

United States  
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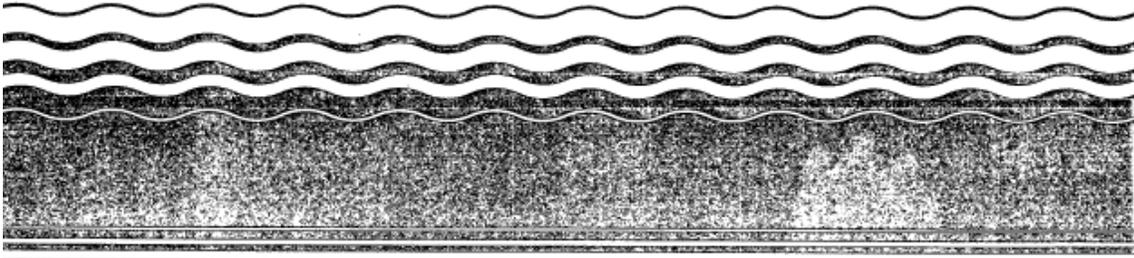
Office of Solid Waste and  
Emergency Response  
Washington DC 20460

EPA540/P-91/006  
January 1991

9360.4-02



# Compendium of ERT Soil Sampling and Surface Geophysics Procedures



## 4.0 General Surface Geophysics: SOP #2159

### 4.1 SCOPE AND APPLICATION

This Standard Operating Procedure (SOP) describes the general procedures used to acquire surface geophysical data. This data is used for delineating subsurface waste, and for interpreting geologic, hydrogeologic or other data related to hazardous waste site characterization.

The media pertinent to these surface geophysical methods are soil/rock and groundwater. The sensitivity or minimum response of a given method depends on the comparison of the object or area of study to that of its background (i.e., what the media's response would be like without the object of study). Therefore, the suitability of surface geophysical methods for a given investigation must be judged on the object's ability to be measured and the extent to which the specific setting of the study interferes with the measurement.

The surface geophysical method(s) selected for application at a site are dependent on site conditions, such as depth to bedrock, depth to target, urban disturbances (fences, power lines, surface debris, etc.) and atmospheric conditions. Detectability of the target is dependent on the sensitivity of the instrument and the variation of the field measurement from the ambient noise. Ambient noise is the pervasive noise associated with an environment. Therefore, the applicability of geophysical methods at a given site is dependent on the specific setting at that site.

Five geophysical methods may be utilized in hazardous waste site characterization: magnetometry, electromagnetics, resistivity, seismology and ground penetrating radar (GPR). Magnetometers may be used to locate buried ferrous metallic objects and geologic information. Electromagnetic methods can be used to determine the presence of metals, electrical conductivity of the terrain, and geologic information. Resistivity methods are used to determine the electrical resistivity of the terrain and geologic information. Seismic methods are useful in determining geologic stratigraphy and structure. GPR may be used to locate disturbance in the soil (i.e., trenches, buried utilities and fill boundaries) and some near-surface geologic information.

These procedures may be varied or changed as required, dependent on site conditions, equipment limitations or limitations imposed by the procedure. In all instances, the procedures employed should be documented and associated with the final report.

### 4.2 METHOD SUMMARY

#### 4.2.1 Magnetics

A magnetometer is an instrument which measures magnetic field strength in units of gammas (nanoteslas). Local variations, or anomalies, in the earth's magnetic field are the result of disturbances caused mostly by variations in concentrations of ferromagnetic material in the vicinity of the magnetometer's sensor. A buried ferrous object, such as a steel drum or tank, locally distorts the earth's magnetic field and results in a magnetic anomaly. The objective of conducting a magnetic survey at a hazardous waste or groundwater pollution site is to map these anomalies and delineate the area containing buried sources of the anomalies.

Analysis of magnetic data can allow an experienced geophysicist to estimate the areal extent of buried ferrous targets, such as a steel tank or drum. Often, areas of burial can be prioritized upon examination of the data, with high priority areas indicating a near certainty of buried ferrous material. In some instances, estimates of depth of burial can be made from the data. Most of these depth estimates are graphical methods of interpretation, such as slope techniques and half-width rules, as described by Nettleton (1976). The accuracy of these methods is dependent upon the quality of the data and the skill of the interpreting geophysicist. An accuracy of 10 to 20 percent is considered acceptable. The magnetic method may also be used to map certain geologic features, such as igneous intrusions, which may play an important role in the hydrogeology of a groundwater pollution site.

#### *Advantages*

Advantages of using the magnetic method for the initial assessment of hazardous waste sites are the

relatively low cost of conducting the survey and the relative ease of completing a survey in a short amount of time. Little, if any, site preparation is necessary. Surveying requirements are not as stringent as for other methods and may be completed with a transit or Brunton-type pocket transit and a non-metallic measuring tape. Often, a magnetic investigation is a very cost-effective method for initial assessment of a hazardous waste site where buried steel drums or tanks are a concern.

#### *Disadvantages*

"Cultural noise" is a limitation of the magnetic method in certain areas. Man-made structures that are constructed with ferrous material, such as steel, have a detrimental effect on the quality of the data. Avoid features such as steel structures, power lines, metal fences, steel reinforced concrete, pipelines and underground utilities. When these features are unavoidable, note their locations in a field notebook and on the site map.

Another limitation of the magnetic method is the inability of the interpretation methods to differentiate between various steel objects. For instance, it is not possible to determine if an anomaly is the result of a steel tank, or a group of steel drums, or old washing machines. Also, the magnetic method does not allow the interpreter to determine the contents of a buried tank or drum.

### **4.2.2 Electromagnetics**

The electromagnetic method is a geophysical technique based on the physical principles of inducing and detecting electrical current flow within geologic strata. A receiver detects these induced currents by measuring the resulting time-varying magnetic field. The electromagnetic method measures bulk conductivity (the inverse of resistivity) of geologic materials beneath the transmitter and receiver coils. Electromagnetics should not be confused with the electrical resistivity method. The difference between the two techniques is in the method which the electrical currents are forced to flow in the earth. In the electromagnetic method, currents are induced by the application of time-varying magnetic fields, whereas in the electrical resistivity method, current is injected into the ground through surface electrodes.

Electromagnetics can be used to locate pipes, utility

lines, cables, buried steel drums, trenches, buried waste, and concentrated contaminant plumes. The method can also be used to map shallow geologic features, such as lithologic changes and fault zones.

#### *Advantages*

Electromagnetic measurements can be collected rapidly and with a minimum number of field personnel. Most electromagnetic equipment used in groundwater pollution investigations is lightweight and easily portable. The electromagnetic method is one of the more commonly used geophysical techniques applied to groundwater pollution investigations.

#### *Disadvantages*

The main limitation of the electromagnetic method is "cultural noise". Sources of "cultural noise" can include: large metal objects, buried cables, pipes, buildings, and metal fences.

The electromagnetic method has limitations in areas where the geology varies laterally. These can cause conductivity anomalies or lineations, which might be misinterpreted as contaminant plumes.

### **4.2.3 Electrical Resistivity**

The electrical resistivity method is used to map subsurface electrical resistivity structure, which is in turn interpreted by the geophysicist to determine the geologic structure and/or physical properties of the geologic materials. Electrical resistivities of geologic materials are measured in ohm-meters, and are functions of porosity, permeability, water saturation and the concentration of dissolved solids in the pore fluids.

Resistivity methods measure the bulk resistivity of the subsurface, as do the electromagnetic methods. The difference between the two methods is in the way that electrical currents are forced to flow in the earth. In the electrical resistivity method, current is injected into the ground through surface electrodes, whereas in electromagnetic methods currents are induced by application of time-varying magnetic fields.

#### *Advantages*

The principal advantage of the electrical resistivity method is that quantitative modeling is possible

using either computer software or published master curves. The resulting models can provide accurate estimates of depths, thicknesses and resistivities of subsurface layers. The layer resistivities can then be used to estimate the resistivity of the saturating fluid, which is related to the total concentration of dissolved solids in the fluid.

#### *Disadvantages*

The limitations of using the resistivity method in groundwater pollution site investigations are largely due to site characteristics, rather than in any inherent limitations of the method. Typically, polluted sites are located in industrial areas that contain an abundance of broad spectrum electrical noise. In conducting a resistivity survey, the voltages are relayed to the receiver over long wires that are grounded at each end. These wires act as antennae receiving the radiated electrical noise that in turn degrades the quality of the measured voltages.

Resistivity surveys require a fairly large area, far removed from pipelines and grounded metallic structures such as metal fences, pipelines and railroad tracks. This requirement precludes using resistivity on many polluted sites. However, the resistivity method can often be used successfully off-site to map the stratigraphy of the area surrounding the site. A general "rule of thumb" for resistivity surveying is that grounded structures be at least half of the maximum electrode spacing distance away from the axis of the survey line.

Another consideration in the resistivity method is that the fieldwork tends to be more labor intensive than some other geophysical techniques. A minimum of two to three crew members are required for the fieldwork.

#### **4.2.4 Seismic**

Surface seismic techniques used in groundwater pollution site investigations are largely restricted to seismic refraction and seismic reflection methods. The equipment used for both methods is fundamentally the same and both methods measure the travel-time of acoustic waves propagating through the subsurface. In the refraction method, the travel-time of waves refracted along an acoustic interface is measured, and in the reflection method, the travel-time of a wave which reflects or echoes off an interface is measured.

The interpretation of seismic data will yield subsurface velocity information, which is dependent upon the acoustic properties of the subsurface material. Various geologic materials can be categorized by their acoustic properties or velocities. Depth to geologic interfaces are calculated using the velocities obtained from a seismic investigation. The geologic information gained from a seismic investigation is then used in the hydrogeologic assessment of a groundwater pollution site and the surrounding area. The interpretation of seismic data indicates changes in lithology or stratigraphy, geologic structure, or water saturation (water table). Seismic methods are commonly used to determine the depth and structure of geologic and hydrogeologic units, to estimate hydraulic conductivity, to detect cavities or voids, to determine structure stability, to detect fractures and fault zones, and to estimate ripability. The choice of method depends upon the information needed and the nature of the study area. This decision must be made by a geophysicist who is experienced in both methods, is aware of the geologic information needed by the hydrogeologist, and is also aware of the environment of the study area. The refraction technique has been used more often than the reflection technique for hazardous waste site investigations.

#### *Seismic Refraction Method*

Seismic refraction is most commonly used at sites where bedrock is less than 500 feet below the ground surface. Seismic refraction is simply the travel path of a sound wave through an upper medium and along an interface and then back to the surface. A detailed discussion of the seismic refraction technique can be found in Dobrin (1976), Telford, et. al. (1985), and Musgrave (1967).

*Advantages:* Seismic refraction surveys are more common than reflection surveys for site investigations. The velocities of each layer can be determined from refraction data, and a relatively precise estimate of the depth to different interfaces can be calculated.

Refraction surveys add to depth information in-between boreholes. Subsurface information can be obtained between boreholes at a fraction of the cost of drilling. Refraction data can be used to determine the depth to the water table or bedrock. In buried valley areas, refraction surveys map the depth to bedrock. The velocity information

obtained from a refraction survey can be related to various physical properties of the bedrock. Rock types have certain ranges of velocities and these velocities are not always unique to a particular rock type. However, they can allow a geophysicist to differentiate between certain units, such as shales and granites.

**Disadvantages:** The seismic refraction method is based on several assumptions. To successfully resolve the subsurface using the refraction method, the conditions of the geologic environment must approximate these assumptions:

- the velocities of the layers increase with depth,
- the velocity contrast between layers is sufficient to resolve the interface, and
- the geometry of the geophones in relation to the refracting layers will permit the detection of thin layers.

These conditions must be met for accurate depth information.

Collecting and interpreting seismic refraction data has several disadvantages. Data collection can be labor intensive. Also, large line lengths are needed; therefore, as a general rule, the distance from the shot, or seismic source, to the first geophone station must be at least three times the desired depth of exploration.

#### *Seismic Reflection Method*

The seismic reflection method is not as commonly used on groundwater pollution site investigations as seismic refraction. In the seismic reflection method, a sound wave travels down to a geologic interface and reflects back to the surface. Reflections occur at an interface where there is a change in the acoustic properties of the subsurface material.

**Advantages:** The seismic reflection method yields information that allows the interpreter to discern between fairly discrete layers, so it is useful for mapping stratigraphy. Reflection data is usually presented in profile form, and depths to interfaces are represented as a function of time. Depth information can be obtained by converting time sections into depth measurements using velocities obtained from seismic refraction data, sonic logs, or

velocity logs. The reflection technique requires much less space than refraction surveys. The long offsets of the seismic source from the geophones, common in refraction surveys, are not required in the reflection method. In some geologic environments, reflection data can yield acceptable depth estimates.

**Disadvantages:** The major disadvantage to using reflection data is that a precise depth determination cannot be made. Velocities obtained from most reflection data are at least 10% and can be 20% of the true velocities. The interpretation of reflection data requires a qualitative approach. In addition to being more labor intensive, the acquisition of reflection data is more complex than refraction data.

The reflection method places higher requirements on the capabilities of the seismic equipment. Reflection data is commonly used in the petroleum exploration industry and requires a large amount of data processing time and lengthy data collection procedures. Although mainframe computers are often used in the reduction and analysis of large amounts of reflection data, recent advances have allowed for the use of personal computers on small reflection surveys for engineering purposes. In most cases, the data must be recorded digitally or converted to a digital format, to employ various numerical processing operations. The use of high resolution reflection seismic methods relies heavily on the geophysicist, the computer capacity, the data reduction and processing programs, resolution capabilities of the seismograph and geophones, and the ingenuity of the interpreter. Without these capabilities, reflection surveys are not recommended.

#### **4.2.5 Ground Penetrating Radar**

The ground penetrating radar (GPR) method is used for a variety of civil engineering, groundwater evaluation and hazardous waste site applications. This geophysical method is the most site-specific of all geophysical techniques, providing subsurface information ranging in depth from several tens of meters to only a fraction of a meter. A basic understanding of the function of the GPR instrument, together with a knowledge of the geology and mineralogy of the site, can help determine if GPR will be successful in the site assessment. When possible, the GPR technique should be integrated with other geophysical and

geologic data to provide the most comprehensive site assessment.

The GPR method uses a transmitter that emits pulses of high-frequency electromagnetic waves into the subsurface. The transmitter is either moved slowly across the ground surface or moved at fixed station intervals. The penetrating electromagnetic waves are scattered at points of change in the complex dielectric permittivity, which is a property of the subsurface material dependent primarily upon the bulk density, clay content and water content of the subsurface (Olhoeft, 1984). The electromagnetic energy which is scattered back to the receiving antenna on the surface is recorded as a function of time.

Depth penetration is severely limited by attenuation of the transmitted electromagnetic waves into the ground. Attenuation is caused by the sum of electrical conductivity, dielectric relaxation, and geometric scattering losses in the subsurface. Generally, penetration of radar frequencies is minimized by a shallow water table, an increase in the clay content of the subsurface, and in environments where the electrical resistivity of the subsurface is less than 30 ohm-meters (Olhoeft, 1986). Ground penetrating radar works best in dry sandy soil above the water table. At applicable sites, depth resolution should be between 1 and 10 meters (Benson, 1982).

The analog plot produced by a continuously recording GPR system is analogous to a seismic reflection profile; that is, data is represented as a function of horizontal distance versus time. This representation should not be confused with a geologic cross section which represents data as a function of horizontal distance versus depth. Because very high-frequency electromagnetic waves in the megahertz range are used by radar systems, and time delays are measured in nanoseconds ( $10^{-9}$  seconds), very high resolution of the subsurface is possible using GPR. This resolution can be as high as 0.1 meter. For depth determinations, it is necessary to correlate the recorded features with actual depth measurements from boreholes or from the results of other geophysical investigations. When properly interpreted, GPR data can optimally resolve changes in soil horizons, fractures, water insoluble contaminants, geological features, man-made buried objects, and hydrologic features such as water table depth and wetting fronts.

### *Advantages*

Most GPR systems can provide a continuous display of data along a traverse which can often be interpreted qualitatively in the field. GPR is capable of providing high resolution data under favorable site conditions. The real-time capability of GPR results in a rapid turnaround, and allows the geophysicist to quickly evaluate subsurface site conditions.

### *Disadvantages*

One of the major limitations of GPR is the site-specific nature of the technique. Another limitation is the cost of site preparation which is necessary prior to the survey. Most GPR units are towed across the ground surface. Ideally, the ground surface should be flat, dry, and clear of any brush or debris. The quality of the data can be degraded by a variety of factors, such as an uneven ground surface or various cultural noise sources. For these reasons, it is mandatory that the site be visited by the project geophysicist before a GPR investigation is proposed. The geophysicist should also evaluate all stratigraphic information available, such as borehole data and information on the depth to water table in the survey area.

## **4.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING AND STORAGE**

This section is not applicable to this SOP.

## **4.4 INTERFERENCES AND POTENTIAL PROBLEMS**

See section 4.2.1 for a discussion of limitations of the magnetic method.

See section 4.2.2 for a discussion of limitations of the electromagnetic method.

See section 4.2.3 for a discussion of limitations of the electrical resistivity method.

See section 4.2.4 for a discussion of limitations of the seismic refraction method and the seismic reflection method.