments of the Federal government with responsibility for the characterization and cleanup of hazardous waste sites had all adopted some form of expedited site characterization process by the end of the decade. One set of technologies that has found a natural application in the context of expedited site characterization has been geophysical characterization technologies.

Increasingly traditional geophysical technologies have found new and innovative uses at hazardous waste sites. Geophysical technologies have been used for decades in other industries, principally the petroleum and mining industries, for their ability to describe geological structures deep within the earth's crust. This proven track record that has been easily transferred to the characterization of hazardous waste sites. In fact, geophysical technologies, such as ground penetrating radar, electromagnetometry, and magnetometry, have been in wide use already at hazardous waste sites to locate buried drums and structures that often constitute source areas. The use of geophysical technologies is rapidly expanding to other applications in hazardous site characterization, including the direct detection of aqueous and nonaqueous phase contamination. In several of the investigations discussed in this volume, geophysical technologies were able to detect the presence of either dense or light, nonaqueous phase liquids (D/LNAPLs).

One of the principal missions of the U.S. Environmental Protection Agency's Technology Innovation Office (EPA/TIO) is to disseminate information on the cost and performance of innovative technologies and approaches applicable to the characterization and remediation of hazardous waste sites. The dissemination of this information can stimulate the adoption and use of innovative technologies and approaches on an ever widening scale. This report contains case studies of the innovative application of different geophysical technologies and methods at 11 hazardous waste sites. The technologies described in these case studies do not represent the entire range of geophysical technologies, but do represent innovative applications of the better-known technologies.

1.0 Methodology for Site Selection

In order to prepare a set of 11 case studies that explored the use of geophysical methods at hazardous waste sites, EPA decided that case studies would be prepared for sites only when:

- the investigation took place within the previous five years, to ensure that knowledgeable information sources could still be readily identified;
- the investigation sought to identify site contamination;

- site contamination problems were similar to those encountered under the Resource Conservation and Recovery Act (RCRA), Superfund, and Underground Storage Tank programs; and
- the technology was used in a full-scale application.

EPA initially set out to identify as many geophysical investigations that met the above criteria as possible. Through contacts in EPA's Office of Research and Development research laboratories, requests for information posted in relevant Internet discussion forums, and requests to members of EPA's Groundwater Forum, a group of technical experts distributed across the ten EPA Regional Offices, EPA identified more than 40 individuals with relevant experience. EPA contacted most of these individuals to collect some basic information and compare it to the above criteria.

Over the same period, EPA performed a review of the technical literature published within the previous three years to identify applications that might be used. The literature review was confined to the following sources:

- *Proceedings from the Symposium of Applications of Geophysics to Engineering and Environmental Problems (SAGEEP)*;
- *Groundwater*;
- *Soil and Groundwater Cleanup*; and
- *Environmental Science and Technology*.

From the individuals contacted and the articles identified, EPA identified 27 applications of geophysical technologies that were recent and relevant to the goals of the project. To reduce this number to 11, EPA applied the following criteria to each geophysical investigation:

- Geophysical investigations demonstrated the technology's capability to directly detect, or facilitate the detection of, contamination;
- Adequate documentation was available for the site and the performance of the technology. Also, EPA could ensure reasonable access to the principal investigator, or another person with knowledge of the application; and
- The site was a Superfund site.

Sixteen of the 27 applications were eliminated using this criteria. In some cases, geophysical investigations were selected that did not meet all of these criteria. The geophysical investigation at the Marshalltown Former Gas Manufacturing Plant (FMGP) and the Crystal Refinery sites were conducted as demonstrations, not as a full-scale applications. The investigation at the Trail Road Landfill did not evaluate a hazardous waste site, but a municipal landfill. In each of these cases, the investigations represented techniques for which full-scale applications could not be identified, yet whose results provided relevant and useful information.

2.0 Overview of Case Studies

The case studies describe a number of geophysical technologies and methods that were used at sites with significantly different geological settings and a wide range of types of subsurface contamination. Table ES-1 presents a summary of the geology, contaminants, and geophysical methods used at the 11 case study sites.

The geological settings in which these technologies have been used ranged from simple geological settings with relatively homogeneous stratigraphy, such as those found at Wurtzsmith Air Force Base to the highly heterogeneous mix of sand and clay layers found at the New Mexico Highway Safety and Transportation Department (NMHSTD) site. Overall, simpler geological settings provided fewer challenges to the collection of high quality geophysical data.

The types of contamination that were being characterized fell primarily into three broad groups, chlorinated solvents, petroleum-related compounds, and polyaromatic hydrocarbons. Inorganic contaminants were investigated at two of the sites. At seven of the sites, contaminants were found in a nonaqueous phase liquid (NAPL), either as a dense (DNAPL) or light (LNAPL) compound.

The types of geophysical technologies represented in the eleven case studies include:

- Ground Penetrating Radar[1/] (GPR);
- Electromagnetometry (EM);
- Electrical Conductivity or Resistivity;
- Seismic Reflection or Refraction;
- Magnetometry; and
- Natural Gamma Logging.

The purposes for which geophysical investigations were undertaken varied from the more traditional characterization of site stratigraphy to directly monitoring contaminants in the media. Some geophysical technologies, such as electrical conductivity, electromagnetometry, and to a lesser extent, ground penetrating radar, were able to directly detect the presence of contaminants by measuring the change in soil conductivities caused by the chemical compounds. Other technologies, such as seismic reflection and refraction, magnetometry, and gamma logging, cannot directly detect the presence of contaminants but are powerful tools in identifying subsurface lithologies that provide preferential pathways for the migration of contaminants.

3.0 Geophysical Technology Descriptions

Ground Penetrating Radar

Ground penetrating radar (GPR) uses high-frequency radio waves to determine the presence of subsurface objects and structures. A GPR system radiates short pulses of

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1/ Ground penetrating radar is a technique that belongs in the larger set of electromagnetometry, but is treated here as a separate technology due to its widespread use.

high-frequency electromagnetic energy into the ground from a transmitting antenna. This wave propagates into the ground at a velocity that is related to the electrical properties of subsurface materials. When this wave encounters the interface of two materials having different dielectric properties, a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display.

Electromagnetometry

The EM method is based on measuring the response of an electromagnetic field induced into the earth. A small coil transmits low frequency signals, one to ten kilohertz. The low frequency, very long wavelength electromagnetic fields produced by the transmitter, induce current flow in electrically-conductive media in the earth. This induced current flow produces secondary electromagnetic fields that radiate back to the surface. A receiving coil detects the secondary field and measures its strength and phase relative to the transmitted signal. The data are presented as the relative amplitude of the secondary signal, in parts per million (ppm).

The depth of penetration of the transmitted field is a function of the frequency of operation. Lower frequencies penetrate deeper, while higher frequencies are attenuated more rapidly. This frequency dependent penetration depth provides the opportunity to interpret multifrequency EM data to evaluate the depth and size of targets.

Seismic Reflection/Refraction

Seismic methods use an artificial seismic source to create direct compressional waves that travel into the ground where they are reflected back to the surface when the waves encounter boundaries between soil layers with different electrical properties. Some waves are refracted along the interface of such layers by traveling along the contact between geologic boundaries. The signals continue until they reach the surface. Subsurface stratigraphy is mapped by measuring the travel time necessary for a wave to pass through one layer to another, refract along the interface, and return to the geophones at the surface.

Reflection energy is received by the geophone and recorded as a trace. Each trace represents a station and each subsurface reflector or event should be visually identifiable on the trace, and connected to other traces within the survey. The ability to visually connect traces with an identifiable reflector, such as the bedrock surface, across ,many such traces can be an indicator of the seismic survey accuracy within localized areas.

Electrical Conductivity/Resistivity

Electrical conductivity is an inherent property of a material to conduct an electrical current and the electrical properties of soils can be measured using conductivity probes. Current is injected into the earth through a pair of electrodes, and the potential difference is measured between the pair of potential electrodes. The current and potential electrodes are usually arranged in a linear array. Common arrays include the dipole-dipole array, pole-pole array, Schlumberger array, and the Wenner array.

Variations in shallow soil conductivity (resistivity is the inverse of conductivity) are caused by changes in soil moisture content, conductivity of groundwater, and properties that can be related to lithology. Soil conductivity is a function of grain size, with finer grains producing higher values and coarser grains resulting in lower values.

Natural Gamma

Natural gamma logging is the continuous physical measurement of the release of natural gamma radiation from the soil and rocks surrounding the length of the borehole. Natural gamma measurement begins by lowering the detector to the bottom of a hole, allowing it to equilibrate to the different subsurface temperature, then reeling the detector up the hole at a steady rate of between five and 10 feet per minute. The gamma log measures the total gamma radiation emitted by a particular stratum in counts per second as the detector is raised in the well column. Interpretation of the gamma log depends as much on the absolute value of the gamma counts as it does on the rate of change in gamma counts as the detector passes from one material to the next. Statistical variations in gamma emissions, significant at low counting rates, are smoothed out by integration over a short time interval. If the hole is logged too quickly, however, the smoothing effect leads to erroneous results by shifting the peaks in the direction of logging.

Magnetometry

Magnetometers measure variations in the magnetic field of the earth, and local disruptions to the earth's field, including the presence of naturally occurring ore bodies and man-made iron or steel objects. Whether on the surface or in the subsurface, iron objects or minerals cause local distortions or anomalies in this field. When used together, the use of both total field magnetic and magnetic susceptibility logs allows for the detection of ferromagnetic minerals. A magnetometer′s response is proportional to the mass of iron in the target. The effectiveness of magnetometry results can be reduced or inhibited by interference (noise) from time-variable changes in the earth′s field and spatial variations caused by magnetic minerals in the soil, or iron debris, pipes, fences, buildings, and vehicles.

4.0 Summary of Performance

In each investigation, the geophysical technologies performed as expected and the results were used by site managers to support a variety of site decisions. Those decisions ranged from remedy selection and design to optimizing the performance of existing remedies. Table ES-2 provides a summary of the results obtained in the 11 geophysical investigations. In five, the geophysical technology was able to directly detect contaminants, greatly aiding the delineation of contamination at those sites. In the remaining investigations, the results described critical geological structures that influenced the migration of contaminants. This information aided site managers in identifying appropriate sampling locations for better delineation of contamination.

Table ES-3 provides a summary of the amount of data that was collected during the geophysical investigation, the approximate cost[2/], and the difficulties encountered. The information in this Table helps to underscore one of the greatest advantages that geophysical technologies offer: their cost-effectiveness. For all but two of the investigations, the approximate cost was less than $10 thousand. In one of the other two cases, the higher costs represented an investigation with a substantially larger scope, while the cost for the remaining investigation could not be separated from the overall cost

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2/ Investigation costs were estimated based on information supplied by the geophysical investigator.

of the soil sampling investigation.

Although no difficulties were reported for five of the investigations, those reported in the other investigations reflect the limitations of some of the technologies used. Ground penetrating radar surveys found that dense clays and silts limited the depth to which measurements could be taken. Standing water and cultural noises, such as airports and railroads, posed difficulties for the collection of seismic data, in some cases. The electrical conductivity probe used at one site often broke when large cobbles or boulders were encountered.

Several of the technologies discussed in this report have been used successfully in investigations of nonaqueous phase liquids (NAPLs). Electromagnetics, including Ground Penetrating Radar (GPR), were used at two creosote site and were able to detect discernable differences in the electrical conductivity of NAPL-saturated soils. At another site, a seismic reflection survey was able to identify deep paleochannels in the bedrock face in which DNAPLs had pooled and through which DNAPLs were migrating.

5.0 Summary of Lessons Learned

Overall, these technologies performed well and provided valuable information. Some of the lessons learned during their application were related to improving data collection, while others were related to the value of the technology, itself. Some of the principal lessons learned included:

- Electromagnetometry can be useful in detecting certain types of contamination in both soils and groundwater. The presence of organic compounds in soil and inorganic compounds in groundwater change the electrical conductivity of the medium from background levels.

- The performance of ground penetrating radar surveys can be improved with the use of different antenna configurations. The typical co-pole configuration, while sensitive to subsurface geometries that are flat and oriented parallel to the ground surface, is less sensitive to angular features in the subsurface. At the Baker Woods site, buried pits and vaults were more clearly identified with a cross-pole configuration, while they were less visible in GPR data collected with a co-pole configuration.

- Electrical conductivity probes are able to detect the presence of NAPLs directly. NAPLs change the electrical properties of the soils in which they reside, and the probes were able to measure these changes. When they occur in soils that should not otherwise be providing such readings, it may be an indication of the presence of a NAPL.

- Geophysical technologies can be used in concert with each other to produce complementary results that increase both perspective and confidence. At the Trail Road site, several different borehole methods were used to gain a comprehensive understanding of the stratigraphy and to identify zones of groundwater contamination. Some of the methods were sensitive to dense, impermeable layers while others were sensitive to coarser, sandy materials. Electrical conductivity and water temperature were used in concert to detect the presence of contaminants in the groundwater.

- Mature petroleum-related LNAPL plumes can be detected as electrically-conductive soils located at the capillary fringe. Natural biodegradation of the compounds works to mobilize inorganic materials in the soils whose presence increases the soil conductivity. This approach was successfully pursued at two of the sites: Crystal Refinery and Wurtzsmith Air Force Base.

- Seismic data collection can be sensitive to cultural sources of noise which can interfere with reflected acoustical energy from bedrock structures. Several statistical procedures were employed during the Tinker Air Force Base investigation to improve the quality of data collected.

Table ES-1: Geophysical Investigation Sites and Technologies

Site Name and Location	Geology	Contaminants	Geophysical Method Used
Baker Wood Creosoting Company Marion, OH	Silty loam over clay	Polyaromatic hydrocarbons	Ground Penetrating Radar Electomagnetometry
Ciba-Geigy Hamblet & Hayes Site Lewiston, ME	Sandy fill over clay	Chlorinated solvents; Petroleum hydrocarbons	Ground Penetrating Radar
Crystal Refinery Carson City, MI	Sandy loam, sand, clay over limestone	Petroleum hydrocarbons	Ground Penetrating Radar Electrical Resistivity
Kelly Air Force Base San Antonio, TX	Sand, gravel, clay mix over limestone	Chlorinated solvents	Seismic Reflection
Kansas UST Salina, KS	Clay over sand	Petroleum hydrocarbons	Electrical Conductivity
Marshalltown FMGP Marshalltown, IA	Glacial till over limestone	Polyaromatic hydrocarbons	Electrical Conductivity
New Hampshire Plating Company Merrimack, NH	Silty clay over granite	Chromium	Seismic Reflection Ground Penetrating Radar Natural Gamma Electomagnetometry
NMHSTD UST Deming, NM	Sandy clay with clay layers over shale	Chlorinated solvents	Magnetometry (R) Electomagnetometry (R) Natural Gamma
Tinker Air Force Base Tinker, OK	Mix of clay, sand layers over sandstone	Chromium Chlorinated solvents	Seismic Reflection Electomagnetometry
Trail Road Landfill Nepean, Ontario, Canada	Sand, gravel over clay and limestone	Dissolved inorganic and organic compounds	Natural Gamma Magnetometry Electrical Conductivity Temperature
Wurtsmith Air Force Base Oscoda, MI	Sand, gravel over clay and sandstone	Petroleum hydrocarbons	Ground Penetrating Radar Electomagnetometry (R) Magnetometry (R)

Note: (R) indicates that the method was used in a reconnaissance survey for buried materials that might interfere with primary technology.

Table ES-2: Summary of Geophysical Investigations

Site Name and Location	Geophysical Method Used	Purpose	Results
Baker Wood Creosoting Company Marion, OH	Ground Penetrating Radar Electomagnetometry	Delineate source areas and soil contamination	GPR identified buried structures that later investigation found to be contaminated. EM delineated near-surface soil contamination
Ciba-Geigy Hamblet & Hayes Site Lewiston, ME	Ground Penetrating Radar	Characterize stratigraphy	Found topographic low where later sampling found pooled DNAPL
Crystal Refinery Carson City, MI	Ground Penetrating Radar Electrical Resistivity	Monitor groundwater contamination	Identified LNAPL mass located at water table
Kelly Air Force Base San Antonio, TX	Seismic Reflection	Map bedrock topology	Identified channels in bedrock where later sampling found pooled DNAPL
Kansas UST Salina, KS	Electrical Conductivity	Characterize stratigraphy	Found saddle-like formation in confining layer that acted as preferential migration pathway for LNAPL
Marshalltown FMGP Marshalltown, IA	Electrical Conductivity	Characterize stratigraphy	Clearly identified lithology, including layers not yet identified; probe able to directly detect DNAPLs
New Hampshire Plating Company Merrimack, NH	Seismic Reflection Ground Penetrating Radar Natural gamma Electomagnetometry	Characterize stratigraphy Monitor groundwater contamination	Delineated stratigraphy; identified zones of groundwater contamination
NMHSTD UST Deming, NM	Magnetometry (R) Electromagnetometry (R) Natural gamma	Characterize stratigraphy for sampling point location	Gamma logs identified clay layers that influenced vapor migration in vadose zone; logs were used to position *in situ* soil gas samplers

Table ES-2: Summary of Geophysical Investigations

Site Name and Location	Geophysical Method Used	Purpose	Results
Tinker Air Force Base Tinker, OK	Seismic Reflection Electromagnetometry	Characterize stratigraphy for new well installation	Characterized stratigraphy; identified permeable layers
Trail Road Landfill Nepean, Ontario, Canada	Natural Gamma Magnetometry Electrical Conductivity Density Temperature	Monitor groundwater contamination	Developed continuous lithologic logs; conductivity and temperature logs identified zones of groundwater contamination
Wurtsmith Air Force Base Oscoda, MI	Ground Penetrating Radar Electromagnetometry (R) Magnetometry (R)	Monitor groundwater contamination	Identified unknown LNAPL plume

Note: (R) indicates that the method was used in a reconnaissance survey for buried materials that might interfere with primary technology.

Table ES-3: Performance of Geophysical Technologies

Site Name and Location	Geophysical Method Used	Benefits/Difficulties
Baker Wood Creosoting Company Marion, OH	Ground Penetrating Radar Electromagnetometry	**Benefits:** 100 traverses over 0.7 acres **Difficulties:** GPR depth was limited by shallow dense clay soils; EM depth was limited by nearby structures
Ciba-Geigy Hamblet & Hayes Site Lewiston, ME	Ground Penetrating Radar	**Benefits:** 85 traverses over 0.1 acres in two days for $4 thousand **Difficulties:** Dense clay limited depth of penetration; swampy areas limited access
Crystal Refinery Carson City, MI	Ground Penetrating Radar Electrical Resistivity	**Benefits:** 2 traverses over 2.3 acres for $5.8 thousand **Difficulties:** No significant problems reported
Kelly Air Force Base San Antonio, TX	Seismic Reflection	**Benefits:** 317 station measurements for $15.9 thousand **Difficulties:** Railroad noise interfered with data collection
Kansas UST Salina, KS	Electrical Conductivity	**Benefits:** 10 logs over 3.7 acres for $3.6 thousand **Difficulties:** No significant problems reported
Marshalltown FMGP Marshalltown, IA	Electrical Conductivity	**Benefits:** 27 logs in 5 days for $7.9 thousand **Difficulties:** Probes broke when encountered cobbles and boulders; weathered bedrock was not distinguishable in logs
New Hampshire Plating Company Merrimack, NH	Seismic Reflection Ground Penetrating Radar Natural gamma Electromagnetometry	**Benefits:** 33 station measurements/7 logs/5,800 ft. of profiles over 13.1 acres for $43.1 thousand **Difficulties:** Dense clay and sediments limited depth of penetration for GPR and seismic signals
NMHSTD UST Deming, NM	Magnetometry (R) Electromagnetometry (R) Natural Gamma	**Benefits:** 33 profiles over 15 acres for less than $70 thousand[3/] **Difficulties:** No significant problems reported

3/ Price includes cost of soil gas survey

Table ES-3: Performance of Geophysical Technologies

Site Name and Location	Geophysical Method Used	Benefits/Difficulties
Tinker Air Force Base Tinker, OK	Seismic Reflection Electromagnetometry	**Benefits:** 17,510 feet of profiles over 100 acres **Difficulties:** Muddy surface conditions interfered with data collection
Trail Road Landfill Nepean, Ontario, Canada	Natural Gamma Magnetometry Electrical Conductivity Density Temperature	**Benefits:** 5 measurements in 8 logs for $4.2 thousand **Difficulties:** No significant problems reported
Wurtsmith Air Force Base Oscoda, MI	Ground Penetrating Radar Electromagnetometry (R) Magnetometry (R)	**Benefits:** 2,700 feet of profiles for $7.7 thousand **Difficulties:** No significant problems reported

Note: (R) indicates that the method was used in a reconnaissance survey for buried materials that might interfere with primary technology.

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6.0 CASE STUDIES

Case Study Abstract

Baker Wood Creosoting Company
Marion, Ohio

Site Name and Location: Baker Wood Creosoting Company Marion, Ohio	**Geophysical Technologies:** Ground penetrating radar Electromagnetic induction	**Date of Investigation:** January and February, 1999
Period of Site Operation: 1890's to 1960's **Operable Unit: N/A**		**Current Site Activities:** Assessment of sediments in the Little Scioto River is being performed. Future plans include installing five or six shallow water wells to determine if the groundwater is contaminated.
Points of Contact: Mark Durno U.S. EPA 25089 Center Ridge Road Westlake, OH 44145 216-522-7260 Mr. Mark Vendl Mail Code SRT-4J USEPA Region 5 77 West Jackson Boulevard Chicago, IL 60604-3507	**Geological Setting:** Two to three feet of silt loam underlain by a firm calcareous clay	**Technology Demonstrator:** U.S. EPA and Ohio State University

Purpose of Investigation: To locate possible buried waste pits or other contaminant-filled structures and to delineate the extent of contamination within the surficial soils.

Number of Images/Profiles Generated During Investigation: 100 GPR traverses

Results: Lateral extent of contamination determined in the shallow subsurface by EM and GPR. GPR was operated in a cross- and co-pole antenna configuration which clearly identified a series of buried vaults containing highly contaminated material.

EXECUTIVE SUMMARY

The former Baker Wood Creosoting Company is located on 60 acres in Marion. The site is located approximately one-half mile northwest of downtown Marion. The Little Scioto River is located one mile to the west of the site. The property was used from the 1890s to the 1960s as a wood treating facility, and the preservatives used were most likely creosote, petroleum, and other solvents. All buildings have been removed from the site, but the concrete pads that supported the creosote storage tanks and a former pump house remain. The geophysical study was conducted within the area that encompasses the former tank area and pump house.

The surficial soils consist of a two- to three-foot surface layer of silt loam, underlain by a firm calcerous clay. Glacial till containing occasional thin interbedded sand layers extends from beneath the surface soil to Silurian limestone/dolomite bedrock, which is present at depths of approximately 13 to 25 feet below ground surface in the area. The limestone/dolomite bedrock appears to contain a shallow and deep aquifer. Regional groundwater flow direction of the deep aquifer is believed to be influenced by the quarry located northeast of the Baker Wood site and by the municipal well field situated west of the site. Typically, the generalized groundwater flow is westward towards the Little Scioto River.

A geophysical investigation was conducted in 1999 to delineate the extent of contamination prior to conducting a time critical removal action. The information in this report was derived from the interpretive report for the geophysical investigation. Two geophysical methods were used during this investigation. A ground penetrating radar (GPR) survey was conducted first, followed by a frequency domain electromagnetic induction (EM) survey. The GPR was used to locate subsurface structures that might contain contamination while EM was used to detect anomalous soil conductivities that might indicate the presence of contamination in the surface and near-surface soils.

The GPR survey identified nine areas with significant subsurface anomalies in the study area. Five of the areas included vaults buried underneath each of four tank pads, a creosote-filled pit, and a trench. The EM survey found areas of low conductivity soils that indicate the potential location of contaminated soil. Areas of low conductivity were less prominent in the lower frequency data than in the higher frequency data indicating that contamination was predominantly present in the near surface. Subsequent exploratory trenching and screening analysis of soils was conducted in the nine areas identified in the geophysical investigation, and significant contamination was found in five of them.

Although soil sampling from 1996 showed contamination in the same area as the GPR survey showed, the lateral extent of contamination was unknown prior to the GPR survey. The GPR survey provided information on lateral extent. Based on the GPR survey, it was estimated that 1800 cubic yards of contamination existed at the Baker Woods site. Because contamination was found to a depth of five and six feet in some locations, and the GPR was only able to see to four feet, an additional 400 cubic yards of contamination was found and removed.

SITE INFORMATION

Identifying Information

Baker Wood Creosoting Company
Holland Road and Kenton Street
Marion, Ohio

Background [1, 2, 3, 4, 5, 7]

Physical Description: The former Baker Wood Creosoting Company is located on 60 acres in Marion, Ohio, in the north-central part of the state, as shown in Figure 1. The Baker Wood Creosoting Company is located at the northwest corner of Holland Road and Kenton Street (State Route 309), and is approximately one-half mile northwest of downtown Marion. The Little Scioto River is located one mile to the west of the site. The topography of the site is flat with a shallow westward gradient.

All buildings have been removed from the site, but the concrete pads that supported the creosote storage tanks and a former pump house remain. The pads and former pump house are located within an area of approximately 130 by 50 feet, just south of a gravel access road. The geophysical study was conducted on a 300- by 100-foot area that encompasses the former tank area and pump house. This part of the site is located in the southeast section of the 60 acres (See Figure 2).

Figure 1: Site Location

Site Use: The property was used from the 1890s to the 1960s as a wood treating facility, and was owned by the Baker Wood Creosoting Company. Historical information indicates that the process used pressure vessels to treat railroad ties and other wood products. The preservatives used were most likely creosote, petroleum, and other solvents. It is currently owned by Baker Wood Limited Partnership and is an inactive site.

It was believed that chemical wastes were discharged to the combined sanitary/storm sewer that is located adjacent to the site, along the southern border. The sewer flows west and discharges directly into North Rockswale Ditch. Drawings indicate that the old sewer tie-ins from the facility may still be in use. This combined sanitary/storm sewer is thought to be a direct link to the surface water contaminant migration pathway leading to the North Rockswale Ditch.

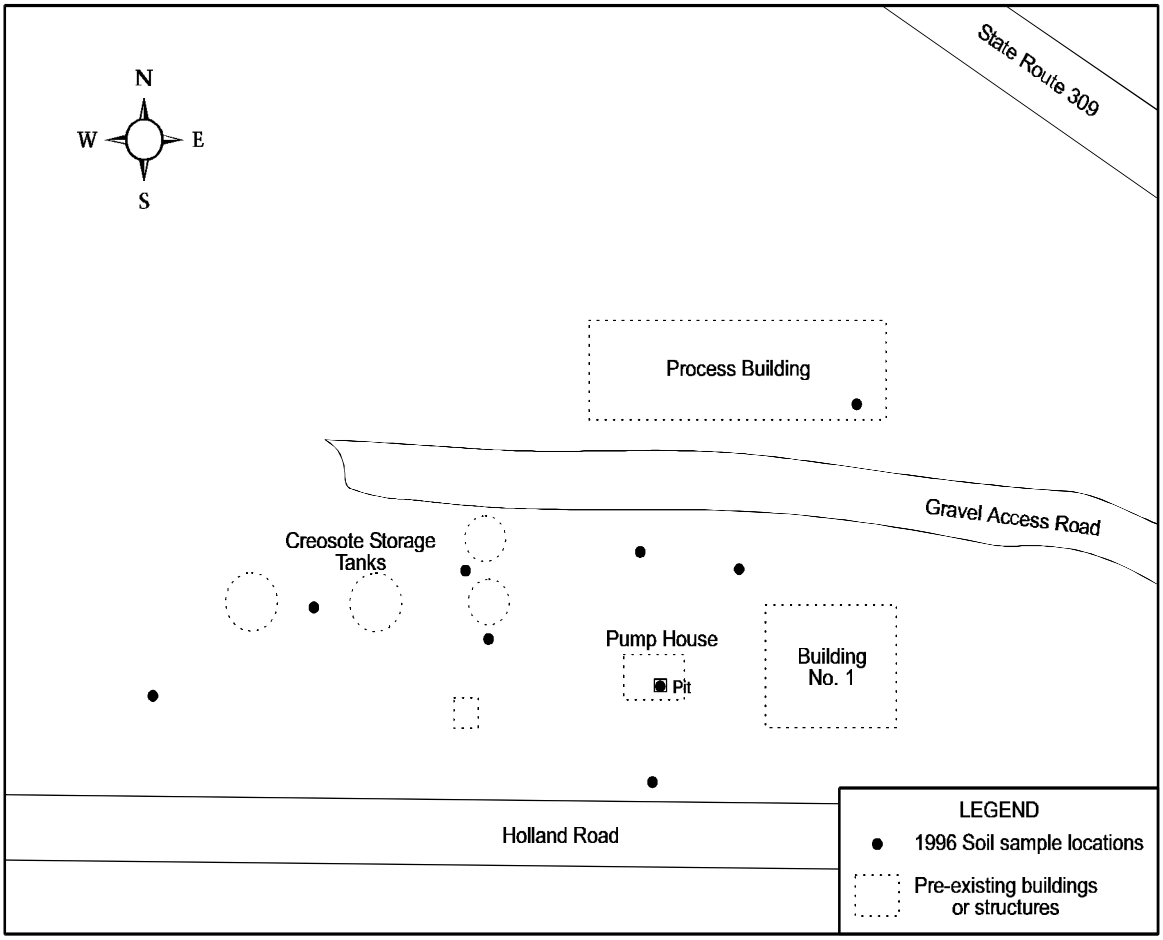


Figure 2: Baker Wood Site Map [1]

Release/Investigation History:

Numerous sampling events have been conducted in and around the Baker Wood site since the 1940s. In 1988 and 1991, the Ohio Environmental Protection Agency (EPA) collected sediment samples from the Little Scioto and Scioto Rivers. Analysis of the samples showed high concentrations of polycyclic aromatic hydrocarbons (PAHs). Investigators observed on both occasions that the banks and bottom sediments of the Little Scioto River were heavily saturated with a black material with a creosote odor. When disturbed, the bottom sediments released an substance that left an oily sheen on the water's surface. The U.S. EPA and Ohio EPA collected soil samples in 1996 around the former creosote storage tanks and pump house. Analytical results from the soil samples revealed some of the highest concentrations of PAHs ever recorded in the published literature.

SITE INFORMATION

Regulatory Context:

The U.S. EPA and Ohio EPA have conducted response actions at the Baker Woods Creosoting Company site under a time critical removal authority provided under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments Reform Act (SARA).

Site Logistics/Contacts

State Lead Agency: Ohio EPA
Federal Oversight Agency: U.S. EPA

Remedial Project Manager:
Mark Durno
U.S. EPA
25089 Center Ridge Road
Westlake, OH 44145
216-522-7260

Site Contact:
Mr. Mark Vendl
Mail Code SRT-4J
USEPA Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3507
312-886-0405

Geophysical Subcontractors:
Dr. Jeffery Daniels
Department of Geological Sciences
Ohio State University
125 South Oval Mall
Columbus, OH 43210-1398
614-292-4295

MEDIA AND CONTAMINANTS

Matrix Identification [3]

Type of Matrix Sampled and Analyzed:
Subsurface soil consisting of silt loam.

Site Geology/Stratigraphy [3, 5]

The surficial soil profile at the Baker Wood site consists of a two- to three-foot surface layer of silt loam, underlain by a firm calcerous clay. Glacial till containing occasional thin interbedded sand layers extends from beneath the surface soil to Silurian limestone/dolomite bedrock, which is present at depths of approximately 13 to 25 feet below ground surface (bgs) in the area. The limestone/dolomite bedrock appears to contain a shallow and deep aquifer. The shallow aquifer is encountered at approximately 40 feet bgs, and the deep aquifer is encountered at about 250 feet bgs.

Regional groundwater flow direction of the deep aquifer is believed to be influenced by the quarry located northeast of the Baker Wood site and by the municipal well field situated west of the site. Typically, the generalized groundwater flow is westward towards the Little Scioto River.

Contaminant Characterization [1]

Primary Contaminant Groups: The primary contaminants of concern at this site are volatile organic compounds (VOCs) and PAHs.

Matrix Characteristics Affecting Characterization Cost or Performance [1]

Clays in the soils and high soil moisture content posed a significant challenge for GPR data collection during the investigation by limiting the depth to which measurements could be taken. Both caused excessive signal attenuation resulting in late signal arrival times. Investigators tried to correct for this interference by using a 300 MegaHertz (MHZ) antenna, but the radio tower, located on the adjacent property, caused interfering noise at that frequency. As a result, a 500 MHZ antenna was used for the investigation, but at this frequency, the investigation depth was limited to three to four feet bgs. The investigation team believed this to be a sufficient depth based on prior knowledge of site conditions.

Standing water, which ranged in depth from 10 to 15 inches, on the site resulted in late signal arrival times, but the standing water was mapped so that the data interpretation would not be affected. The late arrival times were due to the water having a relatively lower velocity than the surrounding areas that did not have water present.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [1]

The goals for this project were to locate possible buried waste pits or other contaminant-filled structures, and to delineate the extent of contamination within the surficial soils.

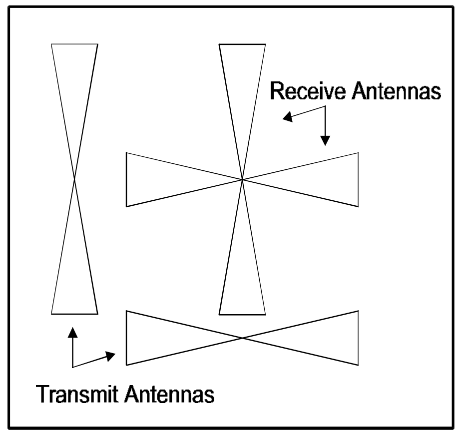
Geophysical Methods [1, 6]

Two geophysical methods were used for this investigation. A ground penetrating radar (GPR) survey was conducted first, followed by a frequency domain electromagnetic induction (EM) survey. The GPR was used to locate subsurface structures that might contain contamination while EM was used to detect anomalous soil conductivities that might indicate the presence of contamination in the surface and near-surface soils.

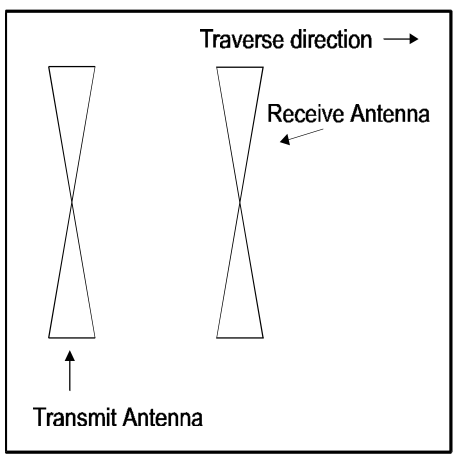
GPR employs an extremely short electromagnetic pulse that penetrates into the earth. A portion of the energy is reflected back to the surface, where it is detected by the receiving antenna. The amplitude of the reflected pulse depends primarily on the soil's dielectric constant, or the measure of electrical conductivity of soils. GPR anomalies result when there is a contrast in the bulk dielectric property between materials, marking a boundary between geologic structures. The time lapse between transmission and receipt of the EM signal it is measured in nanoseconds (ns) and is transmitted to a control unit for processing and display.

The GPR study design for the Baker Wood Site called for the collection of two complementary sets of data. The data were collected using the GPR in a co-pole and then in a cross-pole antenna configuration (See Figure 3). The collection and comparison of the two types of data added an analytical dimension to the GPR data that improved the GPR data, thus improving the interpretation of the results. Each antenna configuration is sensitive to different types of objects in the subsurface.

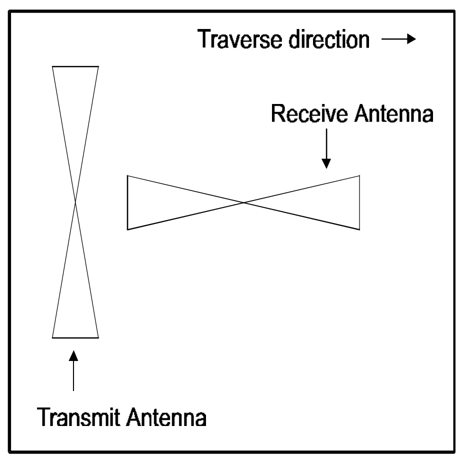
The polarization of reflected electromagnetic energy depends on the geometry of the reflecting surface. Relatively flat subsurface targets or ones with small curvature reflect relatively large currents of linearly polarized signals. Targets that are not planar, or have irregular surfaces, scatter or depolarize the EM waves. A co-pole antenna configuration is primarily sensitive to linearly polarized reflections. The cross-pole configuration is most sensitive to depolarized reflections, while being less sensitive to energy that is scattered parallel to the transmit antenna. Thus, the use of both antenna configurations allowed investigators to identify anomalies representing a wider variety of subsurface geometries.



Multi-component GPR antenna arrangements



Co-pole perpendicular to traverse direction



Cross-pole with transmit antenna perpendicular to traverse direction

Figure 3: Antenna Configurations for Co-Pole and Cross-Pole GPR Measurements

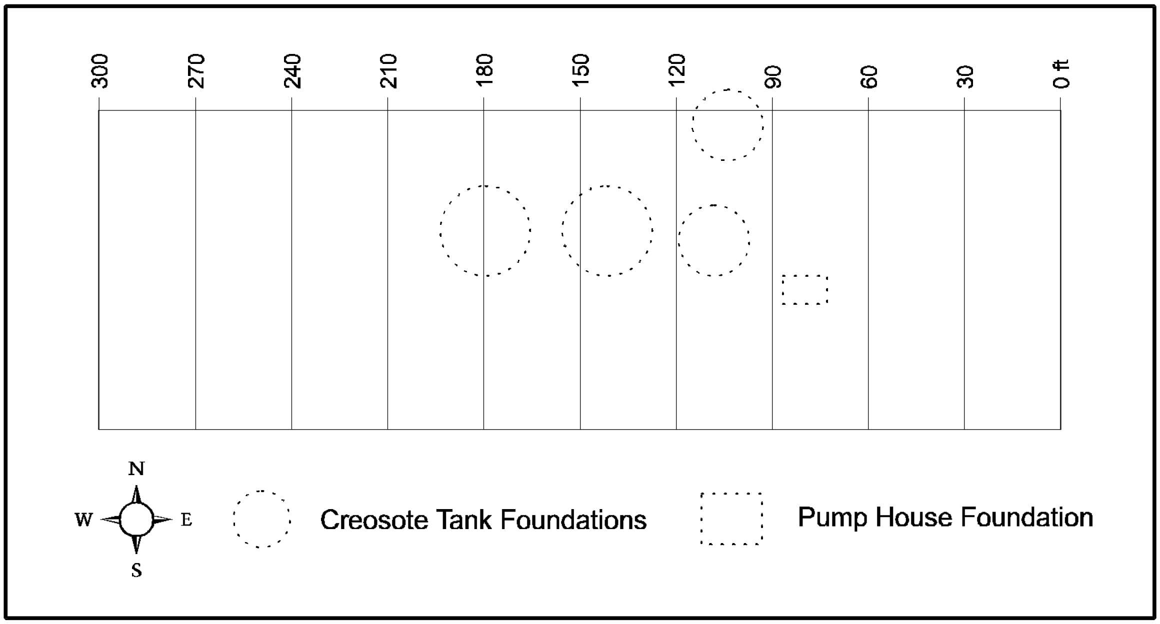


Figure 4: Geophysical Survey Area Showing North-South Traverse Lines [1]

Geophysical surveys were conducted on a 100- by 300-foot grid with a 3-foot spacing between the north-south traverse lines. This area included the foundations of the creosote storage tanks and the former pump house (see Figure 4). Two separate surveys were conducted during January and February 1999. The data from the two surveys was compared to identify variations in the results due to changes in soil moisture. No significant variation was detected in the results of the two surveys.

The GPR survey was conducted using a Geophysical Survey Systems, Inc. (GSSI) 500 MHZ multi-component antenna with a Subsurface Interface Radar (SIR)-10 recording system with a fixed number of traces recorded per distance traveled. The GPR system was towed using a survey wheel to accurately position the data spatially.

The EM survey was conducted to identify the spatial extent of soil contamination, identified b y the survey as areas of anomalous low conductivity resulting from creosote contamination within surficial soils. It has been postulated that when organic contamination interacts with and displaces soil moisture in the vadose zone, a decrease in conductivity can result. In the areas where the highest levels of creosote contamination were found, the EM survey showed the lowest conductivity values in the entire area.

The EM method is based on measuring the response of an electromagnetic field induced into the earth. Low frequency signals, one to ten kilohertz, are transmitted by a small coil. The low frequency, very long wavelength, electromagnetic fields produced by the transmitter induce current flow in electrically conductive media in the earth. This induced current flow produces secondary

GEOPHYSICAL INVESTIGATION PROCESS

electromagnetic fields which will radiate back to the surface. A receiving coil detects the secondary field and measures the strength and phase relative to the transmitted signal.

This EM survey was conducted using a GSSI GEM-300. For the GEM-300 system, the secondary field that is measured is split into in-phase and quadrature components that are expressed in parts per million (ppm) against the primary induced field strength. The in-phase response is sensitive to metal conducting targets and is referred to as the metal detector mode, while the quadrature phase response is sensitive to non-metallic conductors and is referred to as the terrain conductivity mode.

EM measurements were taken every two feet along the same traverse lines on the 100- by 300-foot survey grid used in the GPR survey. Measurements were taken at three different frequencies: 2010 Hz (2kHz), 4410 Hz (4 kHz), and 9810 Hz (9kHz), with the long axis of the instrument oriented parallel to the survey lines and the dipole axis oriented vertical to the plane of the ground. The variation in frequencies provided investigations to different depths. The depth of penetration of the transmitted field is a function of the frequency of operation or frequency of the EM signal. Lower frequencies penetrate deeper, while higher frequencies are attenuated more rapidly.

GEOPHYSICAL FINDINGS

Technology Calibration

No independent calibration information was required for the GPR and EM instruments used in this investigation.

Investigation Results [1]

The GPR survey identified nine areas with significant subsurface anomalies in the study area. Subsequent exploratory trenching and screening analysis of soils at the nine areas found significant contamination in five of them. The five areas included vaults underneath each of four tank pads, a creosote-filled pit, and a trench. The GPR findings discussed in this case study are limited to those that focus on the creosote-filled pit and one of the tank pad vaults as they are representative of the data collected around the other significant anomalies.

Figure 5 shows both two-dimensional (2-D) and three-dimensional (3-D) displays of the cross-pole data collected southeast of the former pump house. Three-dimensional displays were generated by stacking multiple 2-D profiles and provide an enhanced visualization of the GPR anomaly. The anomaly in this profile was determined to be a creosote-filled pit during subsequent sampling and analysis of the soils in the area. Co-pole data collected along the same set of traverses contained more clutter, making identification of the anomaly difficult.

Figure 6 presents 2-D and 3-D views of both co- and cross-pole data collected near the two easternmost storage tank pads. A backfilled-trench, which later was discovered to contain creosote-contaminated drainage tile, can be seen in the profiles, located between the two storage pads. A comparison of the views generated using co- and cross-pole data shows that the cross-pole data contains less clutter and has better resolution. The clutter present in the co-pole data nearly obscures the trenched area between the two pads.

The EM survey in-phase data showed anomalous regions of relative high conductivity in the vicinity of the tank and pump house foundations as a result of rebar within these structures. These regions of relatively high conductivity were also evident in the quadrature responses at the 4 kHz and 9 kHz frequencies measured. Areas of low conductivity, shown as light areas in Figure 7, indicate the potential location of contaminated soil. Research has shown that as the soil moisture becomes contaminated with organic compounds, including those found at this site, the electrical conductivity of those soils decreases. Areas of low conductivity were less prominent in the 4 kHz data than in the 9 kHz data indicating that contamination is predominantly present in the near surface. The 4 kHz data showed areas of low conductivity in the vicinity of the tank foundations, which correlated with soil contamination that was found at greater depths.

Figures 8 shows where the geophysical survey found anomalies and where trenching was to be conducted based on the anomalies. Figure 9 shows where the creosote-filled pits and vaults were located. Comparing the two figures it is apparent that the accuracy with which the GPR survey identified the location of the vaults and pit was within a few feet.

Although soil sampling from 1996 showed contamination in the same area as the GPR survey, the lateral extent of contamination was unknown prior to the GPR survey. Based on the GPR survey, it was estimated that 1,800 cubic yards of contamination existed at the Baker Woods site. During excavation, contamination in some locations was found to a depth of 5 or 6 feet, but primarily, the contamination was excavated from the same depths as those indicated by the EM survey. By the end of the cleanup project, the total soil removed was 2,200 cubic yards. Thus, estimations the results of the geophysical surveys were within 20 percent of the volume of contaminated material excavated at the site.

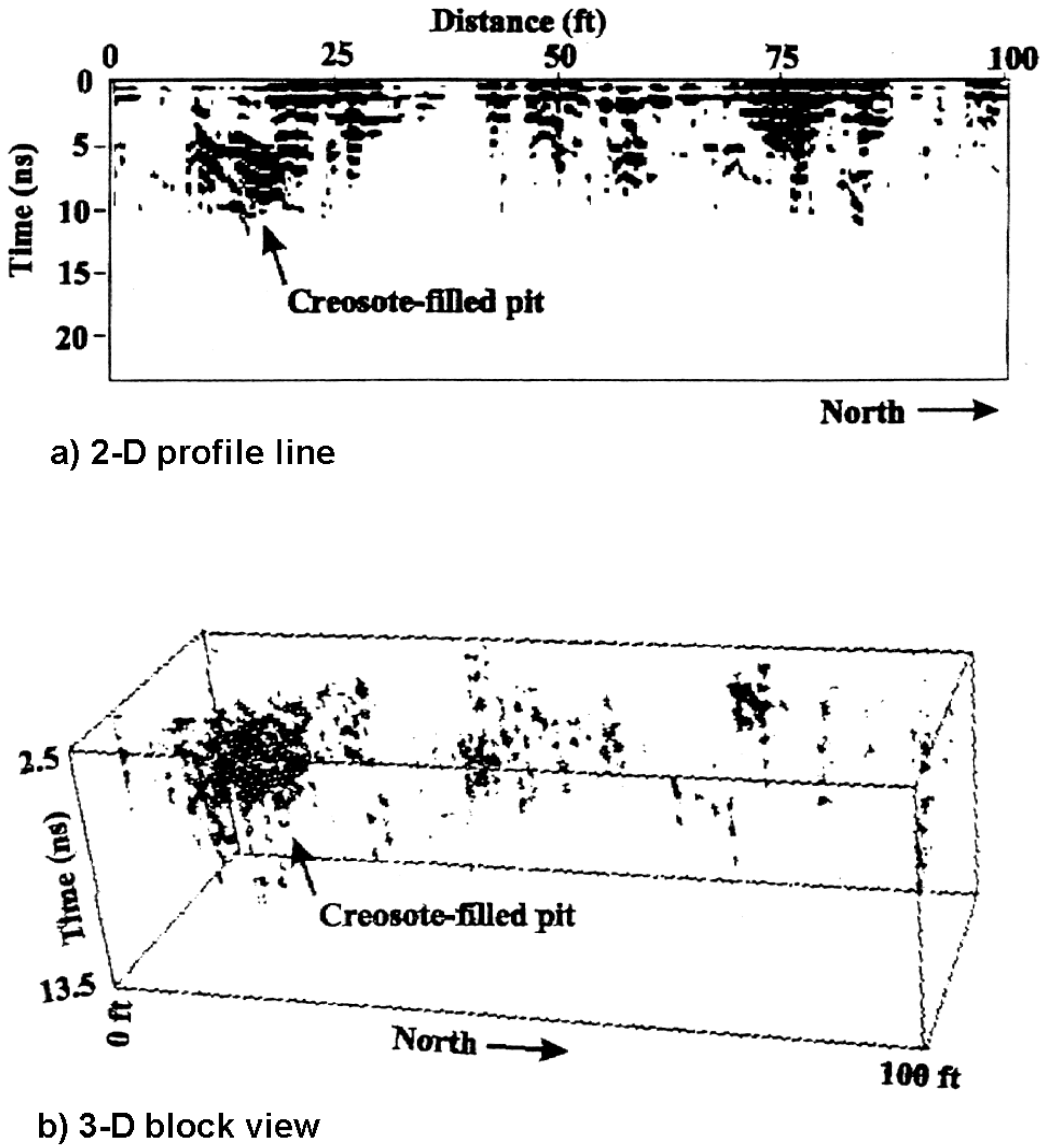


Figure 5: Cross-Pole Data Collected Near Pump House Foundation [1]

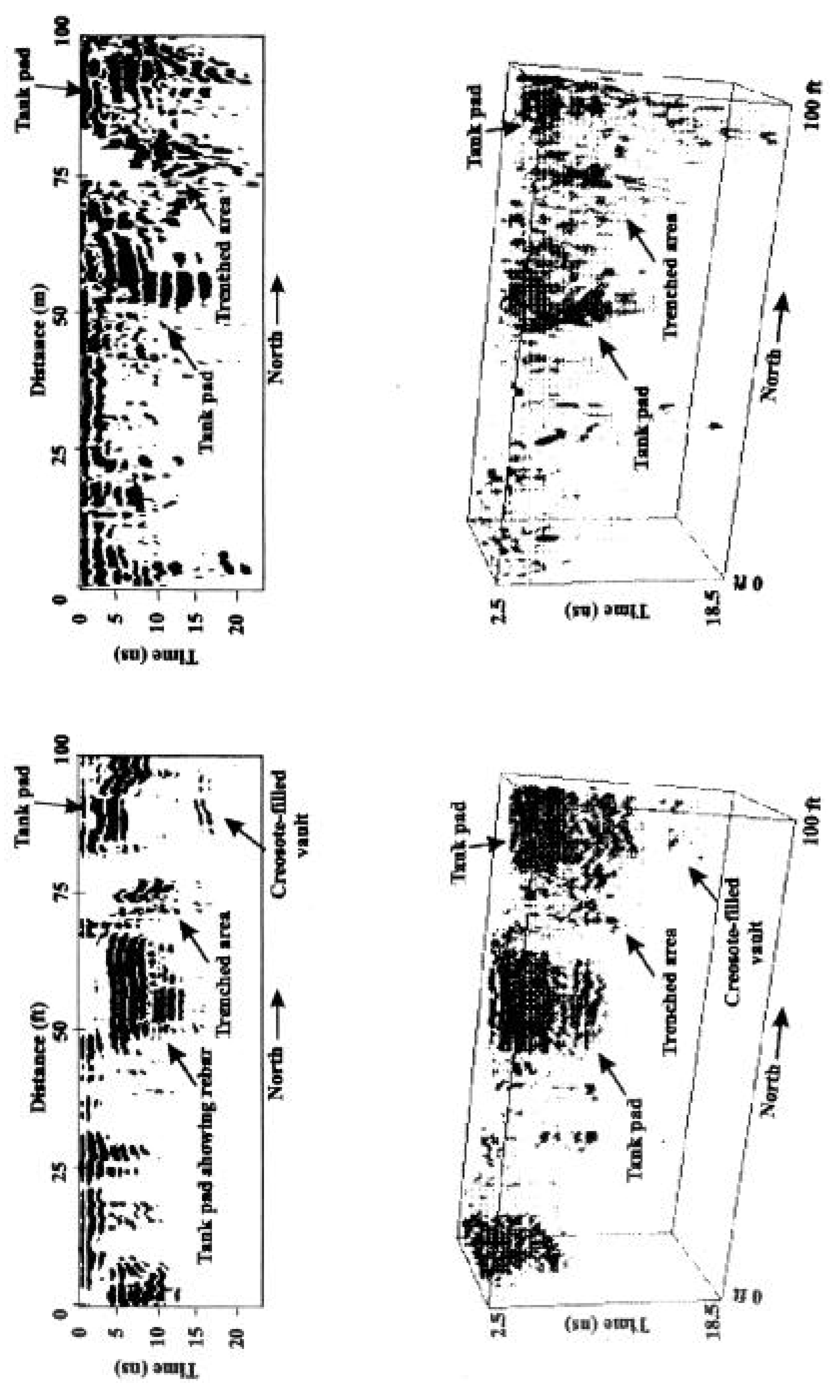


Figure 6: GPR Data Collected Near Eastern Storage Pads [1] [Poor Quality Original]

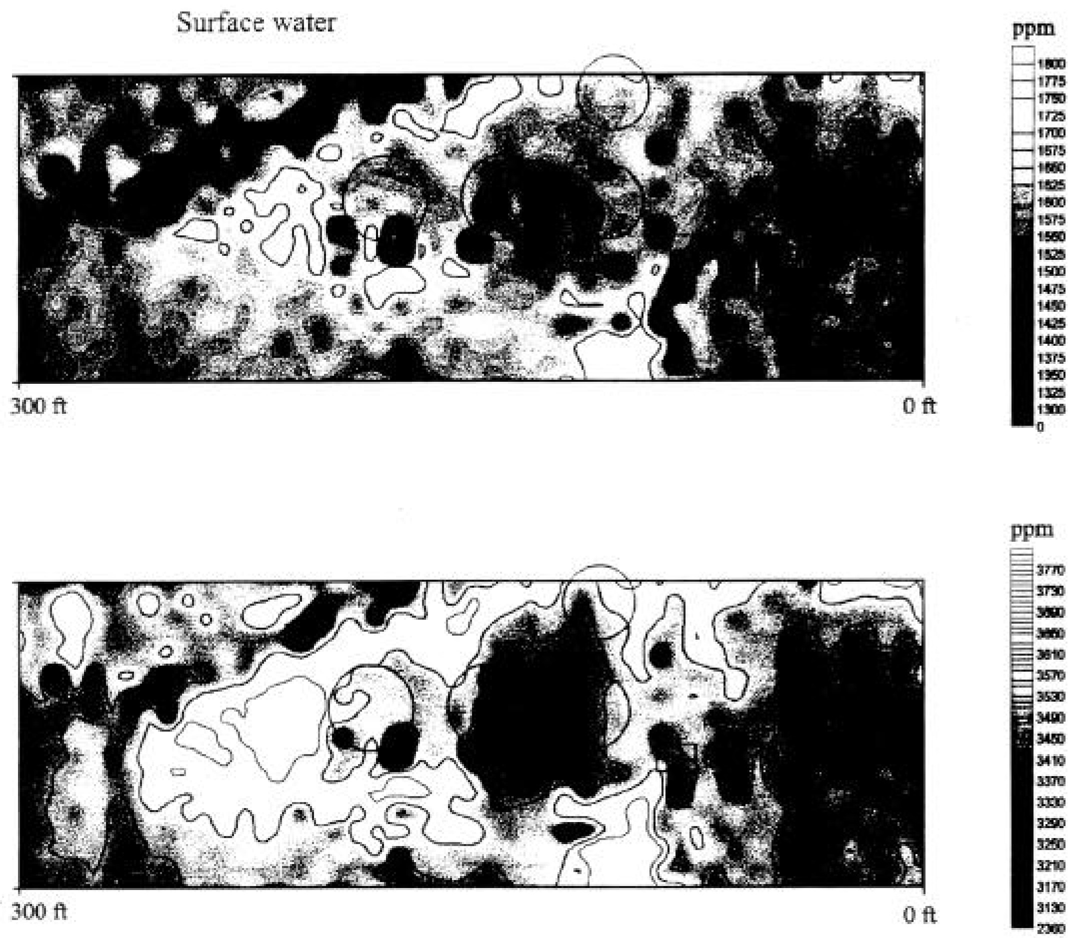


Figure 7: Electromagnetic Conductivity of Soils in Study Area [1]

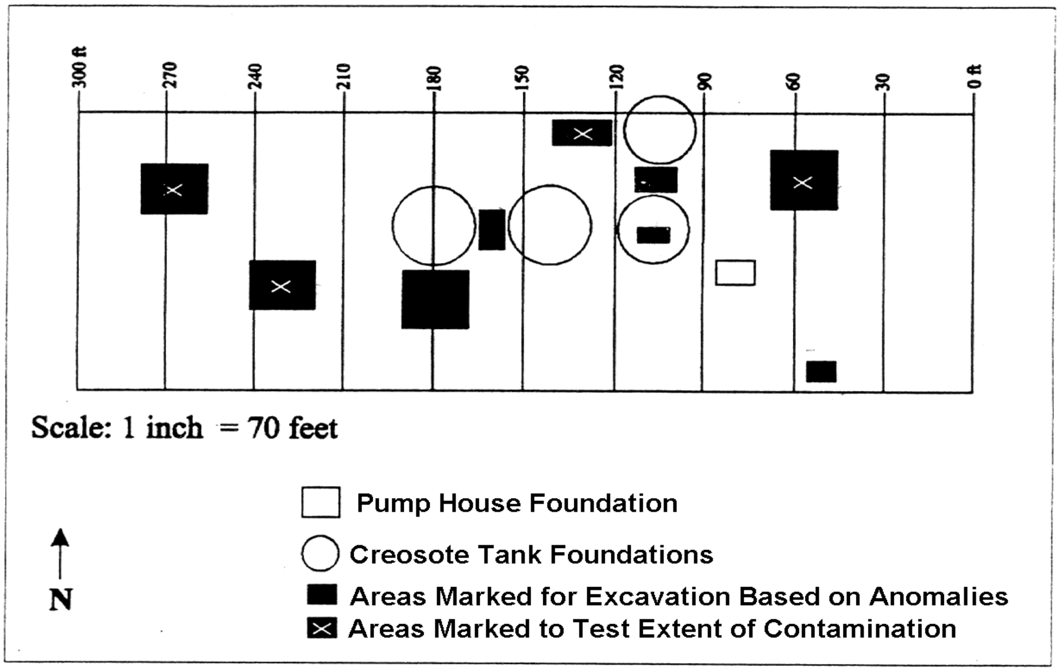


Figure 8: Locations Selected For Screening by Geophysical Surveys [1]

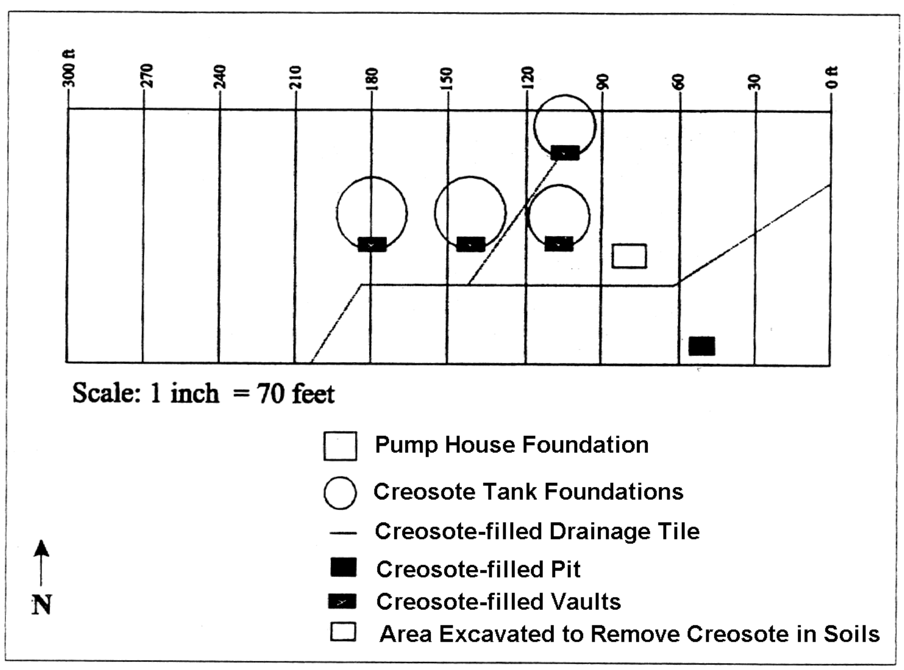


Figure 9: Locations of Significant Soil Contamination [1]

GEOPHYSICAL FINDINGS

Results Validation [1, 7]

Using the GPR and EM results together, investigators were able to identify nine areas for further, invasive investigation. Exploratory trenches were excavated in each of the nine areas and soil samples were taken from the trenches. The soil samples were analyzed in the field using a field portable flame ionization detector. Based on these analytical results, significant contamination was found in five of the nine areas.

LESSONS LEARNED

Some of the lessons learned from this investigation include the following:

- The effectiveness of this GPR survey was improved with the collection and analyses of both co-pole and cross pole data.

- Standing surface water and layered clay soils attenuated the GPR signal in certain portions of the study area, interfering with the interpretation. These areas were mapped. It is anticipated that results would have been clearer in the absence of standing water.

- The GPR survey was successful in identifying subsurface structures that held contaminated material, including a vault hidden beneath a pit. The EM survey was successful in identifying areas of suspected soil contamination. Information from both surveys were used to identify nine areas for investigation. Trenches were excavated and the soils analyzed in each area. Significant contamination was found in five of the areas.

- Although soil sampling from 1996 showed contamination in the same area as the GPR survey showed, the lateral extent of contamination was unknown prior to the GPR survey. Based on the GPR survey, it was estimated that 1800 cubic yards of contamination existed at the Baker Woods site. Because contamination was found to a depth of 5 and 6 feet in some locations, and the GPR was only able to see to 4 feet bgs, an additional 400 cubic yards of contamination was found and removed.

- The low conductivity areas identified in the EM survey correlated with areas of high concentrations of creosote contamination and were verified through soil sample analysis and exploratory trenching.

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5. Ohio Environmental Protection Agency. *Integrated Assessment (IA) Report: Baker Wood Creosoting Site, Marion, Marion County*. 1998.

6. Personal Communication with Mark Vendl of U.S. EPA. September 30, 1999.

7. Personal Communication with Mark Durno of U.S. EPA. September 30, 1999.

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Case Study Abstract

Ciba-Geigy Hamblet & Hayes (H&H) Site
Lewiston, ME

Site Name and Location: Ciba-Geigy Hamblet & Hayes Site	**Geophysical Technologies:** Ground Penetrating Radar (GPR)	**CERCLIS #** Not applicable
Period of Site Operation: 1963 to 1995 solvent repackaging/chemical redistribution **Operable Unit:** Not applicable		**Current Site Activities:** A groundwater pump and treat system and an air sparging/soil vapor extraction system were installed at the site in 1996, and have been operating since early 1997. Additional investigation work on areas where dense nonaqueous phase liquids (DNAPLs) have been found are also ongoing.
Point of Contact: Stephen Walbridge Harding Lawson Associates 511 Congress Street P.O. Box 7050 Portland, ME 04112-7050 (207) 828-3482 swalbrid@harding.com	**Geological Setting:** The surficial unit is the Presumpscot Formation, a marine deposit consisting of varying amounts of clay, silt, and fine sand. Overlying this formation is a unit primarily composed of sandy fill. Below the Presumpscot Formation is a sand and gravel unit.	**Technology Vendor:** Geophysical Survey Systems, Inc. 13 Klein Dr. North Salem, NH 03073-0097 (603) 893-1109 Fax (603) 889-3984 sales@geophysical.com

Purpose of Investigation:
The purpose of the GPR survey was to provide information on the continuity and topographic relief of clay layers in near-surface soils beneath the site. Identifying these high and low points of the clay layer would help identify where DNAPL might accumulate.

Number of Images/Profiles Generated During Investigation: 85 traverses

Results:
The GPR survey successfully identified continuous reflectors that represent silty clay layers in the shallow subsurface soils beneath the site. There was an observed parallel relationship of the various sand, silt, or clay layers that are present in the shallow subsurface soils that suggest the topography of the interpretive layer mimics the topography of the massive silty clay known to exist 19 to 22 feet below the ground surface (bgs) in the area of the GPR survey. This would provide a downward sloping pathway for DNAPL to move along until accumulating in topographically low areas identified, such as beneath the southwest corner of the leachfield.

EXECUTIVE SUMMARY

The Ciba-Geigy Corporation (Ciba-Geigy) Hamblet and Hayes (H&H) site is a complex of buildings located off of Crowley Road in Lewiston, Maine. The facility was primarily known for its solvent repackaging activities. Suspected site contamination was associated partly with an incident which occurred in 1983 when a valve was inadvertently left open and approximately 1,000 gallons of xylenes were spilled onto the ground. An environmental assessment was conducted and revealed that a contaminated groundwater plume and contaminated soil, primarily consisting of chlorinated solvents and xylenes, existed at the site.

The surficial geologic unit is the Presumpscot Formation, a marine deposit consisting of varying amounts of clay, silt, and fine sand. Overlying the Presumpscot Formation at the site is a unit that is composed of sandy fill to an approximate depth of 7 feet below ground surface (bgs). Underneath the Presumpscot Formation is a sand and gravel unit that extends to depths of 45 feet bgs.

As part of the third Phase of the site investigation process, a ground penetrating radar (GPR) survey was conducted to map the top of the clay surface. The information presented in this report was derived from the interpretive report of the geophysical investigation. At least four reflectors were identified. The four reflectors were interpreted to represent the top of the silty clay layers that comprise the upper portion of the marine clay formation found at the site. The uppermost reflector was interpreted to be a silty clay layer and was chosen for further interpretation. The silty clay layer was present on most profiles and determined to be continuous throughout the study area. A topographic low for potential dense non-aqueous phase liquid (DNAPL) pooling was identified near the western corner of the site.

The GPR data were accurate to site conditions and the confidence level of the decisionmakers in the results was high. Their confidence in the level of accuracy of the GPR data was validated through later investigations and comparisons to soil boring data. Overall the GPR survey was an effective tool for identifying continuous reflectors that represented silty clay layers in the shallow subsurface soils beneath the site.

As a result of the GPR survey, the topographic low point of the upper surface of the underlying aquitard was determined. This low point was chosen as a location to install an extraction well, since this would be a potential area where DNAPL might pool. DNAPL was encountered during the installation of the extraction well, confirming the results of the GPR survey. Later comparisons to soil boring data also verified the accuracy of the GPR data.

SITE INFORMATION

Identifying Information

Ciba-Geigy Hamblet & Hayes (H&H) Site
Lewiston, ME 55952
Resource Conservation and Recovery Act (RCRA) Site

Background [1]

Physical Description: The H&H site is a complex of buildings located to the southeastern side of Crowley Road in Lewiston, Maine (Figure 1) which occupies an area approximately 450 feet (ft) wide by 600 ft long on a 5.5 acre parcel of land at approximately 190 ft above mean sea level. The site slopes gently from northeast to southwest, toward No Name Brook. Surface drainage from around the buildings collects and flows into a drainage ditch that encompasses the site. Overall, surface drainage primarily flows southwest from the site into No Name Brook. Swampy conditions exist in the area of monitoring wells MW-205A and MW-205B, which is primarily to the south of the study area (Figure 2). A mounded leachfield was built in 1979 to replace the former leachfield and was used for treating sanitary wastes at the site. The previous leachfield was located beneath what is currently the northeastern portion of the truck loading warehouse/office building.

The study area for the Ground Penetrating Radar (GPR) survey was between Crowley Road and the truck loading warehouse/office building (350 ft by 400 ft in area) and in the immediate area along the southeast side of the building (100 ft by 250 ft in area). This covered an area from the former underground storage tanks (USTs), which is the source area, to the railroad tracks (Figure 2).

Site Use: The facility began operations as a solvent repackaging facility in 1963 as the Polar Chemical Division of Hamblet & Hayes Co. (H&H), which was then was purchased by Ciba-Geigy in 1978. The facility ceased solvent repackaging operations in 1985 and changed to a chemical redistribution facility. While operating as a repackaging facility, bulk chemicals were received by tank truck and railroad freight car and then stored in the warehouse and in a series of eight USTs and two aboveground storage tanks. The USTs were located on the northwestern side of the flammable materials storage building, which is located in the north end of the site. One of the aboveground storage tanks was located adjacent to the flammable materials storage building and the other on the southeastern side of the truck loading warehouse/office building. Chlorinated and non-chlorinated solvents were stored in the storage tank areas. Solvents were pumped from the tanks and repackaged into drums and other containers for distribution. The containers were then loaded onto trucks and shipped for delivery. In 1989, the site was

SITE INFORMATION

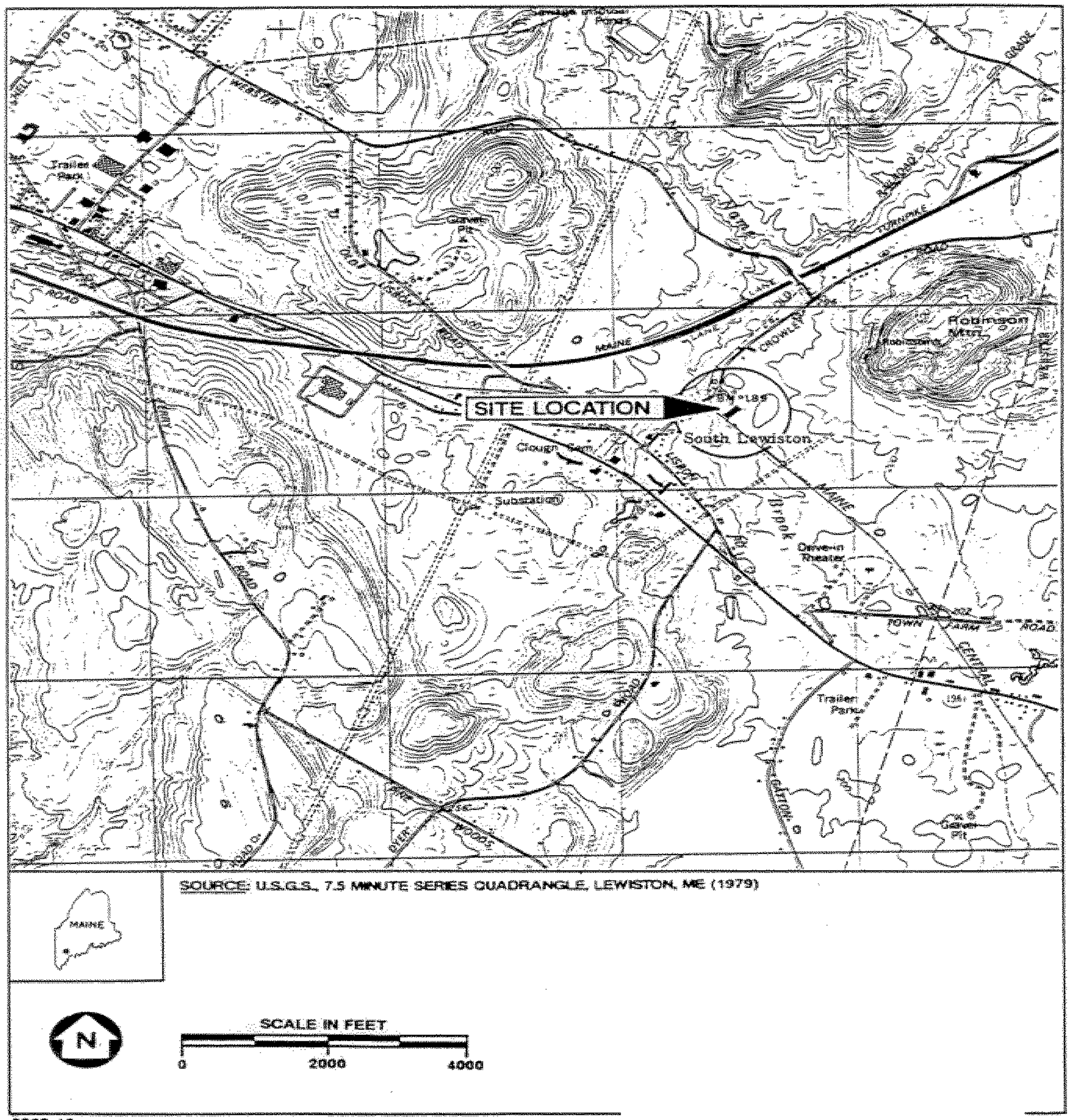

Figure 1: Site Location Map for Ciba-Geigy Hamblet & Hayes[1]

SITE INFORMATION

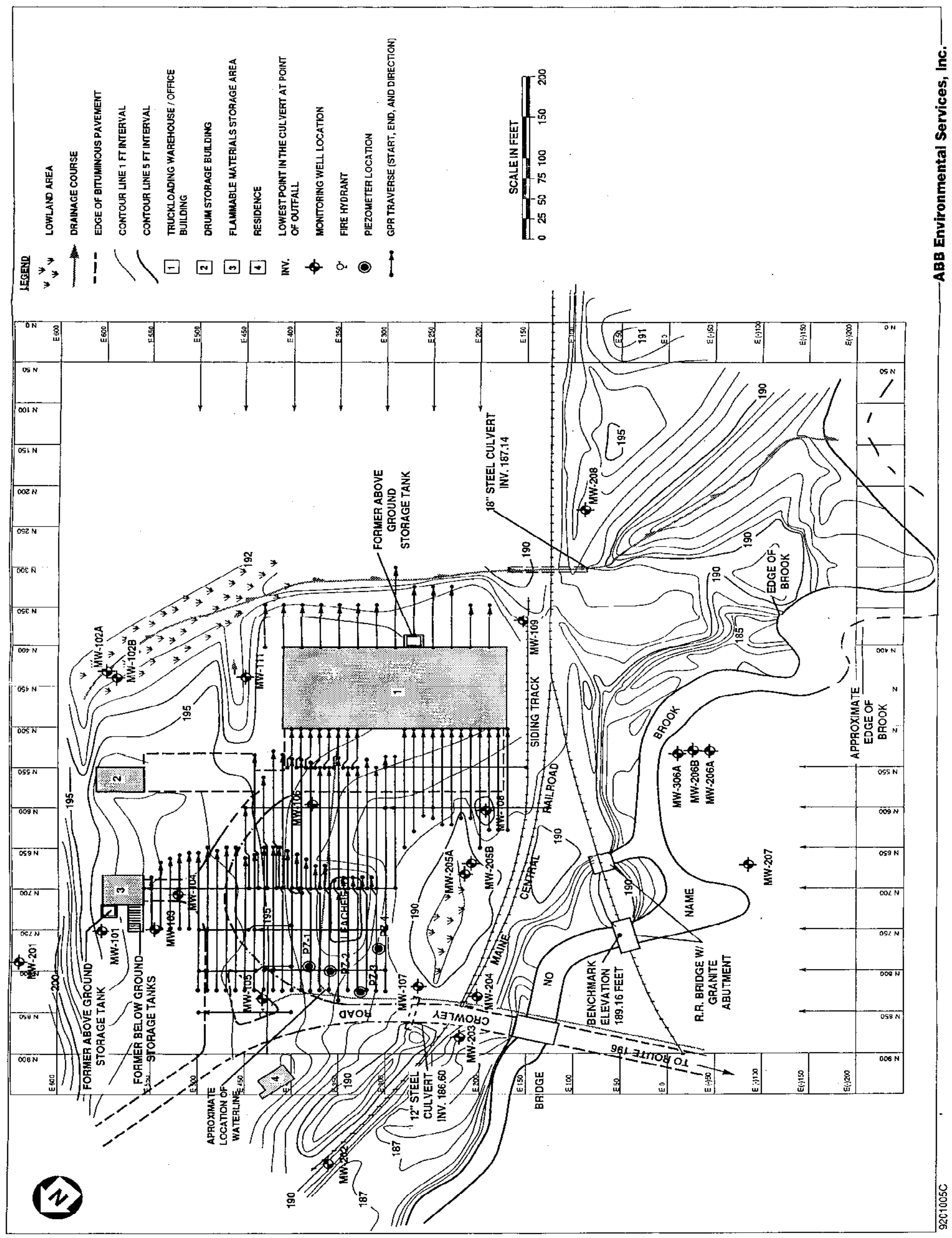

Figure 2: Location of GPR Traverses [1]

purchased by Van Waters & Rogers, Inc., and operations ceased in 1995. In 1997 Ciba-Geigy reacquired the property. Currently, limited truck parking and trailer transferring are the only activities at the site.

A groundwater pump and treat system and an air sparging/soil vapor extraction (SVE) system were installed at the site in 1996, and have been operating since early 1997. The pump and treatment system includes four extraction wells screened in the shallow silty sand aquifer, including EW-401 at the location of dense nonaqueous phase liquids (DNAPLs), and one extraction well (EW-501) screened in the underlying sand and gravel aquifer. The sparging/SVE system is located in the former UST area where light nonaqueous phase liquids (LNAPLs) and very high volatile organic compound (VOC) concentrations have been found in both the saturated and unsaturated zones.

Release/Investigation History: Suspected site contamination occurred in 1983 when a tank valve was inadvertently left open and approximately 1,000 gallons of xylenes were spilled onto the ground. H&H employees reported that xylenes ran along the asphalt driveway surface and ponded in a low area off the asphalt directly across from the front of the truck loading warehouse/office building. The spill was promptly reported to the Maine Department of Environmental Protection (MEDEP) and emergency response crews responded to the spill by excavating the ponded, free product xylenes and contaminated soils. A recovery sump was installed at the corner of the flammable materials storage building in order to recover the portion of xylenes that infiltrated the ground and was floating on top of the groundwater. H&H employees reported that xylenes were skimmed from this sump for approximately four years after the incident. The pumping was discontinued in 1987 due to low or nonexistent levels of recoverable product.

In 1985, the USTs were removed under the supervision of MEDEP personnel. The excavation was backfilled with soils excavated from around the tanks, along with clean, off-site backfill material. The tanks appeared to be in excellent condition, but a solvent odor was noticeable. No soil or water samples were collected as a part of the tank removal process.

The investigation that documented the suspected contamination at the site was a result of the 1989 property transfer Phase I investigation program. ABB Environmental Services, Inc. was contracted by Ciba-Geigy Corporation (Ciba-Geigy) to conduct an environmental assessment and develop a plan for any necessary cleanup of suspected soil and groundwater contamination at the H&H site. This assessment generated enough data to determine that a contaminated groundwater plume, primarily consisting of chlorinated solvents and xylenes, existed at the site. Soil contamination was also identified as being present in the vicinity of the former UST area. Contamination has also been identified in the sediments and surface water of No Name Brook. Recent investigations have been conducted in areas where some DNAPL was identified during the installation of extraction well EW-401. The presence of DNAPL was first confirmed in EW-401 in November of 1994. EW-401 is located adjacent to piezometer PZ-4 (Figure 2).

SITE INFORMATION

Regulatory Context: This is a RCRA site where the MEDEP is providing oversight on all aspects of work done at the site, including work plan reviews and approval and field site visits. On March 27, 1997 the MEDEP entered into a compliance order by consent with Ciba-Geigy. This order detailed the requirements and remedial objectives of the groundwater pump and treatment system that was installed in 1996 and has been operational since early 1997 [5].

Site Logistics/Contacts

Federal Lead Agency: None

State Oversight Agency:
Maine Department of Environmental Protection

Project Manager:
Peter Blanchard
Maine Department of Environmental Protection
17 State House Station
Augusta, ME 04333-0017
207-287-7880
Peter.J.Blanchard@state.me.us

Geophysical Subcontractor:
ABB Environmental Services Inc. (Now Harding Lawson Associates)
511 Congress Street
P.O. Box 7050
Portland, ME 04112-7050
(207) 828-3482

Ciba-Geigy (Now Ciba Specialty Chemicals) Manager:
Tom Smith
Ciba Specialty Chemicals Company
Remediation Services
P.O. Box 71
Oak Ridge Parkway
Toms River, NJ 08754
(732) 914-2867

MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Subsurface soil and clay

Site Geology/Stratigraphy [1]

Native subsurface soils consist of a stratified sequence of outwash sands, peat, marine clay, and sand and gravel layers. The upper layer encountered is a sandy fill layer, which consists of both natural and man-made fill materials that overlay natural organic materials (peat). Debris such as bricks, cinders, and spent coal can also be found in this layer. Beneath the sandy fill layer is a silty sand layer, which consists primarily of fine sands and silts that varies in thickness from 1 foot to 19.5 ft. The silty sand is underlain by a marine clay layer known as the Presumpscot Formation, which was deposited during the recession of the late Wisconsinan glacier. The marine clay primarily consists of a blue-gray silty clay with a trace of fine sand, and with various thickness of fine gray sand lenses with a weathered brown silty clay layer typically overlying the blue-gray material. On average the clay was encountered at 10 ft below the ground surface (bgs) and ranged in thickness from 14 to 61 ft. The layer encountered beneath the clay is the sand and gravel stratum, which consists of a wide range of soils types and gradations, ranging from clean poorly graded sands to well-graded till with cobbles and boulders throughout. This layer was encountered at depths ranging from 15 ft bgs to 73.5 ft bgs. Depth of bedrock was first determined by borings and a seismic refraction survey conducted in 1993. This investigation indicated that depth to bedrock is believed to be at an average of 55 ft bgs [2]. The silty clay, if present in layers or as a massive deposit, is characterized by very low hydraulic conductivities.

Groundwater was encountered in all the soil borings taken during the site investigation, at depths ranging from the ground surface to 6 ft bgs. Direction of groundwater flow is generally southwest across the site toward No Name Brook and into the surface drainage ditches. This holds true for both normal conditions and after heavy precipitation events have occurred. Hydraulic conductivity values for the various subsurface strata are as follows: silty sand layer has a mean conductivity value of 3.7×10^{-4} centimeters per second (cm/sec); silty sand and marine clay interface zone has a value of 1.1×10^{-4} cm/sec; the marine clay has a value of 4.2×10^{-8} cm/sec; and the sand and gravel stratum has a value of 2.0×10^{-3} cm/sec.

Contaminant Characterization [1]

Primary Contaminant Groups: Primary contaminants of concern found at the H&H site include: chlorinated solvents (1,1,1-trichloroethane, tetrachloroethene (PCE), trans-1,2-dichloroethene, and methylene chloride), aromatic hydrocarbons (benzene, ethylbenzene, toluene and xylenes), naphthalene, and ketones. Floating free product organic solvents exist at the former UST area. PCE has been found as a DNAPL at the site.

Matrix Characteristics Affecting Characterization Cost or Performance [1]

Parameters affecting performance of the GPR include a shallow water table and the nature of the soils encountered at the site. To the south side of the truck loading warehouse/office building penetration of GPR was limited by the dense fill that lies above the massive silty clay near the ground surface. Swampy conditions existed in the area of MW-205A and MW-205B to the west of the GPR study area (Figure 2), which limited the use of the GPR system and the extent of the GPR survey, due to limited access to this area. No other factors were reported to impede the effectiveness of the GPR survey or results.

The average depth to be surveyed was between 0 and 15 ft bgs. This is the area where the clay layer is almost always encountered, since the average depth to clay is 10 ft bgs. This was an ideal depth for the GPR survey to be effective in detecting the clay layer and whether or not it was continuous across the study area.

A waterline, which was installed by the City of Lewiston, exists approximately 8 to 10 ft bgs on the southeastern side of Crowley Road (Figure 2). The H&H facility's water line connection between the City of Lewiston water line and the truck loading warehouse/office building parallels the northeastern side of the mounded leachfield and is at a depth of 11 ft bgs. These water lines were not reported to interfere with the effectiveness or the results of the GPR survey.

Investigation Goals [1]

The goal of the geophysical investigation was to provide information on the continuity and topographic relief of the clay layer beneath the site. This would help identify low areas in the clay layer where DNAPL could potentially accumulate.

Geophysical Methods [1]

The GPR technique uses high-frequency radio waves to determine the presence of subsurface objects and structures. A GPR system radiates short pulses of high-frequency electromagnetic (EM) energy into the ground from a transmitting antenna. This EM wave meanders into the ground at a velocity that is related to the electrical properties of subsurface materials (specifically, the relative dielectric permitivity of the materials). When this wave encounters the interface of two materials having different dielectric properties (i.e., soil and water), a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display. The major principles involved for GPR are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy.

For this investigation a Geophysical Survey Systems, Inc. (GSSI) Subsurface Interface Radar (SIR) System-3 GPR system equipped with 100 and 500 MHz antennae were used. Two-way travel times of 50 to 75 nanoseconds were used. The GPR system was towed by hand across the study area at a speed of 0.25 miles per hour (mph).

As part of the site investigation process, a GPR survey was conducted to map the top of the clay surface. However, before the GPR study was conducted at the H&H site, a pilot study was conducted by ABB Environmental Services, Inc. on July 2, 1991. This study indicated that GPR would be effective in profiling the shallow subsurface strata. This led to the more comprehensive survey that was conducted on October 23 and 24, 1991. The survey area was between Crowley Road and the truck loading warehouse/office building and in the immediate area along the southeast side of the building. This covered an area from the former USTs (the source area) to the railroad tracks (Figure 2). An 18-inch steel culvert approximately 50 ft south of the main GPR study area was also examined as part of this investigation. This steel culvert was used for depth of penetration calibration.

The survey consisted of two separate grid areas (Figure 2). One grid area was established in the front yard of the H&H site as a 50 foot by 50 foot grid oriented N30°W (magnetic). For this grid the GPR traverses were conducted in northeasterly and southeasterly directions with 50 foot and 10 foot spacing, respectively. The second grid area was located to the rear of the facility and had GPR traverses spaced 20 ft apart with perpendicular orientation to the southeast wall of the truck

GEOPHYSICAL INVESTIGATION PROCESS

loading warehouse/office building. For the 18-inch steel culvert, two short traverses were oriented perpendicular to the culvert.

Technology Justification

The objective of the geophysical investigation was to determine the topographic relief of the clay layer and whether it was continuous across the site. GPR was considered to be an ideal method for being effective in detecting the clay since the average depth to be surveyed was between 0 and 15 ft bgs.

GEOPHYSICAL FINDINGS

Technology Calibration [1]

Boring log information and an onsite steel culvert were used for depth of penetration calibration.

Investigation Results [1]

Close examination of the 85 GPR profiles revealed a minimum of four reflectors that could be identified on most of the traverse profiles that were generated. These four reflectors were interpreted to represent the top of the silty clay layer surfaces within the transitional zone of the upper portion of the Presumpscot Formation.

The uppermost reflector was found at about 6 ft bgs at the location of MW-106. This was identified on most of the data profiles performed at the site. This uppermost reflector is interpreted to be a silty clay layer within the upper part of the Presumpscot Formation. The surface of this uppermost silty clay reflector generally slopes westward below the survey area at a rate of 5.5 ft per 100 ft. A local topographic low near the western corner of the leachfield exists at approximately 19 ft bgs. This topographic low exists approximately 10 ft below the elevation of the clay surface at the eastern edge of the survey area. Interpretation of data suggested that the topographic low could be part of a trough that trends in a southerly direction. Unfortunately the survey did not extend far enough westward to define the shape of the clay surface in the vicinity of monitoring wells MW-205A, and MW-205B. This was due to the swampy conditions in this area that would not allow access with the GPR equipment.

The depths to the top of the uppermost reflector were tabulated in nanoseconds of two-way travel time. Travel times were then converted to depth using a conversion factor of 5.75 nanoseconds per foot of depth. Depth in feet was then converted to elevation and an interpretive map of elevation contours of the uppermost reflector was created (Figure 3).

Examination of the data collected from the two traverses above the steel culvert indicated that the culvert is not surrounded by transmissive sands and gravels that would act as pathway for groundwater migration. It is thought that the culvert is most likely surrounded by compacted fill.

GEOPHYSICAL FINDINGS

The general conclusion after examining the GPR results was that there was an observed parallel relationship of the various layers of sand, silt, or clay that are present within the shallow subsurface soils of the Presumpscot Formation. This suggested that the topography of the interpreted layer mimics the topography of the top surface of the massive silty clay found at approximately 19 to 22 ft bgs in the area of the GPR survey. Based on this survey and subsurface explorations, the marine clay formation appears to be continuous across the study area. If present, DNAPL could move downslope along the top surface of the silty clay layers and accumulate in the topographical low areas, such as the low area identified near the southwest corner of the leachfield.

Results Validation

Confidence in the level of accuracy of the GPR data was verified through later investigations and comparisons to soil boring data. A digital model created from the soil boring data would produce the same shape when compared with the GPR data [6]. This confirms the results of the GPR survey that the clay formation appears to be continuous across the study area.

An extraction well (EW-401) was installed in November, 1994 at a location previously determined from the GPR survey to be a topographic low point on the upper surface of the clay formation [4]. PCE was found as a DNAPL along with other VOCs at this well; this confirmed that the location identified by the GPR survey was a topographic low point where DNAPL might accumulate.

GEOPHYSICAL FINDINGS

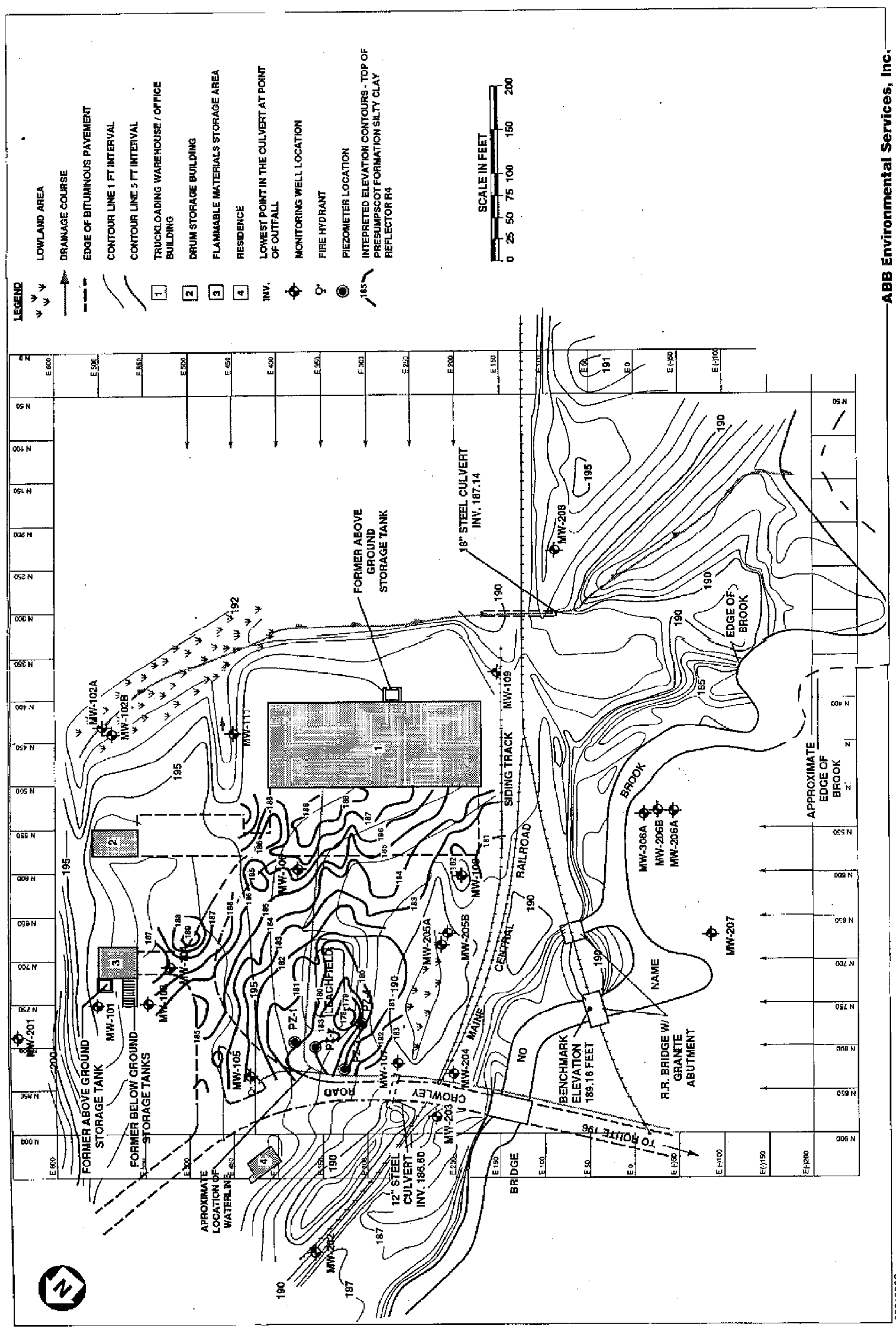

Figure 3: Interpreted Elevation Contours of the Top of Presumpscot Formation (Silty Clay Reflector R4) [1]

LESSONS LEARNED

Some of the lessons learned during this investigation include:

- Overall, the GPR survey was an effective tool for identifying continuous reflectors that represented silty clay layers in the shallow subsurface soils beneath the site [6]. The confidence level of the decisionmakers in the results was high. Confidence in the level of accuracy of the GPR data was verified through later investigations and comparisons to soil boring data.

- Penetration of the GPR survey was limited on the southeast side of the truck loading warehouse/office building, since it did not identify subsurface reflectors. This is interpreted as a result of the presence of dense fill that lies above the massive silty clay near the ground surface [1].

- As a result of the GPR survey, the surface of the clay layer underneath the site was mapped, and the topographic low point of the upper surface was determined. This low point was chosen as a location to install an extraction well, since this would be a potential area where DNAPL might pool. DNAPL was encountered during the installation of the extraction well, as suspected [4].

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- Personnel Communication with Mr. Peter J. Blanchard of the Maine Department of Environmental Protection. September 3, 1998.

- Personnel Communication with Mr. Tom Smith of Ciba-Geigy. September 3, 1998.

- Personnel Communication with Mr. Stephen Walbridge of Harding Lawson Associates. September 18, 1998.

Case Study Abstract

Crystal Refinery
Carson City, MI

Site Name and Location: Crystal Refinery Carson City, MI	**Geophysical Technologies:** Ground Penetrating Radar (GPR) Electrical resistivity	**CERCLIS #** Not Applicable
Period of Site Operation: 1935 to early 1990s **Operable Unit:** Not Applicable		**Current Site Activities:** Groundwater pump and treatment system via French drains/capture trenches
Point of Contact: David Monet, Geologist Environmental Response Division MI DEQ 245 Colrain, SW Wyoming, MI 49548-1013 (616) 246-1739	**Geological Setting:** Alluvial sand and loam soils overlay a shallow, fine to coarse sand aquifer separated from deeper aquifers by a clay aquitard. Bedrock occurs at 350 ft bgs and is composed of sandstone, shale, limestone, siltstone, and clay.	**Technology Demonstrator:** William A. Sauck, PhD Department of Geosciences Western Michigan University Kalamazoo, MI 49008 (616) 387-4991 sauck@wmich.edu
Purpose of Investigation: Investigation of the hypothesis that electrical properties of the zone impacted by a hydrocarbon plume in a natural environment change over time from electrically resistive to electrically conductive due to biodegradation, and that this shift in conductivity can be measured using geophysical methods.		
Number of Images/Profiles Generated During Investigation: 1 GPR profile, 1 dipole-dipole resistivity profile, 1 vertical resistivity probe profile and associated soil boring		
Results: The investigation confirmed the hypothesis that an older light non-aqueous phase liquid hydrocarbon plume in the natural environment will shift the bulk resistivity of the impacted zone from high resistivity to low resistivity over time.		
Project Cost: Estimated total cost for the investigation of this type was approximately $5,795.		

EXECUTIVE SUMMARY

The Crystal Refinery is located in northwest Carson City in central Michigan. To the north and northwest there is a pine forest, and to the east and southeast, there are agricultural lands, residences, and commercial businesses. Site topography is characterized by rolling hills and uniformly western sloping plains. The geology at this site was created by two types of moraines created during the Wisconsin Glacial Period; a ground moraine and two end morainic ridges. The soil in the ridges is composed of clay, while soils deposited by glacial outwash in the ground moraine are sands and loams. The alluvial soils overlay a shallow, fine to coarse sand aquifer which is separated from deeper aquifers by a clay aquitard.

For this geophysical investigation two methods were used. The first was ground penetrating radar (GPR), which uses high-frequency radio waves to determine the presence of subsurface objects and structures. The second method was electrical resistivity, which injects electric currents into the earth through a pair of current electrodes, and the potential difference is measured between a pair of potential electrodes. The investigator chose GPR and electrical resistivity as the best methods to recognize the geoelectric properties of the volume of earth containing a hydrocarbon contaminant plume.

The GPR profile revealed a strong and continuous reflector which was interpreted as the water table at a depth of 10-18 feet. This is in agreement with known water table measurements. A second reflector was visible in the profile just above the water table from the west to approximately 100 meters (m). Depths to this reflector are computed as 2.7 m in the west down to 5.5 m at its lowest point. Soil boring data indicate that this reflector is coincident with the top of a layer containing residual product and exhibiting oil staining and a strong gasoline odor. The dipole-dipole resistivity profile demonstrated high resistivity in the vadose zone and a gradient to low resistivity. The areas of low resistivity were interpreted as the saturated zone and the clay aquitard beneath it. The vertical resistivity probe was placed in a known area of free product. The vertical resistivity probe revealed high resistivity in most of the vadose zone, in correlation with the dipole-dipole profile. However, near the base of the vadose zone and in the uppermost part of the saturated zone, a pronounced resistivity minimum was encountered.

This investigation was done as a field demonstration by Western Michigan University and all the equipment was owned by the University. Therefore, there were no direct labor and equipment costs associated with this geophysical investigation. However, the estimated cost of initiating such an investigation using three different geophysical methods would cost approximately $6,000.

Biodegradation of mature LNAPL plumes can produce geochemical changes in the materials at the capillary fringe that mobilize inorganic compounds from the subsurface materials. The change in pH and ion charge of the materials increases the conductivity of the subsurface materials. This increase in conductivity can be detected using electromagnetic methods, such as ground penetrating radar [2]. Light hydrocarbon free-product and associated dissolved plumes are dynamic systems. Therefore the application of geophysical techniques to investigations such as this should be conducted in conjunction with geochemical investigations [2].

SITE INFORMATION

Identifying Information

Crystal Refinery
Carson City, MI 48811

Background [2]

Physical Description: Crystal Refinery is located on North Williams Street in northwest Carson City in central Michigan. Carson City is a small rural town and the site is located in a residential and commercial area. The Carson City Park is located on the southern border of the site, and Fish Creek forms the western border. To the north and northwest there is a pine forest, and to the east and southeast, there are agricultural lands, residences, and commercial businesses (Figure 1). The center of Carson City is located approximately 3,000 feet to the southeast of the site. The site is approximately 32.5 acres and consists of two separate parcels. The larger southern parcel contains the petroleum refinery, storage tanks, lagoons, loading docks, and several buildings. The northern parcel contains storage tanks, a valve station, and a disposal area. Both parcels are partially fenced and gated. Site topography is characterized by rolling hills and uniformly western sloping plains. Between the two parcels is a cemetery. South of the southern parcel is a city park.

Site Use: Crystal Refinery began processing crude oil in 1935 and operated until the early 1990s. The site received crude oil from both an underground pipeline and railroad cars. The average production of the refinery was approximately 84,000 gallons of oil per day. Total tank storage capacity, including above-ground storage tanks (ASTs) and underground storage tanks (USTs), was an estimated 10,000,000 gallons. Between 1957 and 1962, two additional ASTs were constructed on the northern parcel, adding 2,000,000 gallons to the total tank storage capacity.

Eight cooling lagoons on the southern parcel received waste sludges from site operations. These sludges, copper chloride, Fuller’s Earth, and styrene materials were transferred to and disposed of on the northern parcel until the mid-1970s. In 1970, four french drains were installed. Recovered oil and water from these drains was pumped to an oil/water separator. Remaining liquids were then pumped to a second separator and discharged into one of the lagoons. The site is currently inactive.

Release/Investigation History: Shortly after site operations began, an oil seep was discovered in the north recovery area. The Michigan Department of Natural Resources (MDNR) investigated this seep in 1945, however there is no information regarding the results of this investigation. In 1968, MDNR performed an evaluation of Crystal Refinery to determine the extent of oil contamination in groundwater. Twenty-two wells were installed, both on- and off-site, to establish the lateral extent of contamination and groundwater flow direction. A heavy oil slick was noted on the backwaters of Fish Creek at this time.

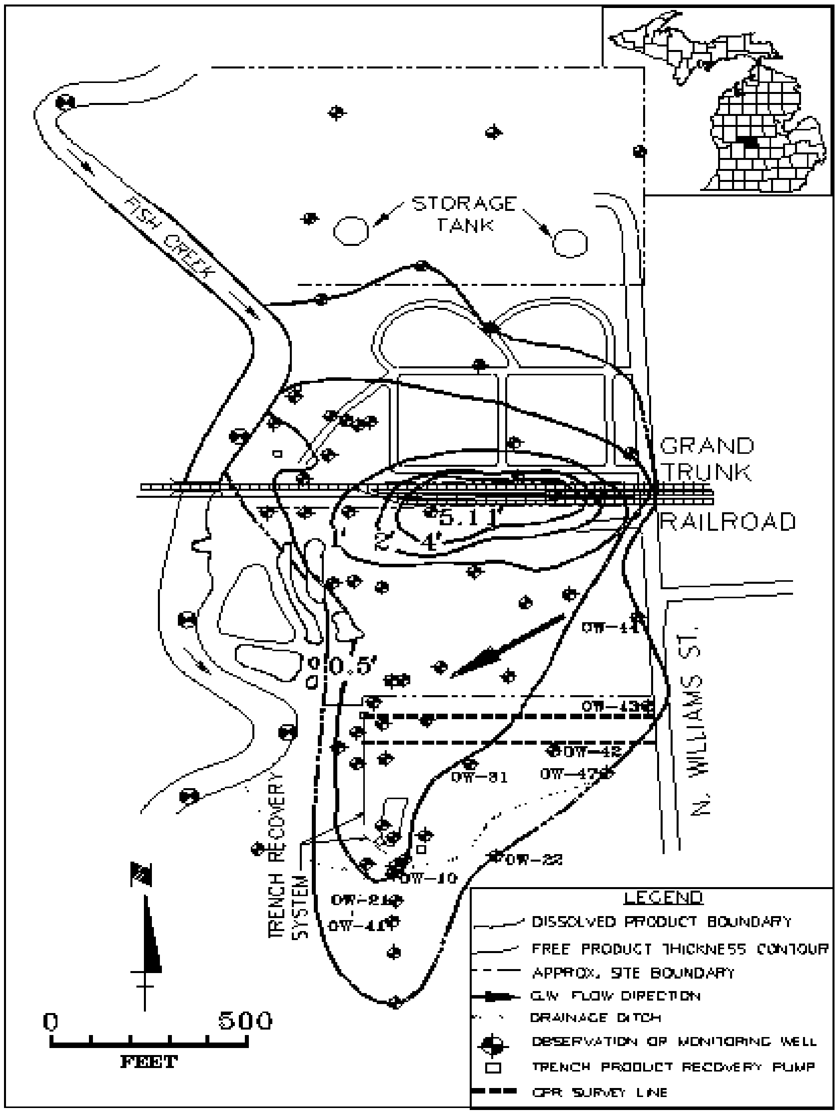

Figure 1: Crystal Refinery Site Map [2]

SITE INFORMATION

A large release of crude oil occurred in January, 1973 when a fractured check valve on a receiving line burst. Eighty-eight thousand gallons of crude oil flowed over frozen ground toward Fish Creek. Although some was intercepted on site, oil did enter Fish Creek. The ensuing cleanup was performed by Crystal Refinery.

In 1982, Crystal Refinery conducted a hydrogeological investigation required by MDNR. More wells were installed to evaluate both the lateral and vertical extent of contamination. This investigation estimated that as much as 4,000,000 gallons of oil in might be present in the groundwater, 117,000 cubic yards of soil might be seriously impacted by oil contamination, and 86,000 cubic yards of soil may have been marginally impacted. In 1983, Crystal Refinery installed purge wells in an attempt to address the groundwater contamination. Water pumped from the wells was skimmed, sent to a separator, and then to one of the lagoons.

A 1989 EPA visit to the site documented degradation of containment measures, such as erosion around the lagoons and degradation of insulation in storage tanks. EPA instructed Crystal Refinery to address these conditions, and in 1992, MDNR required the development of a remedial action plan (RAP) addressing both groundwater and soil contamination. A RAP was completed in 1992 addressing only groundwater issues. MDNR accepted the RAP as an interim response, but stated it was inadequate until soil concerns were addressed. Since 1993, Crystal Refinery has continued to address groundwater, but has not performed any remedial measures addressing soil contamination. The EPA razed (removed) all above-ground facilities in Fall, 1998.

Regulatory Context: MDNR has been the lead agency in overseeing and approving the Crystal Refinery activities and decisions. However, in April 1997, MDEQ (formerly MDNR) referred the site to the US EPA Region 5 Emergency Response Branch.

Site Logistics/Contacts

Federal Lead Agency:
US EPA Region 5 Emergency Response Branch

Project Manager:
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Environmental Response Division
MI DEQ
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State Lead Agency:
Michigan Department of Environmental Quality

Geophysical Subcontractor:
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sauck@wmich.edu

MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Subsurface soils and groundwater

Site Geology/Stratigraphy

The geology at this site was created by two types of moraines created during the Wisconsin Glacial Period; a ground moraine and two end morainic ridges. The soil in the ridges is composed of clay, while soils deposited by glacial outwash in the ground moraine are sands and loams. The alluvial soils overlay a shallow aquifer composed of fine to coarse sand. The shallow aquifer is separated from deeper aquifers by a clay aquitard. The thickness of the shallow aquifer ranges from 15 feet in the western portion of the site to 30 feet in the eastern portion. Bedrock occurs at 350 feet below ground surface and is formed by the Jurassic and Saginaw Formations. The bedrock is composed of primarily sandstone, shale, limestone, clay, and siltstone.

Contaminant Characterization

Primary Contaminant Groups: The contaminants of concern are residual oil and hydrocarbons both as dissolved phase and free product. Hydrocarbons are present as light, non-aqueous phase liquids (LNAPLs). Both crude oil (north) and refined products (south).

Matrix Characteristics Affecting Characterization Cost or Performance [2]

Some fading of the ground penetrating radar (GPR) reflections occurred and may have been related to enhanced soil conductivities which limit the effective depth of penetration of the radio waves. Some of the problems affecting the performance of the electrical resistivity data interpretations were related to equivalence and suppression. Lower resistivities at the fringes of survey lines may have been the result of a shallower water table to the west, and, to the east, lower resistivities may have been caused by the presence of road salt. Other factors such as the surface conditions, and subsurface distribution of conductive zones may also play an important role in controlling the electrical signature of surface geophysical measurements at hydrocarbon impacted sites.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals

The geophysical investigation was undertaken in November 1997 as part of academic research for Western Michigan University's Department of Geology. The purpose of the investigation was to test the proposition that the electrical properties of the soil moisture intermingled with a hydrocarbon plume change over time from electrically resistive to electrically conductive. The conventional model, based on controlled spill and lab experiments, is that groundwater and soils contaminated with hydrocarbons exhibit lower electrical conductivity and lower relative permittivity than the surrounding uncontaminated media. The hypothesis tested in this study is that hydrocarbon spills in the natural environment will change the bulk properties of the impacted zone from electrically resistive to electrically conductive over time due to biodegradation of the hydrocarbons. Conductivity is enhanced by the leaching of inorganics from the soil and aquifer materials by organic acids produced by microbial activity during degradation of the hydrocarbons [1].

Geophysical Methods [2]

For this geophysical investigation two methods were used. The first was GPR, which uses high-frequency radio waves to determine the presence of subsurface objects and structures. A GPR system radiates short pulses of high-frequency electromagnetic (EM) energy into the ground from a transmitting antenna. This EM wave propagates into the ground at a velocity that is related to the electrical properties of subsurface materials (specifically, the relative dielectric permittivity of the materials). When this wave encounters the interface of two materials having different dielectric properties (i.e., soil and water), a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display. The major principles involved for GPR are similar to reflection seismology, except that EM energy is used instead of acoustic energy and the propagation times are much shorter.
The GPR survey was conducted using the Geophysical Survey Systems Inc. (GSSI) Subsurface Interface Radar-10A+ (SIR-10A+) with 300 MHZ bistatic antennae. The modulation frequency was set at 300 MHZ with a recording time of 160 nanoseconds (ns). The survey used a constant gain setting and a 3-scan moving average horizontal filter. The GPR system was towed for 230 meters along two lines 20 meters apart at 15 and 35 meters south of the refinery boundary (Figure 1).

The second geophysical method used was electrical resistivity. During resistivity surveys, current is injected into the earth through a pair of current electrodes, and the potential difference is measured between a pair of potential electrodes. The current and potential electrodes are generally arranged in a linear array. Common arrays include the dipole-dipole array, pole-pole array, Schlumberger array, and the Wenner array. The apparent resistivity is the bulk average resistivity of all pore fluids, soils and rock influencing the flow of current. Resistivity is the inverse of conductivity. It is calculated by dividing the measured potential difference by the input current, and multiplying by a geometric factor (specific to the array being used and electrode spacing).

GEOPHYSICAL INVESTIGATION PROCESS

Models of the variation of resistivity with depth can be obtained using model curves or forward and inverse modeling computer programs.

Electrical resistivity was measured with the Iris Syscal R2 Deep Resistivity-IP System using the axial dipole-dipole array configuration with dipole separations between 1 and 5 and the Wenner array configuration with a 2-inch electrode spacing for vertical resistivity measurements in the vertical probes. Both the dipole-dipole and vertical profiling (not along a line, but a single point) were conducted along a line 20 meters south of the refinery. The Iris Syscal R2 Deep Resistivity-IP System is menu-driven and has internal storage memory and weighs approximately 6 kilograms.

GEOPHYSICAL FINDINGS

Technology Calibration

No calibration was reported as being necessary for this investigation. However, for the resistivity system calibration is usually done digitally by the microprocessor based on correction values stored in memory. The correction values are found in final production testing and are also established during later periodical recommended yearly checks at authorized service centers. Vertical probes have been calibrated in a water tank to determine the correction factor for the body of the probe (2" OD PVC cylinder-perfect insulator).

Investigation Results [2, 3]

The GPR profile revealed a strong and continuous reflector occurring at 40 ns near the west end and 70 ns further east along the profiles (Figure 2). This reflector is interpreted as the water table and a depth of 3.5 to 5.5 m was computed. This is in agreement with known water table measurements. Another, parallel, reflector is visible in the profile just above the water table from the west to approximately 100 meters. At 100 meters, this reflector dips to the east and then merges with the W.T. reflector at 140 meters. After 160 meters, this reflector is visible as a separate event again and rises to 50 ns. Depths to this reflector are computed as 2.7 m in the west down to 5.5 m at its lowest point at 140 meters east. Soil boring data indicate that this reflector is coincident with the top of the layer containing residual product and exhibiting oil staining and a strong gasoline odor. The appearance of this reflector on the GPR profile may be due to viscous residual product in the vadose zone blocking sediment pore space and altering the permeability.

The dipole-dipole resistivity profile demonstrates high resistivity in the vadose zone and a downward gradient to low resistivity (shown as lighter shades in Figure 3). The areas of low resistivity are interpreted as the saturated zone and the clay aquitard beneath it. The fact that no anomalous features attributable to the free product plume were observed is possibly due to problems of equivalence and suppression associated with resistivity interpretations.

The vertical resistivity probe is located in a known area of free product. The vertical resistivity probe revealed high resistivity in the vadose zone (staying around 1000 Ohm-meters on a log scale), in correlation with the dipole-dipole profile. However, at approximately 3.8 m bgs, electrical resistivity suddenly decreases to 15 Ohm-meters. This is lower than background water resistivities of 30 Ohm-meters. According to soil boring data, this zone of low resistivity begins just above the water table and is coincident with the layer containing free product observed between the upper reflector and the W.T. reflector in the GPR survey. This is interpreted to confirm that a natural environment zone which has been saturated with hydrocarbon for a period of time (in this case, 50 years) exhibits an increased conductivity (decreased resistivity), contrary to the conventional model that it will display conductivities less than the uncontaminated areas.

Results Validation [2]

Geochemical data, including dissolved oxygen, pH, and specific conductance was collected from five on-site wells (Table 1). The locations of these wells can be seen in Figure 1. The high measurements of dissolved oxygen and low conductivity in OW-10 and OW-21 indicate minimal impact by hydrocarbon contamination. Similar measurements in OW-43 showed low dissolved oxygen and the highest conductivity. This well is located at the margin of the dissolved phase plume, as is OW-44. Measurements in OW-31 revealed the lowest dissolved oxygen and a corresponding high conductivity. The variations in measurements are attributed to varying rates of biodegradation. Waters from below the impacted zone were 3-5 times more conductive than background. The low dissolved oxygen rates correlate with high conductivities and indicate microbial activity is breaking down the hydrocarbons. The use of ambient dissolved oxygen ultimately results in (involves bacterial process, then chemical leaching process) elevated conductivities.

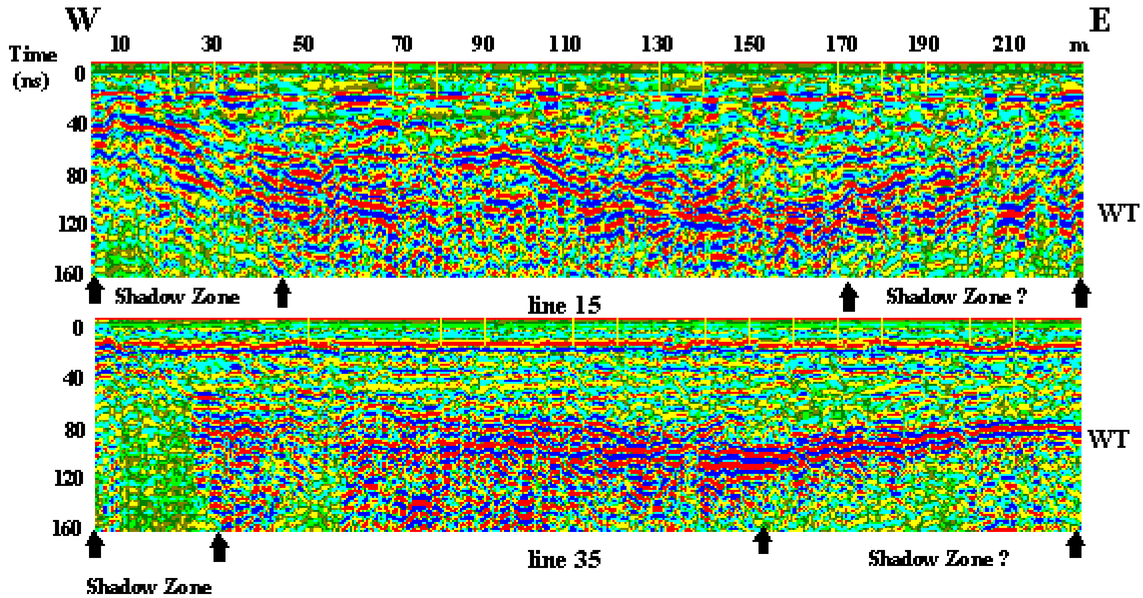

Figure 2: Ground Penetrating Radar Profiles of Line 15 and Line 35 [2]

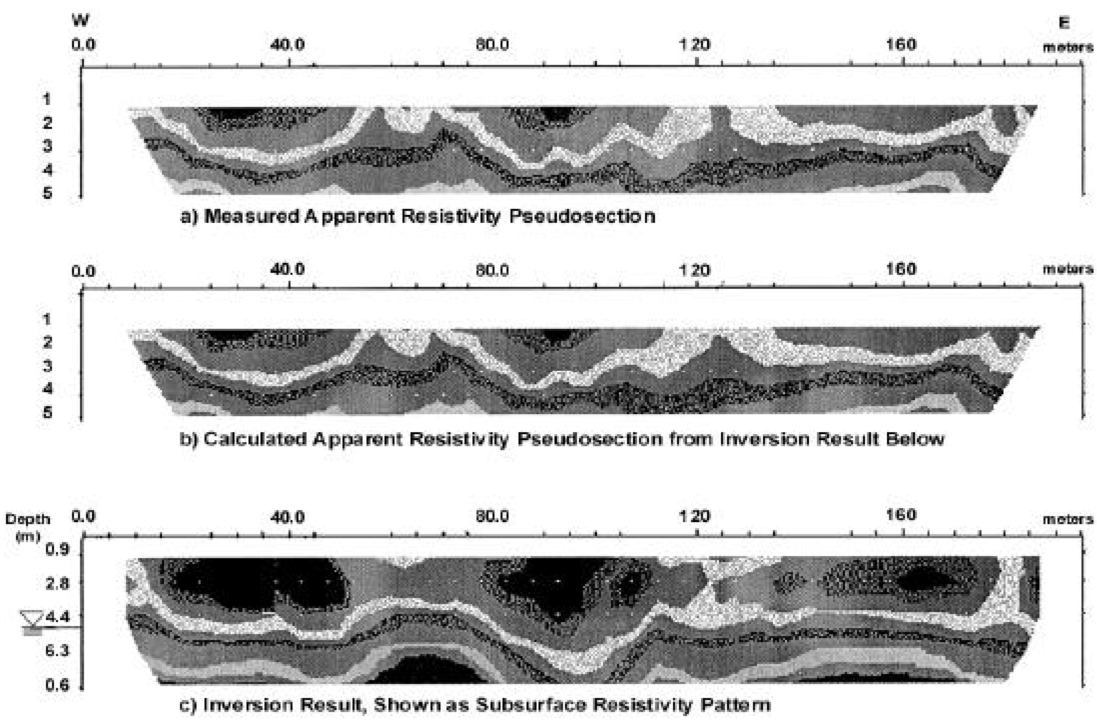

Figure 3: Resistivity Pseudosections [2].

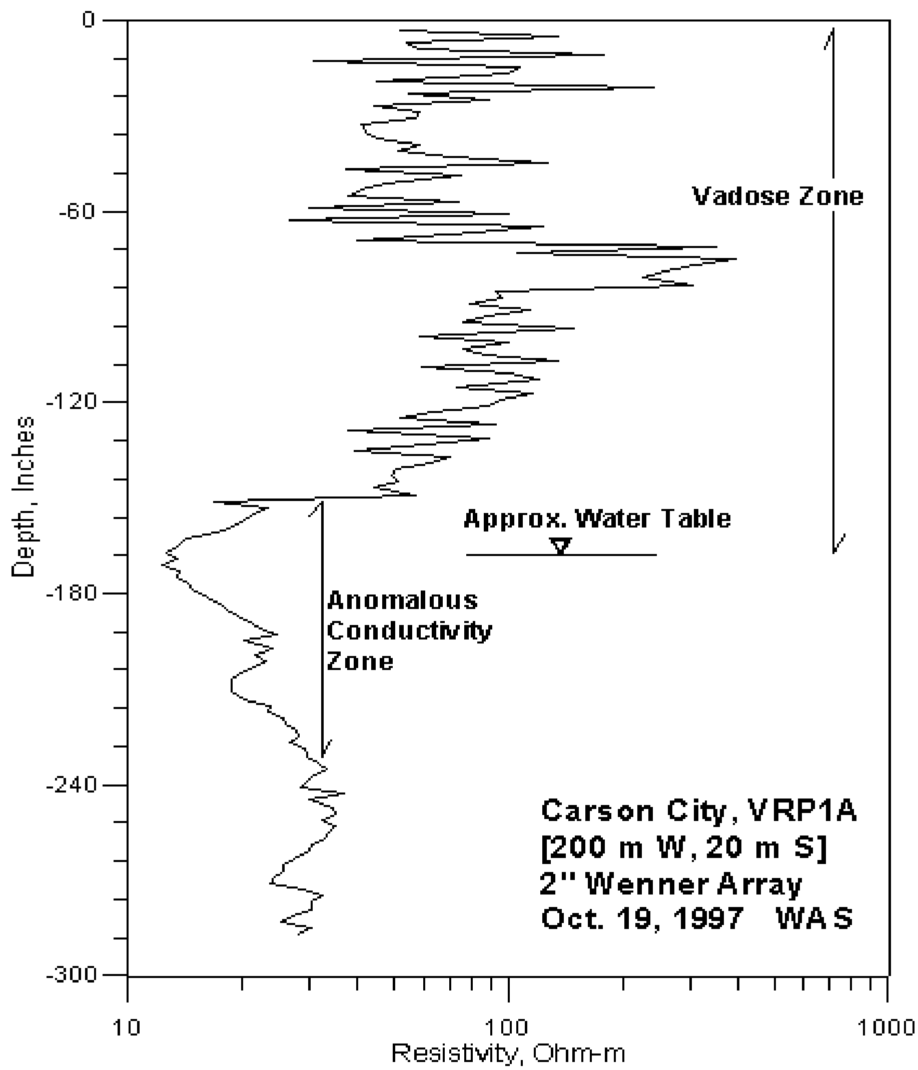

Figure 4: Vertical resistivity probe located at 0.0 mE, 20 mS, 2" Wenner Array, semi-log scale [2].

GEOPHYSICAL FINDINGS

Table 1: Geochemical Data Used in Results Validation

Well ID	Dissolved Oxygen (mg/L)	pH	Specific Conductance (mS/m)
OW-10	7.2	6.4	32
OW-21	7.2	7.1	30
OW-31	0.3	6.37	93
OW-42	0.7	7	90
OW-43	0.6	6.76	158
OW-44	1.2	6.5	101

LESSONS LEARNED

The lessons learned during this investigation are the following:

- Biodegradation of mature LNAPL plumes can produce geochemical changes in the materials at the capillary fringe or zone of mixing that mobilize inorganic compounds from the subsurface materials. The change in pH and ion charge of the materials increases the conductivity of the subsurface materials. This increase in conductivity can be detected using electromagnetic methods, such as ground penetrating radar. This phenomenon will be limited to "mature" plumes, and depending on the specific chemical nature of the plume and the viability of the indigenous microbial population, may not be observed at all sites [2].

- Ground penetrating radar was able to clearly identify the water table and the top of the impacted zone [2].

- No anomalous regions which can be attributed to the free product plume could be observed along the horizontal resistivity profile. This was likely due to the problems of equivalence and suppression, which often plague resistivity interpretations [2]. However, electrical resistivity data from fixed vertical resistivity probes showed resistivity minima which coincide with GPR shadow zones with relation to the depth of the water table.

- Light hydrocarbon free-product and associated dissolved plumes are dynamic systems. Therefore the application of geophysical techniques to investigations such as this should be conducted in conjunction with geochemical investigations [2]. This will result in a better understanding of site conditions.

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- Atekwana, E., W.A. Sauck, and D.D. Werkema, Jr. *Characterization of a Complex Refinery Groundwater Contamination Plume Using Multiple Geoelectric Methods.* Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 1998), pp. 427-436.

- Sauck, William A. *A Conceptual Model for the Geoelectrical Response of LNAPL Plumes in Granular Sediments.* Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 1998) pp. 805-817.

- Personal communication with Phil Sirles of Microgeophysics. Wheat Ridge, CO. December 10, 1998.

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Case Study Abstract

Kansas Underground Storage Tank (UST) Site
Salina, KS

Site Name and Location: Kansas UST Site Salina, KS	**Geophysical Technologies:** Electrical conductivity	**CERCLIS #** Not applicable
Period of Site Operation: Unknown **Operable Unit:** Not applicable		**Current Site Activities:** Long-term Monitoring
Point of Contact: Wesley McCall, 913-825-1842	**Geological Setting:** Low conductivity clays overlying sandy water-bearing units	**Technology Demonstrator:** Geoprobe Systems Salina, KS
Purpose of Investigation: Characterize the subsurface stratigraphy and identify structures that could influence groundwater flow patterns		
Number of Images/Profiles Generated During Investigation: 10 conductivity logs to depths ranging from 50 to 60 feet below ground surface		
Results: The survey identified a continuous confining clay layer overlying and upper and lower aquifer. A contour of the contact surface between the upper aquifer and the confining clay layer was generated and a topographic high was identified that might create a migration pathway for LNAPLs to the northwest, a direction that is opposite from the generalized groundwater flow to the east.		

Kansas Underground Storage Tank (UST) Site

EXECUTIVE SUMMARY

The Kansas Underground Storage Tank (KS UST) site is located within the city limits of Salinas, KS adjacent to an exit off Interstate 70. The site is situated in a light commercial area, with service stations, motels and restaurants on the adjacent lots. The study area was 160,000 square feet in size and is situated behind a former service station where the KS Department of Environment and Health suspected than an unidentified source of groundwater contamination existed.

Groundwater contamination was discovered at the site during a Phase II investigation, conducted in support of a real estate transaction on a nearby property. Groundwater monitoring in the area established a plume of petroleum hydrocarbons moving toward the east. However, contamination was detected in several wells to the north of the suspected source area, as well. The geophysical investigation was conducted in 1995 as a cost-effective method for characterizing the subsurface stratigraphy.

The site geology consists of a surficial layer of low hydraulic conductivity clays and sands to a depth of approximately 46 feet below ground surface (bgs). Below the clay and sand layer, subsurface materials grade into alluvial sands and gravels. Below the alluvial sands lies another clay layer that separates the upper sand layer from another, deeper, sand layer. The Wellington formation forms the bedrock at the site and consists of gray and green shales. Groundwater is encountered at approximately 20 to 40 feet bgs.

The geophysical investigation was carried out using the Geoprobeâ Direct Imageâ Soil Conductivity System. This direct push technology does not require a pre-existing borehole to perform the logging process as the conductivity probe is driven directly into virgin unconsolidated formations. Additionally, no drill cuttings are generated during the logging process, which significantly reduces waste generation and potential exposure hazards. Electrical conductivity logs were calibrated by comparing them with lithologic logs from continuous core samples taken in two locations. Conductivity logs were taken from 10 borings across the study area to depths of 40 to 60 feet below ground surface. The logs indicated the consistent presence of the surficial clay layer to a depth of approximately eight to 10 feet bgs. Furthermore, a comparison of the logs indicated that the surficial clay layer had a saddle-like structure with a ridge trending northward. The investigation concluded that the surficial clay layer acted as a confining layer, and that petroleum contamination floating on the water table was being forced northward beneath this ridge by artesian pressure.

The Soil Conductivity System was found to be a cost-effective approach for characterizing the subsurface stratigraphy. Conductivity logging can provide consistent information on stratigraphy and when accurate surface elevations are obtained from each boring, a contour map can be developed for any of the lithologic units that are identified in the survey. This information can be used to identify subsurface structures that might provide migration pathways for non-aqueous phase liquids, either light or dense.

SITE INFORMATION

Identifying Information

Kansas Underground Storage Tank (UST) Site
Salina, Kansas
Investigation Date: August 1995

Background [1, 2]

Physical Description: The Kansas Underground Storage Tank (KS UST) site is located in a commercial area within the city limits of Salinas, Kansas. Located on a small parcel of land adjacent to the I-70 exit ramp, the site is surrounded by service stations, motels, and a fast food restaurant (see Figure 1). The 160,000 square foot study area for the geophysical investigation was located to the north of Diamond Drive where the Kansas Department of Health and Environment (KDHE) suspected that an unidentified source of groundwater contamination was located. The study area lies in flat terrain with little topographical relief. The Saline River lies to the north at a distance of one mile.

Site Use: The site is the location of a former Amoco service station where past spills of petroleum products had contaminated the soils and the groundwater. There are other potential sources, however, located to the north of the site, such as a former truck stop and several ditches that may have been used to dispose of petroleum products. A motel is presently located on the site.

Release/Investigation History: Groundwater contamination was discovered during a Phase II investigation conducted to support the real estate transaction that led to the construction of a motel on the site of the former service station. The geophysical investigation was conducted in 1995.

Regulatory Context: The KS UST site is managed under the Kansas Underground Storage Tank Fund, and all compliance requirements are set by that program.

SITE INFORMATION

Site Logistics/Contacts

State Lead Agency: Kansas Department of Health and Environment (KDHE)

Federal Oversight Agency: None

KDEH Project Manager:
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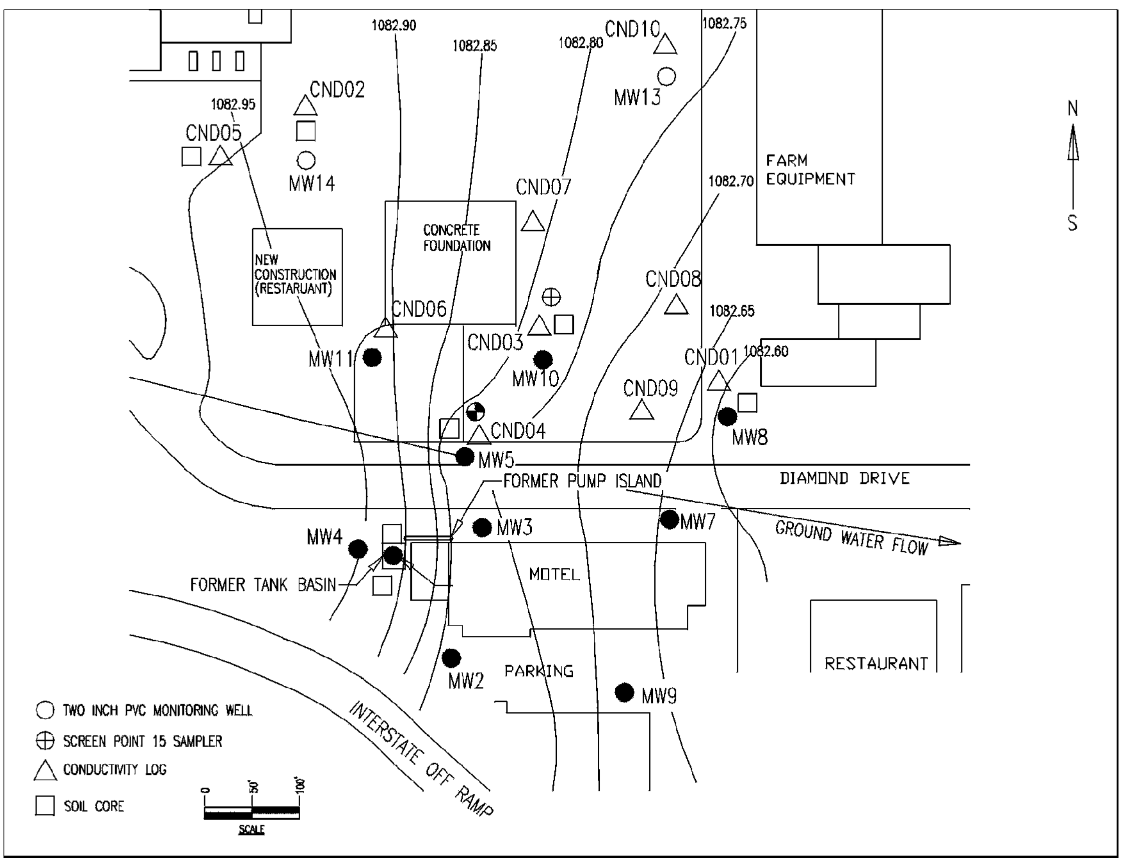

Figure 1: KS UST Study Area with Potentiometric Surface [1]

MEDIA AND CONTAMINANTS

Matrix Identification [1]

Type of Matrix Sampled and Analyzed: Subsurface clays, sands, and gravels

Site Geology/Stratigraphy [1, 2]

Surface and near-surface soils in the study area consist primarily of low hydraulic conductivity clays and sands to a depth of 46 feet below ground surface (bgs). Below this level the clays grade into alluvial sands and gravels overlying another clay layer. This clay layer is continuous throughout the study area and separates the upper sand layer from another sand layer. Bedrock is present beneath the lowest sand layer as the Wellington Formation, consisting of grey and green shales.

The formation from a depth of about 20 to 40 feet bgs grades from clayey-silts to fine sandy silts to medium-grained sands with depth. There is evidence that this upper aquifer exists under confined conditions. When wells are screened at depths of 22 to 24 feet bgs, they do not yield water, yet when screened at, or below, 28 feet bgs the static groundwater level rises to 18 feet bgs. Generalized groundwater flow is to the east and toward the Saline River at an average rate of less than one-half foot per day. A second aquifer exists in the deepest sandy layer overlying the Wellington Formation and is separated from the upper aquifer by a clay-silt layer over five feet thick.

Contaminant Characterization [2]

Primary Contaminant Groups: The principal contaminants of concern include benzene, toluene, ethylbenzene, and xylenes (BTEX). Free product contamination found in some wells indicated that the contaminants were present as light, non-aqueous phase liquids (LNAPLs).

Matrix Characteristics Affecting Characterization Cost or Performance [1,3]

The ground surface in the study area included grass- and gravel-covered areas which posed no problems for the probe. In two areas, however, the surface was concrete and holes were bored through the concrete before beginning the push in these areas.

Consistency in site lithology facilitated the conductivity survey. The site has several geologically distinct layers whose conductivity values are markedly different. Furthermore, the layers are relatively continuous throughout the study area.

Excessive soil moisture that might have interfered with conductivity readings was not a problem at any location in the study area.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [3, 4]

The goal of the investigation was to identify any subsurface structures that might influence groundwater flow directions. The initial investigation found BTEX contamination on the southern side of Diamond Drive, and generalized groundwater flow to the east. When contamination was found in monitoring wells to the northwest of the suspected source area, the question was raised: were there other undiscovered source areas to the northwest, or were there groundwater flow dynamics that could result in the northerly migration of contaminants?

Geophysical Methods [1, 3, 5]

The geophysical survey was carried out using the Geoprobe® Direct Image® Soil Conductivity System, operated in a Wenner array configuration. In this configuration, an electrical current is passed through the soil and the soil conductivity is measured by four electrical contacts. The conductivity value is a function of grain size, with finer grains producing higher values and coarser grains resulting in lower values. The units of measurement for conductivity are milliSeimens per meter (mS/m). The Seimen is the inverse of the Ohm, the standard measure for electrical resistivity.

The Direct Image® system consists of a steel probe running through four stainless steel rings, as is shown in Figure 2. The SC200 probe is eight inches long and varies in diameter from one inch at the tip to 1.125 inches at the base. An electrical grade plastic insulates the rings from the steel shaft. A shielded data transmission cable is attached to the probe by a waterproof seal.

The probe is advanced using a percussion probing machine which weighs 1,680 pounds and is mounted on the back of a truck. The percussion machine delivers as much as 18,000 pounds of downward force to the drive end of the probe. The depth and rate of advancement are measured using a string pot system. When the probe is retracted, the percussion machine can exert as much as 25,000 pounds of retraction force.

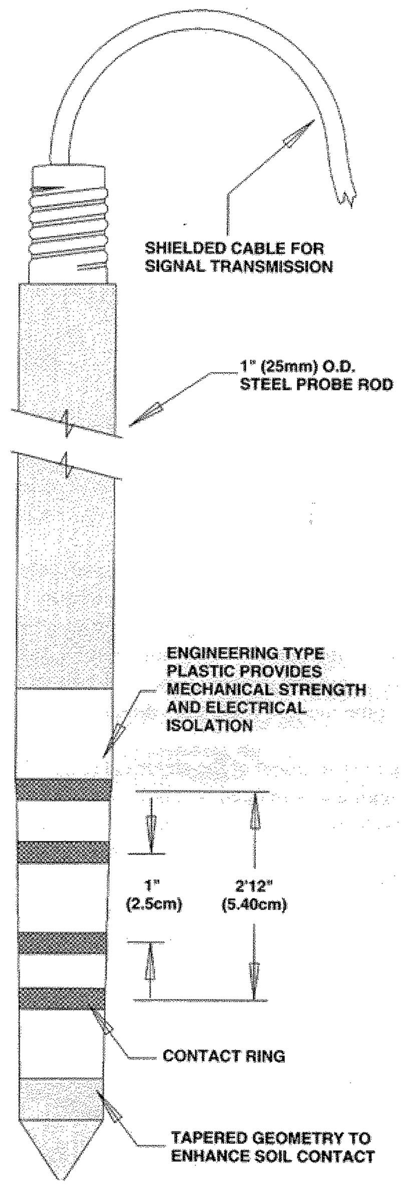

Figure 2: SC200 Electrical Conductivity Probe

GEOPHYSICAL INVESTIGATION PROCESS

The Direct Image® software, running on a PC laptop connected to the instrumentation box, provides a “real-time” display of the conductivity signal, probe depth, and rate of advancement. Individual logs can be printed in the field. Data from the logs can be easily output to a spreadsheet software, or a modeling software, such as SURFER. The Direct Image® software also includes a calibration routine for the probe that should be run before each push to ensure that the probe is operating correctly.

Technology Justification

The presence of the surficial clay layer overlying the surficial aquifer indicated the need for a geophysical technology that would not be impeded by this layer. It was necessary to penetrate this near surface clay layer and delineate the stratigraphy below the clay. The effectiveness of ground penetrating radar would have been limited by this layer and it was too close to the surface for a seismic method to be effective. Therefore, Geoprobe’s® Direct Image® Soil Conductivity System was a more effective and less expensive option to identify any subsurface structures that might influence groundwater flow directions.

GEOPHYSICAL FINDINGS

Technology Calibration [1]

A lithology log was developed from a continuous core sample taken to a depth of 40 feet below ground surface (bgs) at the northwest corner of the study area. Discrete interval samples were collected in a boring located at the northeast corner of the study area at depths of 46 to 48 feet bgs and 54 to 56 feet bgs. The deeper samples provided information on the distinct lithologic units found at those depths. Conductivity logs were taken in the same two locations. The conductivity values were correlated with the visual identification of discrete lithologic units in the core samples. The results of the correlation are shown in Table 1.

There is a unique range of conductivity values for each of the lithologic units with the exception of the units encountered between two and 32 feet bgs. In this interval, there is a silty clay layer that is somewhat coarser than the clay layers above and below it. The electrical conductivity of the silty-sandy clay layer, 70 to 140 mS/m, overlaps that of the over- and underlying clay layers which ranges from 125 to 240 mS/m. Thus, conductivity measures falling between 125 and 140 mS/m are indicative of transition intervals between the low permeability clay layers and the more permeable silty-sandy clay layer.

Below the second clay layer is a sandy layer, known as the upper aquifer whose upper surface was encountered at depths ranging from 36 to 46 feet bgs. The upper aquifer ranges in thickness from 5 to 15 feet. Conductivity values within the upper aquifer ranged from 20 to 40 mS/m. At the base of the upper aquifer is a clay layer that acts as an aquitard between the upper and lower aquifers. The aquitard was found at depths ranging from 46 to 52 feet bgs, and was found to be approximately 5 to 8 feet thick. Conductivity values in the aquitard range from 80 to 100 mS/m, making these materials similar in composition to those encountered between 13 and 32 feet bgs.

Table 1: Correlation of Conductivity Values With Discrete Lithologic Units

Conductivity Range (mS/m)	Depth Range (feet bgs)	Location of Samples	Generalized Lithologic Description
0 to 75	0 to 2	CND02	Organic rich topsoil and gravel fill
125 to >240	2 to 13	CND02	Clays, brown with some caliche development
70 to 140	13 to 32	CND02	Silty to fine sandy brown clays
125 to > 240		CND02	Clays, brown with some caliche development
20 to 40	36 to 46	CND02	Medium to coarse grained granitic sands with sparse fine gravels, water-saturated
80 to 100	46 to 52	CND10	Gray clay-silt
20 to 40	52 to 60	CND10	Medium to coarse grained granitic sands with sparse fine gravels, water-saturated

Source: [1]

Investigation Results

Conductivity logs were collected from 10 borings across the study area to depths ranging from 40 to 60 feet bgs. The locations of the borings can be seen shown in Figure 1, and the logs themselves are shown in Figures 3a and 3b. The uppermost clay layer is visible in each of the 10 logs as a rise in conductivity to values at or greater then 200 mS/m. The densest portion of this clay layer, and consequently the highest electrical conductivity value, was found consistently at a depth of approximately eight to 10 feet bgs. The consistency with which this unit is found in the logs suggests that it is continuous throughout the study area and has a low surface gradient.

The decline in conductivity values that can be seen in each of the 10 logs between 13 and 32 feet bgs can be interpreted as the gradual grading of subsurface materials from the upper clay layer into a coarser silty clay layer. At the base of this silty clay layer, the subsurface materials seem to grade once again into a tighter clay formation. This graduation can be seen in most of the logs as conductivity values rise again due to the finer grain size within the clay layer. In the logs CND01 and CND06, the clay layer is either missing, or its composition is less dense than in other portions of the study area. In the logs for CND08 and CND09, the clay layer appears to be present at shallower depths of approximately 20 to 25 feet bgs. The consistency with which this clay layer seems to be present suggests that it may act as a confining layer to the upper aquifer. This conclusion seems to be supported by the fact that when wells are screened at a depth of 22 to 24 feet bgs, they yield no water, but when screened at or below 28 feet, the static groundwater level in the casing rises to 18 feet bgs.

The sandy gravel layer that constitutes the more transmissive zone of the upper aquifer can be seen clearly in each of the 10 logs at depths ranging from 36 to 46 feet bgs. As the probe passed through these materials, there was a marked decrease in conductivity values. At the base of the upper aquifer, there is a dense layer of clay materials which can be seen in the logs as a sharp increase in conductivity values at depths ranging from 45 to 55 feet bgs. Most logs were terminated at this depth to prevent penetration of the aquitard in highly contaminated zones. The rise in conductivity values as the probe entered this layer is clearly visible, even in the shallower logs. The consistency with which this unit was encountered in the logs suggests that is laterally continuous and may act as an aquitard separating the upper and lower aquifers. The sandy gravel layer that constitutes the lower aquifer can be seen in the logs for CND01, CND02, and CND10.

These borings were the only three pushed to the full 60-foot depth because they were outside of contaminated areas and approximately bound three corners of the site. Because only three borings were advanced to this depth, the continuity of the lower aquifer cannot be determined.

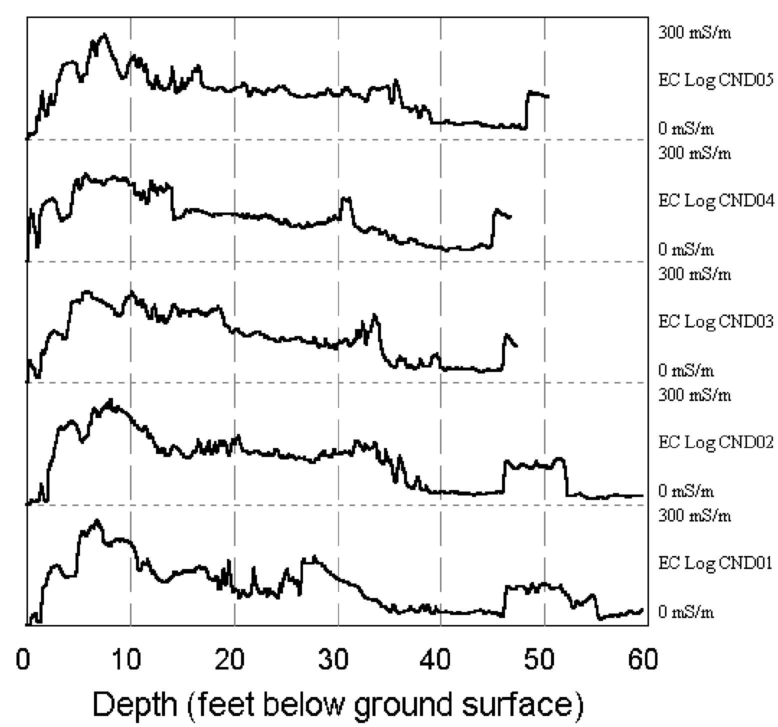

Figure 3a: Electrical Conductivity Log for CND1 - CND05 [1]

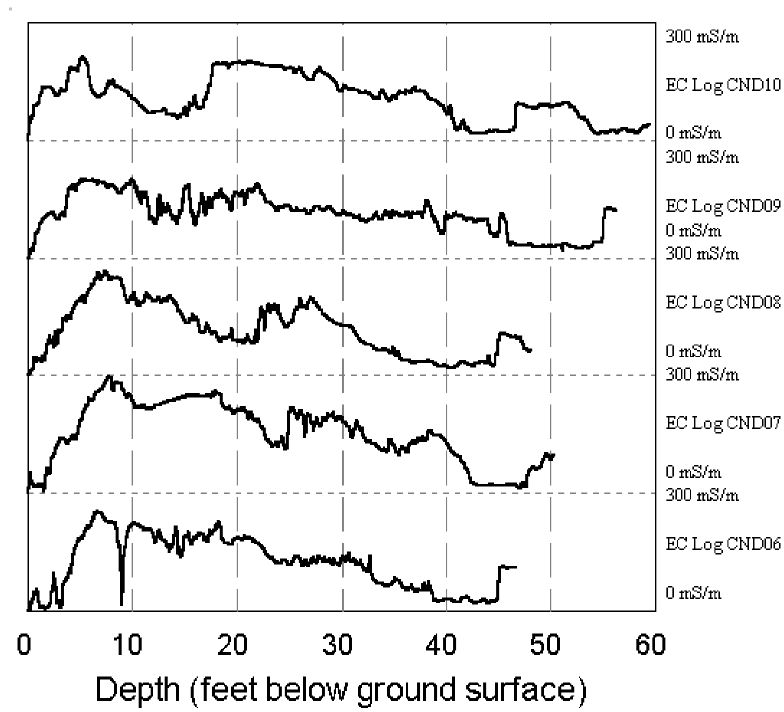

Figure 3b: Electrical Conductivity Logs for CND06 - CND10 [1]

A contour map was generated of the contact surface between the sandy layer of the upper aquifer and the overlying clay layer, and is shown in Figure 4. Surface elevations were taken at each boring location and the distance from the surface to the top of the sandy layer was calculated. Where the transition from the clay to the sand layer was more gradual and less defined, as in the logs for CND02 and CND05, the depth at which the conductivity value reached 75 mS/m was taken as the top of the sandy layer. The calculated depths to the top of the sandy layer were plotted on a site map and the elevations were contoured by hand. In Figure 4, the resulting contours show that the upper contact surface of the sandy layer has a complex saddle-like structure, with a topographic high running to the northwest through CND04 and CND06 and branching northeast toward CND03. Monitoring wells 5, 10, and 11 were highly contaminated and sporadically contained free product. Combining the information provided by this map and the finding that the overlying clay layer is continuous throughout the study area, the investigator concluded that LNAPLs within the groundwater flowing under confined conditions could migrate along the topographic high in a northwesterly direction. This would make the direction of the LNAPL migration contrary to the generalized groundwater flow to the east. The topographic low in this surface at CND09 east of the source also prevented contaminants from moving east with groundwater flow to well MW08, in which no contamination had been detected.

GEOPHYSICAL FINDINGS

Results Validation [4]

No further efforts were undertaken to validate the findings of the geophysical investigation.

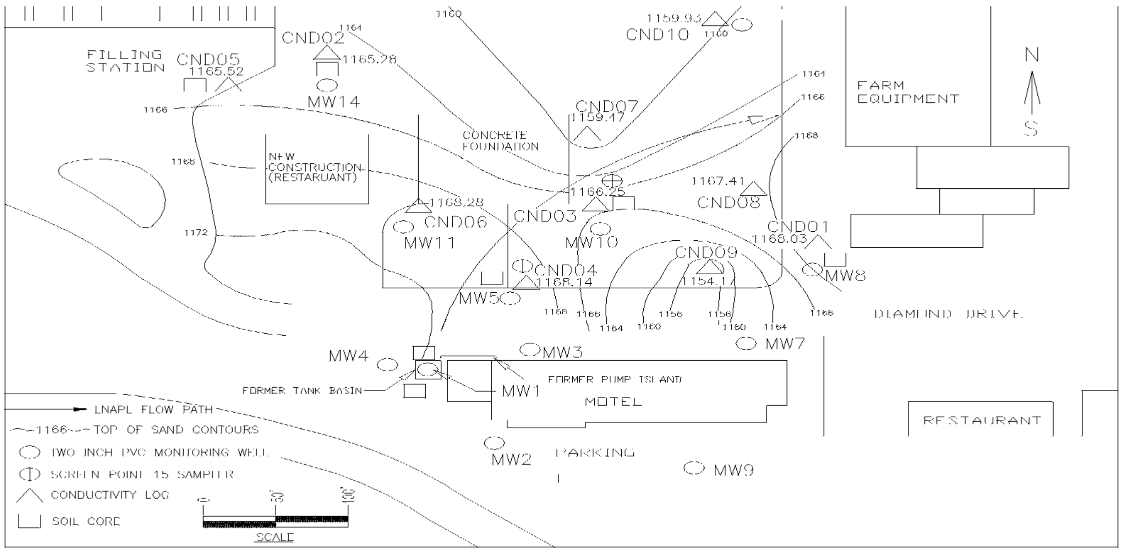

Figure 4: Contour Map of Upper Sand Layer [1]

LESSONS LEARNED

Some of the lessons learned during this investigation include:

- Electrical conductivity logging is a cost-effective approach for characterizing subsurface stratigraphy in unconsolidated materials. Alternative approaches to gathering the same information would use traditional well drilling methods, such as a hollow stem auger. The daily cost of an auger can be as high as $5,000.

- Conductivity logging can provide consistent information on stratigraphy. A review of the 10 logs produced at this site shows that the same lithologic units were identified at consistent depths across the study area. In part, the consistency was due to the similarity of the materials in the various units across the study area.

- When accurate surface elevations are obtained for each boring, a contour map can be developed for any of the lithologic units that were identified in the survey. This information can be used to identify subsurface structure that might provide migration pathways for non-aqueous phase liquids, either light or dense.

GEOPHYSICAL FINDINGS

- Two soil boring logs typically are sufficient to produce an unambiguous correlation between the conductivity results and the observed lithologies. In very heterogeneous formations, additional location/depth targeted samples may be needed.

REFERENCES

1. McCall, Wesley. *Electrical Conductivity Logging to Determine Control of Hydrocarbon Flow Paths in Alluvial Sediments.* Geoprobe Systems. December 1995.

2. Geocore Services, Inc. *Quarterly Monitoring Report for KDHE UST Trust Fund Site*. March 11, 1998.

3. Personal Communications with Scott Lange, KDHE. August 18, 1998.

4. Personal Communications with Wesley McCall, Geoprobe Systems. September 15, 1998.

5. Fax Communication with Geoprobe Systems. September 15, 1998.

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Case Study Abstract

Kelly Air Force Base
San Antonio, Texas

Site Name and Location: Kelly Air Force Base San Antonio, Texas 78241-5842	**Geophysical Technologies:** Vertical seismic profile	**CERCLIS #** Not Applicable
Period of Site Operation: From the 1940s-1980s, Site MP housed metal plating and degreasing operations for aircraft **Operable Unit:** Zone 3 Groundwater Operable Unit SS037		**Current Site Activities:** Soil organic vapor survey complete, second phase began in April 1998 which consisted of (1) a seismic reflection survey of 318 points, (2) soil samples from 83 geoprobe locations and nine soil borings, (3) installation of one recovery and three monitoring wells, and (4) the extraction of approximately 1,000 gallons of dense nonaqueous phase liquid (DNAPL)
Point of Contact: Rhonda Hampton Zone 3 Groundwater Project Manager 307 Tinker Drive Kelly Air Force Base, Texas 78241 (210) 925-3100 Extension 226	**Geological Setting:** Quaternary alluvium overlying several hundred feet of Cretaceous limestones, shales, and clays	**Technology Demonstrator:** SeisPulse Development Corporation 93 Northridge Terrace #27 Medford, Oregon 97501 541-535-4641

Purpose of Investigation:
To map the bedrock surface and determine the locations of structural highs and lows where DNAPL could collect

Number of Images/Profiles Generated During Investigation: 317 shotpoints along 16 seismic reflection lines

Results: The surface of the Navarro Formation was mapped utilizing data acquired from SeisPulse Development Corporation "Vertical Reflection profile" (VRP) method of seismic survey and the SeisPulse seismic source. Depressions on the Navarro Formation were found to contain pooled DNAPL.

EXECUTIVE SUMMARY

Kelly Air Force Base is situated in metropolitan San Antonio within the encircling route 410 freeway. The site is located in the eastern portion of Kelly AFB, north of the Tinker Drive and Berman Road intersection. Surrounded by offices, industrial buildings, and an adjacent Union Pacific Rail yard, the site is approximately 90,000 square feet and consists of two former buildings (258 and 259) and an adjacent container storage area. Surface topography can be described as flat with maximum changes in elevation of 4.17 feet northward across the site.

From the 1940s to the 1980s, Building 258 and 259 housed metal plating and mechanical degreasing operations. Both buildings were leveled in 1981 and only their foundations remain. Solvents leaked from the degreasers, especially in the propeller line, which ran the width of Building 258. In December 1997, during an initial phase of well monitoring, a dense nonaqueous phase liquid (DNAPL) was discovered beneath former Building 258. Based on this discovery, a second phase of field activity began in April 1998, which included a seismic reflection survey, soil sampling, installation of a recovery well and monitoring wells, and the removal of approximately 1,000 gallons of DNAPL.

The Kelly AFB study area is underlain by a thin layer of fill material averaging several feet in thickness. Fill material may be absent in some surface locations, exposing the lower strata. Beneath the fill material are Quaternary alluvial deposits ranging in thickness from 30 to 45 feet, and consist of clay, gravel, and sand.

A seismic reflection survey was conducted in 1998 as part of a larger site investigation. The information presented in this report was derived from the interpretive report of the geophysical investigation. The Vertical Reflection Profile (VRP) (seismic) method was used to determine the structural highs and lows of the confining layer of the shallow aquifer that could provide migration pathways for dense non-aqueous phase liquids (DNAPLs). The seismic survey included the acquisition of 16 seismic reflection lines which radiated in a general northwest to northeast pattern across the site. An estimation of each seismic reflection peak associated with the top of the bedrock was made and the bedrock surface was identified and mapped. Multiple depressions were identified in cross sections produced with the seismic reflection data. The DNAPL was located in one of the depressions.

The “near offset” method of acquisition results in a series of discrete vertical reflection data points. However, obstacles such as buried building foundations act as reflective surfaces and can hinder reflection interpretation associated with the bedrock. Strong acoustical vibrations, such as rail yard activity, act as an additional seismic source and can also interfere with reflections. The bedrock surface was mapped and larger depressions were identified. However, the survey was unable to find small or narrow channels that could also facilitate DNAPL transport. Seismic surveying should be utilized in conjunction with other geophysical methods in understanding the subsurface and possibly contributing to the discovery of DNAPLs.

SITE INFORMATION

Identifying Information

Kelly Air Force Base (AFB), Site MP
San Antonio, Texas 78241-5842
Building 258 SWMU
CERCLIS #: Not applicable
Investigation Date: 16 April to 19 April, 1998

Background [1, 2]

Physical Description: Kelly Air Force Base (AFB) is located in central Bexar County, Texas (Figure 1). The base is situated in metropolitan San Antonio within the encircling Route 410 freeway. The site is located in the eastern portion of Kelly AFB, north of the Tinker Drive and Berman Road intersection, shown in Figure 2. The site is surrounded by offices, industrial buildings, and an adjacent Union Pacific Rail yard, to the southeast. The site is approximately 90,000 square feet of the approximately 371 acres of Zone 3 and consists of two former buildings (258 and 259) and an adjacent container storage area. Surface topography can be described as flat with maximum changes in elevation of 4.17 feet northward across the site.

Site Use: Aircraft operations and maintenance were performed at Kelly AFB from the 1940s to the 1980s. During this period, Building 258 and 259 housed metal plating and mechanical degreasing operations. Both buildings were leveled in 1981 and only their foundations remain. The entire area was then converted to an asphalt parking lot. Currently Kelly AFB is host to several tenant organizations representing Air Force, Army, and other government organizations. Kelly AFB is in transition from an Air Force Base to an industrial park. Transfer of ownership to the city is scheduled for completion July 13, 2001.

Release/Investigation History: Former Buildings 258 and 259 were used for aircraft maintenance and metal plating. Solvents leaked from the degreasers, especially in the propeller line, which ran the width of Building 258. In December 1997, during an initial phase of well monitoring, a dense nonaqueous phase liquid (DNAPL) was discovered beneath former Building 258. Based on this discovery, a second phase of field activity began in April 1998, which included a seismic reflection survey, soil sampling, installation of a recovery well and monitoring wells, and the removal of approximately 1,000 gallons of DNAPL. The asphalt parking surface was removed from the foundations of former buildings 258 and 259 for inspection, sampling, and, cleaning. At the conclusion of the investigation, the area was paved again.

Figure 1: Site Location

SITE INFORMATION

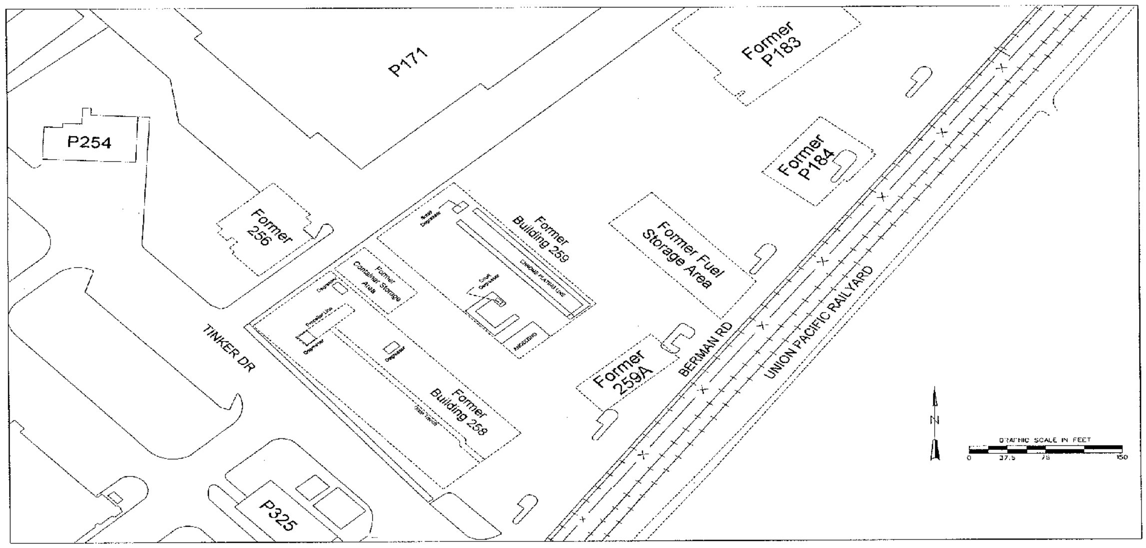

Figure 2: Site Map [1]

Regulatory Context: RCRA and Texas National Resource Conservation (TNRCC) regulations.

Site Logistics/Contacts

Federal Lead Agency: U.S. Air Force

Federal Oversight Agency: EPA

Remedial Project Manager:
Rhonda Hampton
Zone 3 Groundwater Project Manager
SA-ALC/EMRI
307 Tinker Drive
Kelly Air Force Base, Texas 78241
(210) 925-3100 Extension 226

Geophysical Subcontractor:
SeisPulse Development Corporation
93 Northridge Terrace #27
Medford, Oregon 97501
541-535-4641

Site Contact:
Dr. Yuequn Jin Ph.D.
Senior Hydrogeologist
SAIC
4242 Woodcock Drive
Suite 150
San Antonio, Texas 78228
(210) 731-2200
yuequn.jin.@cpmx.saic.com

MEDIA AND CONTAMINANTS

Matrix Identification

Type of Geology Investigated: Bedrock surface

Site Geology/Stratigraphy [1]

The Kelly AFB study area is underlain by a thin layer of fill material averaging several feet in thickness. Fill material may be absent in some surface locations, exposing the lower strata. Beneath the fill material are Quaternary alluvial deposits ranging in thickness from 30 to 45 feet, consisting of clay, gravel, and sand (see Figures 3 and 4). The upper sequence of the alluvial deposits are composed of a black to brown clay ranging in thickness from 15 feet to 28 feet. The lower sequence of the alluvial deposits are composed of a permeable clayey gravel unit ranging in thickness from eight to 25 feet. Interbedded within the clayey gravel unit are sand and silt layers of various thicknesses which tend to laterally grade into gravelly clay and gravel with little clay.

A shallow groundwater aquifer lies within this permeable zone of clayey gravel at approximately 20 to 25 feet below ground surface (bgs). Groundwater generally flows eastward, off base, at 0.07 to 3.2 feet/day with a hydraulic gradient of approximately 0.001. Flow is influenced by compositional variation within the alluvium and channel-like features of interbedded gravel and clayey gravel formed on the bedrock surface. Beneath the alluvium lies several hundred feet of Cretaceous limestones, shales, and clays that compose the Navarro Formation, which acts as a bedrock aquitard. The bedrock separates the near-surface soil from the Edwards Aquifer, which is San Antonio’s sole drinking water source.

Contaminant Characterization [1]

Primary Contaminant Groups: The primary groundwater contaminants at the site are halogenated aliphatics. Groundwater maximum contaminant levels (MCL) were exceeded for chlorinated solvent concentrations including tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC). Inorganic contaminants, including chromium, nickel, manganese, and arsenic were detected below their MCLs.

Matrix Characteristics Affecting Characterization Cost or Performance [1]

The seismic survey was affected by rail yard seismic noise originating northeast of the site. The passing trains of the active rail yard caused earth-penetrating acoustical vibrations that acted as reflective sources, obscuring the actual bedrock reflections. Seismic energy reflects from any change in density, which can be the bedrock surface or a buried foundation. In addition to the rail yard seismic noise, buried structures affected the seismic survey by acting as another reflective boundary. The shallow depth of bedrock did not hinder the survey. The overall homogeneity of the alluvium and lack of topographical relief facilitated the seismic survey.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [4]

The goal of the geophysical investigation was to map the bedrock surface and determine the locations of structural highs and lows that could provide migration pathways for DNAPL.

Geophysical Methods [2]

The SeisPulse Development Corporation patented the SeisPulse Seismic Source, which acquires seismic reflection data utilizing the Vertical Reflection Profile (VRP) method. The VRP method utilizes near-vertical ray reflection paths to acquire data. Since the 1920s, types of seismic sources have included vibrating masses, combustible gas mixtures, weight drops, dynamite, shotguns, and modified rifles. All of these sources produce destructive ground roll and airwave interference. The SeisPulse seismic source inhibits the destructive interference by producing an elastic (deformable) wave.

The SeisPulse system is a propane-combustion lightweight portable seismic source. A high-velocity pressure ridge resulting from the propane-air combustion is directed down an attached funnel-shaped wave guide. This source wave impacts the earth's surface, resulting in a strong seismic wave. Energy travels along the surface and into the earth, where it reflects from subsurface horizons such as lithological boundaries or erosional surfaces. The differences between interval velocities indicate changes in soil or rock properties.

Vertical resultant reflections at the site were received by a Mark Products (Mark 40A) geophone placed at a one-foot distance from the base of the seismic source. Shot point spacing of 10 feet between each station was used with the exception of two stations where seismic data was acquired at five-foot intervals, for a total of 1,606 shot points. The seismic reflection profile was not affected by the shot point station spacing. Reflection data was recorded on a 12-channel Geometric S-12 seismograph. Vertical reflection data from the initial source firing is recorded on channel one, and the next shot is recorded on channel 2 and summed together with the first shot on channel 12. This process is repeated until data acquisition for that specific station is complete. The station data is saved to an individual data file, and the source and geophone are moved to the next station. The data was recorded at a 1/4 millisecond sample interval and a record length of 512 millisecond.

The seismic source and geophone were operated by one technician while another technician acquired the data. At each shot point the records where collected, edited, and summed together to increase the signal to noise ratio. This additive process assumes that all coherent reflective energy arrives at the same time while noise is random and will not arrive at the same time.

Minimal separation of the source and geophone allows the ground roll and air wave to pass over the receiving geophone before the arrival of target data. The "near offset" method of placing the geophone within one foot of the source eliminates the need for large field crews and long cable layouts, which allows interpretation of survey material within 24 hours.

GEOPHYSICAL INVESTIGATION PROCESS

Technology Justification

The choice of seismic reflection for investigating the bedrock topography at the Kelly AFB was based on the need for a cost-effective method for mapping depressions in the bedrock which may represent migration pathways for contaminants. The depth to bedrock was well within the effective range for seismic reflection, yet not so shallow that the return wave would conflict with the ground roll wave.

GEOPHYSICAL FINDINGS

Technology Calibration [2]

A “walk-away” noise test was conducted to assure that data acquired is a reflection and not another source of wave energy such as source signatures or ground roll. The test involves placing a single geophone (receiver), at a one-foot distance from the source, igniting the source, and recording one trace. The geophone is moved in one-foot increments away from the stationary source and the test is repeated. After a typical distance of nine to 11 feet, the returning signals are studied to determine the reflector from the noise background. Ground roll energy will move at a constant velocity whereas reflector energy does not; this velocity difference is used to identify the reflector data from background noise. The ground roll or direct surface wave was identified from the reflector reflection data. The time necessary to complete a walk-away noise test using the SeisPulse system is approximately 30 minutes. Two walk-away tests were conducted at the site.

A geologic description from fifteen borings provided the depth to bedrock data, allowing proper identification and timing of reflection events. Two of the borings were used to complete down-hole velocity check shot surveys. The velocity surveys were initiated by suspending a two-inch diameter down hole geophone tool by means of a cable to the deepest accessible depth. A hammer and plate source were used near the boring and the time required for energy to travel to the geophone was recorded. The geophone was raised three feet and the procedure was repeated. The result was a set of one-way travel times, from the surface to various depth, which were used to determine the interval and average velocity of the overlying alluvium to make a general time-depth calculation required for the upcoming seismic survey.

The ability to visually connect or “time tie” line intersections with an identifiable reflector such as the bedrock surface throughout the survey can be an indicator of the seismic survey accuracy within localized areas. Reflection energy is received by the geophone and recorded as a trace. Each trace represents a station and each subsurface reflector or event should be visually identifiable on the trace, and connected to other traces within the survey. Since the bedrock is a continuous surface, each trace should have a event that marks its boundary and that event can be time tied to the next trace reflection event. This connection of events makes up the seismic profile. The bedrock surface reflectors were “time tied” at all line intersections.

GEOPHYSICAL FINDINGS

Investigation Results [1]

The purpose of this investigation was to map the bedrock surface and determine the locations of structural highs and lows in which DNAPLs could collect. The seismic survey included the acquisition of 16 seismic reflection lines which radiated in a general northwest to northeast pattern across the site. An estimation of each seismic reflection peak associated with the top of the bedrock was made and the bedrock surface was identified and mapped.

Figure 3 shows a geologic cross-section of the typical stratigraphy from northwest to southeast. The bedrock surface is shown at approximately 35 feet bgs and relatively horizontal. In the northwest section, the depression which collected DNAPL was shown. The approximate dimension of the DNAPL pool is approximately 100 feet by 50 feet with a maximum thickness of seven feet.

Figure 4 shows a southwest to northeast cross-section of the bedrock surface approximately 40 to 45 feet bgs. The bedrock surface varies in nature and areas of highs and lows are evident. Two depressions are shown separated by a relatively high area. The southwest depression is approximately 20 feet long and five feet deep. The northeast depression is approximately 30 feet long and five feet deep. DNAPLs were not discovered in either of the low areas.

Results Validation [1]

On May 30, 1998, three hollow-stem auger soil borings were taken to verify the seismic survey data used to map the bedrock surface. Two borings reached the bedrock surface at depths which closely matched the seismic survey reported depths. The third boring encountered a DNAPL pool at approximately 37 feet bgs and was terminated for health and safety reasons. This boring verified the existence of depressions in the clay surface as indicated by the seismic survey.

Comparison of lithologic units encountered at 15 wells or soil borings depths to calculated seismic depths indicate the seismic findings are consistent with actual depths to bedrock. The seismic depth errors ranged between -2.5 to +2.4 feet, and resulted from the use of a constant wave velocity. Interval velocities may have varied from station to station due to near-surface differences within the alluvium. The wells and soil boring locations were chosen based on their close proximity to the seismic lines.

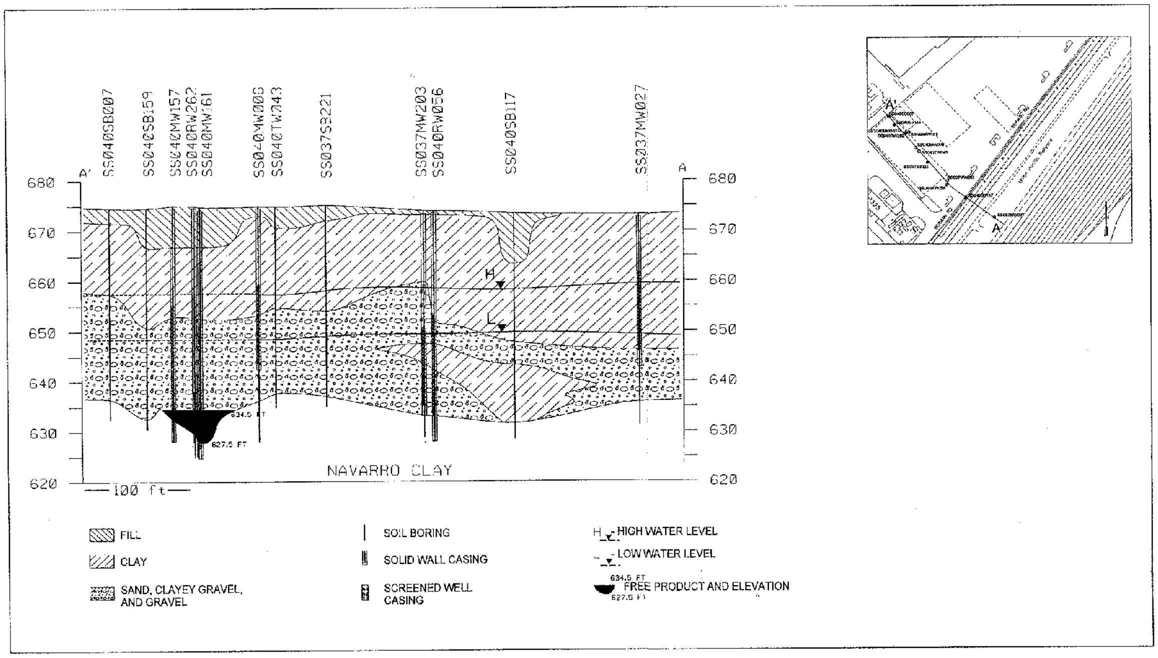

Figure 3: Northwest to Southeast Cross-Section, in Feet Above Mean Sea Level [1]

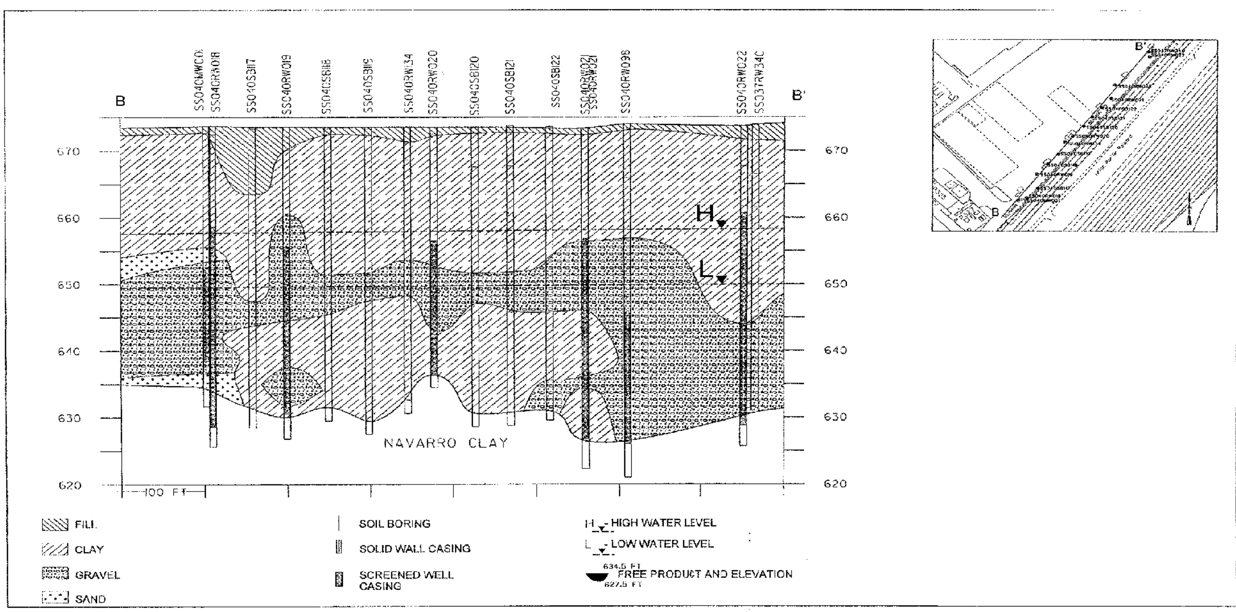

Figure 4: Southwest to Northeast Cross-Section, in Feet Above Mean Sea Level [1]

LESSONS LEARNED

Lessons learned at the Kelly AFB include the following:

- The "near offset" method of acquisition results in a series of discrete vertical reflection data points. However, obstacles such as buried building foundations act as reflective surfaces and can hinder reflection interpretation associated with the target bedrock. Strong acoustical vibrations such as rail yard activity act as an additional seismic source and can also interfere with bedrock reflections.

- The varying nature of DNAPLs suggest that they can follow cracks, offsets, and smaller scale features found on the boundary surface. At the site, the seismic reflection survey was implemented to define areas on the bedrock surface in which DNAPLs could collect and potentially migrate. The bedrock surface was mapped and larger depressions were identified. However, because of the error rates, the survey was unable to find small or narrow channels that would facilitate DNAPL transport. Seismic surveying should be utilized in conjunction with other geophysical methods in understanding the subsurface when investigating to find DNAPLs.

REFERENCES

- San Antonio Air Logistics Center, Environmental Management Restoration Operations. *Current Conditions Report for the Building 258 Solid Waste Management Unit*, Kelly AFB, Texas. Science Applications International Corporation. July 1998.

- Science Applications International Corporation. *Seismic Reflection Geophysical Survey Report*, Kelly AFB, Texas. SeisPulse Development Corporation. May, 1998.

- Personal communication with Mike King, President of SeisPulse Development Corporation, Vancouver, Washington. September 4, 1998.

- Personal communication with Rhonda Hampton. Zone 3 Groundwater Project Manager. Kelly AFB, Texas. September 17, 1998.

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Case Study Abstract

Marshalltown Former Manufactured Gas Plant (FMGP) Site
Marshalltown, IA

Site Name and Location: Marshalltown FMGP	**Geophysical Technologies:** Electrical conductivity	**CERCLIS #** Not Applicable
Period of Site Operation: 1870's to 1946–gas manufacturing and electric generation **Operable Unit:** Not Applicable		**Current Site Activities:** Currently 100 employees still work on-site. Groundwater monitoring is being performed.
Point of Contact: Albert Bevolo Ph.D. Ames Laboratory Iowa State University 125 Spedding Hall Ames, IA 50011 (515) 294-5414	**Geological Setting:** Pleistocene glacial till, glaciolacustrine deposits, fluvial deposits, and loess lie unconformably over discontinuous layers of limestone and dolomite.	**Technology Demonstrator:** Geoprobe Systems Corporate Headquarters 601 N. Broadway Salina, KS 67401 1-800-GEOPROBE

Purpose of Investigation:
The geophysical investigation was undertaken as part of a demonstration under the Department of Energy's Expedited Site Characterization program. The goal of the demonstration was to compare the capability of electrical conductivity surveys with more traditional methods for characterizing subsurface stratigraphy, such as borehole geophysical logging and cone penetrometer testing (CPT).

Goals related to the soil conductivity probe (SCP) were to confirm and further refine the site geologic and contamination conceptual models as defined through Phase I activities. Another goal was to define the topography of the lower cohesive unit (LCU) in order to find low-points where dense non-aqueous phase liquids (DNAPLs) might collect.

Number of Images/Profiles Generated During Investigation:
27 conductivity profiles produced from 700 feet of log in 27 holes

Results:
SCP provided high vertical resolution data from which transitions between high conductivity clay and low conductivity sands could be readily identified. Calibration with soil borings and CPT showed that the main stratigraphic units were readily distinguishable. The SCPs provided clear information on stratigraphic transition depths which were readily integrated with data from CPT and boring logs.

A secondary and unexpected result was the apparent response of the SCPs to DNAPL-saturated soils by distinct decreases in conductivities.

EXECUTIVE SUMMARY

The Marshalltown Former Manufactured Gas Plant (FMGP) site is located in an old industrial area in Marshalltown, Iowa. Gasification by-products of the manufacturing process, including coal tar, coke, and other materials, were stored on-site in unlined pits. A site investigation found polycyclic aromatic hydrocarbons (PAHs) in soil samples at levels substantially above background levels. Another investigation, conducted during an underground storage tank (UST) removal, showed the presence of petroleum hydrocarbons in excess of applicable action levels in soil and groundwater.

The site is situated on the edge of the flood plain of Linn Creek where the ground surface is flat to gently sloping. Near surface soils consist of a wide range of fill materials of low plasticity and varying in thickness from 0.5 to 14 feet. This is underlain by fine-grained cohesive soils consisting of low plasticity silty clay with interbedded sandy and gravelly clays, ranging in thickness from 6 to 14 feet. Limestone bedrock is approximately 50 feet below the ground surface. A steep ridge in the bedrock surface, with about 25 feet of relief, trends northwest-southeast across the site.

The Marshalltown site was used a demonstration site for the comparison of various technologies used in the site characterization process. The focus of this case study is an assessment of the performance of a soil conductivity probe (SCP) used to delineate soil stratigraphy and its utility in the Expedited Site Characterization Process. The information in this report was derived from the interpretive report of the geophysical investigation. A site-specific goal for the SCP was to define the topography of the lower cohesive unit (LCU) to identify low-points where dense non-aqueous phase liquids (DNAPLs) might accumulate. The probe determines soil conductivity by measuring the electric potential across electrodes in direct contact with the soil.

Results of the investigation revealed that the SCP provided very useful and reliable stratigraphic data. The upper cohesive unit (UCU) and the LCU contact was inferred by a distinct rise in the conductivity values. Both of these contacts could easily be identified on most of the soil conductivity logs. A secondary and unexpected result was the apparent response of the SCP to DNAPL-saturated soils, measured by decreases in conductivities.

Since this was a demonstration of the SCP when the product was first developed, no direct costs were associated with this investigation. However, based on current models of equipment and prices associated with them an estimated cost of $7,875 can be associated with an investigation of this type.

The capabilities of the SCP were proven. The probe was very versatile in that it could maneuver into small spaces and could penetrate most soil subsurface materials. The SCP was not able to clearly identify weathered bedrock and probes would break when unexpected bedrock or larger sized gravel and cobbles were encountered. The probe was also operationally efficient and could be operated by a single person if necessary. The information collected by the probe can also be used to enhance the site contamination model. The probe has the ability to provide much more detailed stratigraphic information than conventional auger borings. This is very important when considering the fate and transport of contaminants. The SCP detected DNAPL-saturated soil as a distinct decrease in conductivity.

SITE INFORMATION

Identifying Information

Marshalltown FMGP Site
Marshalltown, Iowa 50158
Operable Unit: --N/A
CERCLIS #: --N/A

Background [1]

Physical Description: The Marshalltown Former Manufactured Gas Plant (FMGP) is located in in an old industrial area of Marshalltown, Iowa (Figure 1). The site contains several buildings from the FMGP and former electric plant and is approximately 2.5 acres in size (Figure 2). The nearest residential properties are located several hundred feet to the north. The site is located on the edge of the floodplain of Linn Creek which flows west to east approximately 800 feet south of the site and discharges into the Iowa River roughly 2.5 miles northeast of the site. Site topography is flat to gently sloping, with approximately 10 feet of relief across the site.

Site Use: A manufactured gas plant operated at the site from the 1870's until 1946. When the site first opened in the 1870's, under the name of Marshalltown Gas Light Company, gas manufacturing was accomplished by coal carbonization. Electrical generation began at the site between 1888 and 1892. In 1892 the Marshalltown Gas Company, the Marshalltown Electric Company, and the Marshalltown Street Railway Company consolidated and became the Marshalltown Light, Power, and Railway Company, which brought the electrical and gas operations under common ownership. Between 1910 and 1921, the gas manufacturing process was converted from coal carbonization to carbureted water gas and the ownership was transferred to the Iowa Railway and Light Corporation. Plant operations continued until 1946.

The FMGP site is currently used as the service and materials distribution center for Alliant Utilities gas and electric operations. The site is currently owned by IES Utilities who merged with other mid-western power generation/distribution companies and is now known as Alliant Utilities. There are 100 employees that work on-site, and the plant is scheduled to close within the next two years so remediation can begin [2].

Figure 1: Site Location

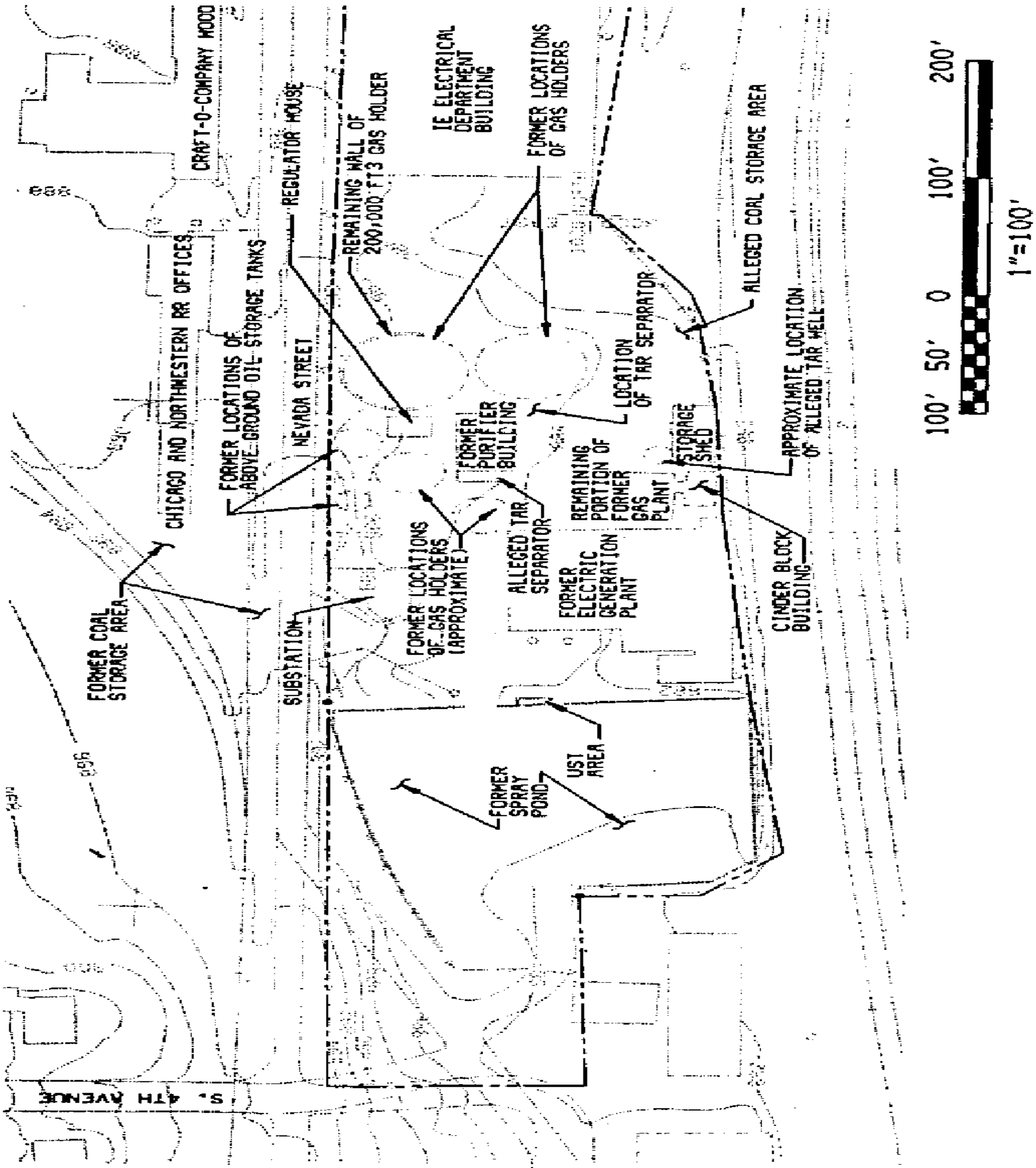


Figure 2: Site Map of Marshalltown FMGP [1] [Poor Quality Original]

SITE INFORMATION

Release/Investigation History: Major by-products of the gas manufacturing process are coke, tar, ash, and spent purifiers. The final disposition of these by-products on the site is unknown, but a substantial portion of the tar may have been disposed on site. The investigation of waste product disposal at the site began with a preliminary study conducted in 1986. In 1987, soil samples collected in a follow-up site investigation revealed the presence of polycyclic aromatic hydrocarbons (PAHs) compounds at levels substantially above background levels. In November, 1988, an underground storage tank (UST) was removed from an area near the west end of the east wall of the former spray pond (Figure 2). Petroleum hydrocarbons in excess of applicable action levels were detected during this removal action. In 1990, a detailed remedial investigation was begun to address requirements under a 1989 Consent Order between the Iowa Department of Natural Resources (IDNR) and Alliant Utilities. The investigation identified a tar pit, two different tar separators, and a tar well as potential contaminant sources. A comprehensive soil and groundwater sampling program was included as part of this investigation. Visible coal tar or fuel contamination was found in the soil sampled from several borings at the site. The site activities that are the focus of this case study include the second phase of the site investigation process and the evaluation of remedial alternatives.

Regulatory Context: The IDNR is the lead agency coordinating all the activities of the Marshalltown FMGP site. The site is being addressed as a result of a 1989 Consent Order entered into between the IDNR and Alliant Utilities. The IDNR is utilizing CERCLA requirements and guidances [3].

Site Logistics/Contacts

State Lead Agency:
Iowa Department of Natural Resources

Project Manager:
Dr. Johanshir Golchin
Iowa Department of Natural Resources
Wallace Building-502 E. 9th Street
Des Moines, IA 50319-0034
(515) 281-8925

Site Contact:
Albert Bevolo P.h.D
Ames Laboratory
Iowa State University
125 Spedding Hall
Ames, IA 50011
(515) 294-5414

Geophysical Subcontractor:
Geoprobe Systems
601 N. Broadway
Salina, KS 67401
1-800-GEOPROBE

PRP Contact:
Dean Hargens
Alliant Utilities
P.O. Box 351
Cedar Rapids, IA 52406
1-800-822-4348

MEDIA AND CONTAMINANTS

Matrix Identification [1]

Type of Matrix Sampled and Analyzed: Subsurface soil and occasional weathered rock

Site Geology/Stratigraphy [1]

The overall stratigraphy of the glacial drift in the area of the site consists of loess over Kansan till, which overlies Mississippian-age limestone and Pennsylvanian shale bedrock. Near-surface soils include a wide range of fill materials (clay, gravel, sand, cinder, and other debris) of low plasticity ranging in thickness from 0.5 to 14 feet. This is underlain by fine-grained cohesive soils consisting of low plasticity silty clay with interbedded sandy and gravelly clays, ranging in thickness from 6 to 14 feet. This layer is also known as the upper cohesive unit (UCU). This is followed by a granular unit comprised mostly of various types of sand. A layer of low plasticity clayey lacustrine soil and low to high plasticity glacial till separates the granular unit from bedrock in most areas of the site. This layer is commonly referred to as the lower cohesive unit (LCU). Depth to bedrock ranges from 20 feet below the ground surface (bgs) in the northern part of the site to 40 feet bgs in the southwestern portion. According to drilling information, a steep ridge in the bedrock surface with about 25 feet of relief trends northwest-southeast across the site. Depth to groundwater at the site averages between 18 to 20 feet bgs. Hydraulic conductivity measurements indicate values that range from 0.0029 to 0.00076 cm/sec for the granular soils. Groundwater in the alluvial sediments tends to flow in a southern direction toward Linn Creek. Bedrock groundwater flow characteristics are not well established and appear to be strongly influenced by the activity of production wells in the area that tap the Mississippian aquifer. The limestone bedrock is part of the Mississippian Burlington and Gilmore City Formations and are part of the regional Mississippian aquifer.

Contaminant Characterization [1]

Primary Contaminant Groups: The primary contaminants of concern at the site include the following: benzene, toluene, ethylbenzene, xylene, phenols, and PAHs, such as naphthalene and phenanthrene. Some contaminants are known to be present as dense non-aqueous phase liquids (DNAPLs).

Matrix Characteristics Affecting Characterization Cost or Performance [1, 4]

Due to surface obstructions encountered on-site, such as buildings, sheds, etc., explorations could not be conducted at some locations. Unexpected cobbles, larger sized rocks, boulders, or bedrock were encountered and posed a problem for the probes. Several probes were broken when these units were encountered.

Factors such as non-uniform infiltration of highly saline solutions from winter road salting operations, poor ground-to-probe contacts at shallow depths, and the diverse nature of the surficial fill contributed to the erratic conductivity data gathered within the top six feet from the surface.

MEDIA AND CONTAMINANTS

Irregularity in the conductivity trace can also be attributed to thinly interbedded seams of silts, sands, clays, and gravels up to depths of approximately 15 feet bgs. Weathered rock did not have a distinct conductivity signature, and could not be distinguished from soils on the basis of its conductivity.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [1, 4]

The geophysical investigation was undertaken as part of a demonstration under the Department of Energy's Expedited Site Characterization program. The goal of the demonstration was to compare the capability of electrical conductivity surveys with more traditional methods for characterizing subsurface stratigraphy, such as borehole geophysical logging and cone penetrometer testing (CPT).

Goals related to the soil conductivity probe (SCP) were to confirm and further refine the site geologic and contamination conceptual models as defined through Phase I activities. Another goal was to define the topography of the LCU in order to find low points where DNAPLs might collect.

Geophysical Methods [1, 5, 6]

The focus of this case study is an assessment of the performance of the Geoprobe® SC100 conductivity probe (SCP) in delineating soil stratigraphy. The determines soil conductivity by measuring the electric potential across electrodes, which are in direct contact with the soil. Electrical conductivity varies with soil type, with clays exhibiting higher conductivities than silts, and sands and gravels having the lowest conductivity. The probe has a vertical resolution of 0.05 feet with a data rate of 20 samples per second, and a maximum depth range of 80 feet bgs. The SCP system is small and very maneuverable.

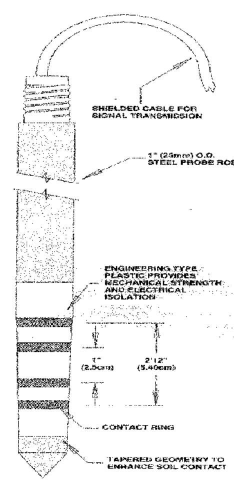


Figure 3: Conductivity Probe [3]

The conductivity probe, shown in Figure 3, consists of a steel shaft running through the center of four stainless steel contact rings. An engineering grade plastic electrically isolates the rings and the shaft from each other. The probe was operated in the Wenner array configuration which reacts linearly to variations in formation conductivity and yields good vertical resolution by using all four electrodes. The probe is approximately eight inches long and has a diameter that tapers from 1-1/8 inch at the top to 1 inch at the point. The taper assures a firm ground-to-probe contact. The probe assembly threads directly to standard Geoprobe® probe rods. A signal cable is threaded through the inside of the rod string and into a PC-based data acquisition system housed in a ruggedized case. Depth measurements are obtained by a stringpot system configured to measure the distance from the driving mechanism to the ground surface. The stringpot signal is used both to determine probe depth and speed at which the probe is advancing.

Technology Justification

The reasons that soil conductivity was selected for the investigation at the Marshalltown site were not site-specific, but were related to the investigation as a demonstration for the expedited site characterization process. However, due to the many cultural interferences at the site such as chain-link fences, stacks of steel piping, steel storage sheds, and vehicle traffic, other geophysical methods such as ground penetrating radar and electromagnetic offset logging could not provide useful results [4].

GEOPHYSICAL FINDINGS

Technology Calibration [1]

In order to calibrate the SCP with local soils at the site, 123 sample soil cores (which resulted in 127 soil samples) were collected from 27 geoprobe locations at specific depths for standard core logging and visual soil classification (Figure 4). These core samples were two feet long and were collected from six subsurface zones at specified depths using another Geoprobe® system. The units of measurement for conductivity are milliSeimens per meter (mS/m). The Seimen is the inverse of the Ohm, the standard measure for electrical resistivity. Direct calibration of the SCP with soils collected from the site revealed the following comparisons in conductivity values: Clayey soils: 60 - 140 mS/m; sandy soils: 30 - 40 mS/m; gravels: 20 - 35 mS/m (Table 1 and Table 2).

The SCP was advanced adjacent to two existing borings for calibration: MW-3A and B-8. Distances between the borings and probes were 16 and 13 feet respectively. The SCP was also calibrated against CPTs. CPT is a reliable direct-push geotechnical method of characterizing soils on the basis of its physical resistance to penetration. The conductivity profiles were compared directly to the stratigraphic logs for these borings and with the CPT results.

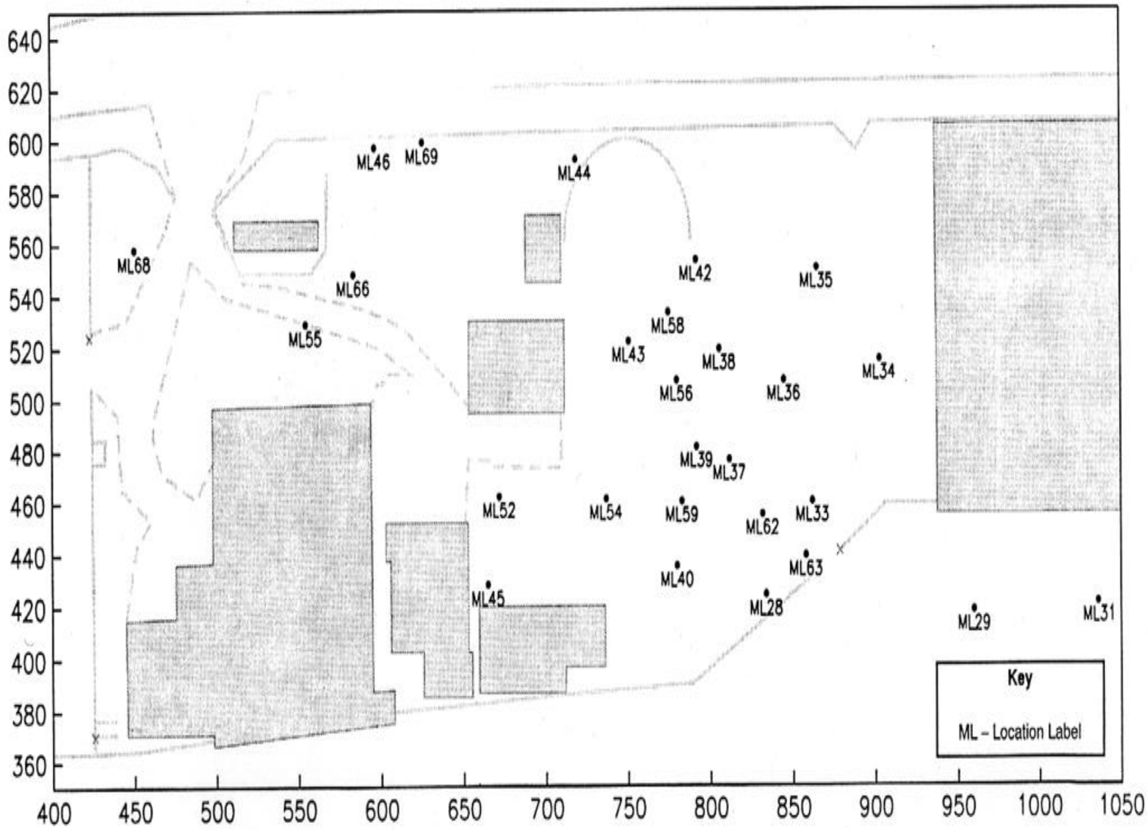


Figure 4: Soil Conductivity Probe Push Locations [1]

Investigation Results [1, 4]

In the Spring of 1994, Geoprobe obtained 27 logs at the Marshalltown FMGP site, using the Geoprobe® 4200 to push the SC100 conductivity probe into the subsurface. Each push was halted upon a confident identification of the lower cohesive unit (i.e., rapid rise in soil conductivity), in locations where the lower cohesive unit was absent, or upon probe refusal. Push depths ranged from 14 feet bgs to 40 feet bgs. The logs were then used to determine the confining bed of clay where contaminants might be found. These logs were merged into 3D models and used to determine soil sampling depths and locations.

The conductivity logging system produced 700 feet of log in 27 holes over a period of 5 working days. The system was operated by a two-man crew. Operation by a one-man crew is possible, although productivity would be significantly lower. The data required minimal post-processing (deletion of negative or repeat values). Digital conductivity and probing speed data and field printouts were provided at the end of each work day for integration into the existing site model.

Twenty-seven SCP penetrations were combined with data from soil borings, Geoprobe® core samples, and CPT penetrations. Locations of the various penetrations are shown in Figure 4. In most conductivity logs, readings from three to five feet bgs exhibited erratic conductivity values. Explanations offered for this phenomenon included infiltration of extremely saline solutions resulting from salting of roads during winter weather and poor ground-to-probe contact at shallow depths. The UCU interface and the LCU interface were easily identified in most locations of the site. The UCU contact with the granular unit could be inferred by the distinct drop in soil conductivity between 14 and 17 feet bgs. The LCU contact with the granular unit above it was identified by an increase in soil conductivity between 30 and 32 feet bgs. Figure 5 shows cross section A-A` showing SCP conductivity profiles and stratigraphic zones as determined by soil boring logs and CPT data. The conductivities of the units and conductivity changes across the transitions in ML-28 and ML-45 are shown in Table 1 and Table 2.

A secondary and unexpected result was the apparent response of the SCP to DNAPL-saturated soils by decreases in conductivities. At the base of the granular unit above the LCU in ML-45, soil conductivity shows a 20 mS/m drop from about 50 mS/m to about 30 mS/m. When depths are adjusted for small stratigraphic variations between sites, the depth of conductivity decrease corresponds closely to a known zone of DNAPL, as seen in the boring logs for B-8.

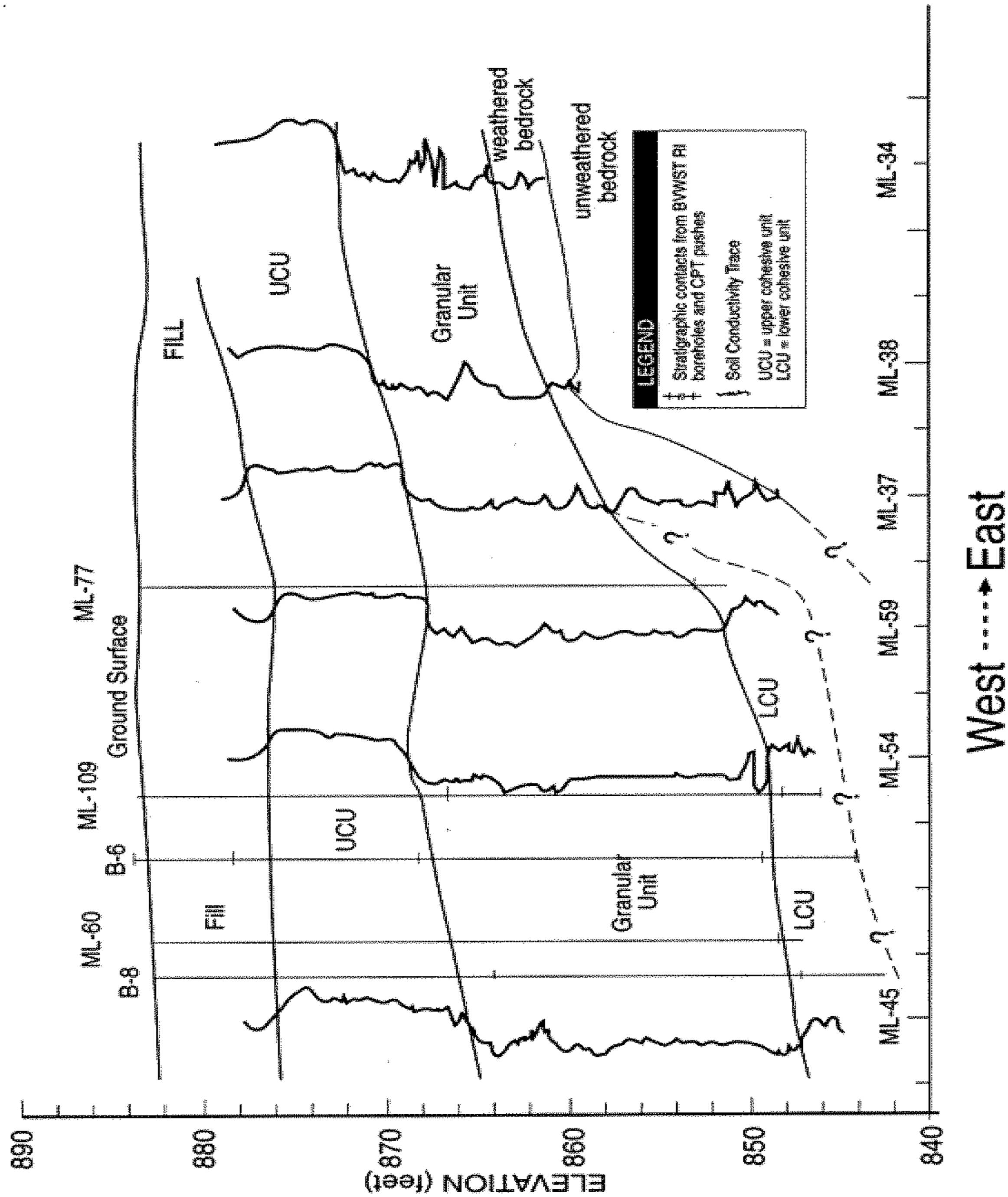


Figure 5: Stratigraphic Cross Section AA` [1]

Results Validation [1, 2]

In addition to comparison with the calibration boring logs and to the discrete soil sample cores, the SCP was also compared to laser-induced fluorescence (LIF) logs that were run in conjunction with the CPT logs. LIF is an innovative method of near-continuous screening for contaminants, in this case PAHs.

The 20 mS/m drop in conductivity at the base of the granular unit above LCU in ML-45 corresponds closely with a high LIF reading indicative of the presence of DNAPLs. There is also a good correlation between high LIF and low conductivities at the contact between the UCU and the top of the granular unit at around 20 feet bgs. The conductivity shows a decrease of about 20 mS/m compared to the more stable value of about 50 mS/m through the relatively uncontaminated section of the granular unit.

Conductivity dips recorded within the granular zone of all profiles at the site were compared with the Geoprobe® soil core logs, with LIF profiles, and with boring logs. The results of this analysis showed that conductivity dips within the granular zone could be attributed to DNAPL contamination 75 percent of the time and to uncontaminated gravel 25 percent of the time.

The SCP filled in absent stratigraphic information between two locations with known stratigraphic profiles. The major stratigraphic unit contacts were very noticeable on the soil conductivity logs and the data was used to generate a database for a three-dimensional site stratigraphic model. When sections from this model were compared to the nearby soil boring logs, a correlation of stratigraphic units within one to two feet was revealed. This was attributed to the difference in stratigraphy over the relative distance between the SCP locations and the soil boring locations, and to the use of different sampling technologies. The investigators believed that the SCP depths were more reliable for sampling because it involved same technology, i.e. Geoprobe direct push depth indicators. Another demonstration at this site used a more invasive Geoprobe® unit to collect large bore soil samples at the identified locations and also confirmed the information in the SCP conductivity logs.

The CPT and conductivity soil profiles show significantly more detail than the boring logs and reveal that the CPT and conductivity soil profiles were in close agreement with the boring logs (Table 1 and Table 2). Depths to stratigraphic contacts between ML-28 CPT and ML-28 SCP are similar, but differ from the soil boring log MW-3A by about two feet (possibly due to differences in stratigraphy as a result of distance between locations). The ML-45 SCP corresponds well with the CPT and soil boring log. Overall, the side-by-side comparisons of the SCPs and the soil boring logs indicated stratigraphic correspondence of the unit contacts to within about one to two feet.

Table 1: Comparison of Soil Stratigraphy Results for ML-28 SCP and CPT, and MW-3A

Stratigraphy	Conductivity mS/m	ML-28 SCP Depth (Feet bgs)	ML-28 CPT Depth (Feet bgs)	MW-3A Log Depth (Feet bgs)
UCU	130-190			
Transition depth for UCU	140->70	16-17	17	17
Granular Unit	20-80			
Transition depth for Granular Unit	50->90	30	29-30	32

Source: [1]

Table 2: Comparison of Soil Stratigraphy Results for ML-45, ML-60, and B-8

Stratigraphy	Conductivity mS/m	ML-45 SCP Depth (Feet bgs)	ML-60 CPT Depth (Feet bgs)	B-8 Log Depth (Feet bgs)
UCU	90-140			
Transition depth for UCU	90->30	17-18	nd	19
Granular Unit	20-80			
Transition depth for Granular Unit	25->85	35-36	34	36
LCU	70-90			

nd=no data
Source: [1]

LESSONS LEARNED

Lessons learned for the Marshalltown site include the following:

- Geophysical survey techniques are an important part of the expedited site characterization process, however not all techniques are appropriate for all sites. Marshalltown had complex stratigraphic conditions that led to significant error and uncertainty in the some of the geophysical survey results. Therefore, potential limitations of each geophysical method must be carefully considered on a site specific basis.

- The stratigraphic correlations between the push technologies (SCP and CPT) and the borehole log data demonstrated that the contacts between soil units can generally be interpreted from the CPT and soil conductivity logs with confidence. Correlations were generally within one to two feet, but this variance was attributed to the distance between SCP locations and the soil boring locations.

- The SCP was more maneuverable and more versatile than the CPT and could penetrate most soil subsurface materials. The probe was also operationally much more efficient than the CPT and could be operated by a single person if necessary. SCP provides reliable high-resolution demarcation between high conductivity clays and silts and low conductivity sands and gravels. With proper calibration from soil borings, the SCP can provide reliable infill information between boring logs and can be used to enhance the site conceptual model. The probe provides more detailed stratigraphic information than conventional auger borings.

- The SCP appears to respond to DNAPL-saturated soil by exhibiting a distinct conductivity dip. Since other factors, most notably sand or gravel lenses, can cause conductivity dips, the SCP cannot by itself detect DNAPLs. However, dips in conductivity in generally low conductivity (sandy permeable) layers immediately above high-conductivity (clayey low-permeability) zones would certainly be a target to investigate pooling of DNAPLs. This would be especially true if the stratigraphic transition occurred at lower elevations compared to surrounding logs. Close inspection of SCP results can provide a good screening tool for the location of accumulated DNAPLs.

- Twenty-seven SCP penetrations were combined with data from soil borings, Geoprobe® core samples, and CPT penetrations. Locations of the various penetrations are shown in Figure 4. The SCP provided high vertical resolution data from which transitions between high conductivity clay and low conductivity sands could be readily identified. Comparison with soil borings and CPT logs showed that the main stratigraphic units were readily distinguishable and that the transition depths agreed among the three methods.

- The SCP was not able to clearly identify weathered bedrock. The probes would break when unexpected bedrock or large gravel/cobbles were encountered. This could be remedied by using more indestructible equipment at developed sites where heterogeneous fill layers would be expected or are already known to exist.

REFERENCES

1. Ames Laboratory, *Ames Expedited Site Characterization Demonstration at the Former Manufactured Gas Plant Site, Marshalltown, Iowa*. Ames Laboratory, Ames Iowa. 1996.

2. Personal Communications with Dean Hargens, Alliant Utilities. September 10, 1998.

3. Personal Communications with Johanshir Golchin, Iowa Department of Environmental Resources. September 17, 1998.

4. Bevolo, A., Kjartanson, B., Stenback, G., and Wonder, J., *Site Characterization, Expedited.* Ames Laboratory, Ames Iowa. 1997

5. Christy, C., Christy, T., and Wittig, V. *A Percussion Probing Tool for the Direct Sensing of Soil Conductivity,* Technical Paper. Geoprobe Systems, Salina Kansas. March 1994.

6. Personal Communications with Albert Bevolo, Ames Laboratory. August 24, 1998.

7. Fax Communication with Geoprobe Systems. September 15, 1998.

Case Study Abstract

New Hampshire Plating Co.
Merrimack, NH

<table>
<tr>
<td>Site Name and Location:
New Hampshire Plating Co.
Merrimack, NH</td>
<td rowspan="2">Geophysical Technologies:
Marine seismic-reflection surveys
Ground-penetrating radar
Natural gamma
EM borehole logs</td>
<td>CERCLIS #
NHD0010091453</td>
</tr>
<tr>
<td>Period of Site Operation:
1962 to 1985

Operable Unit:
N/A</td>
<td>Current Site Activities:
EPA issued a proposed cleanup plan to the public in January 1998. The EPA plans to conduct a treatability study in Summer or Fall, 1999.

In addition, on-going groundwater monitoring is being conducted.</td>
</tr>
<tr>
<td>Point of Contact:
Thomas Mack
U.S. Geological Survey
603-226-7805</td>
<td>Geological Setting:
Alluvial terrace underlain by glaciolacustrine sediments and till. The underlying bedrock consists of schists and phyllites with minor amounts of granite and gneiss.</td>
<td>Technology Demonstrator:
United States Geological Survey</td>
</tr>
<tr>
<td colspan="3">Purpose of Investigation:
To use geophysical methods to identify contamination from the New Hampshire Plating Company and to determine underlying lithology. The geophysical methods used were marine-seismic reflection, ground-penetrating radar, and natural-gamma radiation and electromagnetic-induction borehole logging.</td>
</tr>
<tr>
<td colspan="3">Number of Images/Profiles Generated During Investigation:
Seismic-Reflection Profiles: 3 lines
Ground-penetrating Radar Profiles: 4 lines
Borehole Geophysical Logs: 7</td>
</tr>
<tr>
<td colspan="3">Results: The natural gamma used in combination with the EM logs identified a probable plume of groundwater contamination from the electroplating facility. The contamination is moving toward Horseshoe Pond and Merrimack River.</td>
</tr>
</table>

EXECUTIVE SUMMARY

The New Hampshire Plating Company Site is located on 13.1 acres in Merrimack, New Hampshire. On the property are a former plating facility, a large pond, and four lagoons. The Merrimack River is located about 600 feet (ft) east of the plating facility and the northern end of Horseshoe Pond is located about 500 ft south of the plating facility. From 1962 until 1965 the property was used for electroplating activities. The contamination was a result of the facility discharging 35,000 to 60,000 gallons per day of electroplating wastes into the four unlined lagoons. The wastes consisted of cyanide plating baths and sludges, acids and chlorinated solvents.

The site geology is comprised of an alluvial terrace consisting of sand, silt and some gravel. Under the alluvial terrace is glaciolacustrine sediments and till which consists primarily of sand, silt, clay and some gravel. Under the glaciolacustrine sediments and till is bedrock consisting of schist and phyllites with minor amounts of granite and gneiss. The water table is encountered at depths ranging from five to 20 ft in the study area.

A geophysical investigation was conducted at the site as part of a larger effort to delineate site conditions and the scope of contamination. The information presented in this report was derived from the interpretive report of the geophysical investigation. The geophysical investigation used four different technologies. Continuous seismic reflection and ground penetrating radar surveys were performed to characterize the site geology and locate bedrock structures. The seismic surveys were conducted near the shore of Horseshoe Pond and along the eastern side and the middle of the Merrimack River. The profiles conducted in Horseshoe Pond indicated that the bedrock ranged from the water surface to less than 20 ft below (the survey could only identify to that depth at this location–this may not be true elsewhere). The profiles conducted in the Merrimack River indicated that bedrock ranged from 10 to 50 ft below the water surface. The ground penetrating radar (GPR) method was used to produce geophysical profiles of the land area around the facility and the lagoons. The GPR profiles successfully determined soil types to a depth of 30-35 ft.

Natural gamma logs were used to delineate the stratigraphy of sub-surface materials in eight monitoring wells, and electromagnetic induction (EM) logs were used to identify zones of conductive groundwater that would indicate the presence of contaminated groundwater. The gamma logs correlated well with existing lithologic logs for the wells. The EM logs showed significant spikes, indicating possible zones of contamination. The depths at which the spikes occurred correlated well with measures of specific conductance of groundwater taken as part of the on-going monitoring program in those wells.

The seismic and radar surveys were moderately successful, but some difficulties were encountered due to the presence of fine-grained sediments in the bottom of the pond and in the soils around the facility. Fine-grained sediments limited the penetration of the radar signals, resulting in blank areas on the profiles. The GPR profiles conducted on water bodies were inconclusive because the signal was attenuated by the water column and was unable to penetrate beneath the bottom sediments. The gamma and EM logs were very successful in characterizing the stratigraphy and identifying zones of highly conductive groundwater that may indicate contaminated groundwater.

SITE INFORMATION

Identifying Information

New Hampshire Plating Company
Wright Avenue
Merrimack, New Hampshire

Background [1]

Physical Description: The New Hampshire Plating Company is located on Wright Avenue in Merrimack, Hillsborough County, New Hampshire. The surrounding area is primarily used for light industrial and commercial purposes, with some residential areas nearby. The site covers 13.1 acres of leased property and includes the former plating facility and four lagoons (see Figure 1). The plating facility is located approximately 600 ft west of the Merrimack River. The study area consisted of the land around the former facility and the lagoons, and extended east to the Merrimack River and south to Horseshoe Pond, to determine if the contamination was moving in those directions. The site lies in the 100-year floodplain of the Merrimack River, and the topography of the site has little relief.

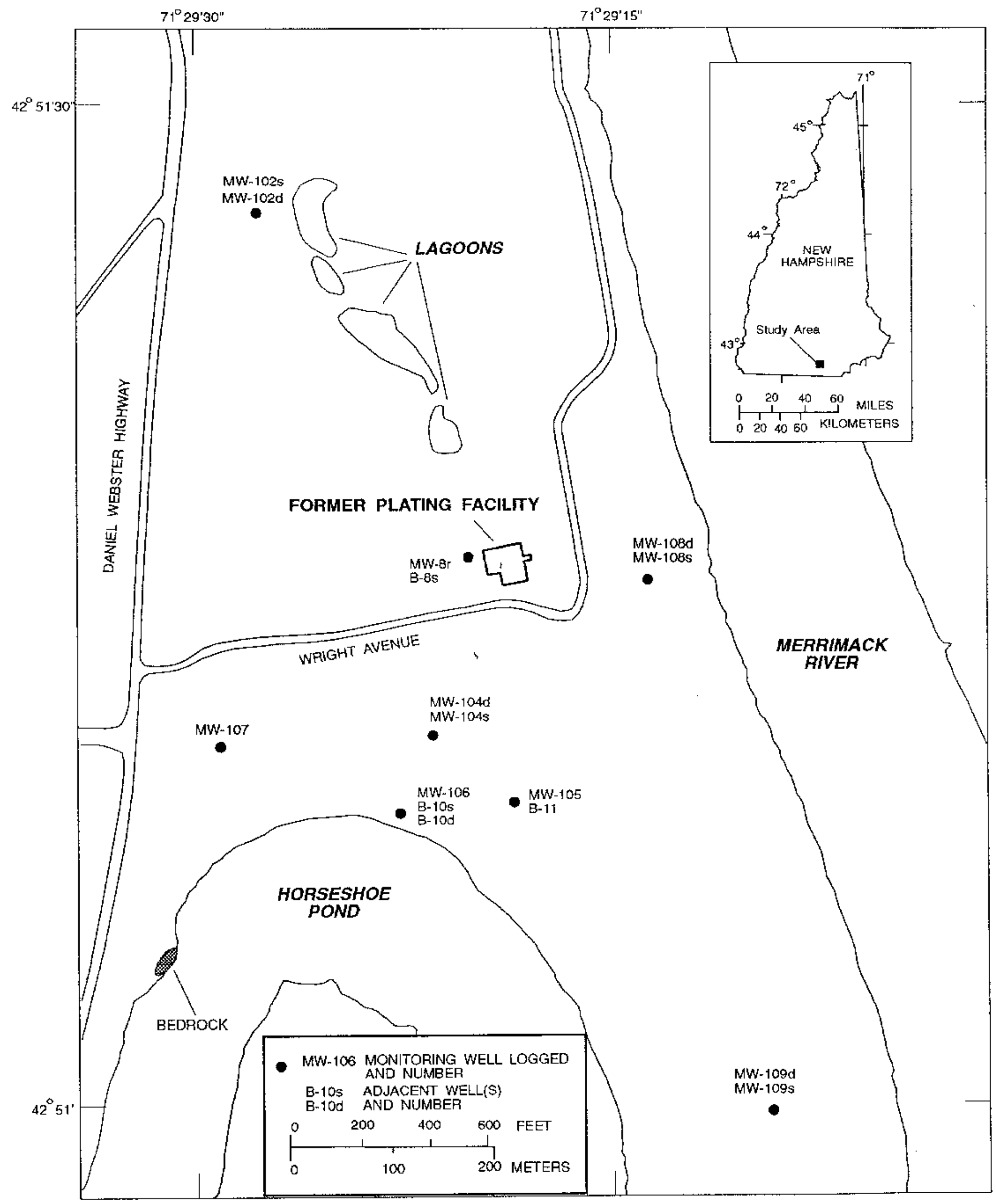
Site Use: The property was used from 1962 until 1985 for electroplating activities. The four lagoons on site were used for disposal of wastes and wastewaters resulting from the electroplating operations. These lagoons were unlined and had no leachate detection or collection.

Release/Investigation History: From 1962 to 1985, the facility discharged on-site 35,000 to 60,000 gallons per day (gpd) of electroplating wastes into a series of four unlined lagoons. The wastes included cyanide plating baths and sludges, acids, and chlorinated solvents. Discharge of degreasing solvents into lagoon was discontinued in the late 1970s. In 1980, the New Hampshire Plating Company (NHPC) notified the EPA that it was a hazardous waste disposal facility under Subtitle C of the Resource Conservation and Recovery Act (RCRA). An inspection by the New Hampshire Department of Environmental Services (NHDES) and the Environmental Protection Agency (EPA) in April 1982 noted several RCRA violations. As a result, the New Hampshire Division of Public Health Services issued a Notice of Violations and Order of Abatement to NHPC. In February 1983, the State of New Hampshire filed a civil suit against NHPC. NHPC halted operations in 1985 because it lacked the financial resources necessary to meet compliance standards and continue hydrogeologic investigations at the property.

In June 1987, a contractor for New Hampshire Division of Environmental Services treated the lagoon system with lime and a sodium hypochlorite solution, removed debris, drums, and plating tank liquids to a regulated disposal facility, and conducted a superficial cleaning of the manufacturing building. In 1990, EPA used emergency funds to solidify the contaminated sludge and soil at the property.

SITE INFORMATION

Regulatory Context: This investigation was conducted to support the characterization of waste under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Manufacturing operations at the site were regulated under Subtitle C of the Resource Conservation and Recovery Act (RCRA), and the New Hampshire Division of Environmental Services.



Base modified from U.S. Army Corps of Engineers, 1:1,200, 1992.

Figure 1: Site Map of NH Plating Company [1]

SITE INFORMATION

Site Logistics/Contacts

Federal Lead Agency: EPA

Federal Oversight Agency: None

Remedial Project Manager:
Jim Dilorenzo
EPA Region 1
617-918-1247

Geophysical Subcontractor:

Thomas Mack
United States Geologic Survey
361 Commerce Way
Pembroke, NH 03275
603-226-7805

MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Sand, silt, fine-grained lake bottom sediments, and coarse-grained stratified drift.

Site Geology/Stratigraphy

Site geology is composed of an alluvial terrace consisting of sand, silt, and some gravel, ranging in thickness from less than five to 25 feet (ft). The total thickness of surficial sediments overlying bedrock in the study area ranges from zero at the northwestern bank of Horseshoe Pond to greater than 120 ft between the center of the Horseshoe Pond and the plating facility, and approximately 20 ft along the northeastern bank of Horseshoe Pond.

The alluvial terrace is underlain by glaciolacustrine sediments and till. The glaciolacustrine sediments consist primarily of sand, silt, and clay with some gravel. Coarse-grained sediments are interspersed with fine-grained lake bottom sediments within this unit. The till is a poorly sorted mixture of silt, sand, and gravel with some boulders and clay. The total thickness of these units could be as much as 100 ft.

Underlying the glaciolacustrine sediments and till is a bedrock unit consisting of schists and phyllites with minor amounts of granite and gneiss. The bedrock surface forms a north-south trending trough and outcrops at the northwestern bank of Horseshoe Pond.

The depth to the water-table is approximately 5 to 20 ft in the study area. Groundwater flows beneath the site to the east toward the Merrimack River and to the south toward Horseshoe Pond.

MEDIA AND CONTAMINANTS

Contaminant Characterization

Primary Contaminant Groups: The primary contaminants of concern include cadmium, chromium, copper, cyanide, iron, nickel, zinc, tin, arsenic, lead, manganese, sodium, and trichloroethylene.

Matrix Characteristics Affecting Characterization Cost or Performance

The effectiveness of the ground penetrating radar (GPR) survey was limited by the fine-grained bottom sediments in the water bodies, as well as by the depth of the water. The fine-grained sediments found along the bottom of Horseshoe Pond limited the penetration of the seismic signal, which had already been attenuated by the water column. Although such sediments were less prevalent in the Merrimack River, similar problems occurred along some of the survey lines there. The fine-grained soils present across the site had a similar effect on the land GPR surveys in some locations, resulting in blank records in the images along certain survey lines. These blank areas on the profiles occurred under fine-grained sediments and also coincided with areas known to contain highly conductive groundwater.

The effectiveness of the seismic survey was limited by the presence of organic sediments on the bottom of Horseshoe Pond, and, to a lesser degree, along the bottom of the Merrimack River. The seismic survey was, however, able to clearly identify the fine-grained sediments that impeded the performance of the GPR survey.

No site characteristics impeded the performance of the natural gamma or EM borehole logs, such as complex lithology, e.g. clay content, organic matter, magnetic minerals content, etc.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals

The goal of the investigation was to confirm stratigraphic information collected during earlier investigations and to characterize zones of highly conductive groundwater that may indicate the presence of a groundwater contaminant plume. Continuous seismic reflection and ground penetrating radar surveys were used to confirm the stratigraphy across the site. Natural gamma logs were used to develop vertical profiles of stratigraphy in existing monitoring wells. Electromagnetic induction logs were used to identify the zones of conductive groundwater.

Geophysical Methods

The continuous seismic reflection method uses an acoustic source to emit a signal downward into the subsurface and measures the travel time of a seismic signal from the surface to subsurface reflectors, i.e. bedrock, and back. Travel time, or velocity, is typically measured in feet per second (ft/s). In New England geology, the velocity of sound through saturated glacial sediments ranges

GEOPHYSICAL INVESTIGATION PROCESS

from 4,000 to 6,000 ft/s [2]. This study used a seismic sound velocity of 5,000 ft/s to calculate penetration depth of the seismic signal. The continuous seismic reflection profile was carried out using Geoacoustic's Geopulse© equipment operated at a frequency of 700 to 1500 hertz.

The ground penetrating radar (GPR) method uses an antenna to radiate short pulses of high-frequency radio waves into the subsurface and a receiving antenna to record variations in the reflected return signal. Interpretations of GPR profiles depend on the sediments penetrated and the scale adjustments as those sediments change. For example, the electromagnetic velocity in saturated unconsolidated sediments is 0.2 feet per nanosecond (ft/ns) as compared to 0.4 ft/ns in unsaturated unconsolidated sediments. The primary factor limiting depth of penetration is the electrical conductivity of the sediments [1]. The type of equipment used was a GSSI System 10 operated at a frequency of 80 megahertz.

Natural gamma logging is the continuous physical measurement of the release of natural gamma radiation from the soil and rocks surrounding the length of a borehole. The gamma log measures the total gamma radiation, in counts per second, as the detector is raised in the well column. In the glaciated sediments of the northeast, fine-grained sediments rich in clay are generally more radioactive than quartz sand or carbonate rocks [1]. The natural gamma data were gathered using Century Equipment Natural Gamma detector which is capable of logging at a rate of 30 ft/min.

The electromagnetic induction method uses a transmitter coil that generates an electromagnetic field that induces currents in the earth. A receiver coil intercepts the electromagnetic fields generated induced current as a voltage that is linearly related to subsurface conductivities. Subsurface conductivities are measured in terms of millisiemens/centimeter (µS/cm). The EM conductivity of unconsolidated glacial sediments is primarily affected by the presence of clay minerals and the conductivity of ground water. The presence of ions in water, such as dissolved metals, increases the electrical conductivity of that water [1]. The EM data were acquired using a Century Equipment EM Flow Meter, Model 9721.

GEOPHYSICAL FINDINGS

Technology Calibration

The only calibration conducted was to focus the EM probe so that the maximum response was obtained from soils about one foot from the probe, or the center of the borehole. This measure was taken to avoid any interference with the well casing materials. The seismic, ground penetrating radar and natural gamma instruments needed no calibration.

GEOPHYSICAL FINDINGS

Investigation Results

Continuous seismic reflection profiles were generated along 16 lines around Horseshoe Pond. Along some lines, organic sediments at the bottom of the Pond impeded the penetration of the seismic wave, resulting in ambiguous results. The profiles generated for Horseshoe Pond indicated that bedrock, overlain at times by coarse-grained sediments, was identified at depths ranging from the surface of the pond to approximately 20 ft below the surface. At the northernmost end of the pond, the method was unable to detect bedrock known to be present at a depth of 100 ft. The investigator believed that the inability of the method along this line was due to the presence of organic bottom sediments that prevented the penetration of the seismic signal.

The seismic survey of the Merrimack River included eight lines along the western shore and five lines taken along the midline of the river. Bedrock was found underneath the river at depths ranging from 10 to 50 ft below the river surface, and to depths of 20 ft along the shoreline. The results from the river survey were markedly better than those for the pond survey. The lack of organic sediments in the river resulted in a better profile of the bedrock surface in all lines.

Ground penetrating radar profiles were generated along 12 lines around the plating facility and extending north and south from the facility. Along most of the lines, the survey found that the subsurface materials consisted mainly of silt, sand, and clay. The subsurface materials graded to a fine sand along the southernmost survey line, close to Horseshoe Pond. Bedrock outcrops can be seen in a few of the profiles. The fine materials tended to limit the penetration of the radar signal to depths no greater than 35 ft, and obscured the water table along most lines. In several of the profiles, blank areas appear below a depths of 10 to 12 ft. These blank areas were interpreted to represent the failure of the radar signal to penetrate fine-grained soils, or the presence of highly conductive groundwater. Radar surveys taken on the pond and the river yielded ambiguous results, as the radar signal was attenuated by the water and failed to penetrate the fine-grained sediments along the pond bottom.
Natural gamma logs were developed for seven existing monitoring wells, one upgradient of the plating facility and its lagoons, and six downgradient. The gamma logs were useful in delineating the stratigraphy of the subsurface materials and identifying permeable and impermeable zones. The EM log was used to vertically delineate zones of increased electrical conductivity to identify potential contaminant plumes.

Three of these logs have been reproduced in Figures 2 to 4. The EM and gamma logs in these figures are shown along with the lithologic logs developed at the time the wells were installed (presented to the right of the geophysical logs). The lithologic logs indicate significant heterogeneity in the distribution of layers of coarse to fine materials. The only consistent stratum found in each of the logs was the near-surface very fine sand layer. The gamma readings in each of these borings correlated closely with the lithologic logs. Gamma readings were clearly higher in strata composed of finer sands and silts and lower in sandy strata. Gamma counts of less than 100 counts per second (cps) consistently were measured in strata that were identified in the lithologic logs as medium to coarse sands. Higher counts, in the range of 100 to 150 cps, were registered in the layers of fine sand and silts.

The EM logs were taken to identify zones of conductive groundwater that may indicate the presence of chromium-contaminated groundwater. In each of the logs shown in Figures 2 to 4, there are significant spikes in the EM readings, indicating possible zones of contamination. MW-8r (Figure 2), which is immediately downgradient of the lagoons and directly west of the plating facility, showed three distinct zones of conductive ground water, centered at altitudes of approximately 15, 58, and 92 ft above mean sea level (msl). In MW-104d which is located to the south of the lagoons, only one such zone can be seen, centered at 75 ft msl (Figure 3). In MW-108d, located to the east of the plating facility, a single zone is seen at 54 ft msl (Figure 4). It is interesting to note that in each of the wells, the spikes in the EM readings occur in strata composed of finer materials.

Results Validation

The results of the EM measurements were compared with water samples that were being collected as part of the ongoing monitoring. Specific conductance was measured in each well and the result printed on the geophysical logs in Figures 2 to 4 (shown to the right of the lithologic log). The altitude at which the conductance log is printed and indicates the depth of the well screen. The measured conductance correlated well with the locations with high conductivity from EM logging in two of the three logs. In MW-8r and MW-108d, the specific conductance was higher at the depths at which the EM measurements were also high. In MW-104d, however, high specific conductance was measured near the bottom of the well, but the EM readings at that altitude were not high relative to a higher location in the well. Measures of specific conductance can be sensitive to naturally occurring ions, as well as ions associated with chromium contamination.

GEOPHYSICAL FINDINGS

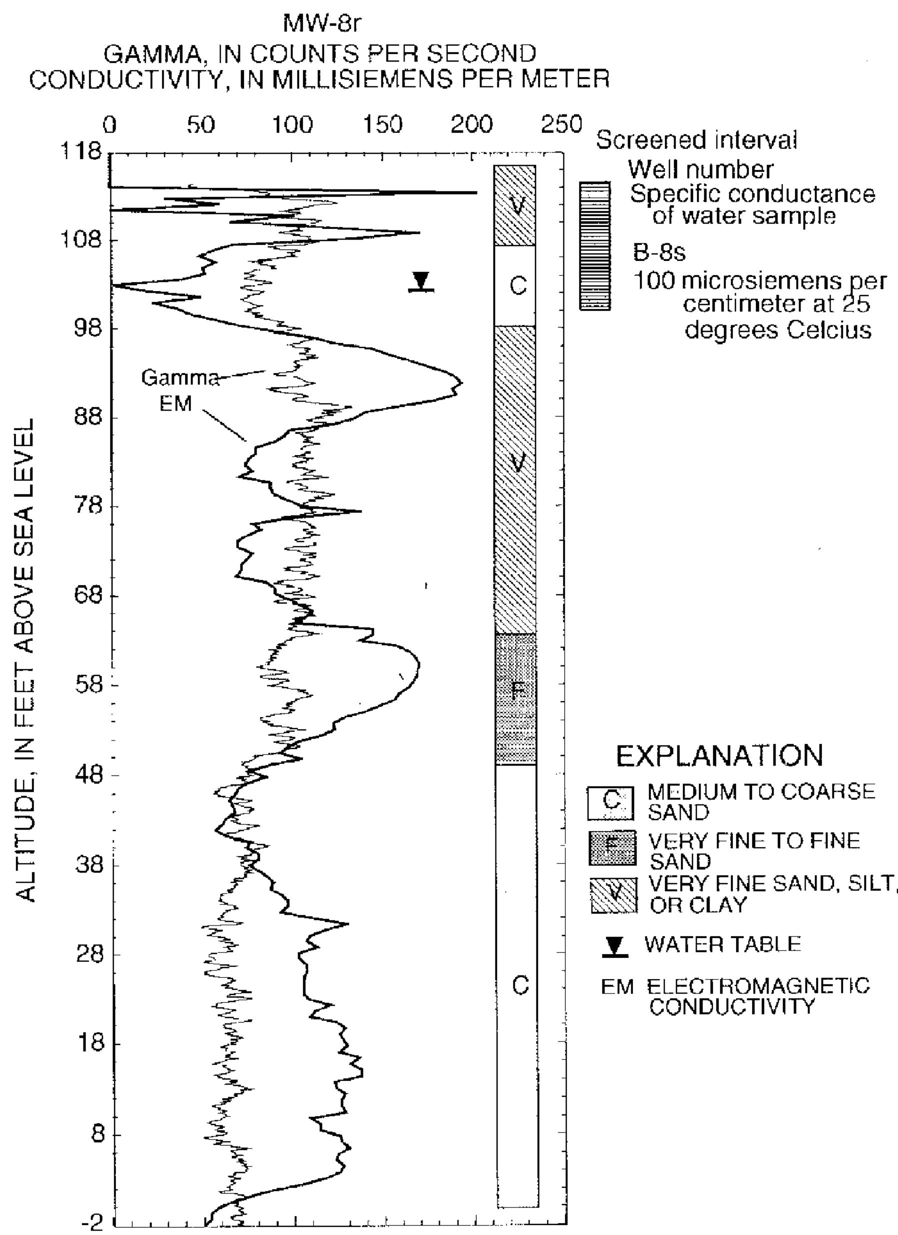


Figure 4. Borehole geophysical logs, lithologic section, screened interval, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-8r.

Figure 2: Geophysical Log for MW-8r [3]

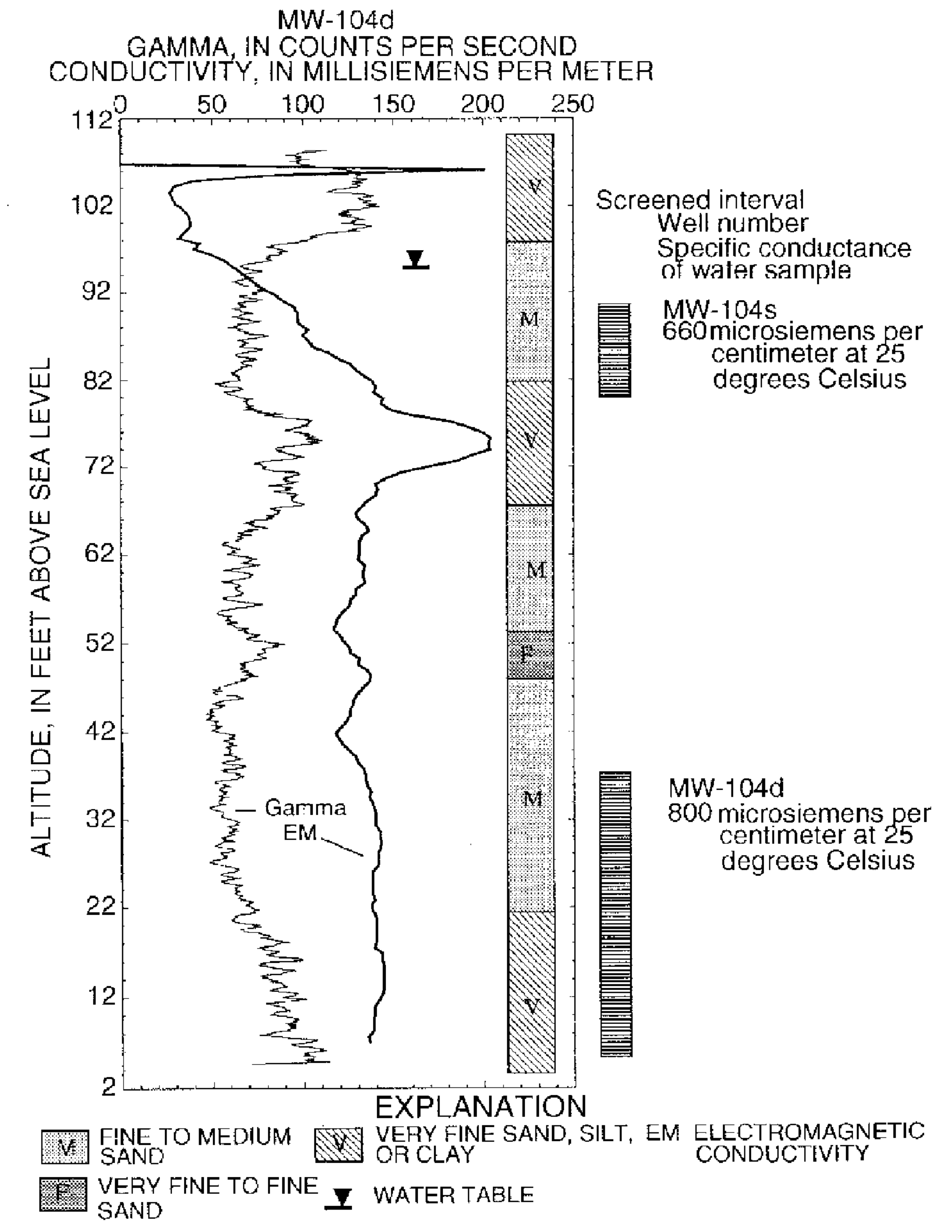


Figure 5. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-104d.

Figure 3: Geophysical Log for MW-104d

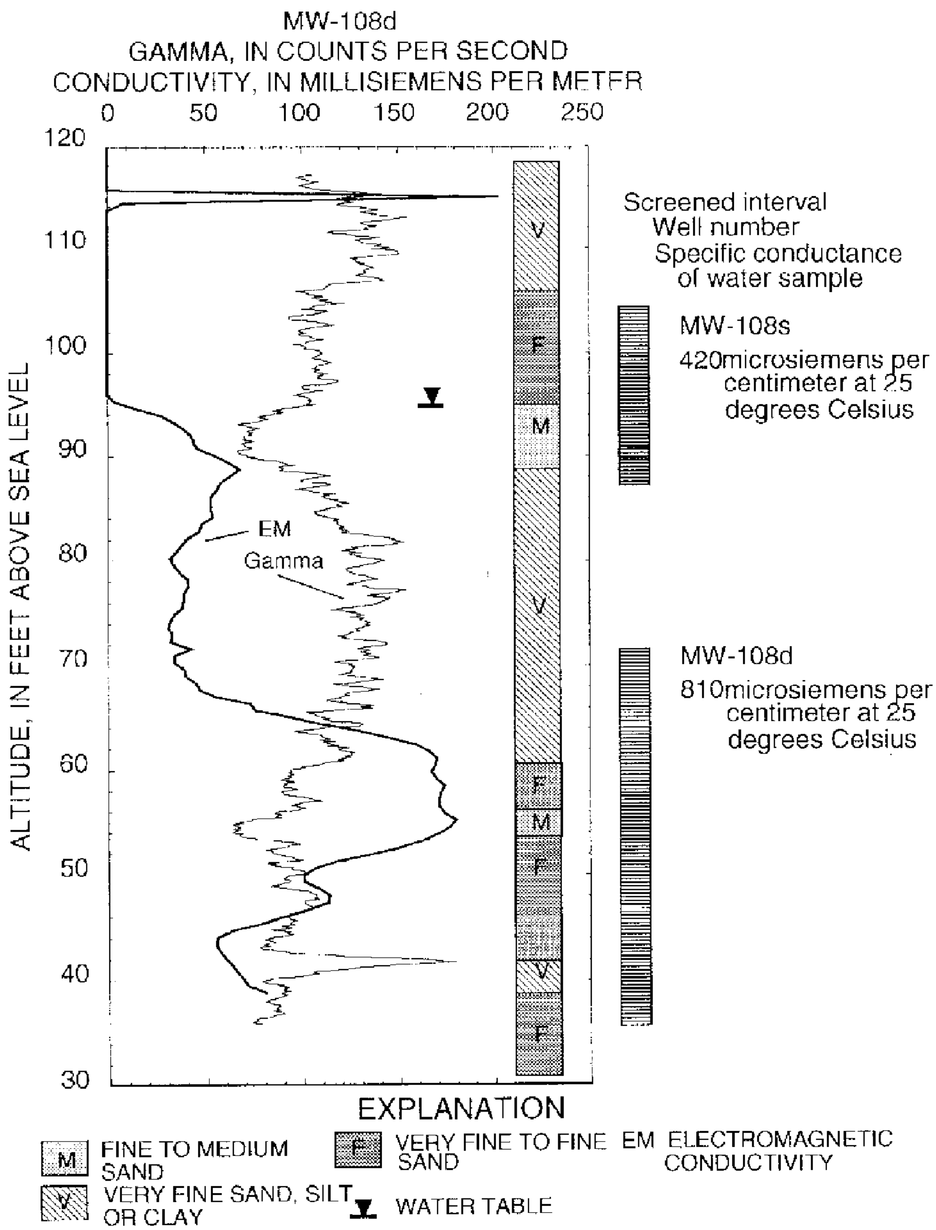


Figure 8. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-108d.

Figure 4: Geophysical Log for MW-180d

LESSONS LEARNED

The lessons learned during this investigation are the following:

- Downhole technologies provide more information on the stratigraphy and potential plumes of contaminated groundwater beyond shallow depths than surface geophysical techniques.

- Downhole technologies are effective in developing contour maps of lithologic units including subsurface structures that might promote or inhibit contaminant pathways.

- The two borehole technologies may be especially effective for large sites with deep contamination and complex stratigraphy. Borehole technologies may be useful along with boring and monitoring well placement during initial site evaluations. For sites with limited areal extent, shallow contamination, and/or simple stratigraphy, borehole technologies may be less cost-effective.

- Caution should be taken not to mistake natural conductivity in EM surveys with contamination.

- Both EM and natural gamma were much more effective in delineating deep subsurface features than seismic-reflection and GPR.

- Interpretation of the results of the investigation is useful in identifying the utility of the borehole technologies and comparison with utility of seismic-reflection and GPR. The following paragraphs discuss the technology usefulness and limitations as they relate to this investigation.

- The wells that had been installed for on-going monitoring missed the most contaminated sections of the aquifer. These wells were unable to identify the contaminated zones with typical monitoring well techniques. EM was useful in identifying likely elevations where plumes of contaminated groundwater exist. However, the levels of peak conductivity in both the measurement of groundwater samples and EM are strong indicators of contamination, for this site, because the background well had much lower conductivity. Further, the pattern of downgradient conductivity was consistent with a groundwater contamination plume pattern.

- Natural gamma logging can provide consistent information on stratigraphy. When accurate surface elevations are obtained for each boring, a contour map can be developed for any of the lithologic units that were identified in the survey. This information can be used to identify subsurface structures that might provide migration pathways for contaminants.

- The two borehole technologies may be especially effective for sites with the following features: unconsolidated sediments, large areal extent, deep contamination that may have traveled far, and for more complex stratigraphy. In these situations, the borehole technologies may be most effective in combination with examination of boring logs and limited initial monitoring well placement. The monitoring wells are cost-effectively placed in combination with the borehole technologies investigation and are useful for correlating results. Following the combination of initial efforts of boring log examination, groundwater monitoring, and borehole technologies evaluations, additional borings and monitoring wells may be placed more cost-effectively, than if only borings and monitoring wells were placed.

- However, for sites with limited areal extent, shallow contamination, and/or simple stratigraphy, borehole technologies (EM and natural gamma) are less cost-effective.

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1. Mack, Thomas J. *Geophysical Investigations in the Vicinity of a Former Electroplating Facility in Merrimack, New Hampshire*: U.S. Environmental Protection Agency, Region 1, 1994.

2. Haeni, F.P. *Application of continuous seismic-reflection methods to hydrologic studies.* Ground Water, 1996, v. 24, no. 1, p. 23-31.

3. Beres, Milan Jr., and Haeni, F.P. *Application of ground-penetrating-radar methods in hydrogeologic studies.* Ground Water, 1991, v. 29, no. 3, p. 375-386.

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NMSHTD District 1 Headquarters

Case Study Abstract

New Mexico State Highway and Transportation Department (NMSHTD)
Underground Storage Tank (UST) Investigation
Deming, New Mexico

Site Name and Location: NMSHTD UST Investigation Deming, NM	**Geophysical Technologies:** Magnetometry Electromagnetics Natural gamma logging Soil gas analysis	**Date of Investigation:** July 1997
Period of Site Operation: 1955 to present **Operable Unit: N/A**		**Current Site Activities:** Planning for Soil Vapor Extraction Remedy
Points of Contact: Phil Ramos, 505-827-5528 Richard Meixner, 505-822-9400 Jim Viellenave, 303-278-1911	**Geological Setting:** Quaternary bolson alluvium underlain by Cretaceous Mesa Verde and Mancos shale	**Technology Demonstrator:** Sunbelt Geophysics P.O. Box 36404 Albuquerque, NM 87176 505-266-8717 TEG Rocky Mountain 400 Corporate Circle, Suite R Golden, CO 80401 303-278-0104

Purpose of Investigation: The overall goal of this environmental investigation was to identify and characterize the source of chlorinated VOC contamination in groundwater beneath the NMSHTD site. The goal of the magnetic and electromagnetic survey was to locate buried materials that might be potential sources of contamination. The goal of the gamma log survey was to guide the placement of the soil vapor sampling points.

Number of Images/Profiles Generated During Investigation: 33 natural gamma profiles.

Results: Magnetometry and electromagnetics identified two areas of concern. Natural gamma logs of direct-push boreholes identified stratigraphic units that influenced the migration of contaminant vapors in the vadose zone. Permanent soil gas sampling points were installed in the units identified by the gamma logs. The soil gas survey provided a representative distribution of the contamination in the vadose zone.

EXECUTIVE SUMMARY

The New Mexico State Highway and Transportation Department (NMSHTD) District 1 Headquarters site is located in Deming, New Mexico in the southwestern part of the state. The site covers approximately 15 acres. The site lies within 10 miles of the U.S./Mexico border. The topography is generally flat with little or no relief across the site. The Mimbres River is located north of the site and is the only nearby water body. The property has been used since 1955 by the NMSHTD for vehicle maintenance, steam cleaning, and other activities. During years of heavy roadbuilding, a materials testing laboratory used 1,1,1-tetrachloroethane (1,1,1-TCA) on a regular basis for asphalt analyses. Spent solvent was either disposed off site or recycled in an on-site still. The aggregate used in testing was apparently rinsed with water, and the contaminated water was regularly rinsed down the drain and into the septic system.

Site geology consists of deposits typical of an arid zone basin that has been filled in by erosion of materials from the surrounding uplands. Locally interlayered sandy clay and clayey sand are present with some gravel. A thick gravel layer was present at depths between eight and 15 feet below ground surface (bgs). Depth to groundwater is 100 to 150 feet bgs.

A geophysical investigation was completed as part of a soil gas survey conducted at the site in 1997. The information presented in this report was derived from the interpretive report of the geophysical investigation. Geophysical methods were used to identify buried materials and to find optimal locations for the placement of soil gas sampling points. A reconnaissance survey was performed over the study area using magnetometry and electromagnetics (EM) to identify buried materials that might be sources of contamination. The reconnaissance survey was conducted over a 25-acre area from July 7 to July 22, 1997. The survey identified numerous areas of buried materials, but only two were of interest. A septic tank was identified to the southeast of the building that had housed the materials testing laboratory. Also identified was another area located approximately 75 feet to the north of the septic tank on the east side of the building. Natural gamma logs taken in direct push boreholes were used to identify clay lenses that might impede the migration of soil gas vapors. Soil gas sampling points were installed just below these lenses.

The gamma logs were successful in locating the clay lenses that were controlling vapor migration in the vadose zone. The resulting soil gas survey identified areas of groundwater contamination related to the septic field that was acting as a source area.

SITE INFORMATION

Identifying Information

New Mexico State Highway and Transportation Department (NMSHTD)
District 1 Headquarters Underground Storage Tank (UST) Site
2912 East Highway 80
Deming, NM

Background

Physical Description: The NMSHTD District 1 Headquarters Underground Storage Tank (UST) site is located in Deming, New Mexico in the southwestern part of the state, as shown in Figure 1. The site covers approximately 15 acres. This investigation was extended off site to investigate various properties that may have contributed to the on-site contamination [1].

Figure 1: Site Location

The site lies within 10 miles of the U.S./Mexico border. The topography is generally flat with little or no relief across the site. The Mimbres River is located north of the site and is the only nearby water body [2].

Site Use: The property has been used since 1955 by the NMSHTD for vehicle maintenance, steam cleaning, and other activities. Figure 2 shows a map of the site and the immediate area. During years of heavy road building, a materials testing laboratory used 1,1,1-tetrachloroethane (1,1,1-TCA) on a regular basis for asphalt analyses. Spent solvent was either disposed off site or recycled in an on-site still. The aggregate used in testing was apparently rinsed with water, and the contaminated water was regularly rinsed down the drain and into the septic system. This improper disposal of 1,1,1-TCA-contaminated water contributed to the contamination of the site [1, 2, 3, 4].

Release/Investigation History: During a tightness test of underground storage tanks at the Deming site in July and August 1989, NMSHTD found leaks in underground storage tanks and petroleum hydrocarbon contamination of subsurface soil. Subsequent investigations confirmed the presence of gasoline-derived and chlorinated volatile organic compounds (VOCs) in groundwater at concentrations in excess of New Mexico Water Quality Control Commission health standards [1, 3, 4].

In June 1996, Daniel B. Stephens & Associates (DBS&A) conducted a shallow soil gas survey using passive soil gas samplers to detect contamination in the vadose zone. The survey was conducted over an area of known VOC-contaminated groundwater, but the only VOC detected was perchloroethene (PCE). Furthermore, the distribution of PCE was not representative of the distribution of chlorinated VOCs known to be present in the groundwater beneath the site. The investigators from DBS&A believed that the local geology affected the movement of contaminant vapors beneath the site, possibly preventing the shallow samplers from registering chemicals known to be present in groundwater approximately 100 feet below ground surface (bgs) [1, 3].

SITE INFORMATION

Regulatory Context: New Mexico UST Regulations and New Mexico Water Quality Control Commission standards [1, 3].

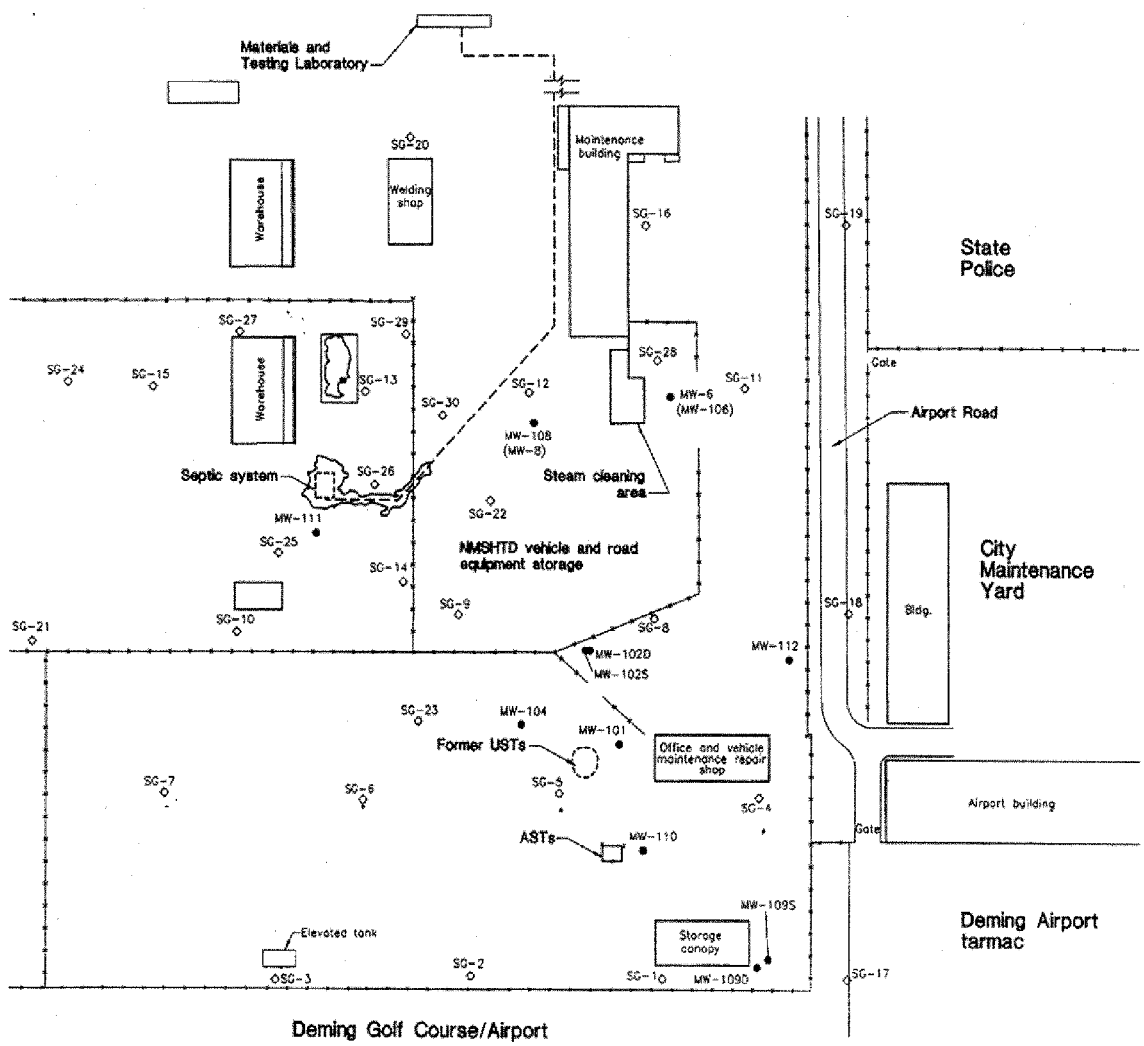

Figure 2: NMSHTD District 1 Headquarters Site [3]

SITE INFORMATION

Site Logistics/Contacts

State Lead Agency: NMSHTD
Federal Oversight Agency: Not applicable

Remedial Project Manager:
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303-278-0104

MEDIA AND CONTAMINANTS

Matrix Identification [3]

Type of Matrix Sampled and Analyzed: Subsurface clays, sands, and gravels.

Site Geology/Stratigraphy [3, 4, 5]

Regional geology in the area of the site consists of Quaternary alluvium underlain by Cretaceous Mesa Verde and Mancos shale. In some areas the eroded materials have been reworked by local streams. The local stratigraphy consists of deposits typical of an arid zone basin that has been filled in by erosion of materials from the surrounding uplands. Locally interlayered sandy clay and clayey sand are present with some gravel. A thick gravel layer was present at depths between eight and 15 feet bgs. Some confining layers are present that may influence the migration of contaminant vapors. Depth to groundwater is 100 to 150 feet bgs.

Contaminant Characterization [1, 3]

Primary Contaminant Groups: The primary contaminants of concern include trichloroethene (TCE), perchloroethene (PCE), 1,1-dichloroethene (1,1-DCE), and 1,1,1-dichloroethane (1,1,1-DCA). A combination of benzene, toluene, ethylbenzene, and xylene (BTEX) was also present but was not addressed in the investigation described here. The most frequently detected chlorinated VOC in soil gas was 1,1-DCE.

MEDIA AND CONTAMINANTS

Matrix Characteristics Affecting Characterization Cost or Performance

The magnetometry survey was affected in three areas by the presence of sources of magnetic interference, such as fences, buildings, etc, to the degree that the survey in those areas was replaced by an electromagnetic survey [3].

The natural gamma detector used at the Deming site was found to be sensitive to temperature change. After it was lowered into the hole, the field team allowed it to equilibrate to the lower subsurface temperature before recording the counts of natural gamma radiation. Later models of the detector are designed to be impervious to temperature differences and has been used in 100°F temperatures [3, 6]. The detector is impervious to humidity and water. It functions in groundwater and has been used in the rain and snow [5].

Certain geologic materials, such as granite-derived cobbles and gravel in conglomeratic deposits, organic rich deposits, and phosphate and potash (K_2CO_3) deposits, have low natural gamma radiation levels, and natural gamma logging may be insufficient to distinguish layers composed of these materials. However, these materials were not present in the alluvial deposits examined at this site [3, 5, 6].

The presence of a gravel layer between eight and 15 feet bgs and a tendency of the deeper materials to collapse when the probe was advanced led the investigators to conduct the gamma logging inside of the drive rods [3].

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [1, 3]

The overall goal of this environmental investigation was to identify and characterize the source of chlorinated VOC contamination in groundwater beneath the NMSHTD site. The goal of the magnetic and electromagnetic survey was to locate buried materials that might be potential sources of contamination. The goal of the gamma log survey was to guide the vertical placement of the soil vapor sampling points.

Geophysical Methods

A reconnaissance survey was performed over the study area using magnetometry and electromagnetics (EM). The magnetometry survey was carried out using a Geometrics G-858 cesium magnetometer. Magnetic data were acquired every two feet along parallel traverses separated by 10-foot intervals. The EM data were acquired using a Geonics EM-61 high precision metal locator every 0.6 feet along parallel traverses separated by five-foot intervals.

Natural gamma data were gathered using a Mt. Sopris Slim Line prototype instrument with a sodium iodide detector to measure the impinging natural gamma radiation. (A commercial version

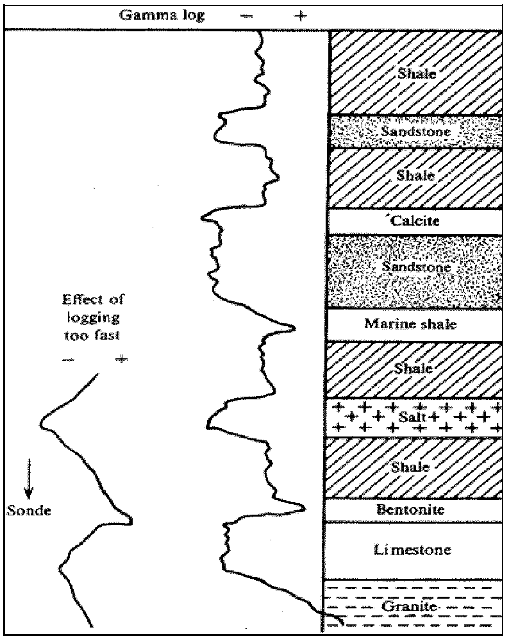

Figure 3 - Typical Gamma Log [7]

of this instrument has been developed since the date of this investigation [9]). The detector was 0.75 inches by 24 inches in size, and was attached to a 200 foot cable. An MGX data logger was connected to the cable. Gamma logging is useful in borings ranging from one to six inches in diameter [1, 3, 6].

Natural gamma logging is the physical measurement of the release of natural gamma radiation from the soil and rocks surrounding a borehole. Natural gamma logging is based on the principle that more intense natural gamma radiation is emitted from clay-rich formations, which are usually higher in naturally radioactive elements, than clay-poor formations. Most natural gamma radiation occurs in clays containing thorium, uranium, or potassium 40. Figure 3 shows a typical natural gamma log for some consolidated sedimentary deposits. Note the higher counts for clay-rich units like shale, particularly marine shale, and bentonite.

Natural gamma measurement begins with the lowering of the detector to the bottom of a hole, allowing it to equilibrate to the different subsurface temperature, and then reeling the detector up the hole at a steady rate of between five and 10 feet per minute (allowing the logging of a 50-foot hole in five to 10 minutes). The level of gamma radiation being emitted by a particular stratum is measured in counts per second (cps). Interpretation of the gamma log depends as much on the absolute value of the gamma counts as it does on the rate of change in gamma counts as the detector passes from one material to the next. Statistical variations in gamma emissions, significant at low counting rates, are smoothed out by integration over a short time interval. If the hole is logged too quickly, however, the smoothing effect leads to erroneous results by shifting the peaks in the direction of logging. The lower left-hand portion of Figure 3 illustrates the result of logging too fast [8].

Multiport soil gas wells were installed at depths between 20 and 60 feet bgs using direct push/hammer (Strataprobe®) technology. The Strataprobe® unit consisted of a dual ram with a hydraulic hammer vibrating component capable of producing a high-frequency impact with an 8,000 pound static reaction weight and more than 35,000 pounds of pullback capacity. The truck-mounted hydraulic percussion hammer unit was used to advance 1.75-inch outer diameter rods with an expendable 2-inch diameter tip into the subsurface until downward progress ceased due to refusal [1, 3].

After refusal, the rods were disconnected at the surface in order to conduct a subsurface natural gamma profile in the borehole to depths of approximately 50 feet bgs. The probe was pushed to total depth (averaging 50 feet), and the gamma logging was conducted from inside the pipe. Permanent vapor sampling points were installed as the pipe was withdrawn [1, 3, 6].

GEOPHYSICAL FINDINGS

Technology Calibration [1, 3]

No calibration of the magnetometer or the EM detector were performed, as this is not general practice.

To calibrate the natural gamma log readings for the Deming site, gamma logs were taken in three existing monitoring wells: MW-102, MW-109, and MW-111. The gamma readings were correlated with the lithology and stratigraphy that had been previously described for these wells. Figures 4 through 6 show the lithologic logs for these wells on the left and the corresponding gamma log on the right.

An examination of the logs revealed an acceptable level of correlation. In each of the gamma logs, the presence of a near-surface layer of silty clay was indicated by an increase in the gamma counts as the detector passed through that material. The individual logs, however, did show a difference in the absolute values of gamma counts for this layer, as gamma counts rose to levels of 115 to 135 cps in MW-109 and MW-111, and to levels of approximately 275 cps in MW-102. The difference in the absolute level of gamma counts probably indicated that the silty layer in MW-109 and MW-111 contained a smaller proportion of coarser materials than it did in MW-102. The near-surface silty layer was present in each of the lithologic logs.

The layer of coarse gravel that was identified in the monitoring well logs at depths ranging from eight to 15 feet bgs can be seen in each of the calibration logs as both a small decline in absolute gamma counts to levels of less than 100 cps and as an increase in the distance from peak to peak in the log. Again, there appears to be a higher proportion of silty materials mixed with the gravel in the log for MW-102, as evidenced by the higher gamma counts for similar materials shown in that log than in the other two gamma logs.

The layer of silty materials present in the lithologic log for MW-109 and MW-111 at approximately 25 feet bgs is identifiable in the gamma logs for those wells. The grading from coarser sand materials into a silty clay can be seen as the gamma count rises above 100 cps. That silty layer was not present in the lithologic log for MW-102, and no indication of such a layer can be seen in the gamma log for that well.

The next interval in the lithologic logs is composed of predominantly sandy materials, although the size of the interval varies across the three wells. In MW-102, this interval extends to an approximate depth of 40 feet bgs, and the gamma log for that well shows small variations in gamma counts which remain in the 150 to 225 cps range. In MW-109, the sandy layer extends deeper to an approximate depth of 48 to 50 feet bgs. This layer can be seen in the gamma log for MW-109 as an interval over which the gamma counts remain largely within a narrow range between 63 and 75 cps. The interval between 25 and 55 feet bgs in MW-111 is largely composed of sand with gamma counts varying between 50 and 100 cps. This interval is interrupted at a depth of approximately 38 feet bgs by a sandy clay material that can be seen in the gamma log as gamma counts rise to approximately 125 cps.

The lithology of these wells over the remaining interval is significantly different. The lithology of MW-102 below 40 feet bgs grades from sandy silt to sandy gravel and back to sandy silt at a depth of 84 feet bgs. The short interval of sandy gravel, shown on the lithologic log from 65 to 75 feet bgs, can be seen in the gamma log as a lower set of gamma counts beginning at approximately 68 feet bgs and extending to 78 feet bgs. The lithologic log shows a gradual coarsening of materials below a depth of 50 feet bgs in MW-109 to a depth of 78 feet bgs. The gamma log for this well, instead, shows a similar coarsening over the interval from 50 feet bgs to 60 feet bgs as the gamma counts gradually decline. From 60 feet bgs to a depth of approximately 75 feet bgs there appears to be a gradual increase in gamma counts. Such an increase may only indicate the presence of silty materials mixed in with the sand that are not readily evident in a visual inspection of the same materials.

Overall, there appears to be an adequate correlation between the lithologic logs and the gamma logs for the three monitoring wells for successful calibration. In addition, the gamma logs reveal the presence of fine-grain materials when the same materials are not noted in the lithologic logs. This may be due to the fact that the lithologic logs were developed for another use and were used here as a matter of convenience, or that gamma readings provide a more sensitive measure of subtle changes in stratigraphic units than can be achieved with a visual inspection.

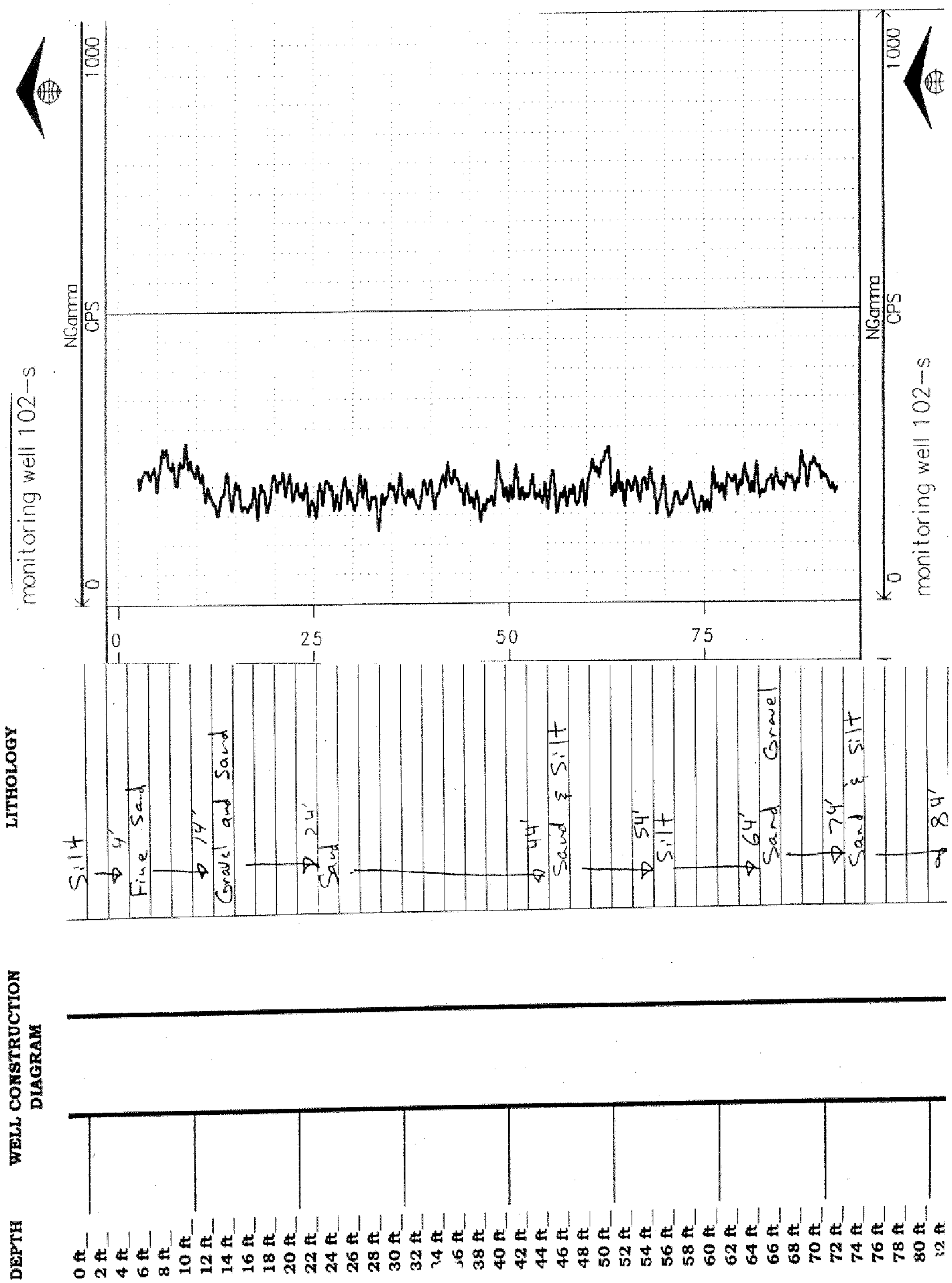

Figure 4: Calibration Logs for MW-102 [3]

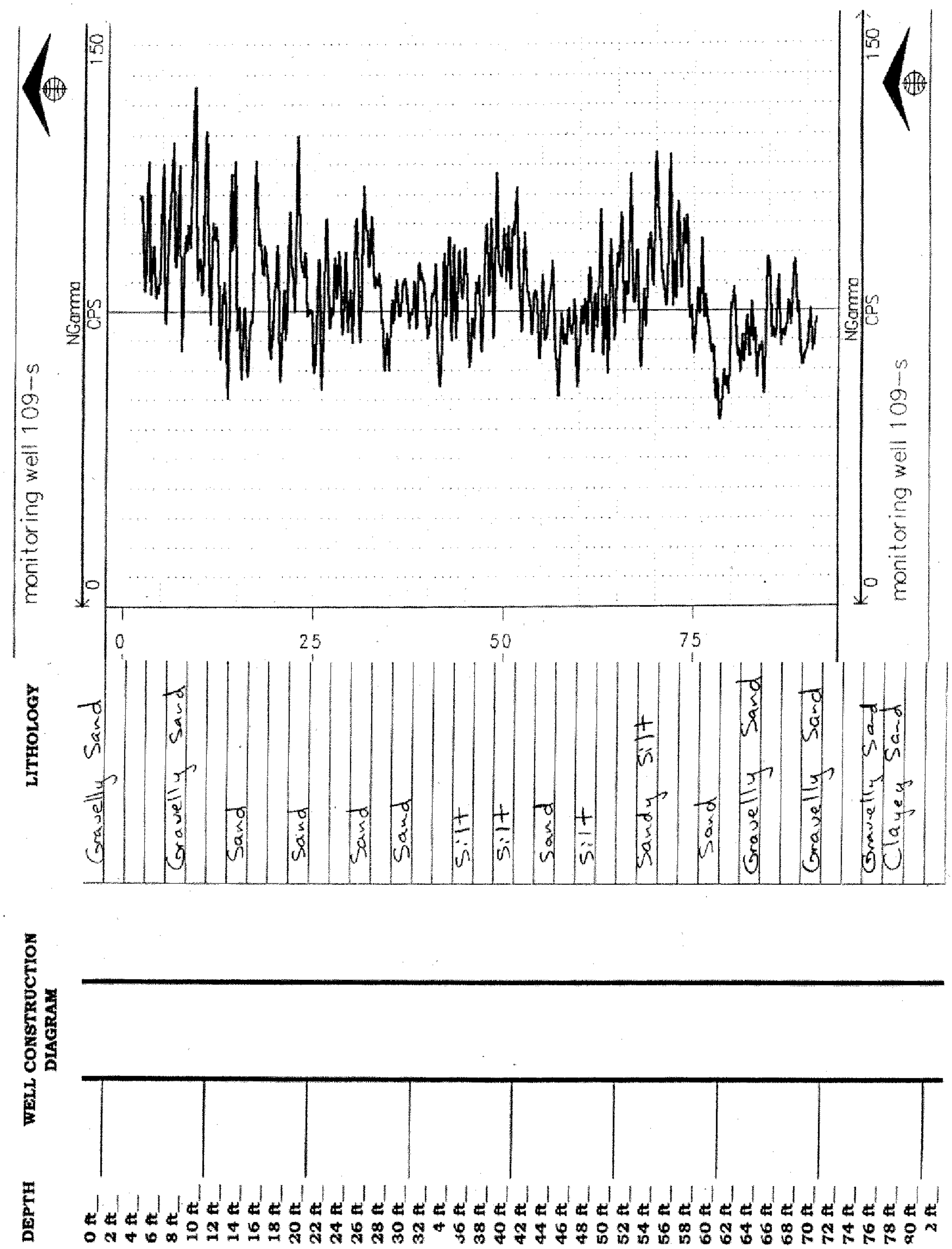

Figure 5: Calibration Log for MW-109 [3]

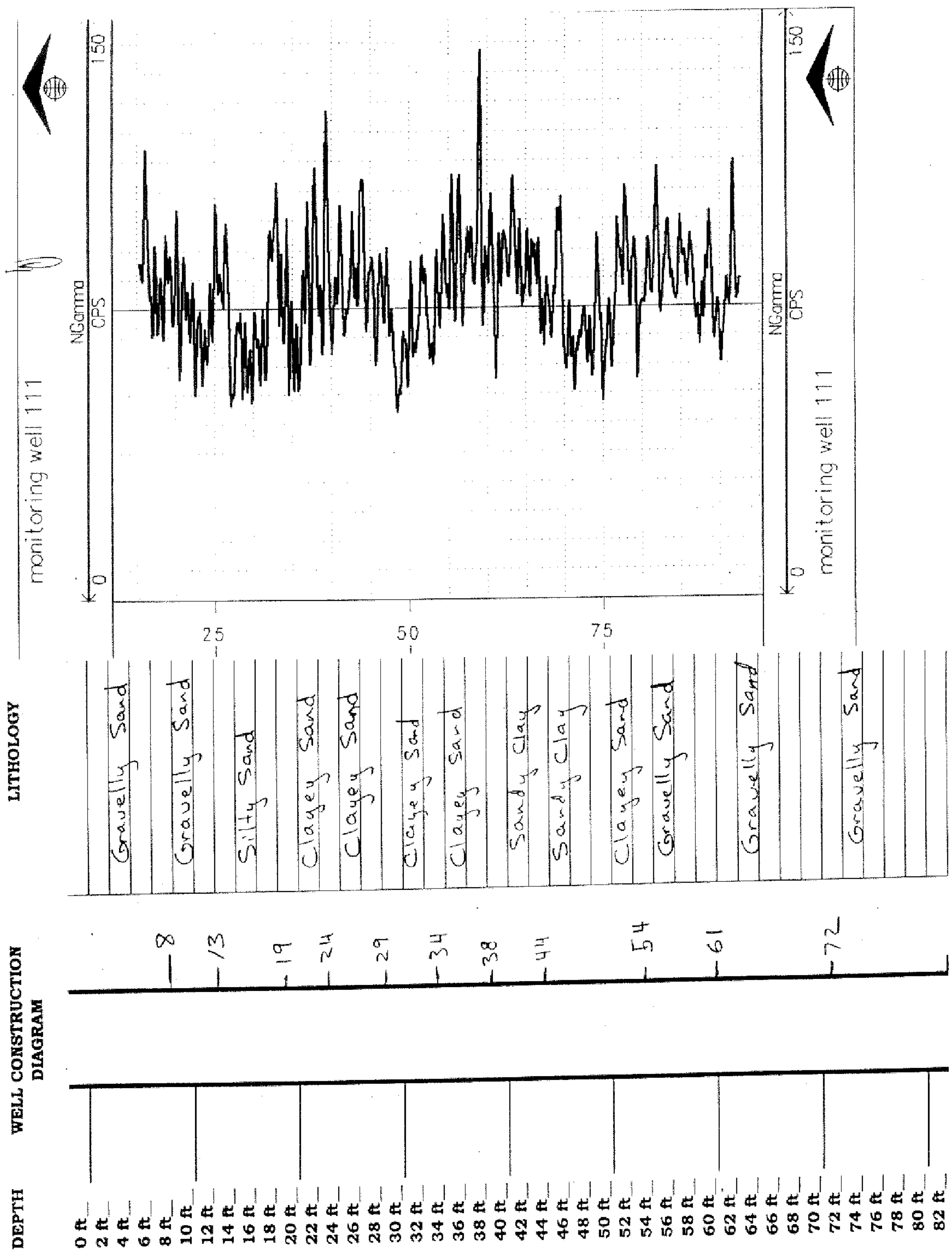

Figure 6: Calibration Log for MW-111 [3]

GEOPHYSICAL FINDINGS

Investigation Results [3]

The reconnaissance survey was conducted over a 25-acre area from July 7 to July 22, 1997. The survey identified numerous areas of buried materials, but only two were of interest. A septic tank was identified to the southeast of the building that had housed the materials testing laboratory. Also identified was another area located approximately 75 feet to the north of the septic tank on the east side of the building. The latter area was described as a concentration of buried metal materials of unknown origin.

The gamma logging and the installation of the soil gas wells occurred between July 8 and July 25, 1997. The installation of the soil gas wells began in the southern part of the Deming site near the septic tank and the area of buried materials to the north in order to determine whether chlorinated VOCs were present in the vadose zone. The area over which vapor sampling points would be placed was based on the results of the reconnaissance survey. The vertical placement of vapor sampling points was based on the field reading of geologic units as indicated by natural gamma logs. Specifically, the gamma logs were used to find permeable layers positioned below impermeable layers. This geologic setting forms a migration pathway for contaminant vapors, and the characterization of migration pathways is an important step in contaminant detection.

An examination of the gamma logs from several holes revealed the presence of a series of fairly consistent layers of sandy clay or similar material beginning at about 15 to 22 feet bgs (just below the gravel), 27 to 32 feet bgs, and finally at 38 to 50 feet bgs, particularly in those wells near the septic system. Beneath each of these layers the subsurface materials tended to grade into coarser, sandy materials. The gamma log signature was reviewed in the field, and from this information certain intervals were selected for the installation of gas points. A more permeable sampling interval (identified by lower gamma counts) was selected for each gas point location. Examples of three gamma logs indicating the presence of clay layers and the location of vapor sampling points are shown in Figures 7 through 9.

In Figure 7, the first vapor sampling point was placed in a screened interval between 25 and 30 feet bgs. At this level, the sampling point was located below the silty material that was present from 20 to 25 feet bgs, shown in the gamma log where the gamma count rises through 124 cps. The silty materials would impede the upward movement of contaminant vapors. The screen was placed in the relatively coarser material (located just below the silty material) through which vapors would be likely to migrate. The second and third screen intervals were similarly located in coarser materials located just below a less permeable layer, indicated in the gamma log by sharp increases in gamma counts.

In Figure 8, the first sampling point is located just below the thin silty layer encountered at a depth of approximately 21 feet bgs. At this depth, it appears that there is an interval of approximately 19 feet of coarse sandy material, and the screen was positioned at the top of this interval. The second sampling point was located in a screened interval between 38 and 43 feet bgs. At this depth, the screen is located toward the bottom of a layer of coarse materials that extends from 31 to 47 feet bgs. The silty layer that would be expected to impede the migration of contaminant vapors is at least eight feet above the top of the screened interval. The third sampling point is located in a screened interval between 55 and 60 feet bgs. In this position, the sampling point is located directly below the silty material that can be see at a depth of 53 feet bgs, where the gamma counts rise sharply to nearly 90 cps.

Figure 9 shows the gamma log for SG09, in which only two vapor sampling points were placed. The first point was located in a screened interval between 21 and 24 feet bgs. At this depth, the sampling point was located directly below the silty layer seen at 21 feet where the gamma counts peak at approximately 70 cps. The lower sampling point was placed in a screened interval between 46 and 55 feet bgs. This screen was placed more to take advantage of the coarse materials located in that interval than to use a distinct impermeable layer located directly above. The coarsing of the materials in this interval can provide a migration pathway for contaminant vapors.

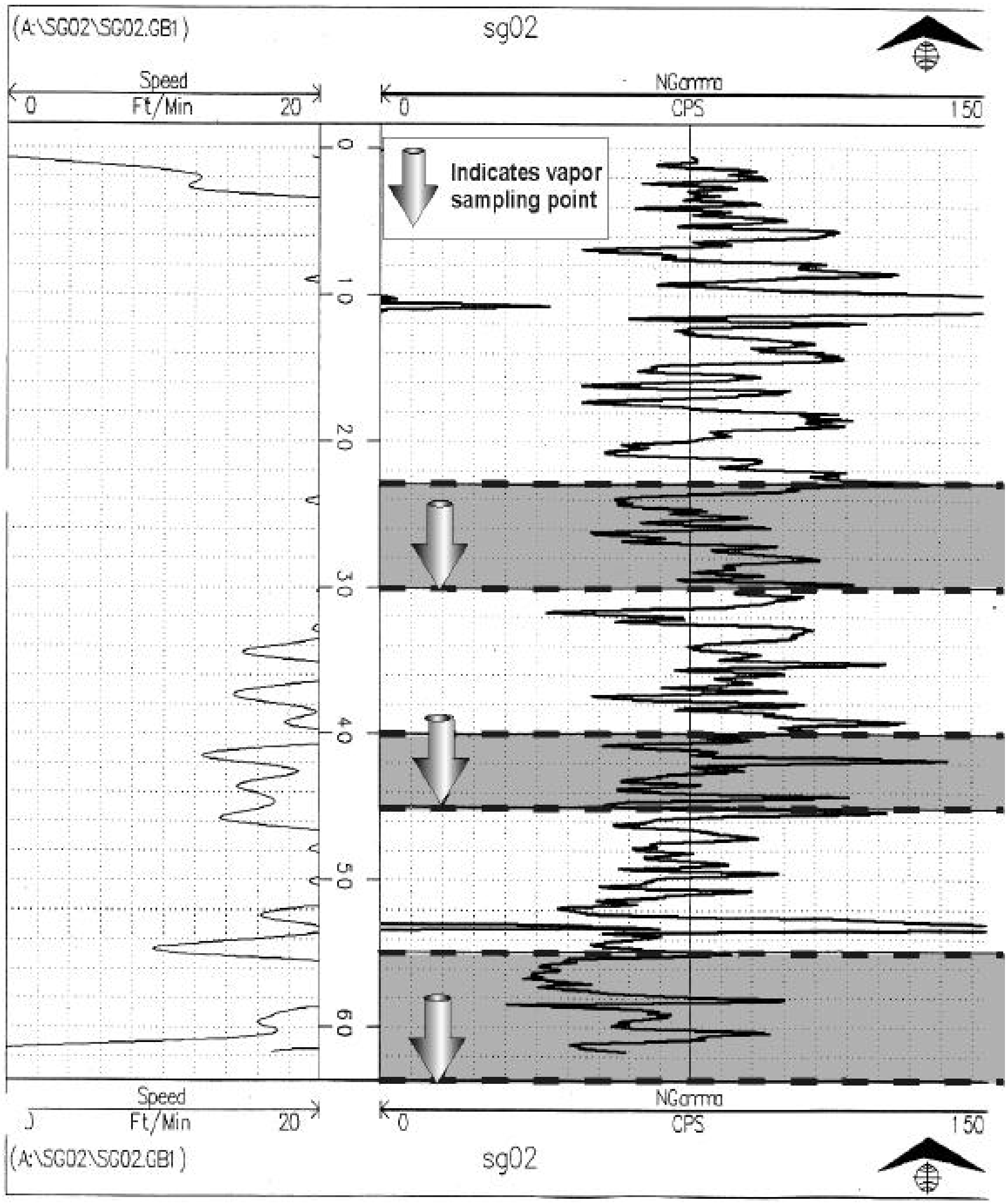

Figure 7: Vapor Sampling Points in SG02 [3]

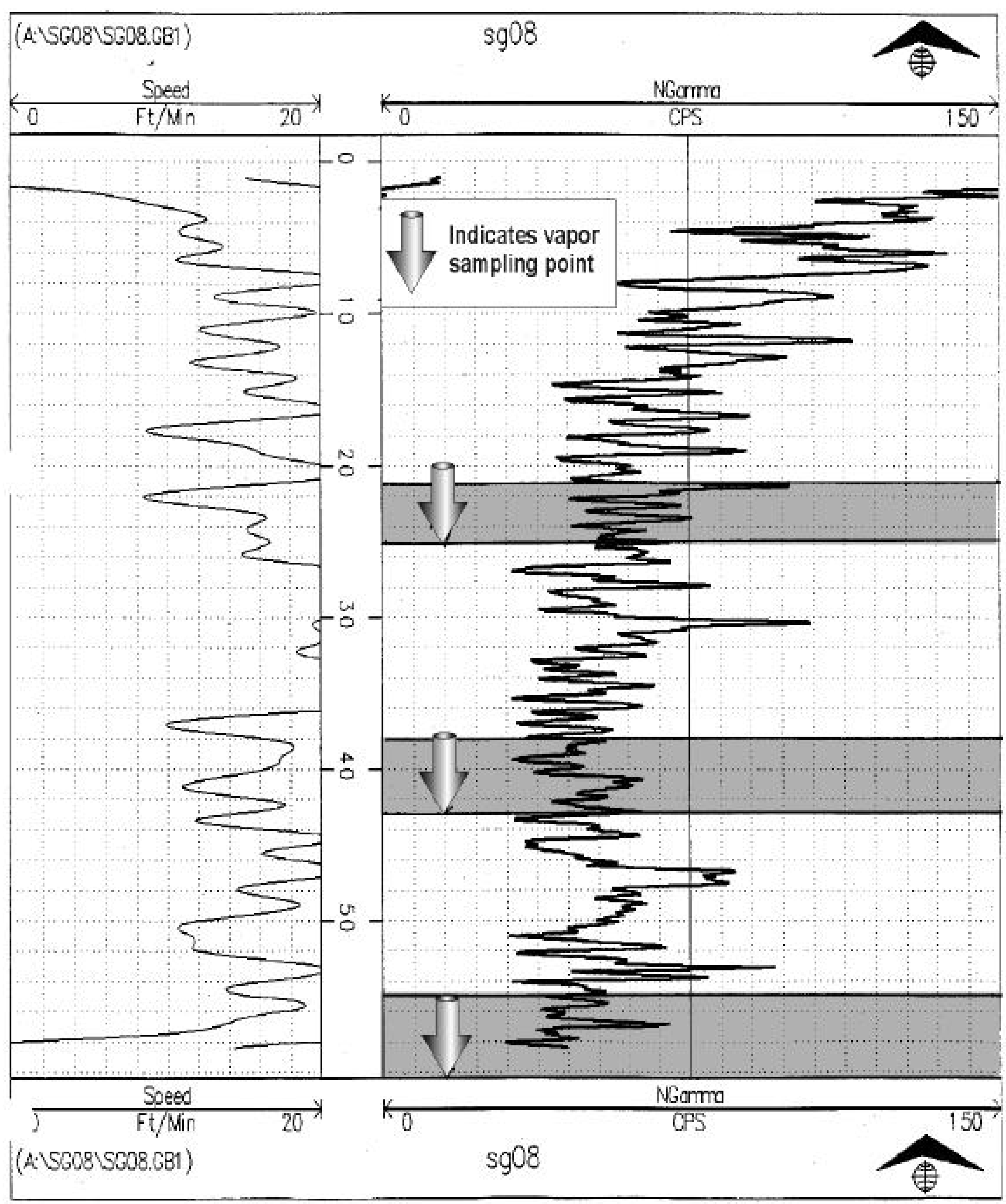

Figure 8: Vapor Sampling Points in SG08 [3]

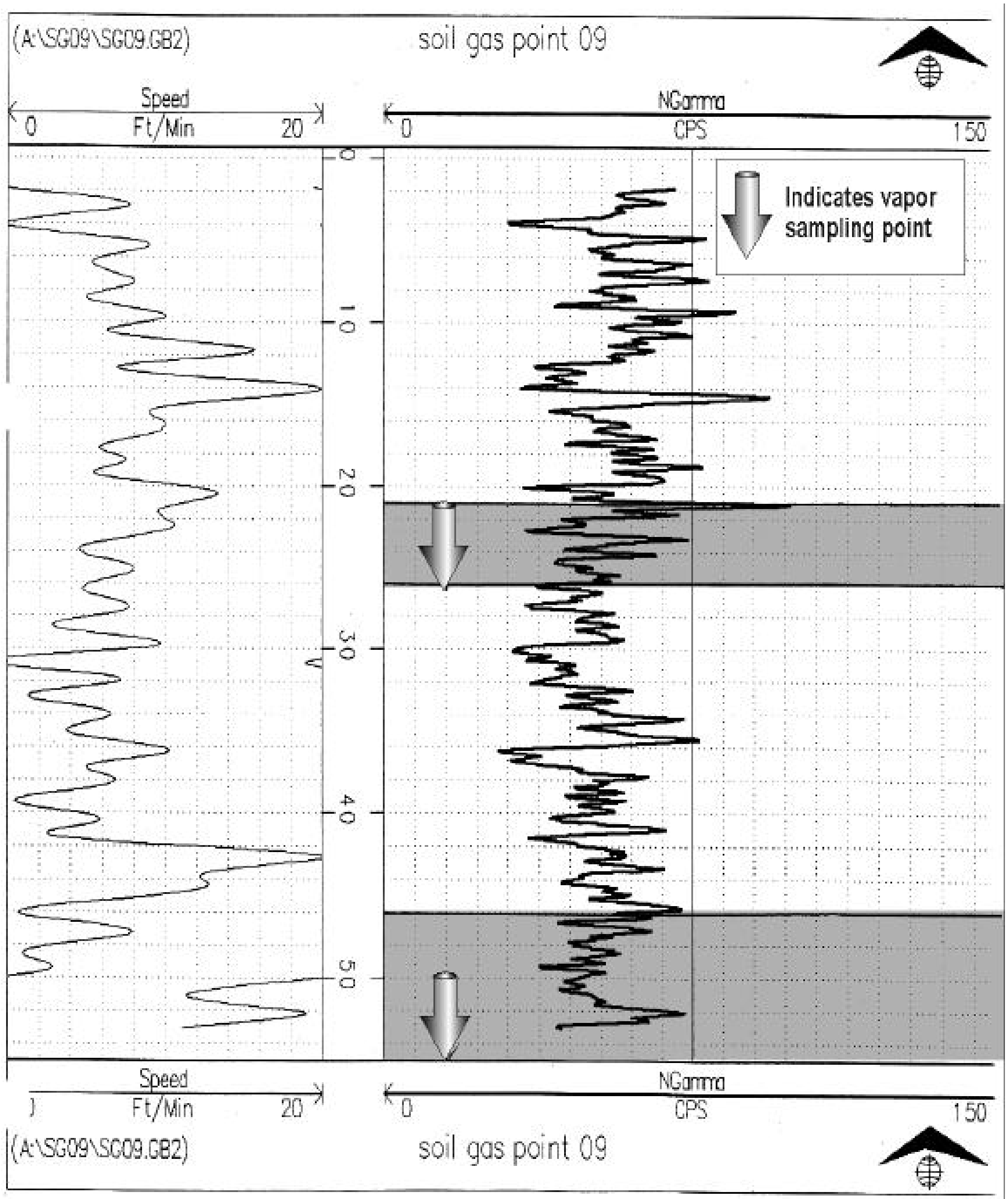

Figure 9: Vapor Sampling Points in SG09 [3]

GEOPHYSICAL FINDINGS

Results Validation [1, 3]

No additional activities were conducted to validate the findings of the natural gamma logging. The results of the soil gas sampling conducted after the installation of the permanent sampling points served as an indirect validation. The distribution of VOC contamination that was revealed was representative of previous sampling, and was centered around the two source areas that had been identified by the reconnaissance survey.

LESSONS LEARNED

There were several important lessons learned during the Deming investigation. These are discussed below.

- Natural gamma readings should be calibrated to the site stratigraphy using site-specific knowledge of local geology. The use of lithologic logs from existing wells can save the time and effort that would be expended if the logs had to be generated during the same investigation.

- Natural gamma logs appear to be more sensitive to subtle changes in stratigraphy than is the visual inspection of lithologic logs, which often is based on the personal interpretation of the geologist.

- The natural gamma logs were used successfully to make well point placement decisions in the field at the time when the sampling points were being installed. In less dynamic investigations, well point placement decisions might be delayed rather than made in the field, potentially resulting in delays in the investigation.

- Because the natural gamma signature does not degrade or decay over time, this information is representative for present and future investigations as well. The same information that was used to guide sampling point locations can be used at a later date to guide the installation of screening intervals for a soil vapor extraction system.

- Gamma logs are a useful tool for identifying interbedded impermeable layers that may be thin and difficult to locate. This tool can be used to guide the placement of subsurface sampling points, or screening intervals for soil vapor extraction or pump and treat systems in geologically heterogenous materials.

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9. Personal communication with Jim Viellenave, TEG Rocky Mountain, Inc. September 15, 1998.

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Case Study Abstract

Tinker Air Force Base
Oklahoma City, OK

Site Name and Location: Tinker Air Force Base	**Geophysical Technologies:** Electromagnetics Seismic reflection Seismic Modeling	**RCRA Permit #** 1571724391
Period of Site Operation: 1942 - present **Operable Unit:** Not applicable		**Current Site Activities:** Portions of the base are undergoing investigation and remediation under the Installation Restoration Program
Point of Contact: Sara Sayler OC-ALC/EMR 7701 Arnold Street, Suite 221 Tinker Air Force Base Tinker, OK 73145-9100 405-734-3058 sara.sayler@tinker.af.mil	**Geological Setting:** Permian-age sedimentary rocks overlain by Quaternary alluvium, sand dunes, and terrace deposits	**Technology Demonstrator:** IT Corporation 312 Directors Drive Knoxville, TN 37923-4799 Phone - 423-690-3211 Fax - 423-690-3626

Purpose of Investigation:
To help identify and map possible conduits for preferential groundwater flow in the shallow subsurface. The site-specific decision being supported was to obtain additional information in planning the optimal placement of the installation of groundwater recovery wells.

Number of Images/Profiles Generated During Investigation:
17,510 linear feet of seismic profiles collected along 8 survey lines. This case study focuses on the modeled and interpreted compressional (p-wave) results from a portion of Line 4 and an intersecting portion of Line 5. These lines were selected to represent typical site data and anomalies. This intersection is also the location of an interpreted sand channel near the intersection of the two lines, making it easier to demonstrate the continuity of the interpreted sand channel.

Results:
Interpretation of the seismic data indicates several places where sand channels cut into the Upper Saturated Zone/Lower Saturated Zone (USZ/LSZ) aquitard. The seismic reflection survey results will be used to recommend the placement of Phase II recovery well drilling locations. The results of Phase I groundwater recovery well yield tests indicated good correlation with several of the seismic anomalies identified in the target zones by the seismic survey. Seismic modeling was conducted to provide support for the interpretation of the seismic results. A EM-31 terrain conductivity survey was conducted along the eight seismic lines to screen for large scale anomalies caused by metallic objects that might interfere with the seismic survey. Most of the anomalies were due to surface metal, such as the chain-link fences, nearby structures, and monitoring well monuments.

EXECUTIVE SUMMARY

Tinker AFB covers 4,277 acres and is located on the southeast edge of the Oklahoma City metropolitan area. The base is situated within the North Canadian River drainage basin and drains into the Crutcho and Soldier Creeks and overlies a complex aquifer system that includes the Garber-Wellington Formation. The Southwest Quadrant Stabilization System (SQSS) Area is the location of two landfills that were used sporadically for disposal over a forty-year span from the 1940s to the late 1960s for disposal of sanitary and industrial wastes, including paints and solvents.

Near-surface geology at Tinker AFB consists of clays and clayey silts that are interbedded with thin, clayey sand layers, reaching a maximum thickness of approximately 60 feet in the western and southwestern parts of the base. The deeper geology is comprised of mostly unconsolidated materials, which are composed of predominantly fine-grained sandstone, with lesser amounts of siltstone and shale. Bedrock formations dip to the southwest by approximately 0.5 degrees, or by 40 to 50 feet per mile. Groundwater occurs at the site in four water-bearing units, but only the surficial unit was the target for this study. Groundwater can occur at depths as shallow as 20 feet, but public water supplies are drawn from depths of greater than 400 feet.

The purpose of the seismic survey was to locate permeable layers in the subsurface that might indicate preferential pathways for groundwater flow. This information is being used to site new extraction wells for the groundwater pump and treat system. Seismic methods were chosen as a cost-effective method for gathering information on the subsurface stratigraphy. The geology of the area is highly complex and other investigative methods, such as soil borings, would have yielded less information at a higher cost.

Two geophysical methods were used during this investigation: electromagnetic (EM) reconnaissance survey, and a seismic survey. The EM survey was conducted to screen for subsurface conditions that might cause interference in the seismic data collection. The seismic survey was conducted to identify conductive layers in the subsurface that might be paths for groundwater migration. Seismic modeling was conducted to provide analytical support for the interpretation of the seismic results.

The seismic survey revealed the presence of sand channels that were incised into the uppermost aquitard and sand lenses located within that aquitard. Seismic modeling significantly improved the investigator's understanding of the seismic anomalies that were found by providing an analytical benchmark against which to compare the seismic results. Strong correlation was found between the location of significant seismic anomalies and known groundwater flow pathways.

The target structures were relatively shallow and groundroll effects were not a significant source of interference. Poor surface conditions and cultural sources did, however, posed difficulties to data collection. Several seismic data processing techniques, such as refraction statics, spectral whitening, and mute analysis, significantly reduced the level of interference in the data and allowed for increased frequency and resolution of the seismic results.

SITE INFORMATION

Identifying Information

Tinker Air Force Base (AFB)
Oklahoma City, OK
RCRA Permit # 1571724391
Southwest Quadrant SMU

Background [1, 2]

Physical Description: Tinker AFB covers 4,277 acres and is located on the southeast edge of the Oklahoma City metropolitan area (see Figure 1). The base is bordered by Sooner Road to the west, Douglas Boulevard to the east, interstate highway I-40 to the north, and SE 79th street to the south The base is situated within the North Canadian River drainage basin and drains into the Crutcho and Soldier Creeks. The base overlies a complex aquifer system that includes the Garber-Wellington Formation .

Figure 1: Site Location

The topology of the seismic study area, located in the southwest portion of the base, is characterized by nearly level plains to gently rolling hills, with surface elevations ranging from 1,240 to 1,270 feet above mean sea level. The surface consists of alluvial soils near streams and flood plains, and residual soils resulting from weathered bedrock [1].

Site Use: The Southwest Quadrant Stabilization System (SQSS) Area is the location of two landfills that were used sporadically for disposal over a forty-year span from the 1940s to the late 1960s. Landfill #2 was used during the 1940s and 1950s for disposal of sanitary and industrial wastes, including paints and solvents. Landfill #4 was used from 1961 to 1968 for the disposal of drummed solvents, and sludges from petroleum and solvent storage tanks.

Release/Investigation History: On-site disposal of industrial wastes occurred from 1942 until 1979 when off-site disposal became the standard disposal practice. Organic solvents, including trichloroethylene (TCE), tetrachloroethylene, and l,2-dichloroethylene, were used for degreasing and aircraft maintenance. In the past, waste oils, solvents, paint sludges, and plating waste generated from maintenance activities were disposed in Industrial Waste Pits Numbers 1 and 2, located about l mile south of Soldier Creek and Building 3001. In 1997, a groundwater treatment system was installed to treat contaminated groundwater.

Regulatory Context: Actions at this site are being undertaken in compliance with Federal and State regulations under the Resource Conservation and Recovery Act (RCRA).

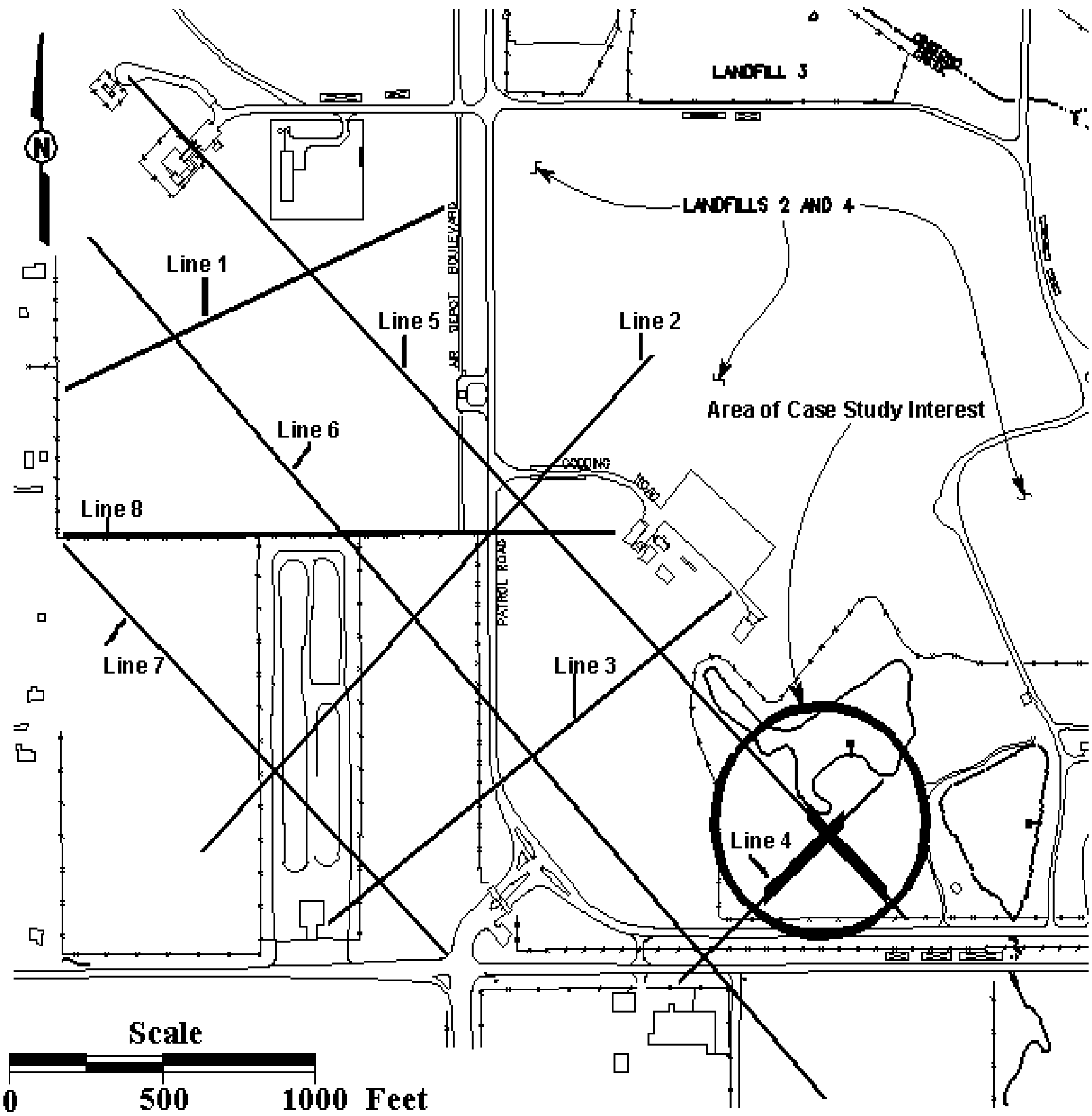

Figure 2: Site location map with seismic survey lines [1].

SITE INFORMATION

Site Logistics/Contacts

Federal Lead Agency:
United States Air Force

Federal Oversight Agency:
Environmental Protection Agency

Site Contact:
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Dallas, TX 75202-2733
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Geophysical Subcontractor:
IT Corporation
312 Directors Drive
Knoxville, TN 37923-4799
423-690-3211

MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Subsurface soil/Bedrock

Site Geology/Stratigraphy

Near-surface geology at Tinker AFB consists of the Permian-age Hennessey Group and the Garber-Wellington Formation. The Hennessey Group is composed of clays and clayey silts that are interbedded with thin, clayey sand layers, reaching a maximum thickness of approximately 60 feet in the western and southwestern parts of the base. The Hennessey Group is underlain by the mostly unconsolidated materials of the Garber Formation, which are composed of predominantly fine-grained sandstone, with lesser amounts of siltstone and shale. The deeper Wellington Formation has a similar lithology to the Garber Formation, and together the two comprise the 1,000-foot thick Garber-Wellington Formation. Bedrock formations dip to the southwest by approximately 0.5 degrees, or by 40 to 50 feet per mile.

Groundwater occurs at the site in four water-bearing units, that include the Hennessey Water Bearing Zone (HWBZ), the Upper Saturated Zone (USZ), the Lower Saturated Zone (LSZ), and the Producing Zone (PZ). The HWBZ consists of fine-grained sediments with very low transmissivity and large vertical hydraulic gradients. Beneath the HWBZ, the USZ is the uppermost waterbearing zone of the Garber-Wellington aquifer. The USZ is made up of permeable sand channels and lenses. It is generally believed that the HWBZ and the USZ are not hydraulically connected. The USZ/LSZ aquitard is comprised of overlapping clay layers with interbedded thin sand lenses and is not of uniform thickness. The aquitard ranges in thickness from

MEDIA AND CONTAMINANTS

less than 10 feet to more than 25 feet, with the base of the aquitard occurring at a depth of approximately 110 feet below ground surface (bgs) in the southwest portion of the study area. The LSZ ranges between 140 and 200 feet in thickness, and is separated from the underlying PZ by the 30- to 100-foot-thick LSZ-PZ aquitard. The PZ extends from between 210 and 280 feet bgs to more than 1,000 feet bgs, and is used as the primary source of groundwater on the base and elsewhere in the Oklahoma City area. Groundwater can occur at depths as shallow as 20 feet, but public water supplies are drawn from depths of greater than 400 feet.

Contaminant Characterization

Primary Contaminant Groups: Volatile organics such as TCE.

Matrix Characteristics Affecting Characterization Cost or Performance [1, 2]

Certain subsurface structures, such as utilities and buried metallic objects, can cause interference, or noise, in the seismic data. To screen for such structures, frequency-domain electromagnetic (EM) data were acquired along the seismic lines. No significant sources of subsurface interference were found.

Significant interference with the seismic data collection was caused by muddy surface conditions and standing water along portions of the survey lines, particularly along Line 8. The seismic energy was significantly attenuated as it passed through the saturated soils, resulting in poor seismic data quality along those lines. Other surficial sources of interference included cultural noises, such as pumps, vehicles, wind and aircraft.

Groundroll can cause interference in data collection and interpretation. Groundroll is caused by seismic waves that travel horizontally toward the geophone sometimes obscuring the collection of seismic waves originating from deeper structures. During the investigation at Tinker AFB, the the high velocity surface materials reduced interference from the slow groundroll and the targets of principal interest were shallow and mostly located outside of the groundroll noise cone.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [2, 3]

To help identify and map permeable materials in the USZ and the USZ/LSZ aquitard that might indicate preferential groundwater flow in the shallow subsurface. This information was used to place extraction wells to optimize the groundwater extraction system. The primary target of interest was near-surface sand channels and lenses within the USZ aquifer and the USZ/LSZ aquitard which may form preferential flow channels in the subsurface [2].

GEOPHYSICAL INVESTIGATION PROCESS

Geophysical Methods [1, 2]

Two geophysical methods were used during this investigation: electromagnetic (EM) reconnaissance survey, and a seismic survey. The EM survey was conducted to screen for subsurface conditions that might cause interference in the seismic data collection. The seismic survey was conducted to identify conductive layers in the subsurface that might be paths for groundwater migration.

The EM survey was performed to detect sources of potential interference to seismic data collection. The EM survey sought to identify variations in the electrical conductivity of subsurface materials that might be caused by buried objects, conductive fluids, or geologic discontinuities. By artificially applying a known electromagnetic field to the ground surface by means of a transmitter, investigators measure the presence of disruptions to the known electromagnetic field with a receiver. These disruptions, termed EM anomalies, can result from either geological changes or the presence of metallic objects, such as pipes, drums, cables, tanks, etc., in the subsurface. The EM survey conducted at Tinker AFB was used to identify buried materials that might interfere with seismic survey by scattering or attenuating seismic waves. A Geonics Limited EM-31 terrain conductivity meter coupled to an Omnidata DL720 digital data logger was used to collect quadrature-phase and in-phase component data along the length of each seismic line in the survey area.

The seismic reflection method was used to collect seismic data in the subsurface with which permeable layers in the subsurface can be identified. These permeable layers may act as groundwater migration pathways, and may be good locations for future extraction wells. In a seismic reflection survey, an artificial seismic source is used to create an acoustic wave that propagates downward through the soil layers. When the wave reaches a soil layer whose seismic conductivity is significantly different from that of the overlying soils, a portion of the wave is re-directed to the surface. A geophone, or electromechanical transducer, is used at the surface to receive the reflected wave energy. Subsurface stratigraphy is then mapped by measuring the travel time necessary for a wave to pass through one layer to another, refract along the interface, and return to the geophones at the surface. Seismic field equipment used to conduct the survey consisted of three 48-channel Geometrics Strataview® seismographs in a master-slave configuration, totaling 144 channels. Single, 40-Hz vertical geophones were used for collection of p-wave data.

Seismic modeling was conducted to provide support for the interpretation of the seismic results. Seismic models were developed to depict the anticipated seismic response of various types of subsurface stratigraphy that might be encountered in the study area, i.e. sand channels cutting into the aquitard or sand lenses embedded in a clay layer. Well lithologies and sonic logs acquired in wells located within the survey area were used to develop estimates of the seismic velocities of the various soil types found within the study area. These estimates were used to construct hypothetical seismic models of subsurface structures of varying thickness and composition. When seismic anomalies were encountered in the survey data, the actual seismic response was compared to the modeled response of different stratigraphic features to help identify the type of subsurface stratigraphy that might create such an anomalous response. The use of seismic models greatly aided investigators in their interpretation of the seismic results by providing a set of benchmarks against which actual results could be compared [4].

Seismic lines were chosen to satisfy three criteria:

- The survey area should include parallel and perpendicular coverage of a known geologic strike. The lines within the area were located so that velocity data could be acquired in at least one well on at least one line of the survey, and each of the lines were to have at least one tie with another line in the survey.

- The survey area should include areas in which known contaminant plumes were present; and

- The survey lines should be placed in areas whose groundwater is under hydraulic control from the groundwater pump and treat system.

Prior to collecting geophysical data, each seismic survey station was geospatially surveyed using a Global Positioning System (GPS). The ability to geospatially reference the seismic profiles allowed investigators to understand the relationships between the individual seismic profiles and the larger site geology. Horizontal and vertical geospatial accuracies were kept within 0.5 feet and 0.1 feet, respectively.

A field test of the seismic parameters was used to evaluate the relative merits of collecting different types of seismic wave during the survey, and to determine the optimal distance between the seismic source and the geophones. Data on two types of seismic waves: compressional (p-wave) and shear(s-wave) wave, were acquired along a short test section of Line 5 to evaluate and compare the results such surveys would produce at the site. While p-wave data, the seismic wave that is projected downward, were less complex to collect and interpret, s-wave data often provide a higher resolution. S-wave data are collected as the seismic energy is transmitted horizontally from the source to the receiver. Along this test section, p-wave data were recorded using vertical source impacts and vertical geophones, and s-wave data were recorded using horizontal impacts and horizontal, s-wave, geophones. Based on the noise tests conducted in the field and the depth of the target, a 5-foot station and l0-foot shotpoint (energy source) spacing were used for the survey. The investigators decided that the p-wave data would provide sufficient resolution to identify the targeted subsurface structures, and, therefore, no additional s-wave data were collected.

GEOPHYSICAL FINDINGS

Technology Calibration [1, 2]

The calibration needed for a successful seismic survey is to establish the relationship between the depth of an anomaly in the subsurface and the time it takes a seismic wave to propagate to that anomaly and return back to the surface. In other words, the seismic time must be "tied" to depth. To establish this link at Tinker AFB, investigators collected vertical seismic profiles (VSPs) and sonic logs. The sonic logs were used to construct synthetic seismograms. A synthetic seismogram is a statistical comparison of seismic velocity, soil density, and depth values used to convert seismic velocity data into depth.

The VSP data were acquired in two monitoring wells with maximum depths of approximately 150 feet in order to better understand the subsurface velocities. For each profile, a geophone is locked in a well at regular depth intervals and used to record the energy from a surface source at each interval. The time lapse recorded between source and receiver is a measure of the time necessary to go from the surface to the geophone in the well is displayed as a time versus depth graphic.

Data from an existing sonic log in a nearby well was also used to link the seismic time data to depth. Together, the sonic log and the VSP data, were used to generate a synthetic seismogram. The seismogram provides a correlated display of seismic velocities, time and known depths to reflectors. These correlations establish the link between the seismic velocity of certain subsurface materials and the depths at which those materials were encountered.

Investigation Results [1, 2]

The EM-31 reconnaissance survey was conducted along the eight seismic lines and revealed large-scale anomalies caused by metallic objects. Most of the anomalies were caused by surface metal, such as the chain-link fences, nearby structures, and monitoring well monuments. Subsurface anomalies were also identified as subsurface pipelines that cross the area, such as a north-to-south trending pipe that exists in the western part of the site.

More than 17,000 linear feet of seismic data were collected along eight survey lines and the resulting profiles identified four reliable locations for future extraction wells. For the purposes of this case study, however, the discussion presented focuses only on the interpreted and modeled results from the intersecting portions of Lines 4 and 5, as shown in Figure 2 on page 3. The seismic results along both lines showed a sand channel near the intersection of the lines, increasing the reliability the interpreted sand channel and its continuity. None of the EM anomalies, discussed above, were located within this area [3].

Muddy surface conditions and standing water along portions of the survey lines caused significant variation in and interference with the quality of the seismic data collected. Two statistical solutions were applied to improve the quality of the data. Refraction statics, proved most effective in minimizing the noise in the data. The adjusted data had less variation and improved resolution.

GEOPHYSICAL FINDINGS

The seismic reflection survey was conducted along each line using a 5-foot interval between geophones and a 10-foot shotpoint interval. Data were acquired using a 0.5-millisecond (msec) sampling rate; the record length was 1,024 msec. As data quality warranted, source impacts per shotpoint were adjusted along each line.

The seismic profile generated along Line 4 at its intersection with Line 5 is shown in Figure 3. In this profile, the top of the USZ/LSZ aquitard was interpreted to be at approximately 70-75 feet bgs (25 msec), and the bottom of the aquitard was interpreted to be at approximately 110-115 feet bgs (35 to 40 msec). Although only the USZ was targeted for this study, other structures can be seen in Figure 3, such as the base of the LSZ, where the LSZ/PZ aquitard occurs, at approximately 295 feet bgs (75 msec). One significant anomaly can be seen in this Figure, centered on Station 295, and is outlined by hash marks. This feature was interpreted to be a large sand channel within the upper portion of the USZ/LSZ aquitard which is laterally continuous and was considered to be part of a larger structure that can be seen nearby on the Line 5 section. The channel was presumed to trend north to northeast, roughly in line with the high-yield B6 and B7 recovery wells. The seismic model data indicate that this anomaly could be caused by the presence of a low conductivity materials (i.e. sand) embedded in higher conductivity materials (i.e. silts and clays). Above this channel, the seismic data indicate the presence of a low velocity medium, likely a sand within the USZ aquifer. This channel was suggested as a good location for a future extraction well.

The seismic profile generated along Line 5 at its intersection with Line 4 is shown in Figure 4. The bottom of the USZ/LSZ aquitard can be seen at a depth of 110-115 feet bgs and a noticeable low in this area (represented by the dashed line) indicated the presence of materials with similar seismic velocity incised into the base of the aquifer, and/or the accumulation of slower velocity materials locally, such as would be expected from a sand channel. Two anomalies appear in the Line 5 data shown in Figure 4. A broad and subtle anomaly extending between stations 680 and 693 at a depth of approximately 75-80 feet bgs was interpreted as a small incised sand lens at the bottom of the USZ aquifer. The feature extending from station 650 to 667 at a depth of 80-90 feet bgs was interpreted to be part of the same large sand channel that occurs along Line 4.

A seismic interpretation map of the entire survey area with the locations of interpreted channels and lenses above and within the upper portion of the USZ/LSZ aquitard is shown in Figure 5A. Several channels were interpreted near the bottom of the USZ/LSZ aquitard, and several deep channel systems were interpreted within the LSZ (not discussed here). There is a substantial concentration of interpreted lower aquitard channels in the southern and southeastern portion of the survey area, and deep channel systems in the central and southeastern portions of the survey area.

GEOPHYSICAL FINDINGS

Results Validation [1]

Seismic data indicating areas of high hydraulic conductivity were compared to well yield test results from the existing Phase I recovery wells which were drilled to an average depth of 80 to 90 feet. All of the Phase I wells were drilled in locations based on engineering factors, plume location, and groundwater flow direction. Wells A8, B3, B6, and B7 were drilled near anomalies identified by the seismic data discussed in this case study. Figures 5A and 5B show the correlation between higher yield zones, as determined with pump tests on the Phase I wells, and the locations of the sand channel identified at the intersection of Lines 4 and 5. On Line 5, anomalies centered on Station 658 correspond to high yields on the B6 and B7 recovery wells. Another anomaly found along Line 5 and interpreted as a sand channel, centered on Station 205, corresponds to the high yield recovery well B3. On Line 6, the anomaly centered near Station 390 corresponds to the high yield A8 recovery well. Several other interpreted sand channels have not been verified at this time. These areas present target locations for possible future Phase II recovery wells.

Further validation was provided by sonic logs taken in five of the extraction wells that were located on or near the seismic survey lines. These helped to confirm reflector identification and also demonstrated good correlation between the seismic findings and well tests [3].

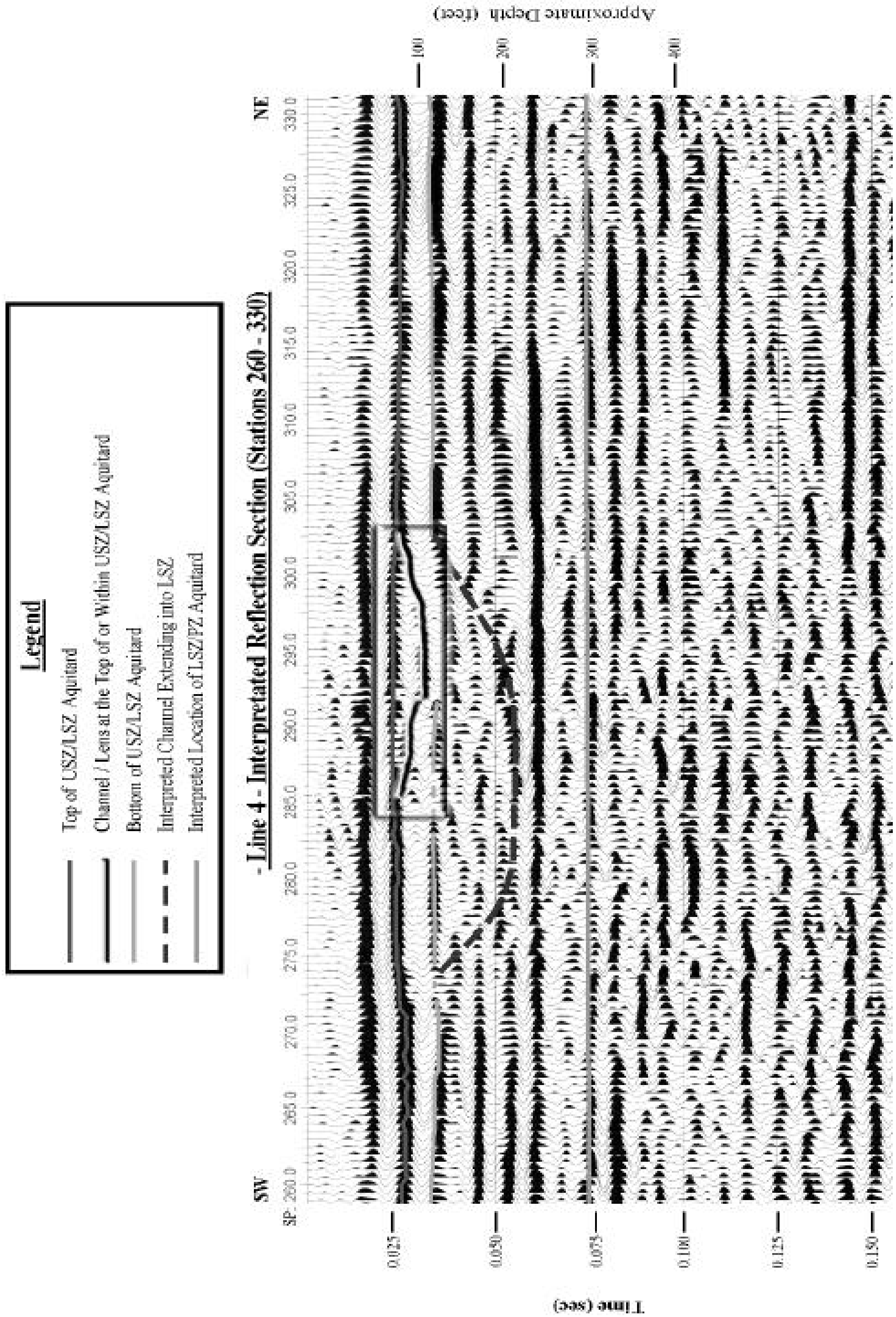

Figure 3: Interpreted Reflection Section on Line 4 [2].

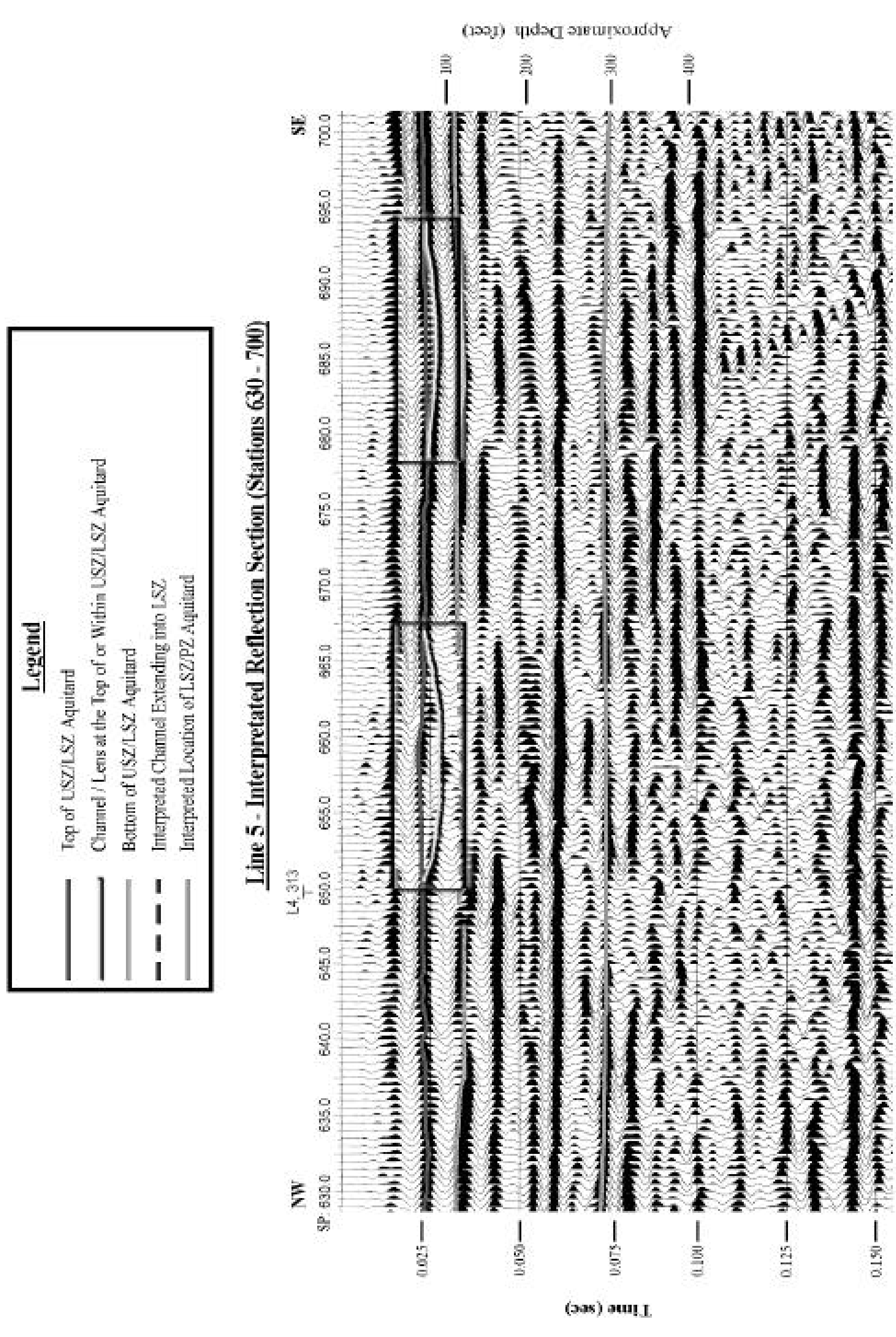

Figure 4: Interpreted Reflection Section on Line 5 [2].

GEOPHYSICAL FINDINGS

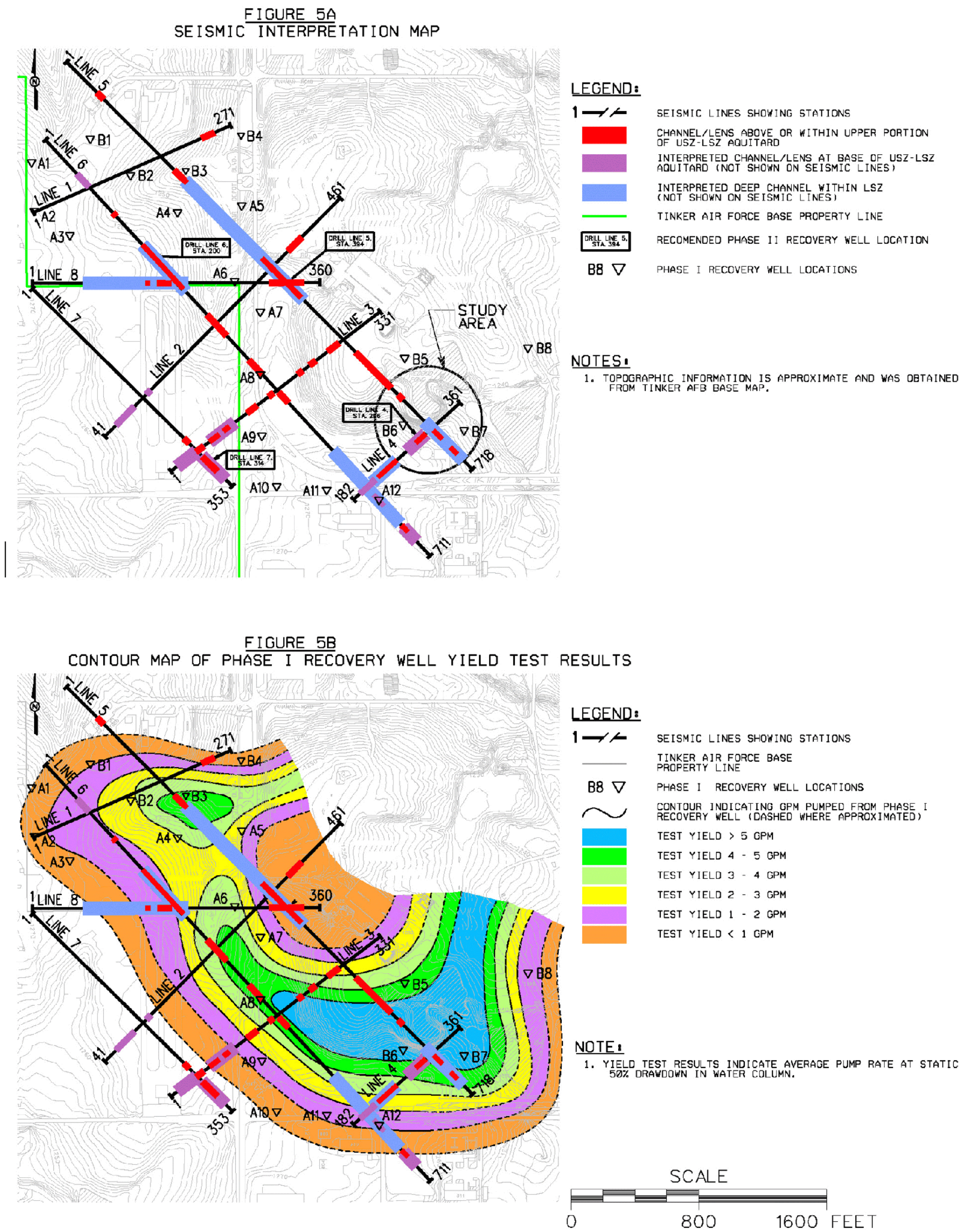

Figure 5: Location of Significant Seismic Anomalies and Correlation with Well Yields[2]

LESSONS LEARNED

Lessons learned at the Tinker AFB study site include the following:

- The seismic survey results identified several areas in which permeable zones in the subsurface are located and which may be favorable locations for future well installation. Four of these sites represent locations where the highest potential for drilling into significant sand channels is thought to exist [1].

- The EM survey successfully identified large scale anomalies caused by metallic objects, such as the chain-link fences, nearby structures, and monitoring well monuments. The EM anomalies found did not present a problem for the seismic data quality.

- Existing well yield data correlates well with several of the anomalies that are interpreted as channels. Incorporation of recently acquired sonic log data and lithologic logs from extraction wells drilled near any of the seismic lines with the seismic data will be particularly useful for refining stratigraphic and depth correlation [1].

- The relatively high seismic velocities in the unconsolidated sediments at this site reduce the spatial resolution that can be attained from the data. S-wave data should increase resolution compared to the p-wave data. However, for this site, the s-wave data proved inferior when compared to p-wave data, especially when the additional cost for acquiring and processing the s-wave data is considered[2].

- The results developed for this site are only valid for two-dimensional cross sections of the subsurface beneath each seismic line. If delineation of the spatial distribution of features between lines is required, the acquisition of three-dimensional data should be considered at this site [2]. Three-dimensional seismic techniques were the preferred method, but due to the large areal extent of the survey area and associated data acquisition and processing costs, the two-dimensional method was used [1].

- The application of seismic data processing algorithms, such as refraction statics and spectral-whitening, reduced the level of interference in the data. This, combined with thorough velocity and mute analysis along the seismic lines, allowed for increased frequency and resolution of the seismic results [1].

- Seismic results often reveal a number of anomalous results attributable to a large variety of conditions, such as poor surface conditions, interference from cultural sources, or variation in seismic wave generation. These anomalies may, on the other hand, represent the target structures. The use of seismic models in this survey aided the investigators by helping them quickly identify whether the anomalous results were due to difficulties in data acquisition or target structures. Moreover, by comparing seismic anomalies to model results, investigators were able to refine their interpretation of the anomalous responses by helping them to distinguish between different lithologic changes, such as a discontinuity in a clay layer and a sand channel incised into the clay layer [4].

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