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Research and Development

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Project Summary

Geophysical Techniques for Sensing Buried Wastes and Waste Migration

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Descriptions of the use of six geophysical techniques are presented to provide a broad understanding of the application of these techniques for sensing buried wastes and waste migration. Technical language and jargon are avoided as much as possible so that those with limited technical background can acquire a general understanding of current techniques and sufficient background to define project requirements, select professional support, and monitor and direct field programs.

Emphasis on cost-effective investigations at hazardous waste sites requires an integrated, phased approach: (1) preliminary site assessment involving the use of aerial photography, on-site inspections, and readily available information to approximate site boundaries and locations of waste concentrations, as well as probable site geology; (2) geophysical surveys to pinpoint buried wastes, estimate quantities, and delineate plumes of conductive contaminants in groundwater; and (3) confirmation of groundwater contamination through monitoring well networks designed on the basis of plumes and subsurface stratigraphy defined by the geophysical surveys.

The six geophysical techniques described include metal detection, magnetometry, ground penetrating radar, electromagnetics, resistivity, and seismic refraction (Figure 1). Metal detectors and magnetometers are useful in locating buried wastes. Ground penetrating radar can define the boundaries of buried trenches and other subsurface disturbances. Electromagnetic and resistivity methods can help define plumes of contaminants in groundwater. Resistivity and seismic techniques are useful in determining geological stratigraphy.

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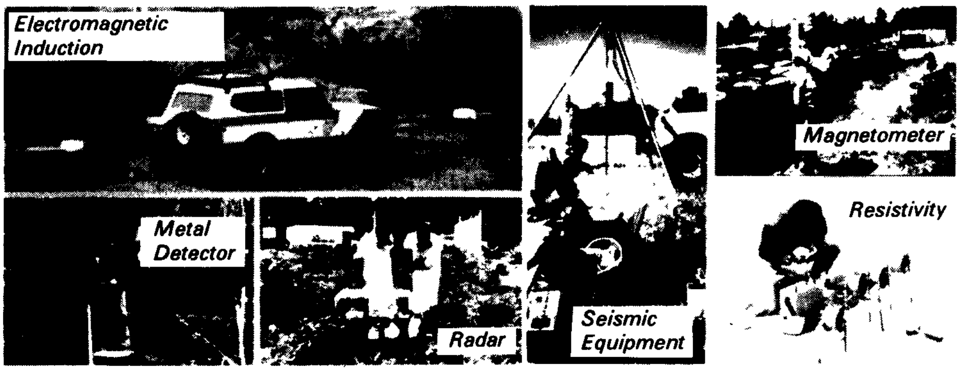

Figure 1. *Geophysical sensing techniques.*

Systems Laboratory, Las Vegas, NV, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The cost-effective investigations of hazardous waste sites involve an integrated, phased approach: (1) preliminary site assessment, involving the use of aerial photography, onsite inspections, and readily available information to approximate site boundaries and locations of waste concentrations, as well as probable site geology; (2) geophysical surveys to pinpoint buried wastes and estimate quantities, and to delineate plumes of conductive contaminants in groundwater; and (3) confirmation of groundwater contamination through monitoring well networks designed on the basis of plumes and subsurface stratigraphy defined by the geophysical surveys.

Geophysical Sensing

Figure 2 diagrams the operation of simple metal detectors, which respond to changes in electrical conductivity caused by the presence of metallic objects, both ferrous and nonferrous. Figure 3 is a schematic of a simple magnetometer, which can be used to detect perturbations in the earth's geomagnetic field caused by buried ferromagnetic objects such as drums, tools, or scrap metal. Magnetometers can sense ferrous objects at greater depths than metal detectors, and can be used to locate objects even in the presence of interferences created by fences, power lines, and buried pipes and cables. Figure 4 is a schematic showing the various components of a ground-penetrating radar (GPR) system which radiates short-duration electromagnetic pulses into the ground from an antenna near the surface. These pulses are reflected from interfaces in the earth (such as trench boundaries) and are picked up by the receiver section of the antenna.

Figure 5 shows the basic principle of operation of electromagnetic (EM) conductance measuring devices, which yield a signal proportional to the conductivity of the earth between the transmitter and receiver coils. Figure 6 shows EM profiles from a hazardous waste site investigation over a 25-acre site, together with the locations of monitoring wells which were installed without benefit of the geophysical measurement data. In this instance, use of the geophysical surveys would have enabled a more efficient monitoring well network to be designed and could have reduced the total number of wells installed. Figure 7 shows the traces resulting from passes across a barrel-filled trench with a metal detector, magnetometer, electromagnetic induction instrument, and GPR.

Figure 8 shows a common electrode configuration, called a Wenner array, for resistivity soundings. In this configuration, a current is injected into the ground by a pair of surface electrodes, and the resulting potential field is measured between a second pair of surface electrodes. The subsurface resistivity is calculated from the electrode separation, applied current, and measured voltage. The measured resistivity is a function of the total geohydrologic section, including soil, rock, and groundwater. Interpretation of resistivity measurements provides information on layering and depths of subsurface horizons as well as lateral changes in the subsurface.

Figure 9 shows a schematic view of seismic waves traveling through a multilayered system of soil and rock strata; at each interface between layers energy is reflected back to the sensor. Using knowledge of travel times in rock strata, the approximate depths of the various strata can be estimated.

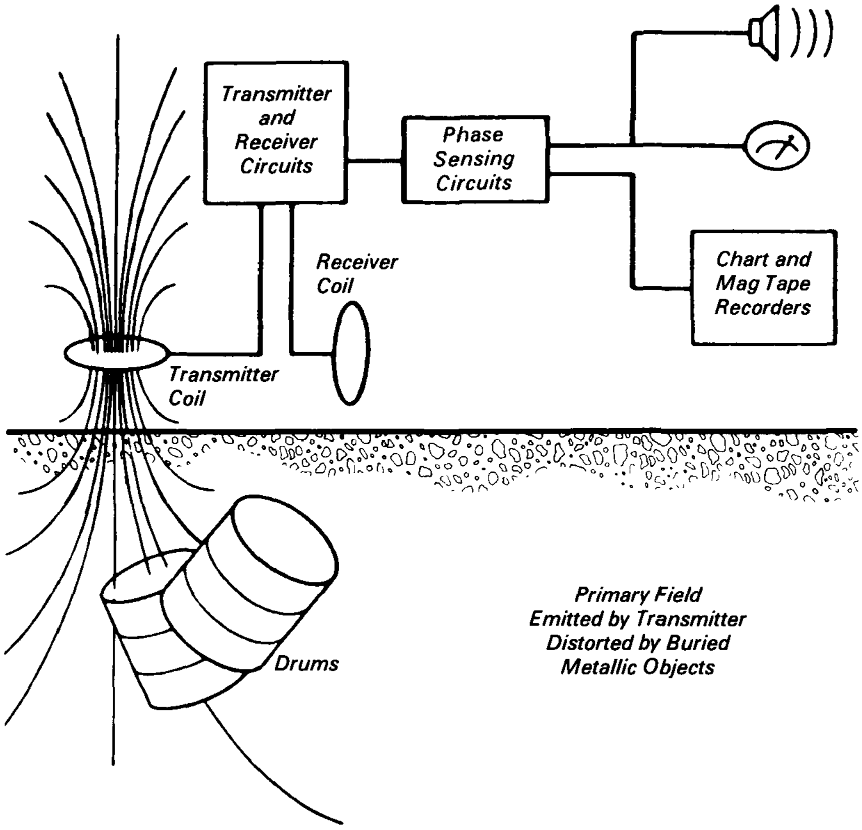

Figure 2. *Metal detector.*

Metal Detectors

At hazardous waste sites, metal detectors are primarily used to determine the presence, location, and definition of trench boundaries. They can also be used to assist in the process of selecting a site for drilling, so that metallic containers and underground utilities are not accidentally struck during the drilling operations. Buried tanks and pipes which may be sources of leaks can be located, and in addition, the location of utilities may serve to define areas representing more permeable passageways in which contaminants may flow.

Metal detectors will detect any kind of metallic material, including ferrous metals, such as iron and steel, and nonferrous metals, such as aluminum and copper. (In contrast, the magnetometer responds only to ferrous metals.)

Metal detectors have a relatively short range. They can detect quart-sized conmeter. The response of a metal detector increases with the target's surface area; therefore larger objects, like 55-gallon drums, may be detected at depths up to 3 meters, and massive piles of metallic materials may be detected at depths up to 6 meters. Specific performance is highly dependent upon the type of metal detector used. Generally, most metal detectors are incapable of responding to any targets, no matter how large, at depths much greater than 6 meters.

An experienced operator can usually make a reasonably accurate estimate of target size and depth. However, any attempt at detailed calibration will likely be useless, because of the many variables involved.

Metal detectors are very susceptible to noise caused by some natural soil conditions, unwanted metallic debris, pipes, fences, vehicles, buildings, etc.

There are many different types of metal detectors available commercially, each with its own advantages and limitations. The choice of a metal detector should be determined by the type of targets to be located, their depth, the nature of the soil, the size of the search area, site conditions, and other project requirements.

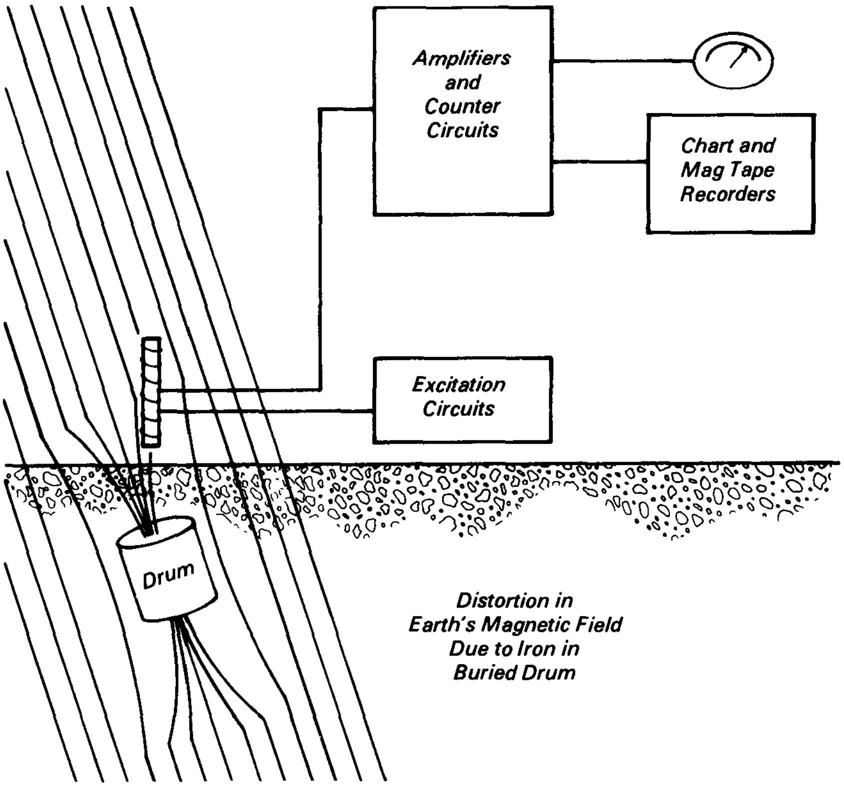

Figure 3. *Magnetometer.*

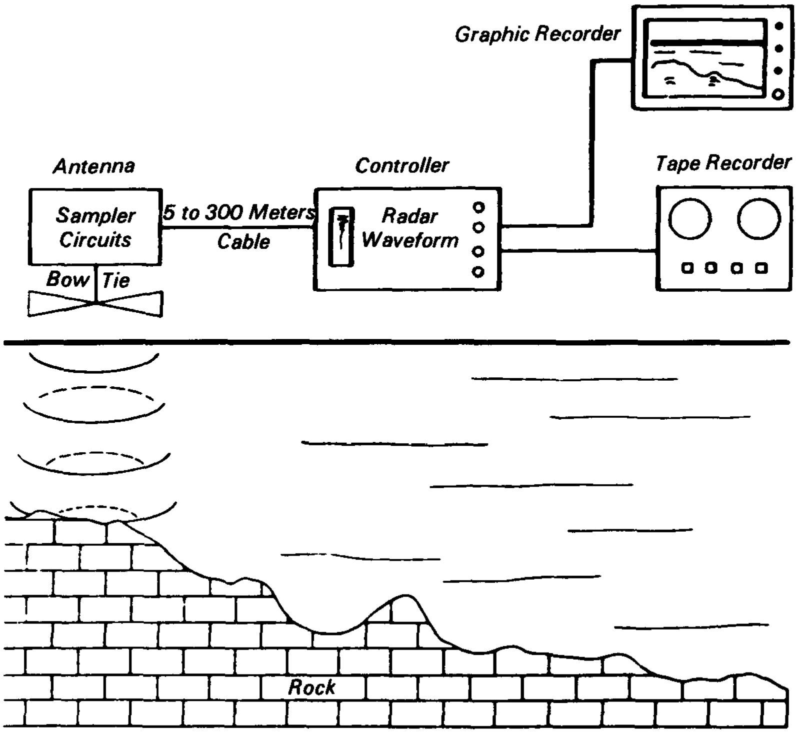

Figure 4. *Ground-penetrating Radar.*

Magnetometer

A magnetometer responds to the presence of buried ferrous metals. At hazardous waste sites, magnetometers may be used to:

- Locate buried 55-gallon drums;
- Define boundaries of trenches filled with ferrous containers;
- Locate ferrous underground utilities, such as iron pipes or tanks, and the permeable pathways often associated with them;
- Aid in selecting drilling locations that are clear of buried drums, underground utilities, and other obstructions.

While several factors influence the response of a magnetometer, the mass of a buried target and its depth are the most important. A magnetometer's response is directly proportional to the mass of ferrous metal present and varies by one over the distance cubed ($1/d^3$) for total field measurements. If a gradiometer is used, the response falls off even faster, as one over the distance to the fourth power ($1/d^4$). With sensors of equal sensitivity, the total field system provides the greater working range. Typically, a single drum can be detected at distances up to 6 meters, while massive piles of drums can

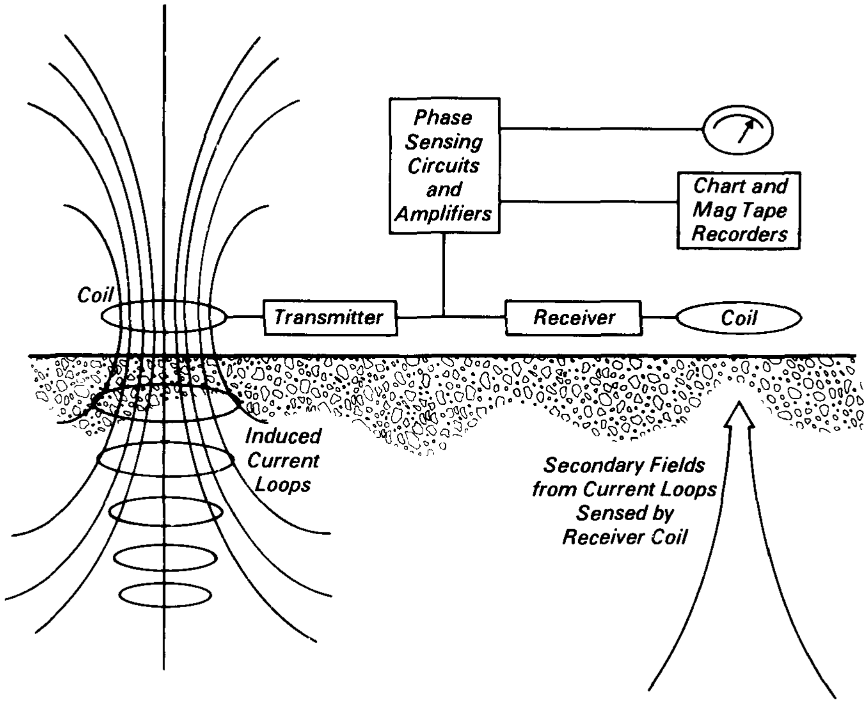

Figure 5. *Electromagnetic measurement of conductance.*

tainers at a distance of approximately one be detected at distances up to 20 meters or more. There is a wide variety of magnetometers available commercially; specific performance is highly dependent upon the type of magnetometer and the field conditions. While the number and depth of buried drums may be calculated, such results should be considered only approximations because of the number of variables associated with target, site conditions, and calculations. Actual results may vary considerably.

A magnetometer with continuous recording capabilities can be used to produce a strip chart of the field data. A strip chart is helpful in assessing signal-to-noise ratio, anomaly shape, and target location, and provides a means of exercising quality control over field data. This continuous coverage is much more suitable for high-resolution requirements and the mapping of extensive areas.

The effectiveness of a magnetometer can be reduced or totally inhibited by noise or interference from time-variable changes in the earth's field and spatial variations caused by magnetic minerals in the soil, or iron and steel debris, ferrous pipes, fences, buildings, and vehicles. Many of these problems can be avoided by careful selection of instruments and field techniques.

Ground Penetrating Radar

In areas where sufficient ground penetration is achieved, the radar method provides a powerful assessment tool. Of the geophysical methods discussed in this document, radar offers the highest resolution. The method provides continuous spatial sampling and can be carried out very rapidly at traverse speeds from 0.5 to 8 km/h. Its continuous graphic format permits rapid semi-quantitative interpretation for in-field analysis.

Radar performance is highly site-specific. Depth of penetration is primarily dependent upon soil properties and pore fluids which influence electrical conductivity. In the wide range of natural soil/rock conditions found throughout the United States, ground penetrating radar penetration varies from less than a meter to more than 30 meters. Typical maximum penetrations at any given site are 1 to 10 meters.

Interpretation of radar data is relatively straightforward if site conditions are simple and a strong dielectric contrast exists between the features of interest and the surrounding soil. As subsurface conditions increase in complexity, interpretation of the data becomes difficult, and more elaborate interpretation and processing may be necessary. High quality radar data is not commonly obtained in the field; however, experienced interpreters are usually able to cope with field data of lower quality.

A radar system is a complex instrument. The results of a radar survey are dependent on many interacting system controls, various field procedures, site conditions, and interpretation. Therefore, the successful application of the radar method requires personnel with an understanding of electronics, physics, and basic earth sciences. The more complex the site problem, the greater the amount of training and experience required.

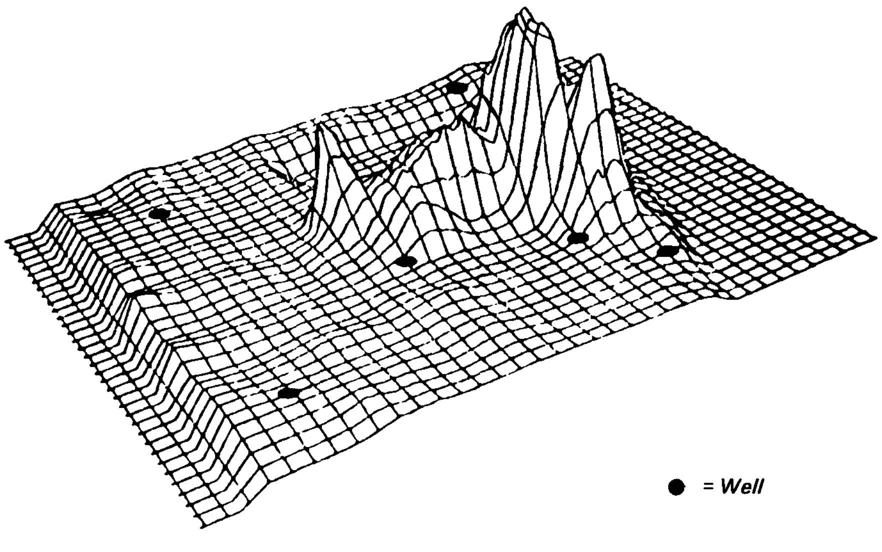

Figure 6. *Three dimensional representation of conductivity data, showing location of buried hazardous materials.*

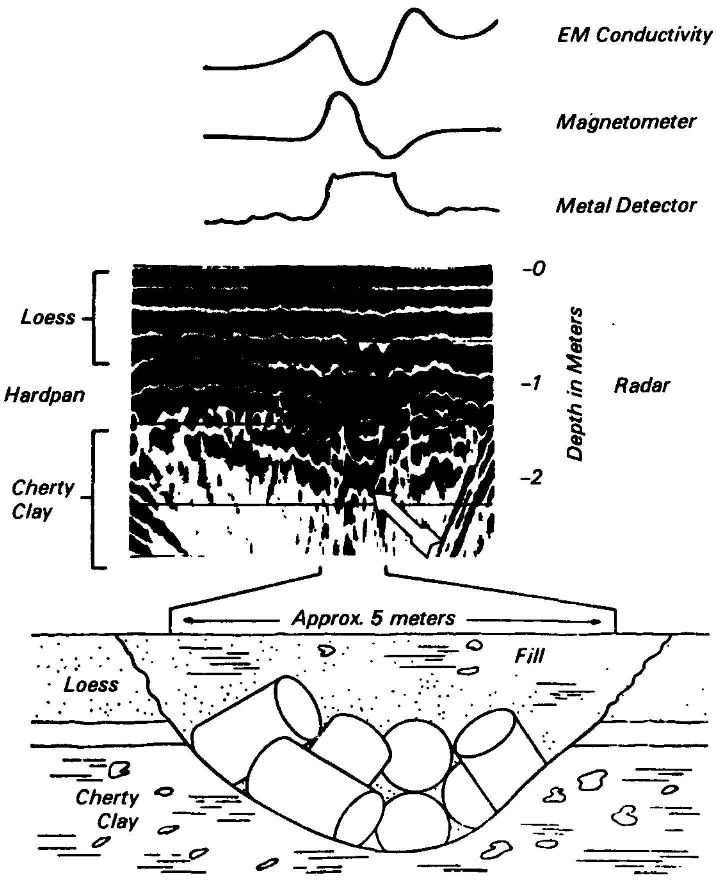

Figure 7. Four geophysical profiles.

Electromagnetics (EM)

Although the EM technique can be used for profiling or sounding, profiling is the most effective use of the method. Profiling makes possible the rapid mapping of subsurface conductivity changes, and the location, delineation, and assessment of spatial variables resulting from changes in the natural setting or from many contaminants.

EM is a very effective reconnaissance tool. The use of qualitative non-recorded data can provide initial interpretation in the field. If site conditions are complex, the use of a high-density survey grid, continuously-recording instruments, and computer processing may be necessary in order to properly evaluate subsurface conditions. When continuously-recording instruments are used, total site coverage is feasible. More quantitative information can be obtained by using conductivity data from different depth ranges. At present, three different systems must be used to acquire data from 0.75 meters to 60 meters. Very often, however, data from two standard depths, e.g., 6 and 15 meters, is adequate to furnish depth information.

Resistivity

The resistivity method provides a means of measuring one of the electrical properties of the geohydrologic section including soil, rock, and groundwater. These measurements may be used to assess lateral changes and vertical cross sections of the natural geohydrologic settings. Since the resistivity of soils and rocks is predominantly controlled by porosity, permeability, amount of water, and concentrations of dissolved solids in the water, the method provides a tool to evaluate contaminant plumes and to locate buried wastes at hazardous waste sites.

The resistivity technique may be used for "profiling" or "sounding." Profiling provides a means of mapping lateral changes in subsurface electrical properties. This field technique is well-suited to the delineation of contaminant plumes and to the detection and location of changes in natural geohydrologic conditions. Profile lines and contour maps can be used to locate geologic variations or contaminant plumes. The apparent resistivity values are typically used because the primary objective is to use the data for location purposes. Relative trends and semi-quantitative analyses are often immediately obvious to the experienced interpreter from a plot of sounding data.

Sounding provides a means of determining the vertical changes in subsurface electrical properties. Interpretation of sounding data provides the depth and thickness of subsurface layers having different resistivities. Commonly 3 to 4 layers may be resolved with this technique. The resistivity sounding method is in general a more effective method than the EM sounding method described. The analysis of resistivity sounding data requires that the interpreter be knowledgeable about the resistivity method, the conditions under which the data are obtained, the geohydrologic conditions, as well as the specific techniques, computer models, or curve matching.

The operator must insure that adequate space is available at the site and that it is relatively clear of buried pipes and fences. Finding sufficient space for a long profile array with an overall length nine to twelve times the depth of interest can sometimes be a problem.

Although resistivity sounding methods are primarily intended for use in uniformly layered geological conditions, useful data may be obtained from the complex subsurface conditions often found at hazardous waste sites. With both profiling and sounding techniques, inhomogeneities in the nearsurface soils may introduce noise in the data. Some surface conditions such as dry surface materials, concrete roads, or parking lots may preclude the use of the resistivity method.

The resistivity method is inherently limited to station measurements, since electrodes must be in physical and electrical contact with the ground. This requirement makes the resistivity method slower than a non-contact method such as EM.

Seismic Refraction

The seismic refraction method can be used to aid in defining natural geohydrologic conditions, including thickness and depth of soil and rock layers, and depth to bedrock or water table. Generally two- or three-layer systems can be analyzed in

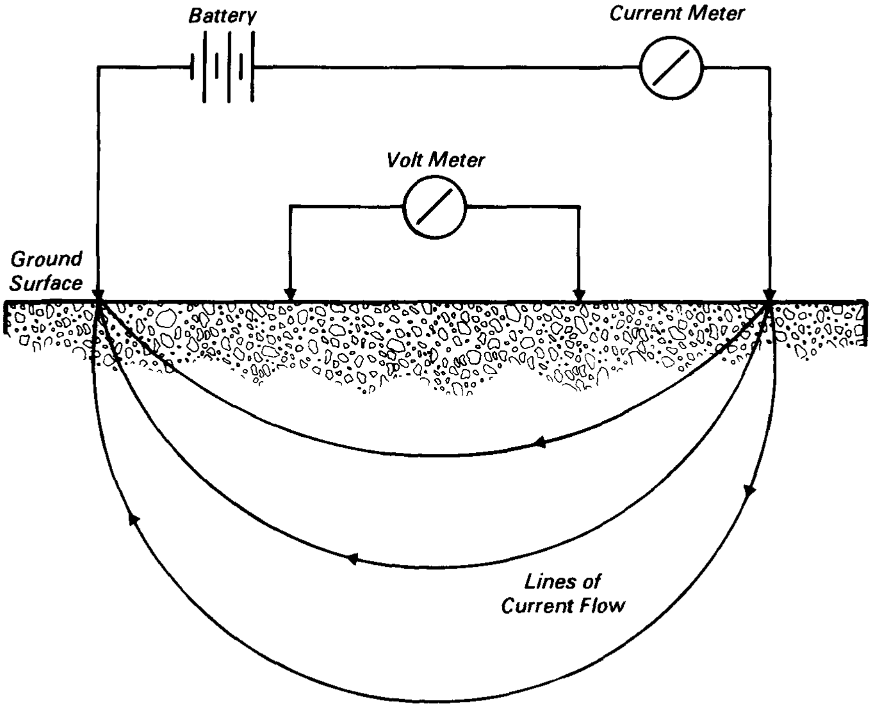

Figure 8. *Resistivity measurement.*

the field by the use of nomograms and simple calculations. More complicated sites having three to four layers with dip will require a programmable calculator or a small computer to solve the seismic equations.

Since seismic wave velocity is directly related to the material properties of the layer such as density and hardness, lateral variations in composition or an irregular interface between layers will show up as geologic scatter on a time/distance plot. This is a valuable indicator of variations in site conditions. The analysis of this data requires that the interpreter be knowledgeable about the method, the conditions under which the data was obtained, and the geohydrologic conditions.

The seismic line must be three to five times the maximum depth of interest. Lateral resolution in the data is determined by the geophone spacing.

Depending on site conditions, a hammer source is useful for obtaining seismic data to depths of 10 to 15 meters, while a 500-pound drop weight is required for depths of 50 to 100 meters. Explosives or projectile sources may be used to obtain deeper data.

Since the seismic method measures small ground vibrations, it is susceptible to vibration noise from a variety of natural and cultural sources.

The seismic method is inherently a station measurement because geophones must be implanted in the surface of the ground. This makes the method relatively slow when compared to the other continuous techniques.

Conclusions

Geophysical methods cannot be expected by themselves to provide all the information that an investigator may need in the assessment of a hazardous waste site. Nevertheless, the information gathered can be helpful in completing the picture that is developed solely from monitor well data. Similarly, no one geophysical method can be expected to provide all the answers. The authors of this document have sought to show that six existing geophysical methods in experienced hands can be effectively employed in the study of hazardous waste sites provided the capabilities and limitations are understood.

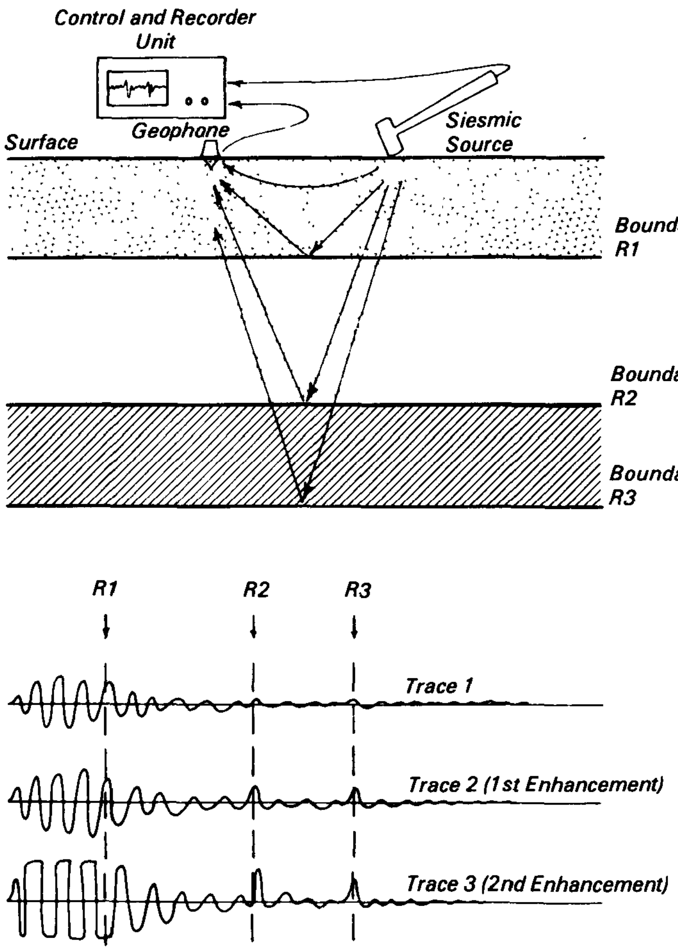

Figure 9. *Basic seismic reflection technique.*

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The complete report, entitled "Geophysical Techniques for Sensing Buried Wastes and Waste Migration," (Order No. PB 84-198 449; Cost: $22.00, subject to change) will be available only from:

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