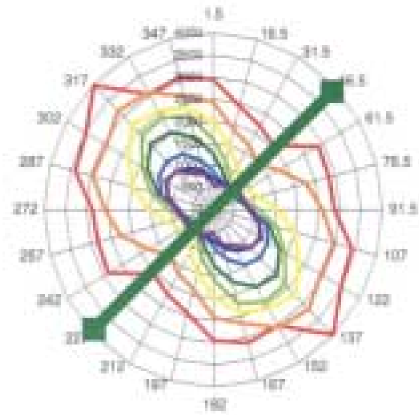
# Field-Based Geophysical Technologies Online Seminar



Presented by the U.S. Environmental Protection Agency's Technology Innovation Office

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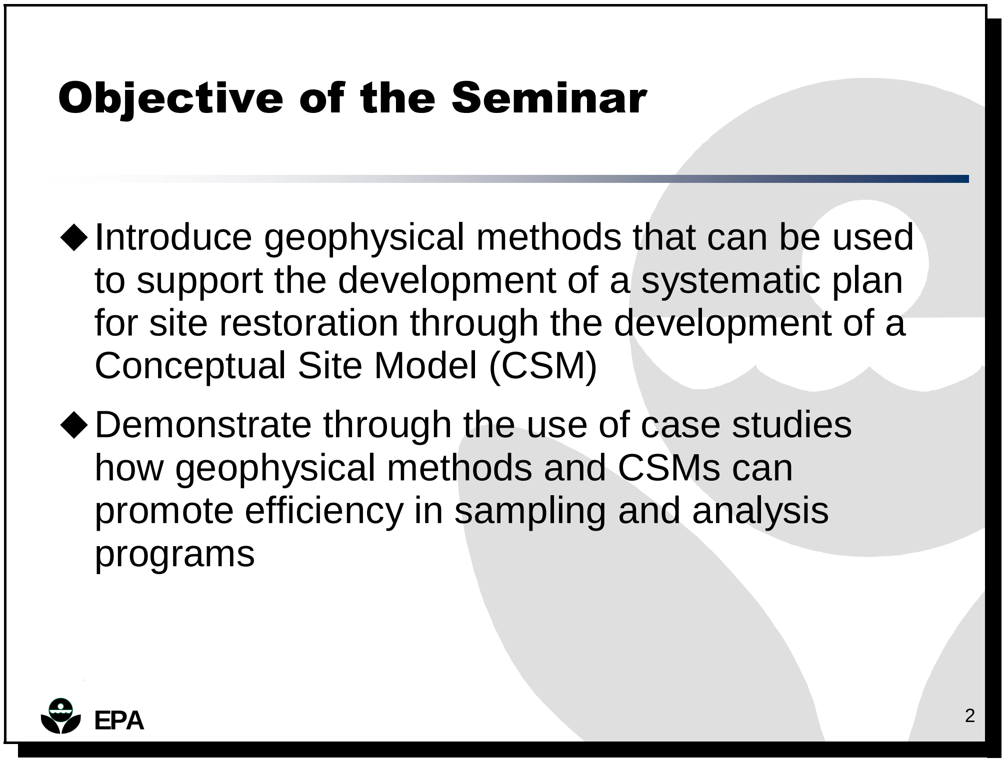
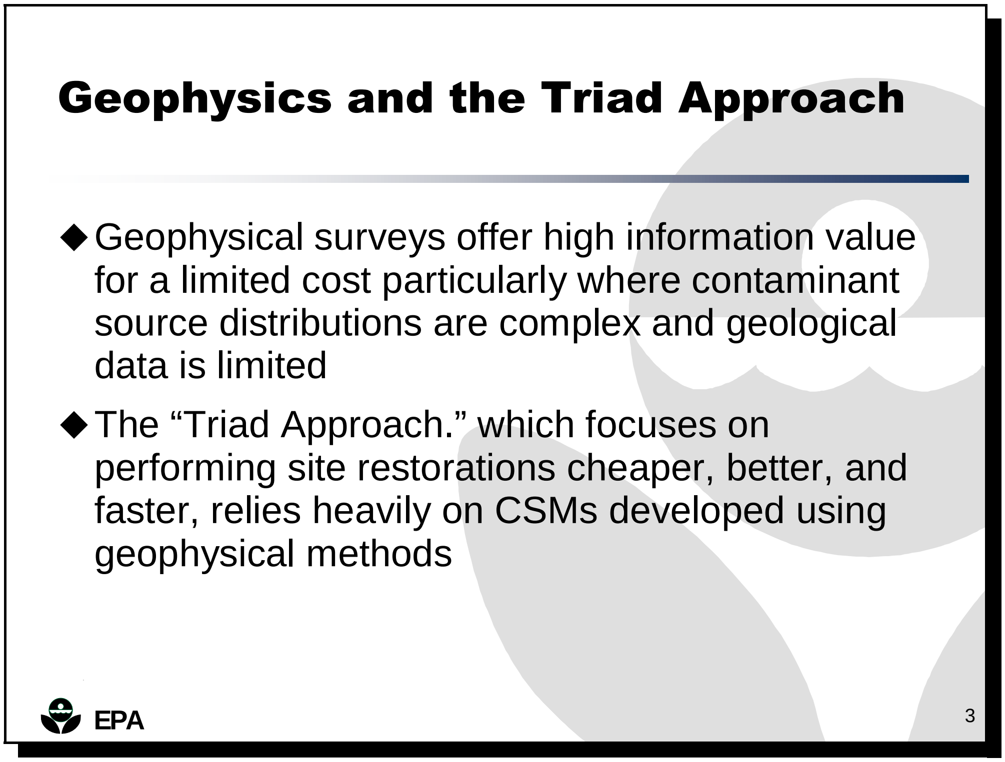
*Instructor:* *Explain to participants that this seminar examines geophysical characterization techniques and is excerpted from EPA TIO's Field-Based Technologies Training Program.*




**Notes:**

C The objective of this seminar is to introduce participants to various types of geophysical methods that can be used to assist in the development of systematic plans used for managing site restorations. A systematic plan based on a well-defined conceptual site model (CSM) will assure site managers that projects are performed in the most efficient and defensible way possible.

C During the online presentation, a series of case studies will be presented to demonstrate how geophysical methods described in this seminar are applied at some real hazardous waste sites. The complete case studies will be available through the links to additional resources section at the beginning and end of the seminar.




**Notes:**

C Geophysical methods offer project managers high information values at a reasonable cost, particularly where contaminant distributions are complex and where geologic information is limited. In fractured media, preferred pathways can go undetected when standard drilling methods are used. Geophysical surveys can assist in such cases to ensure that preferred pathways are identified and wells and other monitoring and measurement methods are focused where needed.

C The Triad Approach, or the use of systematic planning, dynamic work plans, and field-based measurement technologies (including Geophysics) is an initiative that focuses on performing site restorations cheaper, better, and faster. Paramount to this approach is the use of a well-defined systematic plan based on a CSM. Early in a project's life, geophysical methods can ensure that funds allotted for monitoring and measurement activities are expended wisely. Pincushion sampling at complex sites usually is not possible because of economic constraints. Geophysical techniques offer an alternative approach that will provide the broad data coverage required to ensure that project decisions are defensible at a reasonable costs.

## Systematic Plan Using the Triad Approach and Geophysical Surveys

- Collect and evaluate existing data
- Conduct Geophysical surveys
- Optimize intrusive monitoring and measurement activities

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**Notes:**

C When using the Triad Approach it is recommended that project managers use existing data to the maximum extent possible. Gathering available information will ensure that a data collection scheme is focused efficiently on areas where uncertainty is the highest relative to project decision-making. Geophysical surveys should then be considered at sites where little or no geologic information is available or where the complexity of site conditions suggests that an intrusive sampling technique will be inefficient or economically unfeasible unless well directed.

C Based on the geophysical results obtained, a project manager then can refine a sampling and analysis scheme that targets most efficiently those areas with the highest uncertainty and most bearing on the project decisions attempting to be made.

## Geophysics Overview

- Geophysics methods that will be reviewed include:
  - » Magnetics
  - » Resistivity
  - » Conductivity
  - » Ground Penetrating Radar (GPR)
  - » Borehole
  - » Seismic

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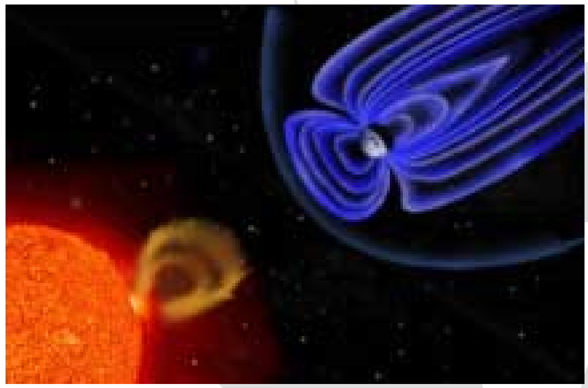
**Notes:**

- In this seminar, we will focus on several of the commonly used methods that can assist project managers in developing systematic plans for site restorations.

## Magnetic Surveys — Physical Basis

- Magnetic susceptibility
- Remanent magnetism and susceptibilities of earth materials
- Magnetic field of the earth



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**Notes:**

C A body placed in a magnetic field acquires a magnetization that typically is proportional to the field. The constant of proportionality is known as the magnetic susceptibility. For most natural materials, susceptibility is very low. However, ferromagnetic and ferromagnetic materials have relatively high magnetic susceptibilities. The susceptibility of a rock typically depends only on its magnetite content. Sediments and acid igneous rocks have relatively low susceptibilities, while basalts, gabbros, and serpentinites usually have relatively high susceptibilities.

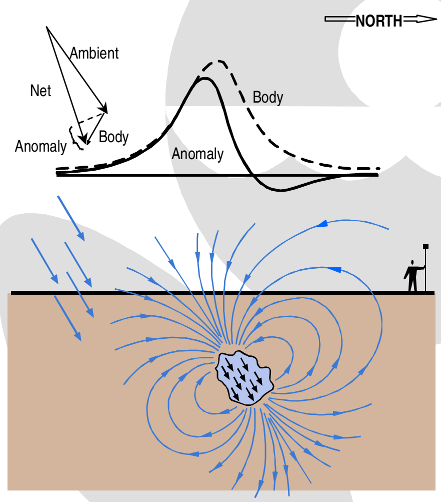
C Ferromagnetic and ferromagnetic materials have permanent magnetic moments in the absence of external magnetic fields. An object that exhibits a magnetic moment is characterized by a tendency to rotate into alignment when exposed to a magnetic field.

C The magnetic field of the earth originates from electric currents in the liquid outer core. Earth's magnetic field strengths typically are expressed in units of nanoTesla (nT). Sunspot and solar flare activity can create irregular disturbances in the magnetic field. Such changes are referred to as magnetic storms.

*Instructor:* *Explain that the sun can affect the measurement of the magnetic field of the earth. Solar activity may strongly alter the field for brief periods of time, or cause slow variations in the measured field.*

## Magnetic Field

- Found in the vicinity of a magnetic body or electrical medium that is carrying current

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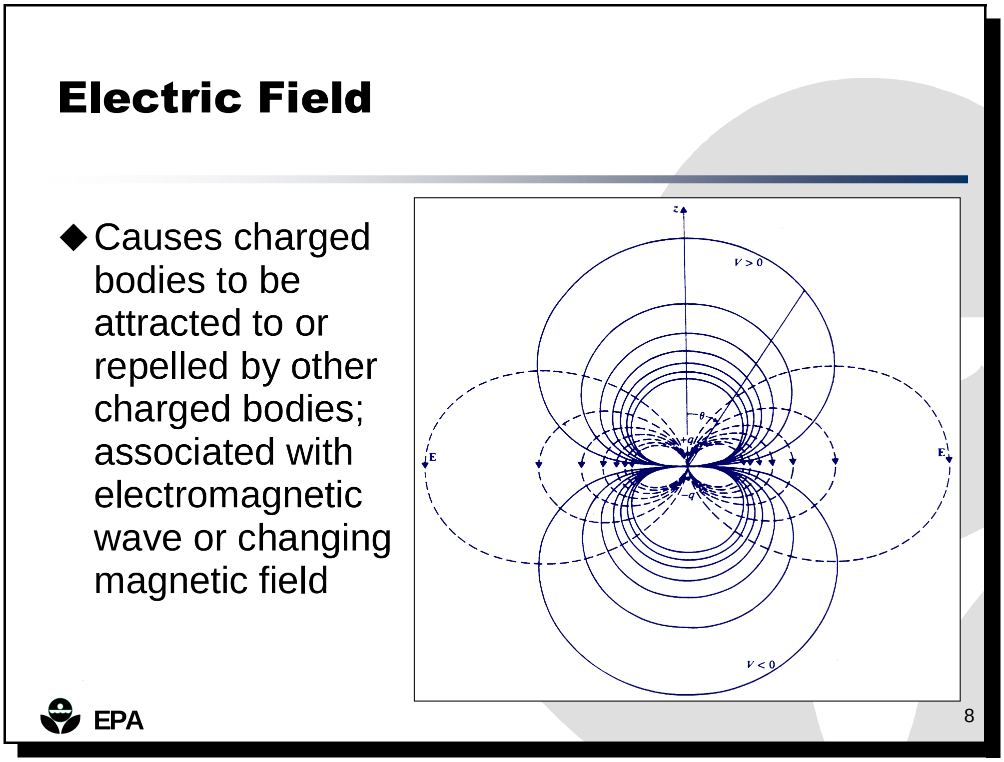
**Notes:**

- The earth's magnetic field induces a magnetic moment per unit volume in buried ferromagnetic debris (bottom), causing a local perturbation (anomaly) in total magnetic field (top).

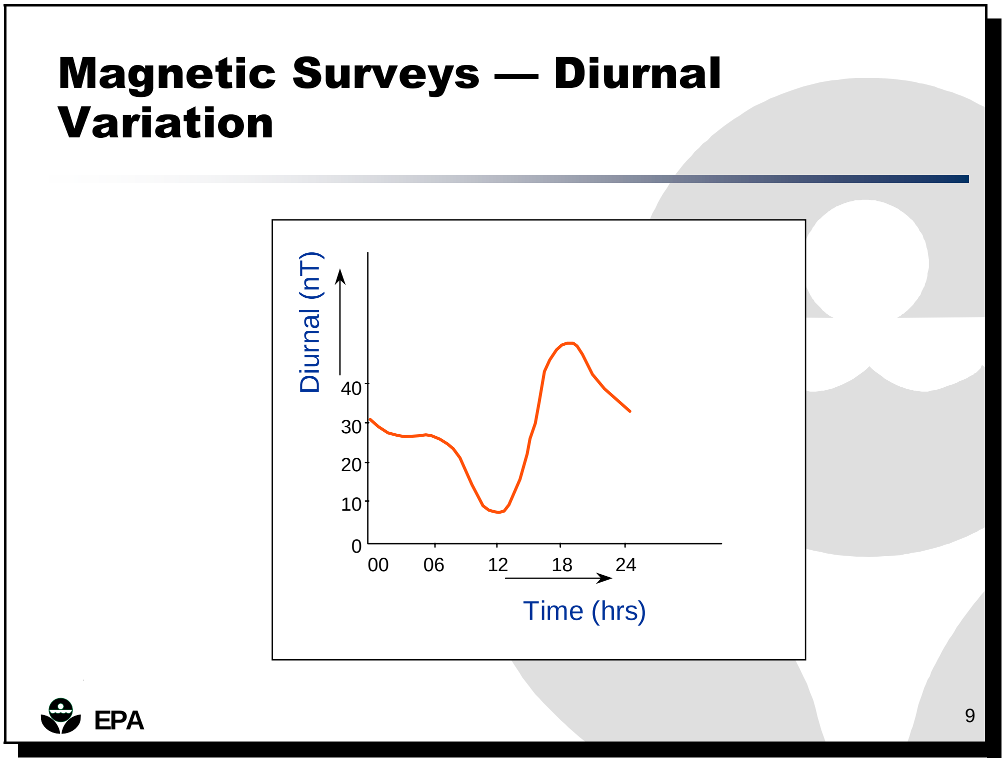
- The total magnetic field measured is a vector sum of the ambient earth's magnetic field, plus local perturbations caused by buried objects.

*Instructor:* *Use the graphic to illustrate why the shape of the characteristic anomaly occurs. It is simply a process of vector addition. Ask the participants how their strategy for locating buried ferrous objects would differ if they were making gradient, rather than total intensity, measurements. The key concept to illustrate is that objects typically are located at maximum gradients, but not maximum total field anomalies.*




**Notes:**

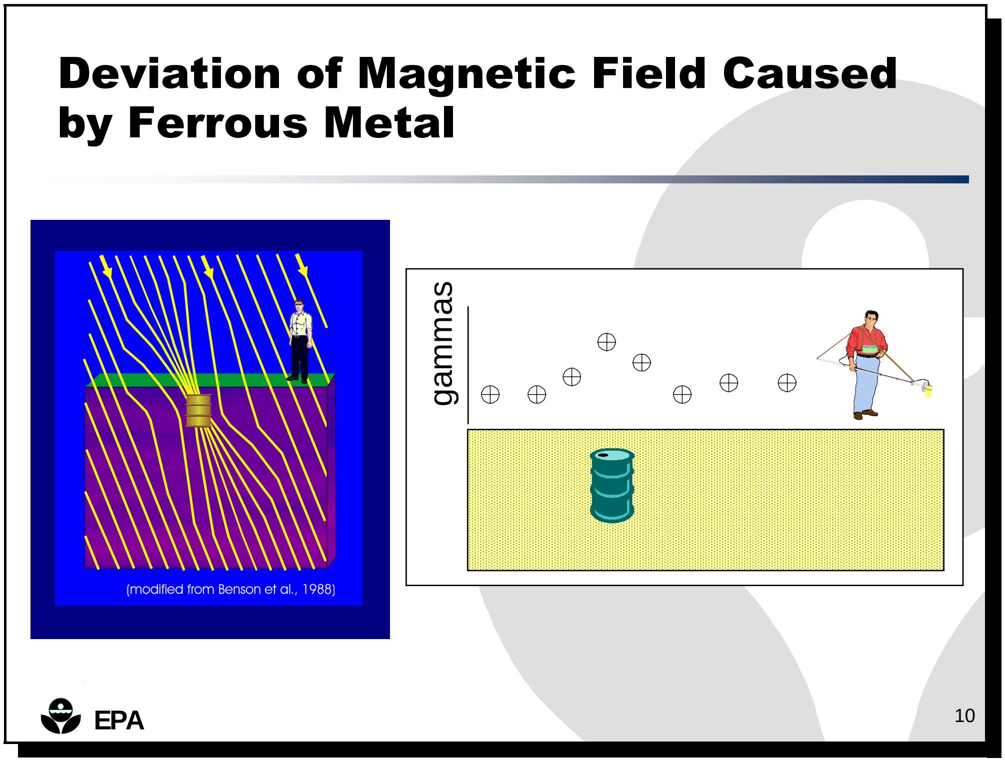
C The graphic depicts field lines and contours of equal field strength around two static, oppositely charged objects. The electric field intensity of a small charged object has a magnitude proportional to the charge and inversely proportional to the square of the distance from the charge. Note the similarities and differences to the magnetic field depicted in the previous slide.




**Notes:**

C The field varies during the day because of changes in the strength and direction of currents circulating in the ionosphere; those changes are referred to as diurnal variation.

*Instructor:* *Explain that the graphic depicts normal daily diurnal variation in the magnetic field at a single point. Ask the participants to identify which hours of the day appear to be most affected by the rate of change of diurnal variation. Compare those hours (afternoon) with typical survey work hours to emphasize the need to account for diurnal variation.*




C Magnetometers are used to measure the earth's magnetic field.

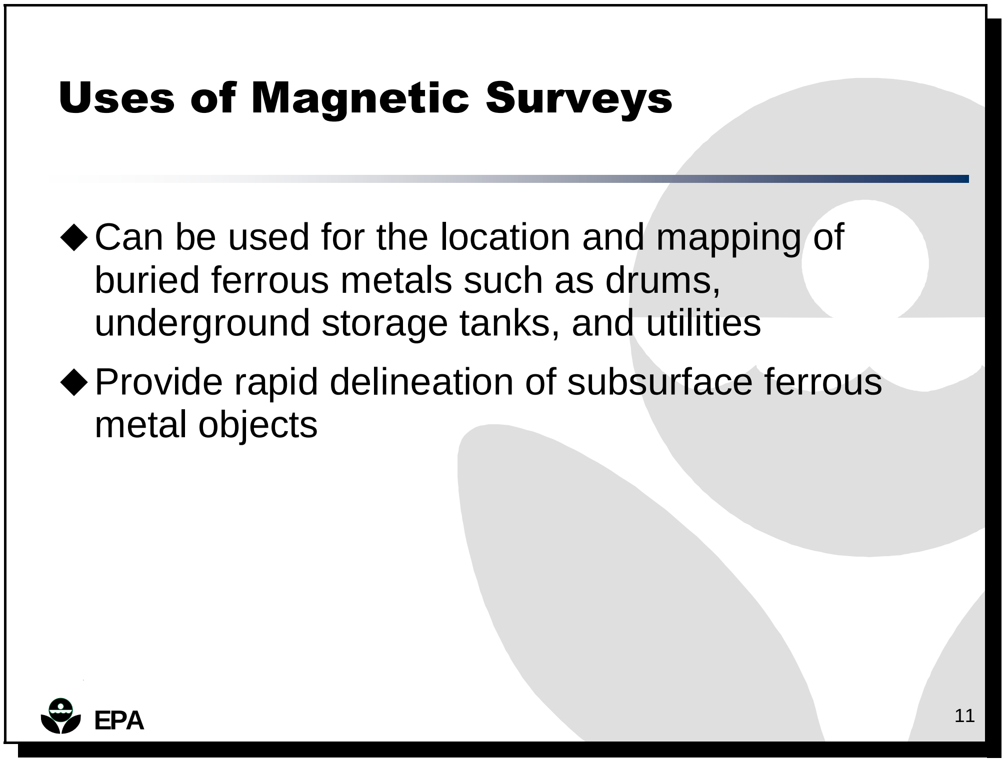
C Deviations of magnetic field intensity are caused by ferrous minerals in the soil or ferrous metals.

*Instructor:* *Explain to the participants that this illustration shows lines of equal magnetic intensity. A ferrous object, such as a drum will change the intensity causing an anomalous measurement of the field.*

C This diagram shows a typical response when a magnetometer passes over a ferrous object. In this case, the anomaly is associated with a single drum.

C This profile illustrates the change in the magnetic field as the sensor passes over a ferrous object.

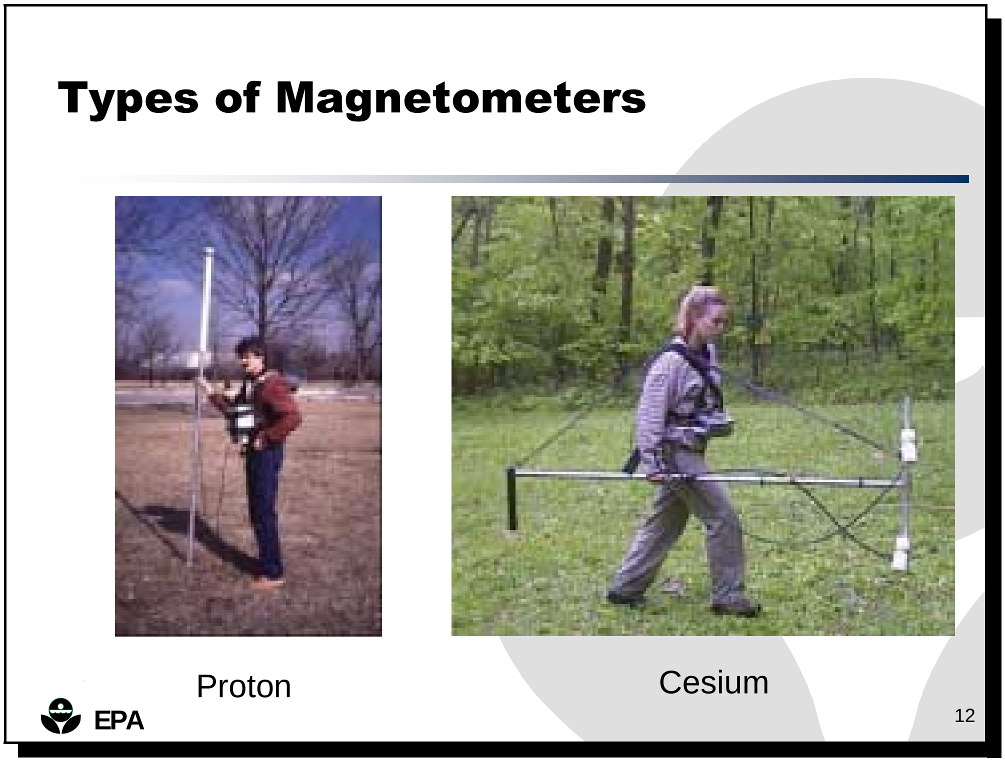
*Instructor:* *Explain to the participants that the measured anomaly caused by a ferrous object can vary. An anomaly may be positive or negative. In fact, there is a possibility that an object may be oriented within the earth's magnetic field such that no anomaly will be detected.*




**Notes:**

C Magnetic surveys are used to map subsurface ferrous metal objects such as tanks, pipes, and utilities.

*Instructor:* *Point out to the participants that magnetic surveys are often a rapid method to delineate the location of suspected buried drums, define the location of underground storage tanks and locate isolated buried steel water lines.*

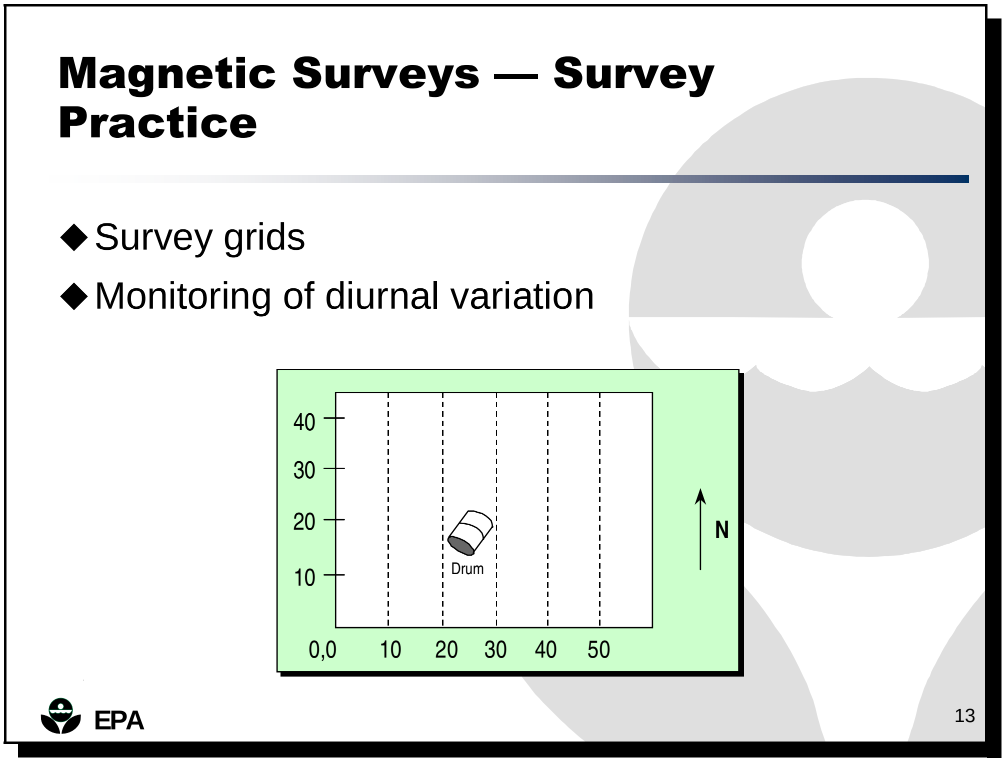



**Notes:**

C This slide shows a proton and a cesium magnetometer.

C Proton precession, fluxgate, and cesium vapor magnetometers used for surface geophysical surveys are portable, self-contained units that require a single operator. Most modern proton precession, fluxgate, and cesium vapor magnetometers support recording and retrieval of data.

C Proton precession magnetometers can be rented for approximately $300 per month or $10 per day, with a mobilization fee of about $95. The cesium vapor magnetometer can be rented for approximately $1,770 per month or $59 per day, with a mobilization fee of about $95. A fluxgate magnetic locator can be rented for approximately $180 per month or $6 per day, with a mobilization fee of about $55.




*Instructor:* *Inform the class that proton precession magnetometers require more time to sample the magnetic field and surveys are usually on a regularly spaced grid point. The Cesium vapor magnetometer is more commonly set up on a regularly spaced time interval (for example, every 5 feet for proton precession and every 0.1 seconds with cesium vapor magnetometers).*

**Notes:**

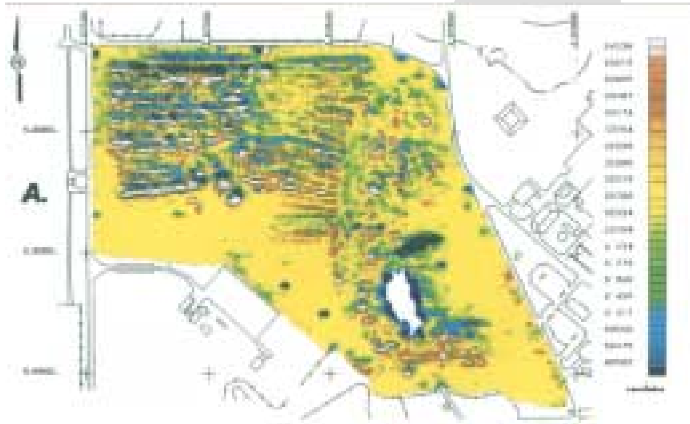
C Proton precession instruments usually are used to obtain measurements along regularly spaced grid points. The surveys are also conducted along regularly spaced lines. This survey procedure is common for most surface geophysical surveys. Fluxgate magnetometers are used in serpentine search or clearance patterns, in addition to the grid-based data acquisition approach. Cesium vapor magnetometers are used extensively today because they support rapid acquisition and storage of data, and are usually set up on a time interval for measurement intervals along equally spaced lines.

C When total field measurements are being obtained, as is the case with long baseline instruments, a separate stationary magnetometer should be used to measure diurnal changes in the ambient magnetic field, as well as possible effects of magnetic storms. Magnetic measurements are susceptible to noise related to ferrous content of buildings, fences, vehicles, and utility fixtures.

*Instructor:* *Ask participants whether they think it is important to select a data collection spacing and why?*

## Magnetic Surveys — Interpretation

◆ Contouring-based interpretation

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**Notes:**

C The illustrated magnetic data in this slide is from a survey to delineate the presence of disposal trenches. This data was provided from a paper presented at the annual meeting of the Engineering and Environmental Geophysical Society (EEGS) symposium. The data was collected at Tinker Air Force Base. Various means of spatial predictions can be used to prepare contour maps to present the magnetic properties across an area of interest. Contours of total field or magnetic gradient commonly are used as interpretation tools. Other advanced processing can be done to minimize the variety of anomaly shapes encountered in magnetic surveys.

C Survey design for magnetic surveys, and other “grid based “ geophysical methods is an important consideration. Line spacing and sample intervals are important considerations. These parameters are based upon the expected size of the object or feature being investigated, which could range from defining a single tank or drum or delineating the extent of a landfill or plume.

## Magnetic Surveys — Advantages and Limitations

- Advantages
  - » Detects objects at a greater distance from the sensor
  - » Can assist in delineating geologic formations containing ferrous minerals
- Limitations
  - » Detects only ferrous materials
  - » Anomaly shape often is complex
  - » Interferences from nearby ferrous objects may mask objective

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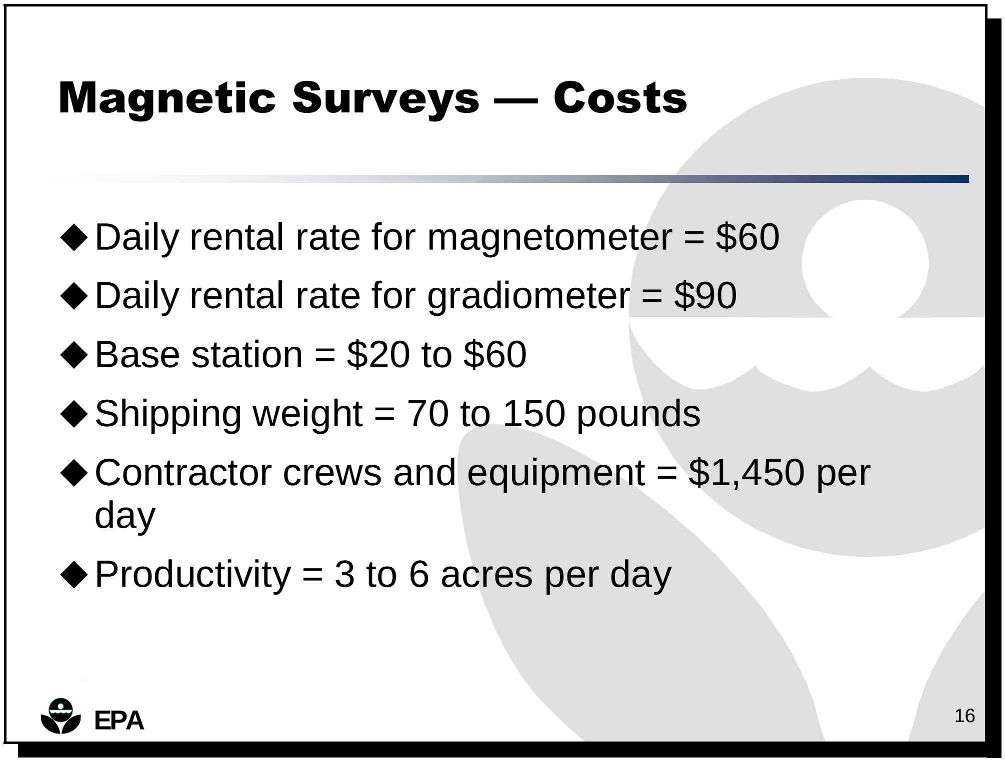
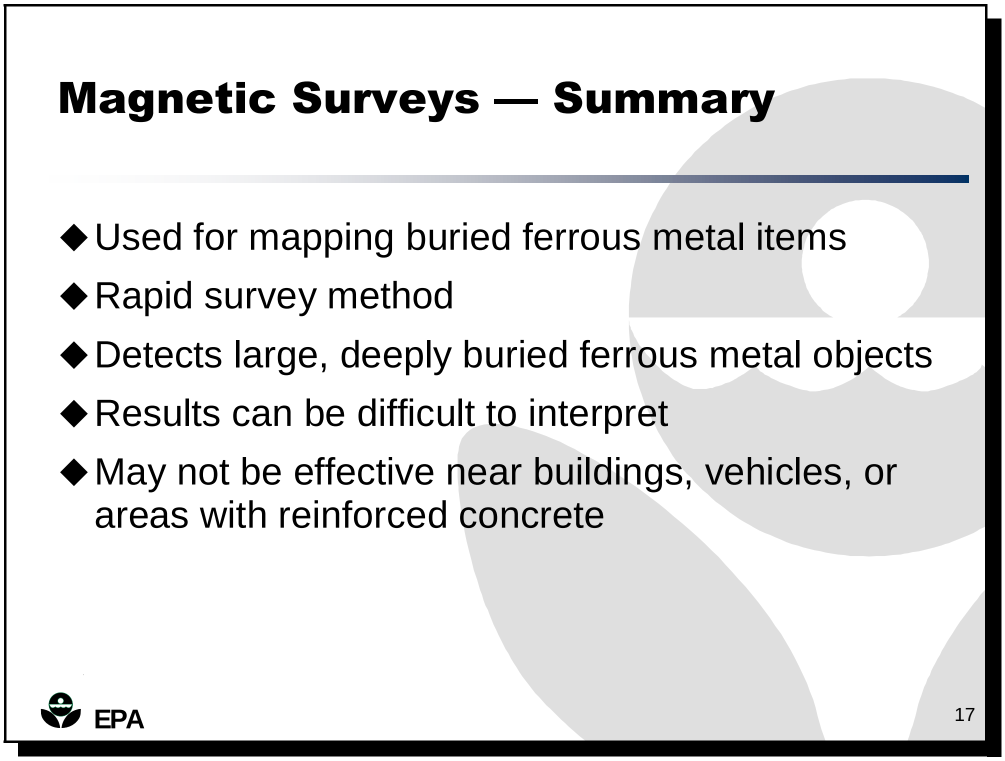
**Notes:**

C Magnetometers are used for the detection of magnetic or ferrous objects and minerals. Magnetometers are not effective in sensing other metals such as aluminum or brass. Nearby objects such as fences, steel posts, automobiles, steel well casings will mask subsurface ferrous objects that may be the focus of an investigation. Careful consideration should be conducted to determine if a magnetometer survey can be conducted at the site. Other methods may be better suited for subsurface investigations.




**Notes:**

C There are a number of vendors that rent geophysical equipment. Links to these vendors are provided later in this discussion. Typical rates for magnetometer equipment are about $60 to $90 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,450 per day plus mobilization and reporting.




**Notes:**

- Magnetometers are used to detect buried ferrous metal objects such as drums, tanks and pipes.

- Magnetometers allow rapid characterization of a site.

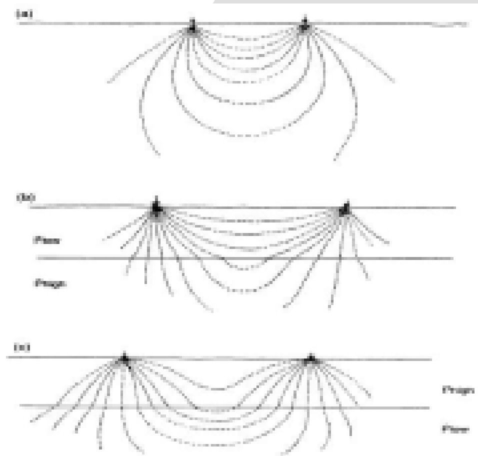
- Magnetic surveys can detect large, deeply buried ferrous metal objects. However, smaller objects at depth may not be detected by this method.

- The results from magnetic surveys can be difficult to interpret, but recent developments in data analysis software have made data interpretation easier and more effective.

- Magnetometers may not be effective near buildings, vehicles, power lines or in areas with reinforced concrete, such as parking lots.

## Resistivity — Physical Basis

- Electrical resistivities of common materials (a)
- Contact resistances (b)
- Apparent resistivity (c)



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**Notes:**

- The resistivity of a rock is roughly equal to the resistivity of the pore fluid divided by the fractional porosity.  In general, soils have lower resistivity than rock, and clay soils have lower resistivity than coarse-textured soils.

- Measurement of resistivity in the earth is defined as apparent resistivity because it is unlikely that the material into which electrodes are inserted, and of which measurements are taken, is homogenous.

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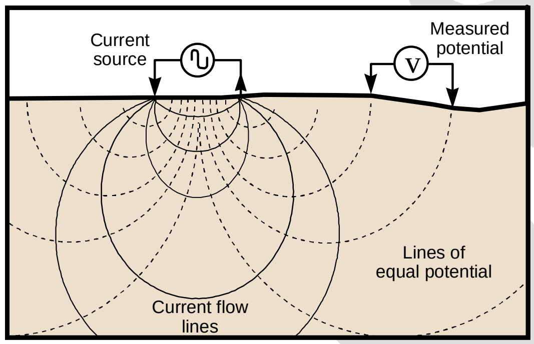


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**Notes:**

C Resistance (R) is measured in ohms when current (I) is in amps and potential (V) is in volts. The resistance of a unit cube to current flowing between opposite faces is termed resistivity. Resistivity is measured in units of ohm-meters (S-m).

C In geophysics, resistivity involves applying a current into the subsurface and measuring the resulting potential between two other electrodes.

C The resistivity of a rock is roughly equal to the resistivity of the pore fluid divided by the fractional porosity. In general, soils have lower resistivity than rock, and clay soils have lower resistivity than coarse-textured soils.

C Measurement of resistivity in the earth is defined as apparent resistivity because it is unlikely that the material into which electrodes are inserted, and of which measurements are taken, is homogenous.

*Instructor:* *Describe the use of electrodes placed into the subsurface using metal rods. Explain that there are current electrodes that apply a direct current into the ground. Two additional electrodes are used to measure the resultant potential voltage. Information about the applied current and the resultant measured voltage provide information about the subsurface apparent resistivity. The next page provides ranges of resistivities of earth materials.*

**Typical Values of Electrical Resistivity of Earth Materials**

| Earth Material | Resistivity Range (S-m) |
|---|---|
| Saline groundwater | 0.01 – 1 |
| Clay soil | 1 – 30 |
| Fresh groundwater | 2 – 50 |
| Calcareous shale (or Chalk) | 10 – 100 |
| Sand (SP[1], moderately to highly saturated) | 20 – 200 |
| Shale (mudstone/claystone) | 1 – 500 |
| Shale (siltstone) | 50 – 1,000 |
| Limestone (low-density) | 100 – 1,000 |
| Volcanic flow rock (scoriaceous basalt) | 300 – 1,000 |
| Lodgement (dense, clayey, basal) till | 50 – 5,000 |
| Sandstone, uncemented | 30 – 10,000 |
| Ablation (dry, loose, cohesionless) till | 1,000 – 10,000 |
| Fluvial sands and gravels (GW[1], unsaturated) | 1,000 – 10,000 |
| Loose, poorly sorted sand (SP, unsaturated) | 1,000 – 100,000 |
| Metamorphic rock | 50 – 1,000,000 |
| Crystalline igneous rock | 100 – 1,000,000 |
| Limestone (high-density) | 1,000 – 1,000,000 |

[1] GW and SP above are Unified Soil Classification terms for well-graded gravel and poorly-graded sand, respectively.

## Resistivity — Instruments

- Electrodes and arrays

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**Notes:**

- The device that applies a measured current in a resistivity survey is known as the transmitter. Transmitters usually are designed to reverse the direction of the current, with a cycle time from 0.5 to 2 seconds. The reversal of the current helps minimize electrode polarization effects. Power is provided by a battery or a generator.

- Voltage measuring devices often are referred to as receivers.

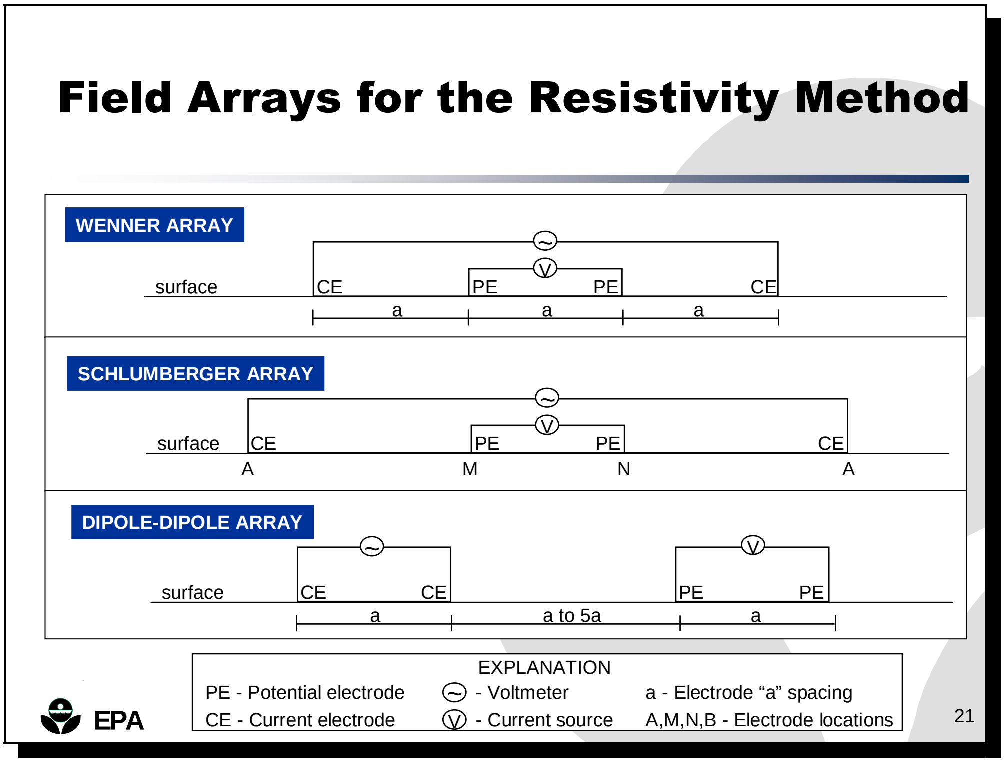
- In newer instruments, the transmitter and receiver equipment generally are housed in a single unit, with microprocessor control and internal data storage.

- Earth resistivity meters can be rented for approximately $300 per month or $10 per day, with a mobilization fee of about $65.

*Instructor:* *This slide shows a typical resistivity layout using multiple wires and electrodes. Note that the operator has control of both the transmitter and the receiver.*

- Current electrodes typically are metal stakes. Voltage electrodes can be metal, but more often consist of a "pot" of nonpolarizing material, such as porcelain or unglazed ceramic. Inside the pot is a copper rod surrounded by copper sulfate solution. Contact with the ground is made through the solution, which leaks into the base of the pot.
- Resistivity profiling is a technique in which transects are used to detect lateral changes in subsurface resistivity. The geometric perimeters of the array are kept constant, and the

depth of penetration therefore varies only with changes in subsurface materials and variations in layering of geologic materials.




**Notes:**

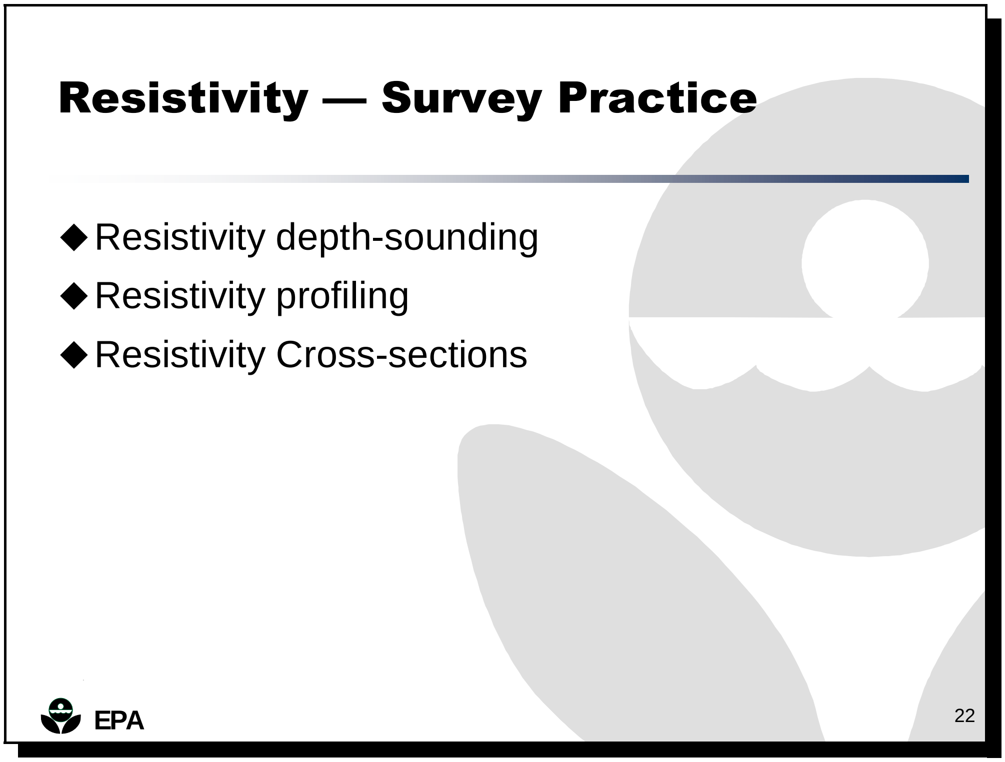
C Electrodes are placed in well-defined geometric patterns known as arrays. Commonly used arrays include:

- Wenner
- Schlumberger
- Dipole-Dipole
- Gradient

Shown are three of the commonly used DC resistivity arrays.

- The Wenner and Schlumberger arrays are commonly used for vertical electrical soundings.

- The Dipole-Dipole array is used to produce a two-dimensional cross sectional profile over a site.




**Notes:**

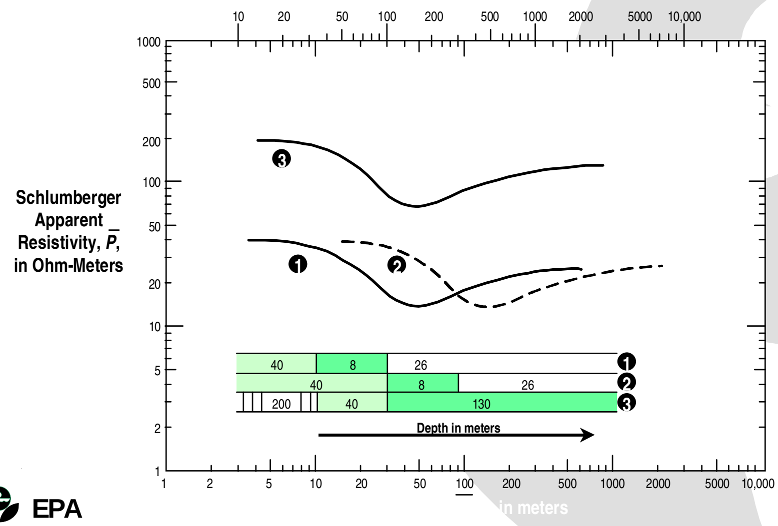
- The resistivity depth-sounding technique uses arrays in which the distances between some or all of the electrodes are increased systematically. Apparent resistivities are plotted against changes in the geometry of the array. With this technique, information about the change in resistivity as a function of depth is inferred.

- Soundings provide a single point vertical profile of subsurface electrical properties.

- Some limitations and interferences include: (1) contact resistance effects; (2) effects of cultural features, such as buried utilities; and (3) noise levels at the site. Data interpretation is another potential limitation because it is fairly subjective and requires an expert. Resistivity surveys also are relatively slow because of the need to move electrodes and cables between each measurement.

- Resistivity cross sections commonly are generated from the depth-profiling data. The calculation is made by entering site information about depths and soil or rock units. The data may be available from borehole information or general geologic maps of an area.

# Vertical Electrical Sounding Examples

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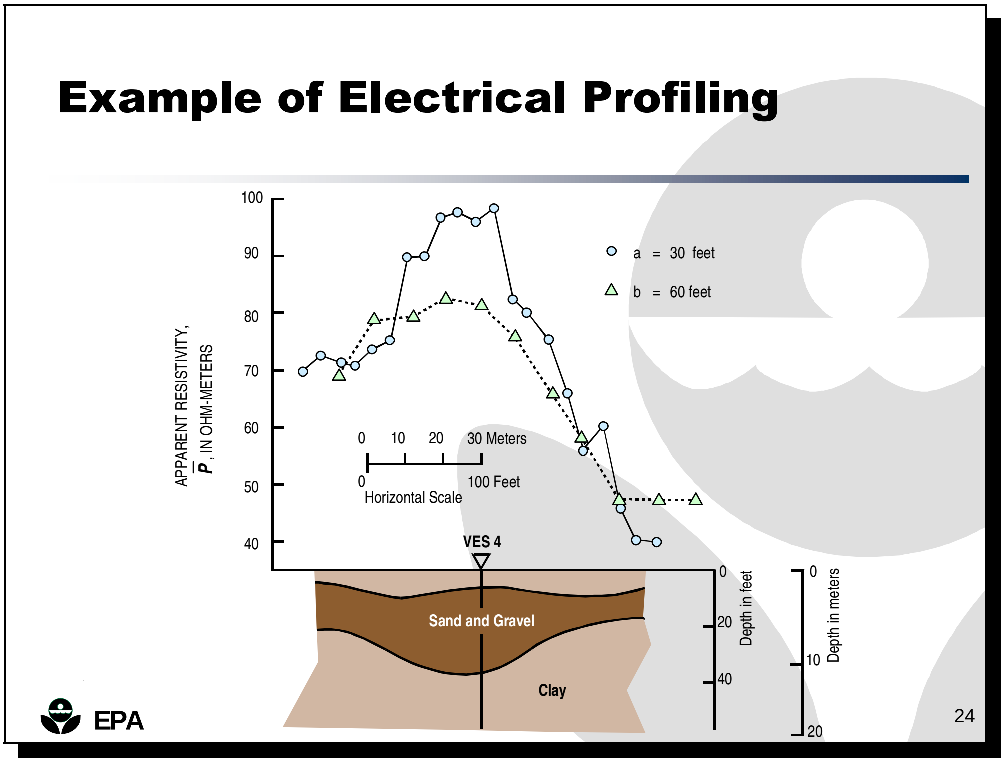
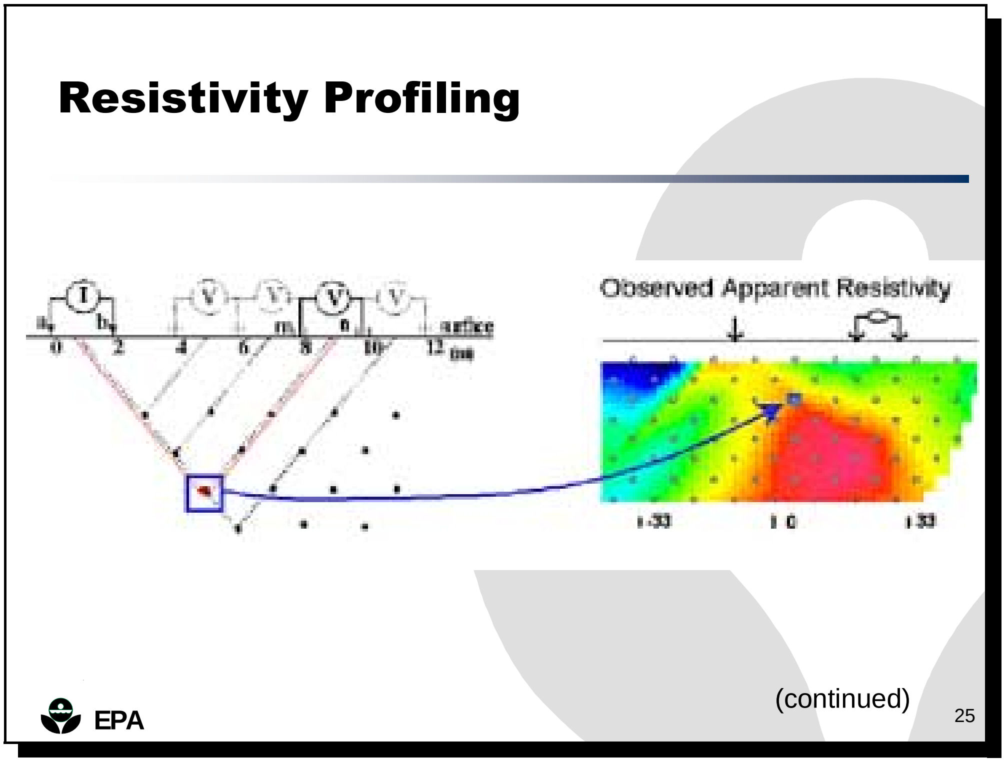
*Instructor:* *Ask the participants what a background or representative value of resistivity might be for areas not affected by landfilling. Explain that, in the field, media values often are used as an approximation. Ask the participants which measure—resistivity or resistivity gradient—seems to be a more effective means of locating the boundary of the landfill.*




**Notes:**

C The data shown at the top of the figure are taken at two electrode spacings. Wider spacing usually provides information about deeper subsurface materials.

C The information at the bottom of the figure is an interpretation of the data. "VES 4" is a vertical electric sounding. Likely, the data from VES 4 indicate the presence of three geologic layers within the depth of investigation of the sounding.

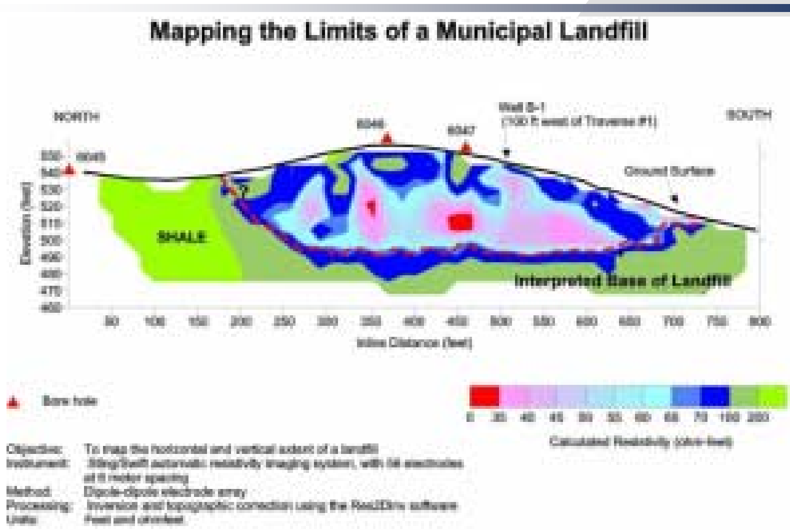



**Notes:**

- This graphic illustrates the resulting measuring point from a single electrode position measurement.

- Each move of the current and potential electrodes results in a particular location and depth of measurement.

## Resistivity Profiling

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**Notes:**

C Resistivity profiling or soundings can provide information including depth of fill and lateral extent of landfills.

C This cross-sectional view was created using a dipole-dipole resistivity array. The data was processed using a recently developed software program Res2Dinv. The software uses the calculated apparent resistivity data and enter it into a modeling program. The program calculates and interpolates depths of resistivity layers and produced the cross-sectional view.

*Instructor:* *Discuss the cross section stressing the contrasting resistivities from background shales to the foreign municipal landfill.*

## Resistivity — Advantages and Limitations

- Advantages
  - » Surveys are relatively inexpensive
  - » Provides information about multiple soil layers in the subsurface
  - » The method is effective in shallow areas of investigation
- Limitations
  - » Sufficient space is required to lay out electrode array
  - » Difficult to place electrodes in rocky soils
  - » Lateral variations in soil may affect result

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**Notes:**

C Resistivity surveys are a cost effective way to obtain information about subsurface soil and rock units. The method is better than time domain electromagnetic soundings for the analysis of shallow layers such as a thin clay cap over a landfill. The method does however require adequate space in order to lay out an array. Lateral variations in soils may affect the result of sounding surveys.

## Resistivity Profiling — Costs

- Daily rental rate = $50
- Accessories = $25
- Shipping Weight = 75 to 150 pounds
- Contractor crews and equipment = $1,400 to $1,800 per day
- Productivity generally in number of soundings per day (2-20) or line mile coverage per day (one-forth mile to 1 mile per day). These productivity rates vary because of site conditions, depth objectives, and required resolution.

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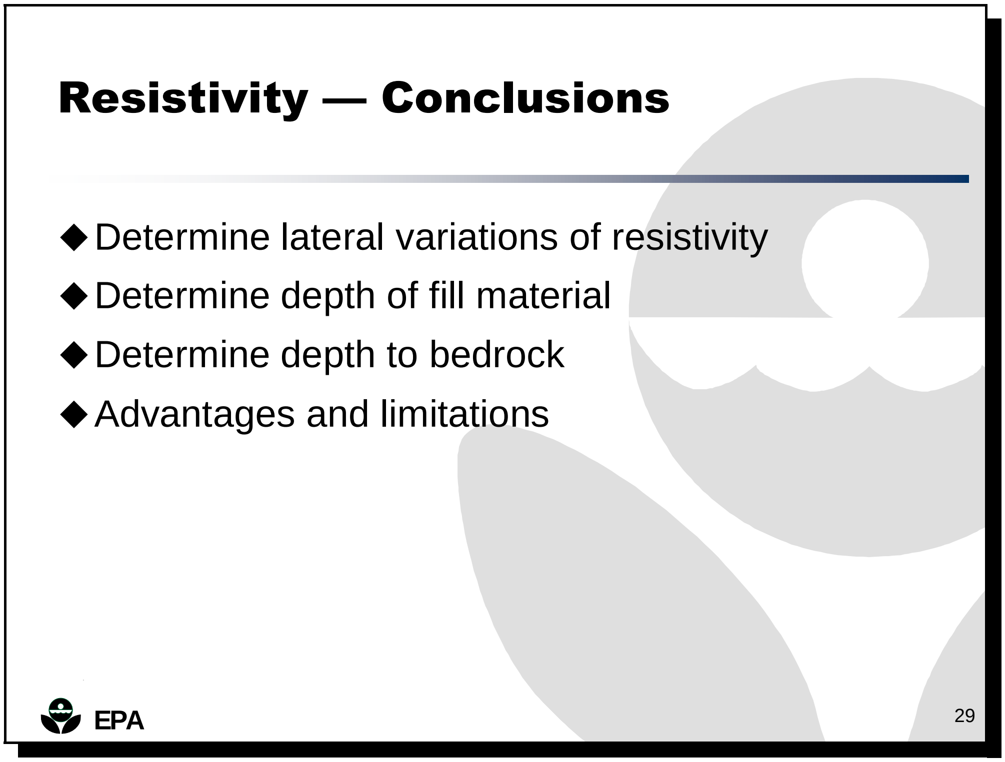
**Notes:**

- There are a number of vendors that rent geophysical equipment. Links to these vendors are provided later in this discussion. Typical rates for near surface resistivity equipment are about $75 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,400 to $1,800 per day plus mobilization and reporting.




**Notes:**

C Direct current resistivity can be a useful tool for mapping lateral variations of earth resistivity for site characterization.

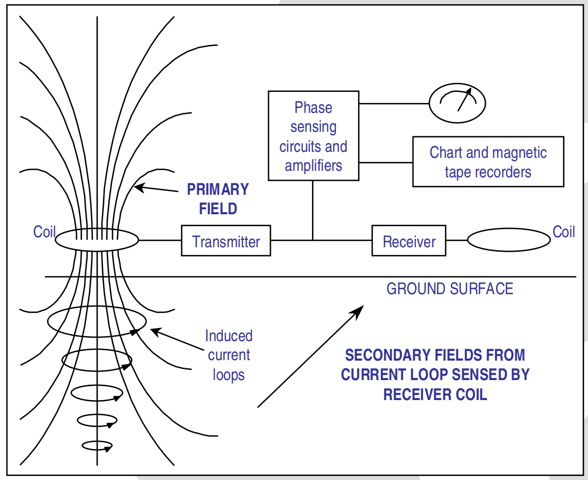
C The method is useful for determining depth of fill and depth to bedrock in certain geologic and site environments.

C Direct current resistivity is better suited than seismic refraction for determining depth of fill.

C The direct current method requires good ground contact. Rocky surfaces may limit effectiveness. At landfill sites, metals in the subsurface may interfere with the data.

## Electromagnetic Conductivity Surveys

- Active electromagnetic induction techniques
- Applications
  - » Profiling
  - » Sounding

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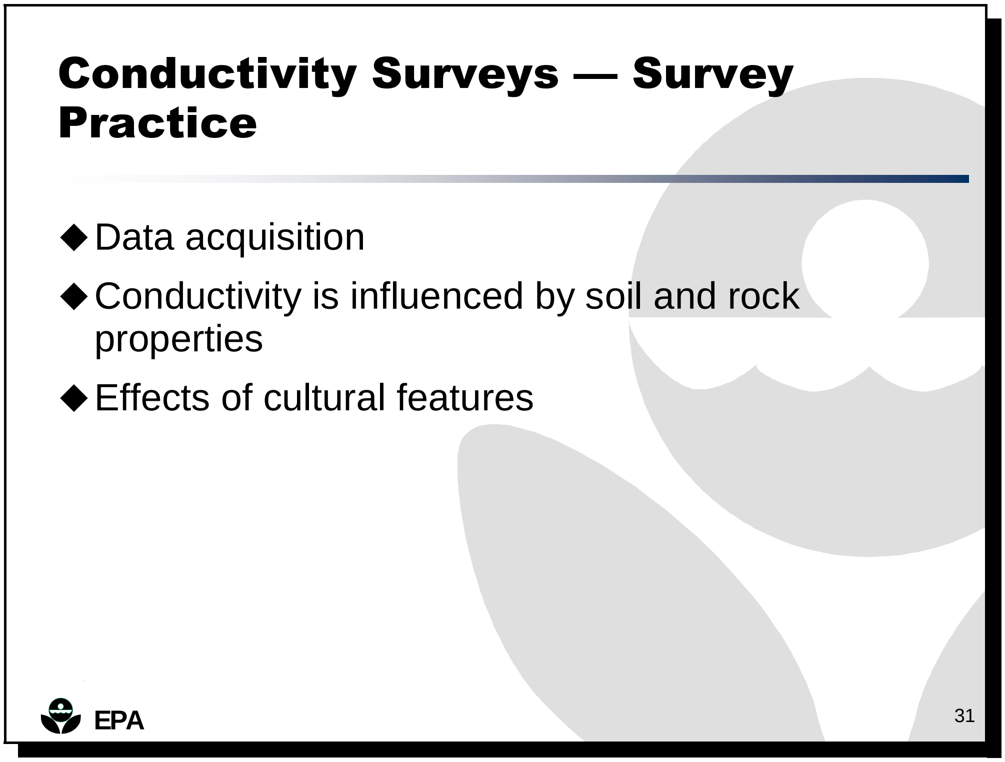
**Notes:**

C Conductivity methods also are known as active electromagnetic induction techniques, and can be used to detect both ferrous and nonferrous metallic objects.

C These methods use a transmitter coil to establish an alternating magnetic field that induces electrical current flows in the earth. The induced currents generate a secondary magnetic field that is sensed by a receiver coil. The character and magnitude of the secondary field are governed by the frequency of the transmitted current and the distribution and magnitude of the electrical properties in the nearby subsurface.

C Profiling is accomplished by making fixed-depth measurements along a traverse line.

C Sounding is accomplished by making measurements at various depths at a fixed location by varying the coil orientation or separation of the transmitter and receiver.




**Notes:**

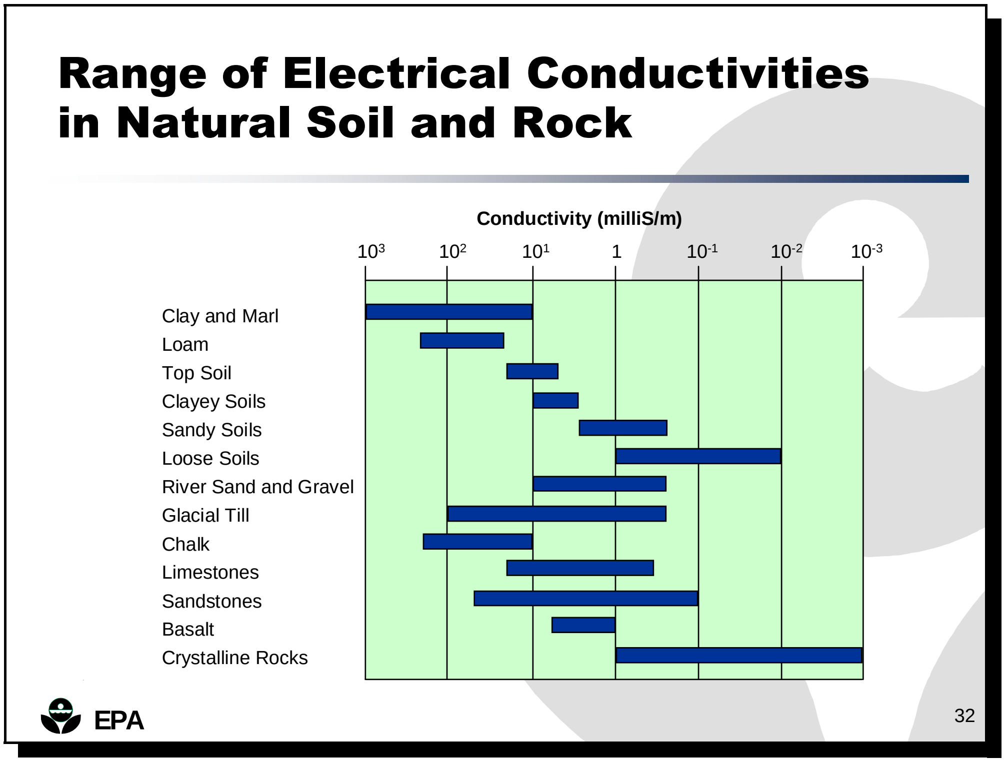
C Approaches to conductivity surveys are similar to those used in resistivity surveys. Profiles involve continuous or station-based conductivity measurements obtained along a transect. Measurements can be obtained along a grid of transects to support contouring of the data. Data usually are recorded digitally for rapid transfer to a computer for processing.

C Most soil and rock minerals have low conductivities when dry. A unique conductivity value cannot be assigned to a particular material because of variations in composition and structure of soils and in pore fluids. A range of conductivities, based upon field and laboratory measurements has been determined.

C The presence of surface conductors (for example, railroad tracks) must be noted carefully in the survey log.

C The ranges of conductivity aid in the interpretation for determining or inferring the subsurface geologic properties.

*Instructor:* *State that the next slide provides some ranges of conductivity of common earth materials.*



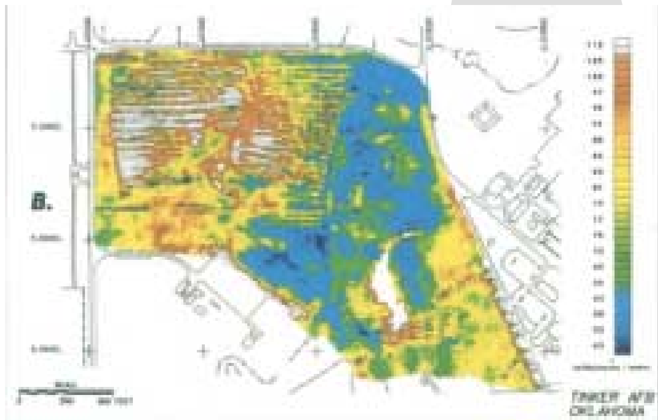

**Notes:**

- This illustration shows the range of conductivity that can be encountered in various terrain materials from a variety of climatic zones. The ranges have been compiled for different terrain materials from a variety of survey and laboratory measurements.

- In general, clays or fine-grained materials have high conductivity values, gravels, and sand have moderate conductivity values, and consolidated bed rock has low conductivity values.

## Conductivity Surveys Interpretation

- Data contouring




EPA

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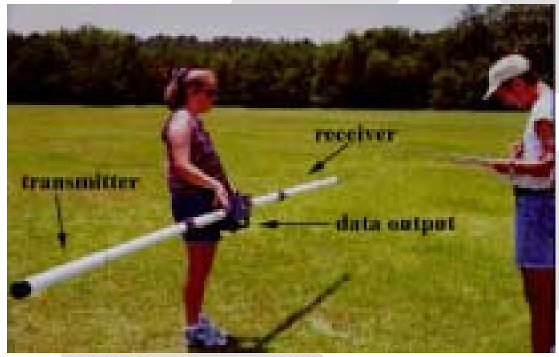
**Notes:**

C Various means to obtain spatial representations, such as magnetic surveys, also can be applied to conductivity measurements. Color contour maps usually are represented using available software packages that generate these types of maps. This illustration is of a the same site illustrated in the magnetometer example (Tinker Air Force Base, Oklahoma) from the proceedings of the EEGS. The objective of the survey was to determine the locations of waste pits and also areas where waste pits were absent.

## Electromagnetic (EM) Surveys

◆ The EM method provides a means of measuring the electrical conductivity of subsurface soil, rock, and groundwater




EM31

EPA

34

**Notes:**

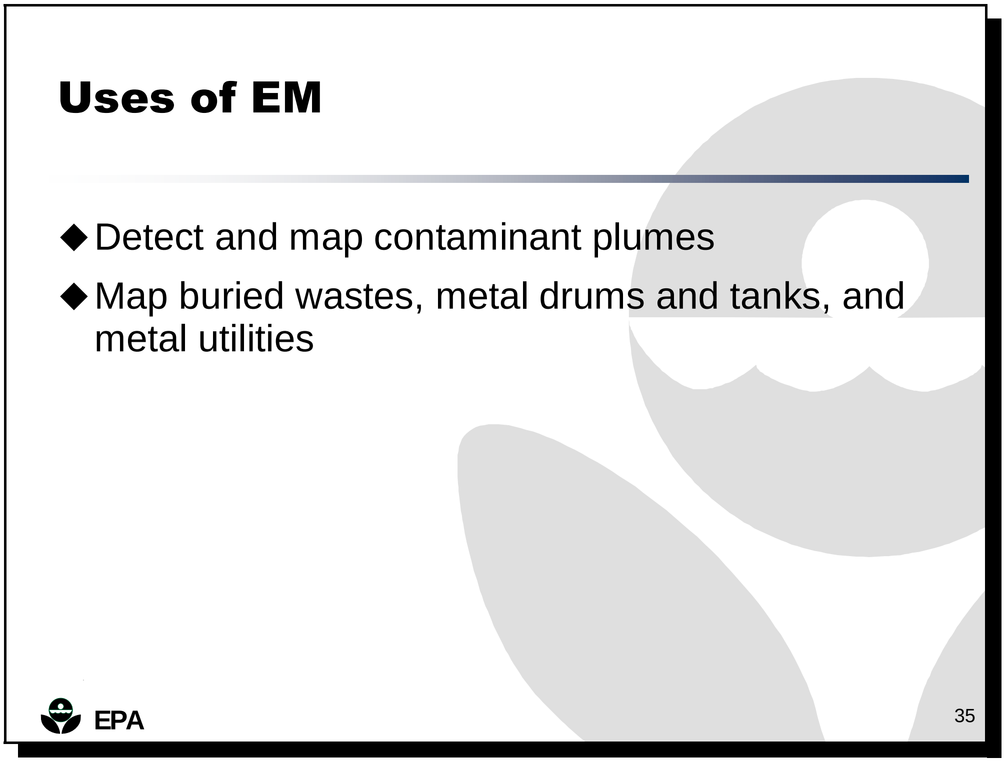
- The electromagnetic method (EM) measures electromagnetic properties of subsurface media and can determine subsurface variations of conductivity.

- This slide shows an EM31 terrain conductivity meter, discussed in more detail later in this section.

- This slide shows the components of an EM31 terrain conductivity meter. The EM31 is a fixed geometry instrument. The transmitter is located on one end and the receiver is on the other. In the center, near the operator, the electronics and data logger can be found.

- The EM31 can be used for bulk conductivity measurements up to about 18 feet in depth. A focused bulk conductivity measurement to about 7.5 ft can be obtained by rotating the instrument such that the transmitter and receiver coils are in the horizontal dipole position.

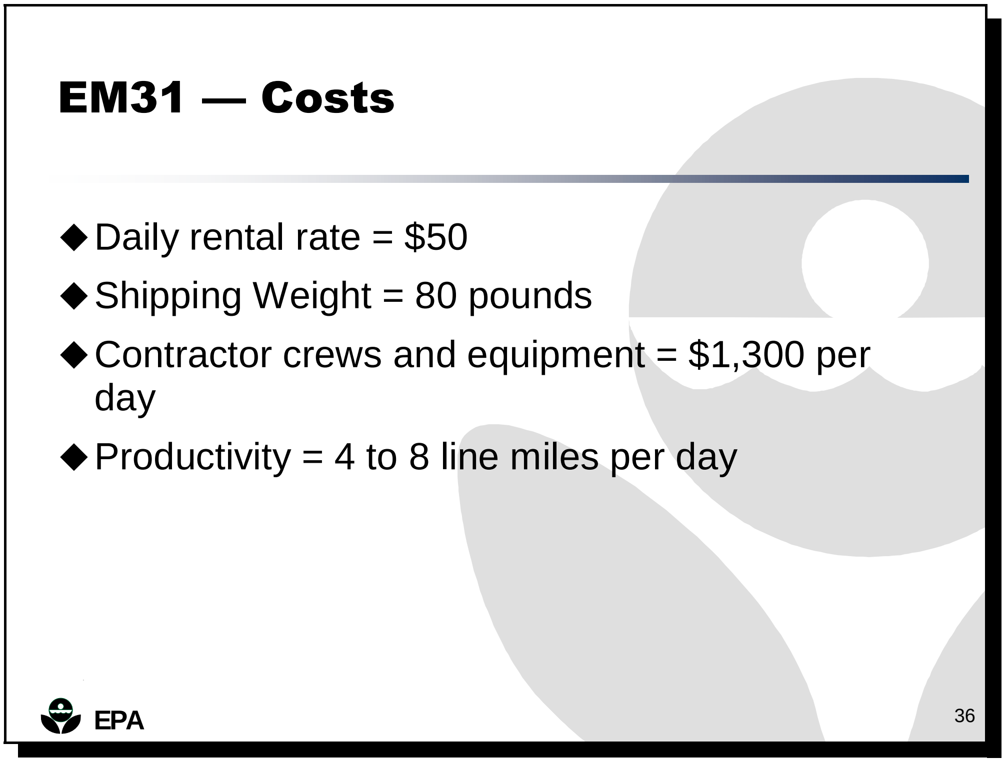
*Instructor:* *Ask the class why it may be useful to obtain both horizontal or vertical dipole measurements, or why one measurement may be favored over the other. The standard operation is the vertical dipole mode, for maximum depth of exploration.*




**Notes:**

C The EM terrain conductivity method can be used for mapping contaminant plumes. The method can be used to detect geologic areas that may be preferential pathways for contaminant migration.

C This method is also useful for detecting buried waste, drums, tanks, and utilities.




**Notes:**

C There are a number of vendors that rent geophysical equipment. Links to these vendors are provided later in this discussion. Typical rates for EM31, and other conductivity instrument equipment, are about $50 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,300 per day plus mobilization and reporting.

## Geonics EM34 Terrain Conductivity Electromagnetic System

EPA

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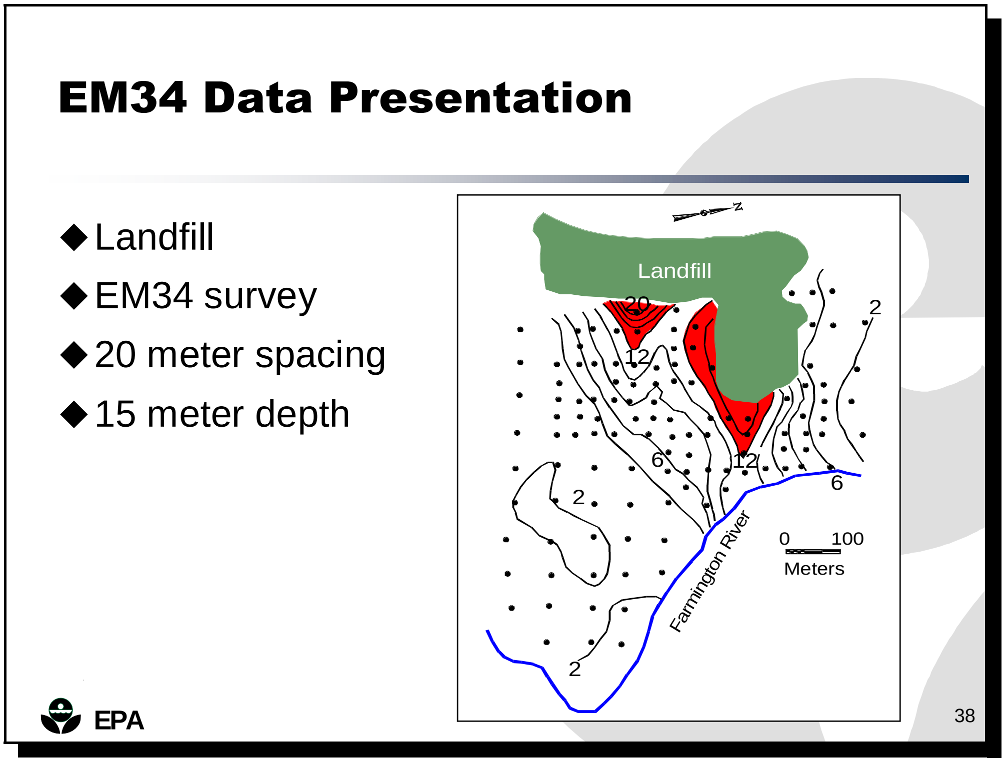
**Notes:**

- This slide shows a typical layout of an EM34 terrain conductivity meter. The transmitter and operator are in the background, and the receiver and operator are in the foreground.

- The EM34 is a variable geometry instrument. The transmitter and receiver can be separated at 10, 20 and 40 meters. Depth of exploration increases with increased coil separation. Maximum depth of exploration is about 100 ft.

*Instructor:* *Ask the class if they can provide examples where the EM31 or EM34 may be appropriate for geophysical surveys. Can they provide any example site?*

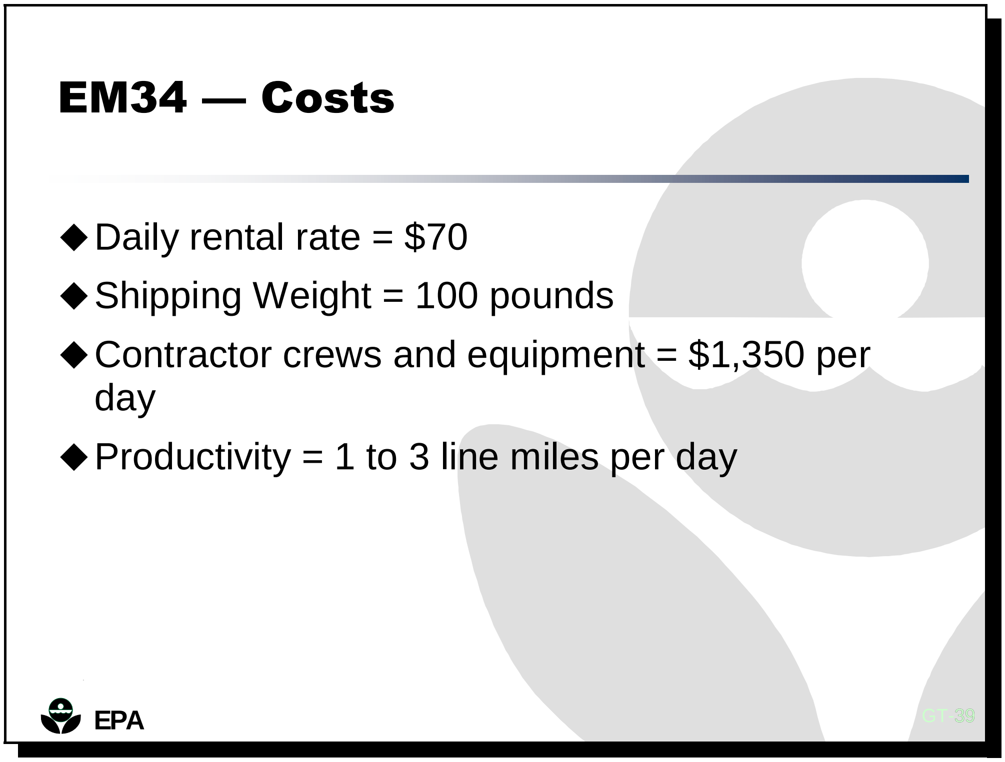



**Notes:**

C This graphic illustrates a simplified electromagnetic terrain conductivity survey over a landfill. The data was collected using a 20 meter coil separation using the horizontal dipole mode of operation. This results in a bulk apparent conductivity measurement to about 15 m or 50 feet in depth.

C This example illustrates an EM34 survey of a landfill.

*Instructor:* *Ask the class if they can determine what material is represented by the 2 millisieman measurements. Have the class look back to the chart on Slide SG-17 "Range of Electrical Conductivities in Natural Soil and Rock."*




**Notes:**

- There are a number of vendors that rent geophysical equipment. Links to these vendors are provided later in this discussion. Typical rates for EM34 conductivity instrument equipment are about $70 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,350 per day plus mobilization and reporting.

## Uses of Metal Detectors

- ◆ Used to locate buried metal containers, drums, tanks, and utilities
- ◆ Includes time domain (EM61) and frequency domain metal detectors

EM61

EPA

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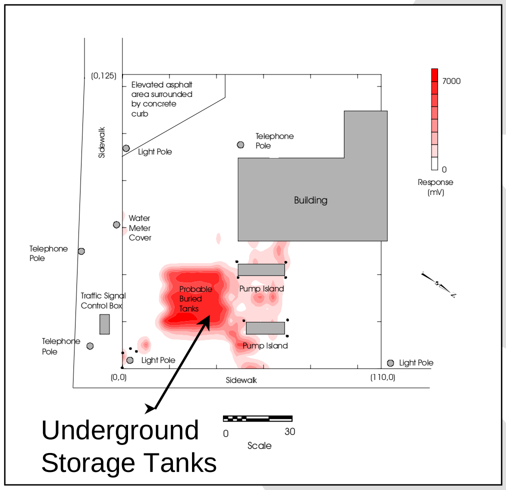
**Notes:**

C The Geonics EM61 is a time domain metal detector used to detect subsurface metals of all types.

C The system transmits a time varying electromagnetic pulse in the subsurface. The receiver measures secondary signals in the subsurface created in metallic objects. The measured quantity is the millivolt. Higher value measurements are related to either near surface or large objects.

C The Geonics EM61 is a cart mounted system with two coils. The lower coils acts as a transmitter and receiver. The upper coils acts as a secondary receiver used to estimate depth of burial. The operator carries a back pack and a data logger. The wheel system contains an odometer that triggers data collection at about 0.6 feet per measurement. The position is automatically recorded along with the signal measurement.

## EM61 Survey

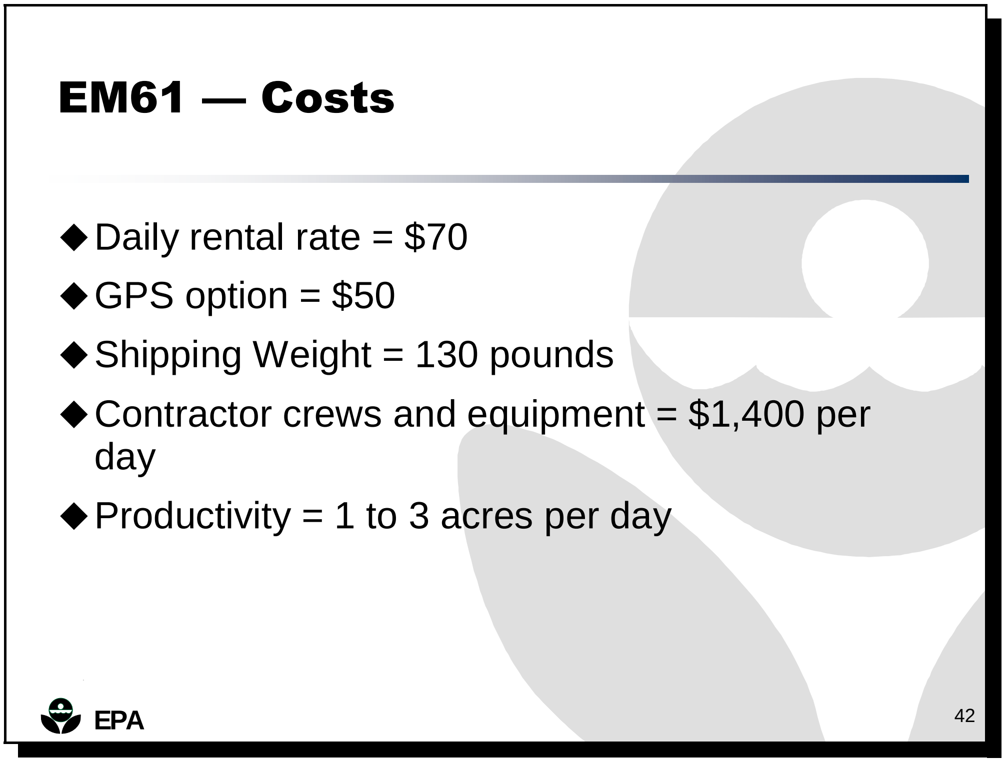



Abandoned Gas Station, East St. Louis, Illinois

EPA 41

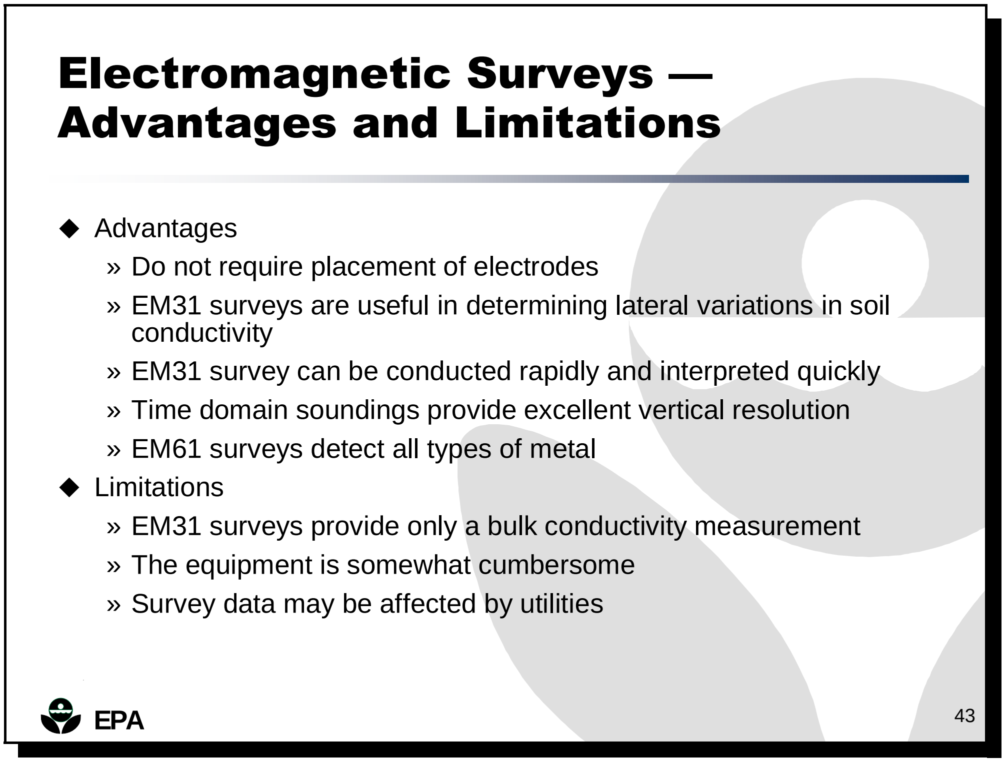
**Notes:**

- This map shows EM61 metal detector data from an underground storage tank survey at a gas station. The bar graph on the upper right shows the range of measured millivolt signal. The contours clearly increase in magnitude in the vicinity of the underground storage tanks.




**Notes:**

C There are a number of vendors that rent geophysical equipment. Links to these vendors are provided later in this discussion. Typical rates for EM61 equipment is about $70 per day. A GPS option is about $50 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,400 per day plus mobilization and reporting.




**Notes:**

C Electromagnetic surveys can be a cost effective way of determining the physical properties of the subsurface. Many methods are available including the EM31 terrain conductivity method, time domain electromagnetic sounding surveys, and EM61 metal detection, and other methods such as the GEM electromagnetic system. Limitations of electromagnetic surveys exist. These include effects from other electromagnetic sources such as power lines and other utilities. Some of the equipment may be cumbersome and require frequent rest during surveys.

## Case Study: Taylor Lumber, Wood Treatment Facility, Sheridan, Oregon

- Problem Statement:
  - » Identification of preferential flow paths for dissolved phase pentachlorophenol and cresote
  - » What is the configuration of the bedrock aquitard surface below the site and what impact will it have on the accumulation of dense non-aqueous phase liquids (DNAPL)?

EPA 44

**Notes:**

C At this active wood treatment facility, pentachlorophenol and cresotes are known to have impacted groundwater. Both of these contaminants also can occur as dense non-aqueous phase liquids (DNAPLs). This study uses both time domain electromagnetic soundings and inductive conductivity measurements to identify preferential flow paths (alluvial channels) and the topography of bedrock (a dense clayey siltstone) to focus follow-on monitoring and measurement activities.

## Taylor Lumber Site — Map

EPA

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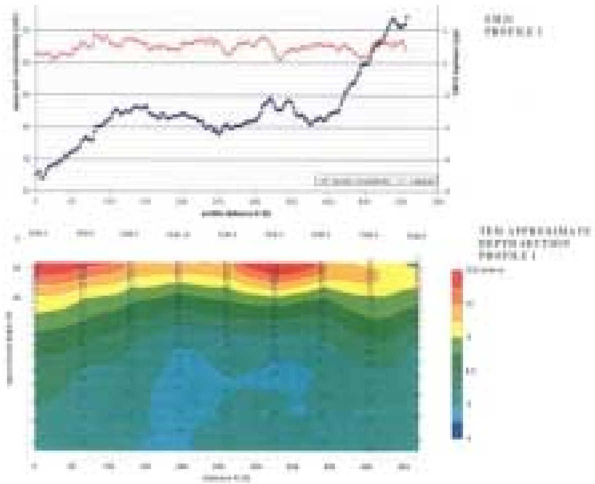
**Notes:**

C The slide presents a site map of the wood treatment site showing geophysical lines, TEM profiles, and sounding numbers.

## Taylor Lumber Site — EM31 Conductivity Profile 1 and TEM Resistivity Sections



EPA

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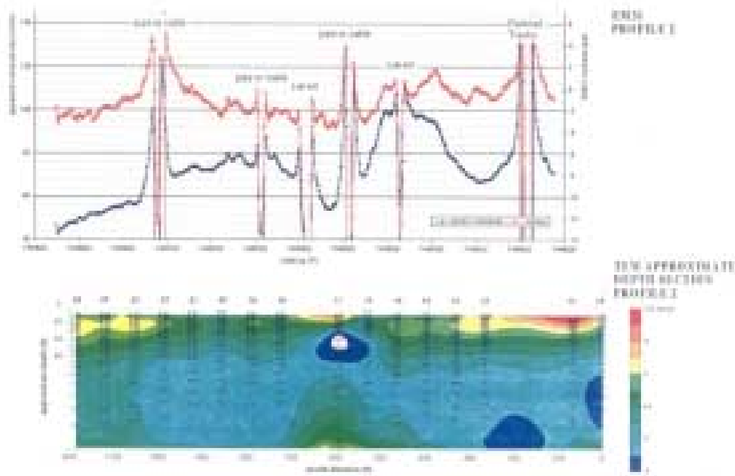
**Notes:**

C The slide presents an EM31 data plot and TEM approximate depth calculations versus resistivity section along Profile 1.

## Taylor Lumber Site — EM 31 Conductivity Profile 2 and TEM Resistivity Sections



EPA

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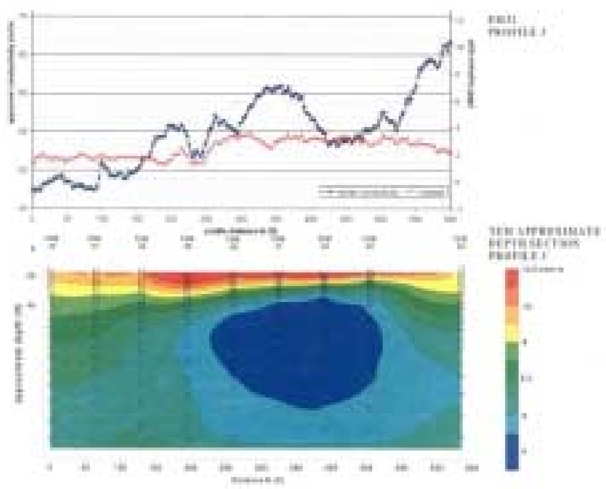
**Notes:**

C The slide presents an EM31 data plot and TEM approximate depth calculations versus resistivity section along Profile 2.

## Taylor Lumber Site — EM 31 Conductivity Profile 3 and TEM Resistivity Sections



EPA

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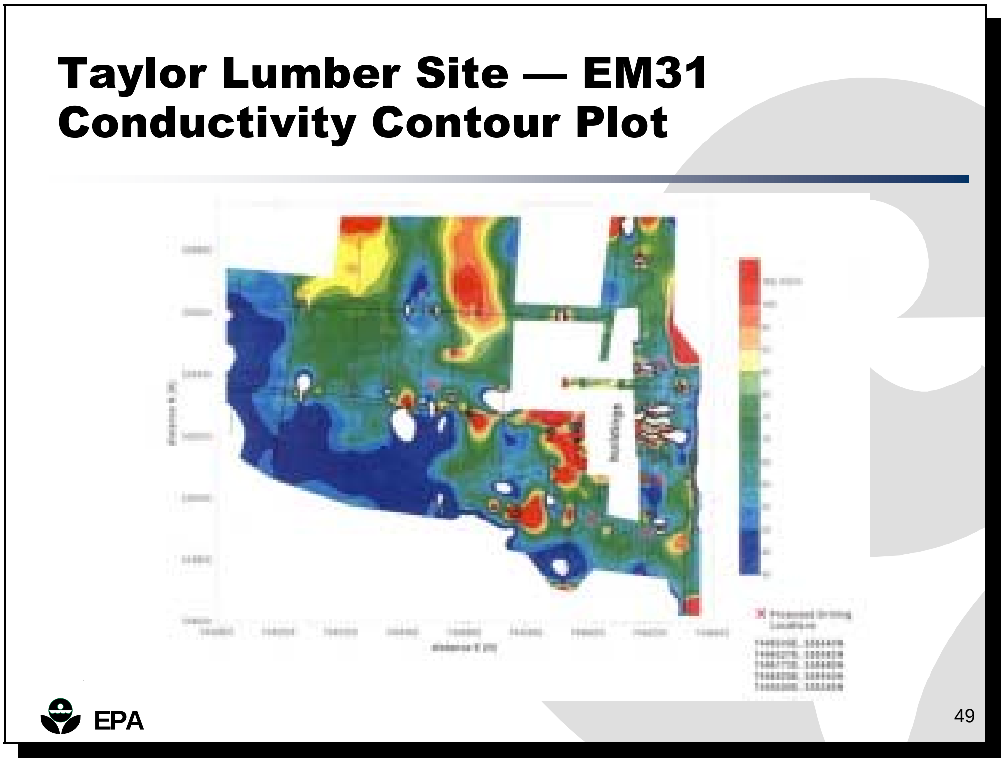
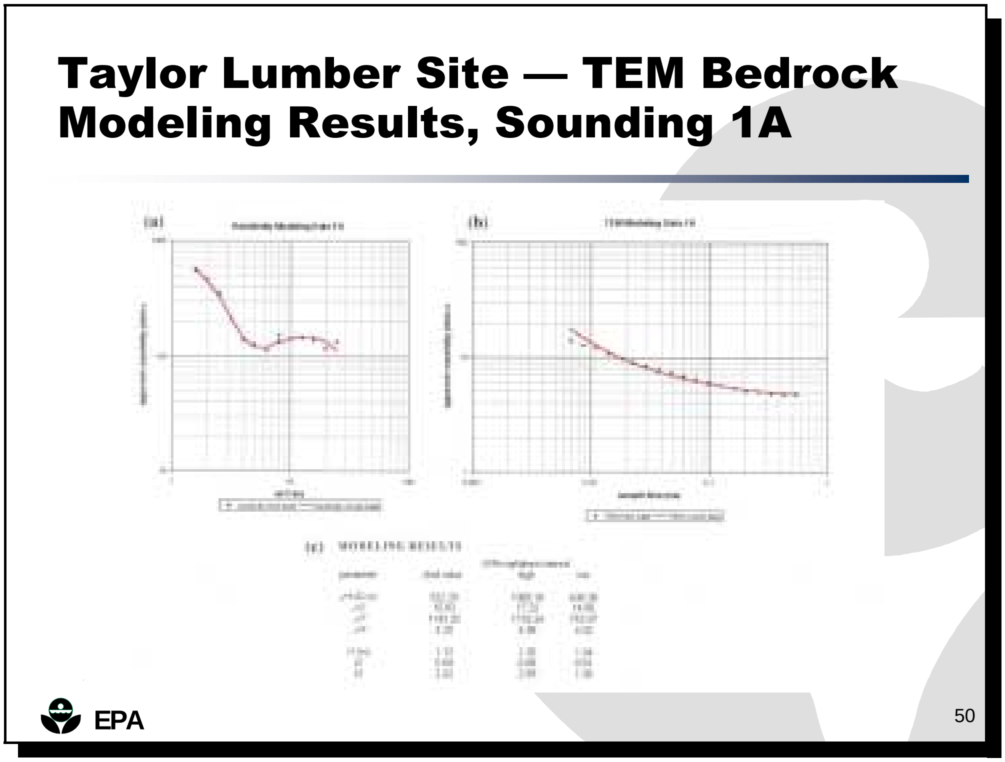
**Notes:**

- The slide presents an EM31 data plot and TEM approximate depth calculations versus resistivity section along Profile 3.




**Notes:**

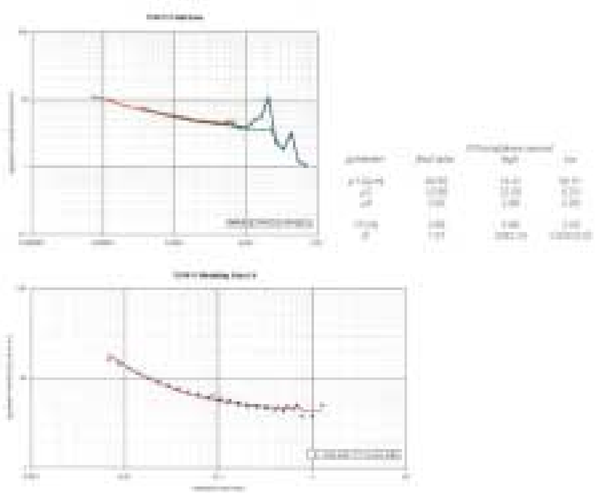
C The slide presents an EM31 terrain conductivity map for the entire wood treatment site.




**Notes:**

C The slide presents simultaneous inversion modeling results for the sounding TEM1A. The data fits are shown for (a) resistivity data, and (b) TEM data. TEM values are late-time apparent resistivities. Modeling results are presented in (c).

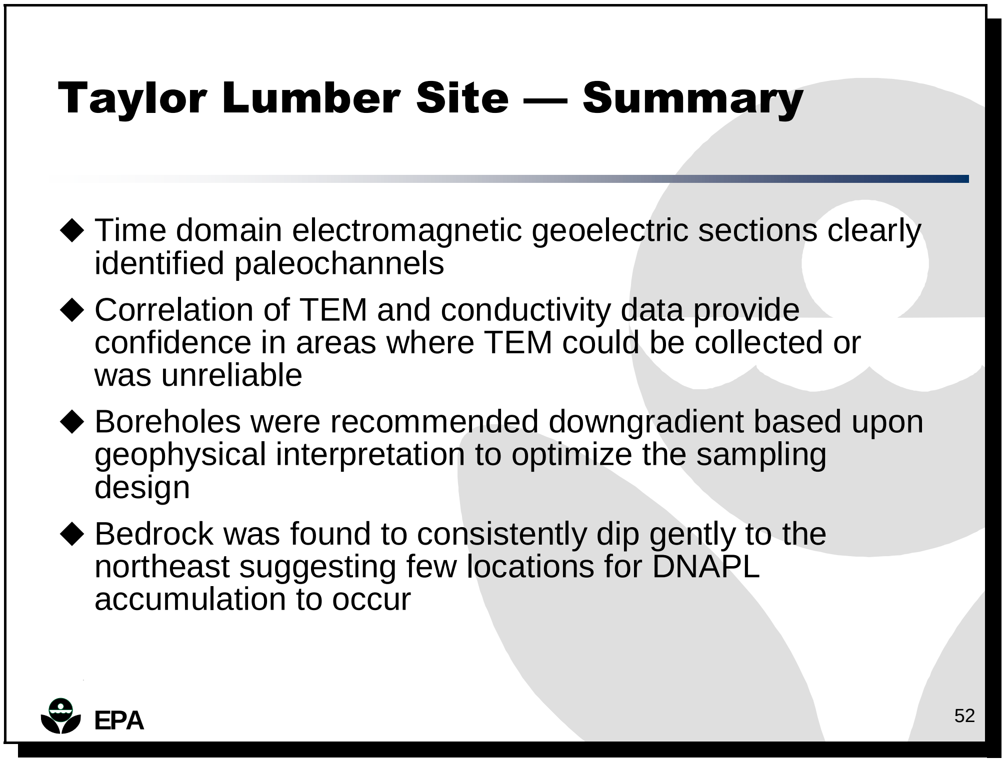
## Taylor Lumber Site — TEM Bedrock Modeling Results, Sounding 11



EPA 51

**Notes:**

- TEM 11 modeling results are presented in this figure. Note the following, (a) represents field data values using all time apparent resistivity, (b) are the results using late time apparent resistivity, and (c) is the resulting layered earth parameters and 95% confidence interval.




**Notes:**

C The combined use of the two techniques employed at the site were used to focus well placements downgradient of the facility within the paleochannels on the site. Coarse grained deposits most likely to act as conduits to transport the contaminants were localized within the southeastern portions of the facility.

## GPR Surveys — Physical Basis

- Principles of GPR
- Generation of the electromagnetic wave
- Propagation and scattering of the electromagnetic wave
- Applications
- Conclusions

EPA 53

**Notes:**

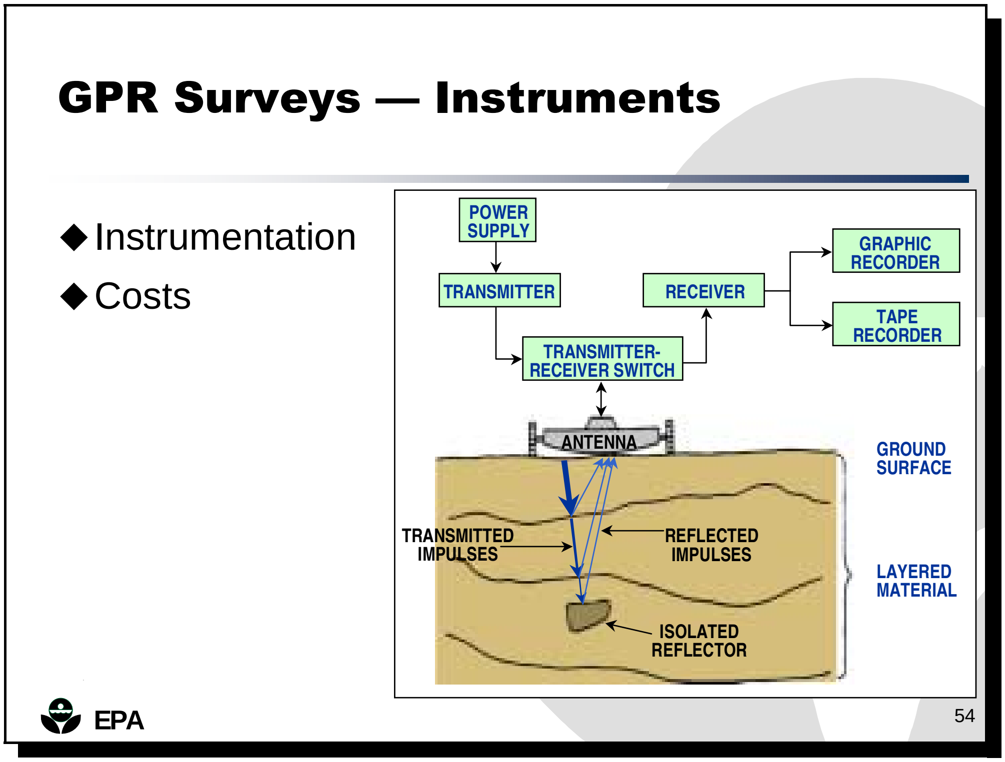
- GPR technologies use the transmission of pulses of electromagnetic energy (radar waves) into the ground. The signals transmitted travel into the ground and are reflected by buried objects. Reflected signals travel back to the receiving unit, are recorded, and are processed into an image.

- GPR transmitter antennas are designed to radiate a broadband pulse of only a few nanoseconds' duration when excited. For optimal performance, the GPR antenna should be positioned perpendicular to the ground surface.

- The propagation of electromagnetic waves in the subsurface is primarily dependent on the frequency of the wave, conductivity of the ground, soil moisture content, and relative permittivity of the subsurface. Abrupt changes in conductivity or relative permittivity create interfaces in the subsurface where reflection or refraction can occur.

- Under optimal conditions, GPR technologies are capable of detecting both metallic and nonmetallic objects.

- The main limitation of GPR is its reduced effectiveness in highly conductive soils (such as wet clay soils).




**Notes:**

C GPR instruments consist of a control unit, antennas and cables, a printer or digital data recorder, and a power supply. The control unit generates timing signals to key the transmitter on and off and synchronize the keying with the receiver. The unit controls the scan rate, the time range over which echoes are compiled, and the gain applied to the echoes. The transmitting antenna is excited by a semiconductor device (therefore, it is a transducer). A separate, but identical, receiver is used because echoes can return from near-surface targets before the transmitting antenna has stopped radiating. Transmitting antenna frequency ranges of 80 megahertz (MHz) to 500 MHz are used most often in environmental applications.

C GPR equipment can be rented for approximately $3,000 to $7,000 per month or $150 to $350 per day, depending on accessories. Typical mobilization fees are approximately $300.

*Instructor:* *Explain that the graphic provides a schematic illustration of a typical GPR system. Most instruments provide either digital or strip-chart recording of processed data. Data recorded digitally sometimes are enhanced through additional signal processing.*

## Uses of GPR

- Obtain cross-section of natural geologic and hydrogeologic conditions
- Locate buried man-made objects and structures
- Detect and map some contaminant plumes and buried wastes
- Best resolution of all surface geophysical methods
- Borehole

EPA 55

**Notes:**

C The typical display of GPR data shows a cross-sectional view of received reflections of the subsurface. Data processing and interpretation can provide a cross sectional representation of the subsurface in some cases.

C GPR is often useful in detecting man-made objects and structures including tanks, pipes and foundations.

C In site-specific instances, GPR has been effective in detecting contaminant plumes and buried waste.

C GPR, when it is applied in the optimum geologic or site setting, can provide the best resolution of subsurface conditions of all surface geophysical methods.

## Complete GPR System


EPA

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**Notes:**

C This is a photograph of a complete, portable GPR system, the Subsurface Interface Radar (SIR) 2 system developed by Geophysical Survey Systems Inc. (GSSI). The system consists of a real-time color display and controller that is carried by the operator, a battery pack, a thermal printer (for hard copies of data), and a GPR antenna. In this case, a high-frequency antenna is used to detect shallow targets — for example, to determine the thickness of reinforced concrete pavement.

## Low-Frequency Bistatic GPR Antenna

EPA

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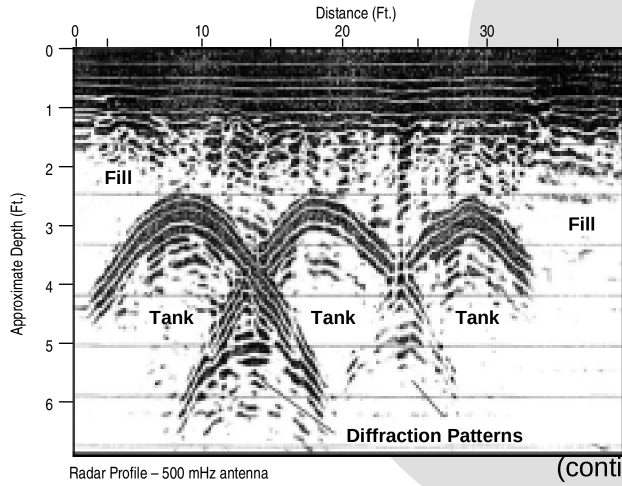
**Notes:**

- This illustration shows a pair of 100 MHz GPR antennae. The antennae are designed for deeper exploration. An operator is shown pulling the antennae across the ground surface. Also shown in the foreground is the cable that supplies power to the antennae and transmits signals back to the controller-receiver.

## GPR Surveys — Interpretation

- Profiles and qualitative signal for pattern recognition




EPA

(continued)

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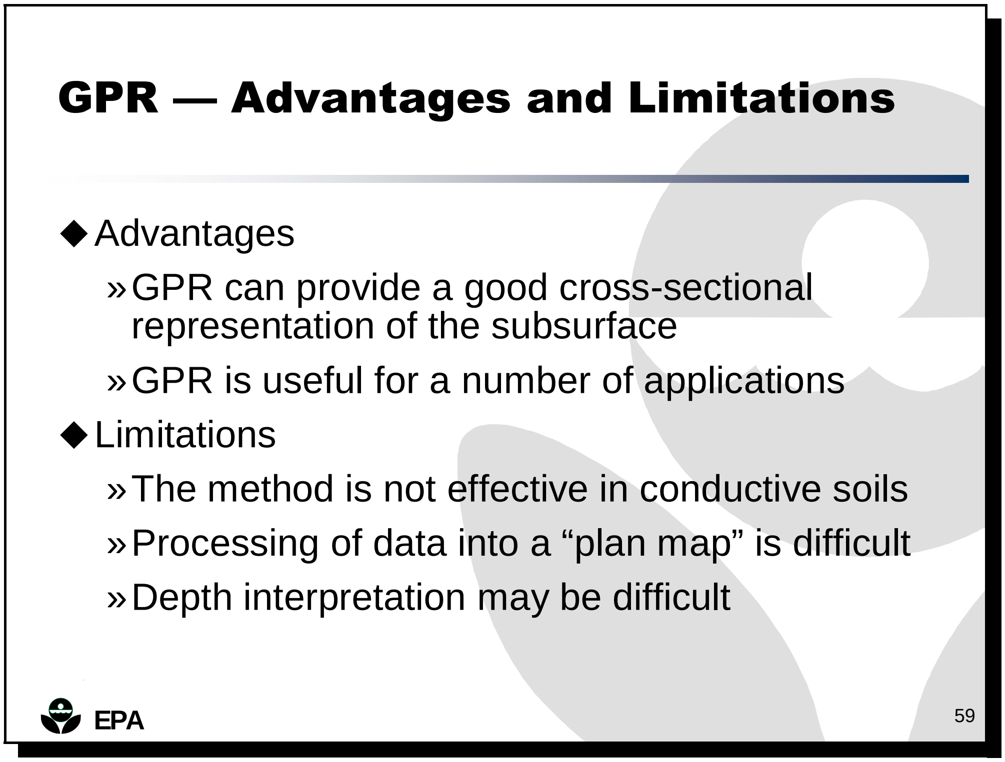
**Notes:**

- The interpretation of unprocessed GPR data is relatively subjective and yields only approximate information about the shape and location of buried objects. The depth of investigation typically is no greater than 10 to 15 meters and may be considerably less in soils that exhibit relatively high electrical conductivity. For example, a near-surface steel underground storage tank (UST) buried in sand could be completely invisible to GPR if it were covered by a 6-inch layer of highly conductive, clay-rich soil. Further, the equipment is relatively bulky, and its operation requires a power source (such as a car battery).

*Instructor:* *Use the "invisible UST" example noted to stress the utility of using more than one method to support the investigation. In that example, an inexpensive magnetometer or EM61 metal detector could be used to locate such a tank quickly.*

- This slide shows the interpretation of the data presented in the previous slide.




**Notes:**

- GPR surveys can provide a good cross-sectional representation of the subsurface. The method is useful for a number of applications such as detecting drums, utilities, shallow bedrock, fractures, and so on. The GPR method is very site specific. The method is effective only in low conductivity soils such as sands. Clay and silt (conductive soils) attenuate GPR signals and limit the depth of investigation. Lateral variations in soil affect the performance of the system. These lateral variations will also affect the interpretation about depth of measurement.

- The project team should carefully consider the limitations of GPR when considering the method for a site.

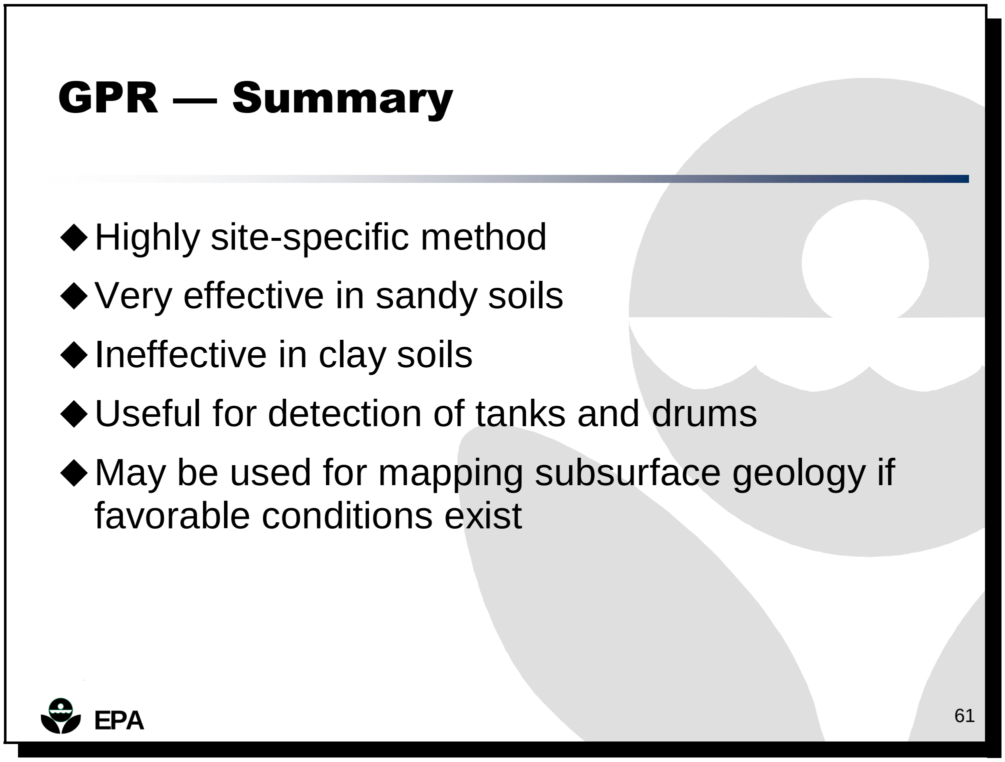
## GPR — Costs

- Daily rental rate = $105 to $225
- Accessory antenna = $25
- Shipping Weight = 100 to 200 pounds
- Contractor crews and equipment = $1,400 per day
- Productivity varies from 1,200 feet per day to more than 20 miles per day depending upon logistics and objectives

EPA 60

**Notes:**

C There are a number of vendors that rent geophysical equipment. Links to these vendors are provides later in this discussion. Typical rates for GPR equipment are about $105 to $225 per day. Shipping weights vary and should be considered in costing a project. If a contractor were hired to perform the work, costs can vary from about $1,400 per day plus mobilization and reporting.




**Notes:**

C GPR is useful only under certain site conditions.

C The method requires relatively low conductivity soils such as sand.

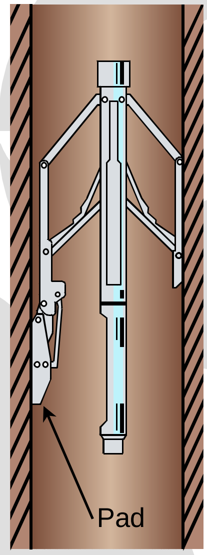
C The GPR method is not effective in clay soils or in areas where reinforced concrete is present.

C GPR can be useful for the detection of subsurface tanks, drums or for mapping subsurface geology, if favorable conditions exist.

*Instructor:* *Inform the class that it is important to have significant site knowledge before selecting GPR for a site investigation.*

## Borehole Geophysical Methods

- Direct measure of heterogeneity
- Geologic control and rapid interpretation of data
- *In situ* analysis of physical parameters
- Site-specific and inter borehole applications in combination with surface method results




(continued)

EPA

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**Notes:**

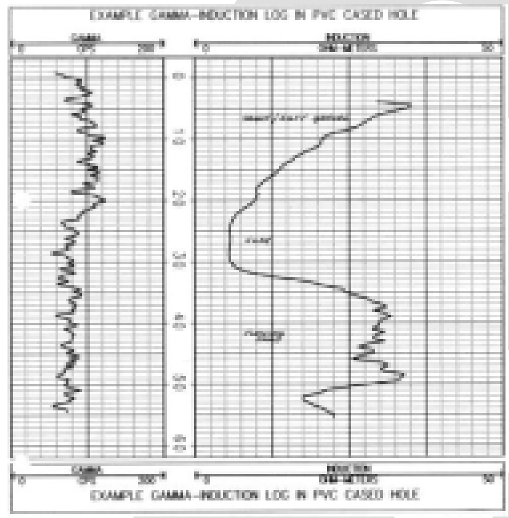
- Borehole geophysics can be used to obtain geologic data, including information about geologic control and *in situ* analysis of physical parameters, especially in heterogeneous conditions.

- With borehole geophysical data, rapid interpretation is possible. When combined with surface geophysics, application of borehole geophysical methods offers a three-dimensional understanding of conditions.

- Selection of a logging program should be considered carefully. Factors such as project goals, geophysical information desired, instrumentation, and surface and subsurface conditions will affect the logging program.

## Borehole Geophysical Methods

- Electrical and magnetic
- Nuclear (gamma and neutron)
- Caliper
- Sonic
- Video
- Nuclear magnetic resonance
- GPR




EPA

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**Notes:**

C Electrical and magnetic borehole logging techniques generally are used for (1) identifying general lithology, (2) performing stratigraphic correlation studies, and (3) performing water quality studies.

C Nuclear borehole logging techniques generally are used for (1) identifying clay and shale layers, (2) performing stratigraphic correlation studies, and (3) measuring bulk density, porosity, and moisture content.

C Caliper borehole logging techniques generally are used in conjunction with other borehole methods. The caliper log identifies changes in the diameter of the borehole as a function of depth.

C Sonic borehole logging techniques generally are used for (1) performing lithologic characterization, (2) measuring porosity, and (3) identifying fractures and solution openings.

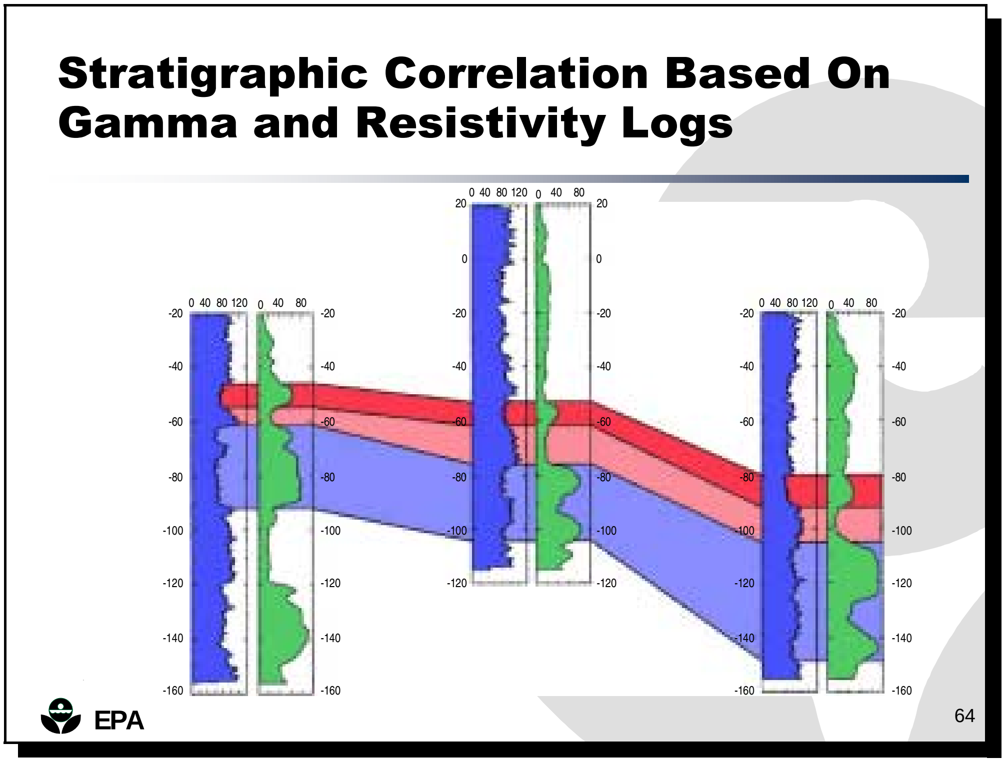
C Video borehole logging techniques generally are used for (1) inspecting the integrity of monitoring well casings, (2) identifying fractures and solution openings, and (3) performing lithologic characterization.

C Nuclear magnetic resonance techniques generally are used for evaluating porosity, permeability, moisture content, and water content.

C Other borehole logging techniques include (1) dipmeter surveying that identifies the correlation of sedimentary structures and fractures and (2) directional surveying that identifies the position of the borehole.

C It is important to understand that application of such methods as neutron and gamma-gamma (nuclear techniques) requires a radioactive source. Use of such sources generally requires a special license and may not be allowed in some states.

*Instructor:* *Inform participants that borehole logging techniques are traditional oil-field characterization tools that, in the environmental field, are not used as frequently as in situ and surface geophysical techniques.*

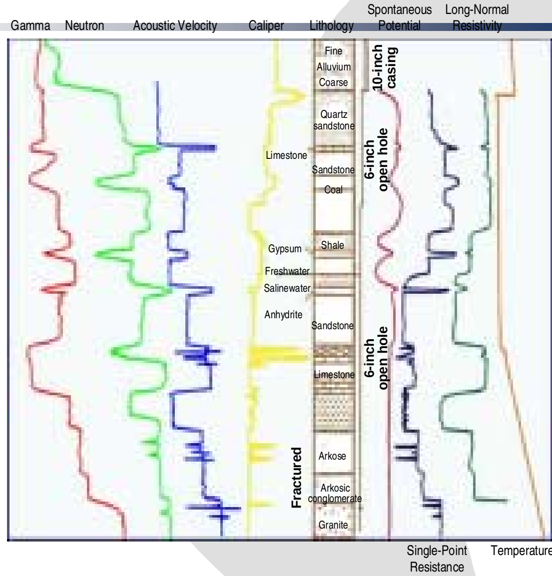



**Notes:**

- This illustration shows three boreholes spaced approximately 100 feet apart. The vertical differences are related to changes in surface elevation. Notice the similarities in the measured gamma and resistivity from borehole to borehole in this example of stratigraphic correlation of geologic units. The gamma data are shown on the left, while the apparent resistivity is shown on the right of each borehole. Low resistivity and high gamma count are likely related to clay zones or fine-grained geologic materials.

## Overview

- Instrument packages and coincident grid surveys




EPA

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**Notes:**

C It is common practice to combine several instruments (for example, caliper, gamma ray, and neutron) in one "package" and obtain measurements simultaneously in a single downhole logging run. Similar approaches are used for surface geophysics when two or more sensors are mounted to a survey vehicle in a package format. Both downhole and surface geophysics approaches use multiple sensors or instruments to obtain measurements during a single run or transect. As an alternative, two or more sensors can be used in the same borehole or along the same transect, but not simultaneously. That approach often is referred to as coincident surveying or the multisensor approach.

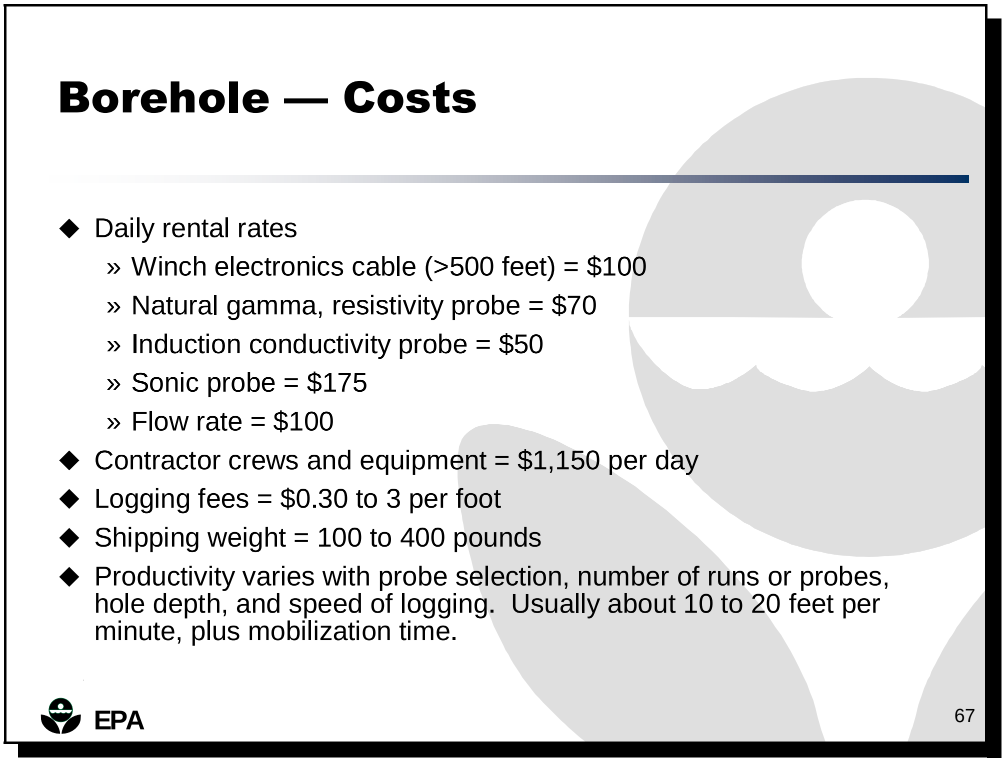
## Borehole — Advantages and Limitations

- Advantages
  - » Assists in determining details missed in geologic lithologic logs
  - » Assists in the selection of surface geophysical tools and interpretation
- Limitations
  - » Most probes can only be used in open holes

EPA 66

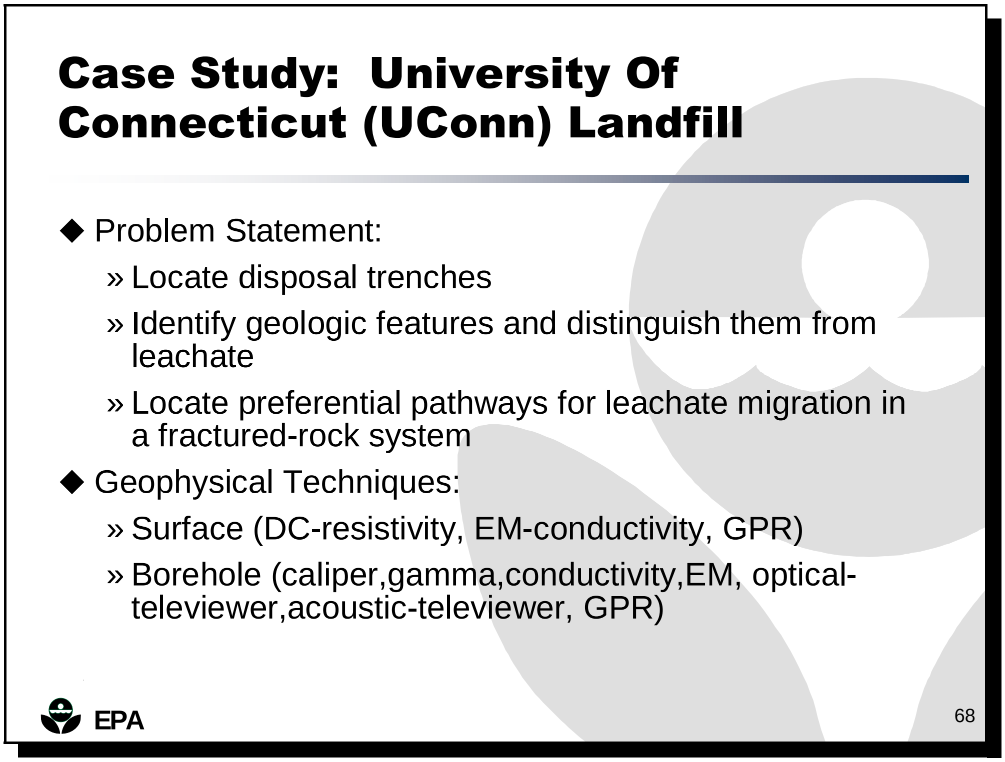
**Notes:**

- Borehole geophysical surveys are useful for the determination of specific details about a geologic formation that may be missed in some borehole situations. The borehole tools can provide detailed information about the physical properties of the subsurface. These physical properties can assist in the selection of the proper geophysical tool to use for surface geophysical surveys. Consideration of borehole techniques should be conducted in advance of construction of monitoring wells or well completion. Uncased holes can be used by a variety of borehole tools. PVC-cased holes can be surveyed using natural gamma and electromagnetic induction conductivity. Steel-cased holes can be used by limited borehole techniques.




**Notes:**

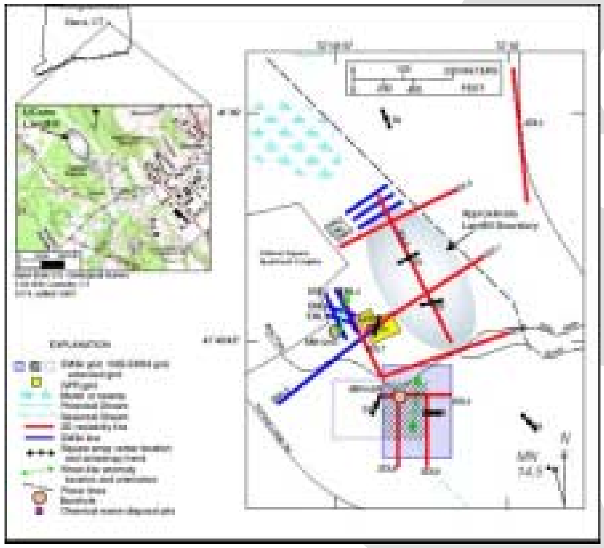
C Daily rental rates are wide ranging for borehole systems. A common system includes the winch, basic Natural Gamma - Resistivity - Self Potential probe and costs about $170 per day. Additional probes are from about $50 up to about $175 per day. Shipping costs are a consideration due to the length of probes and weight of the system. A contractor may charge about $1,150 per day plus logging fees per foot. Typical logging rates are about 10 feet per minute depending on resolution and probe used.




**Notes:**

C An integrated suit of geophysical methods were used to characterize the hydrogeology of a fractured bedrock aquifer to identify contamination or pathways for contamination migration near a former landfill at the University of Connecticut (UConn). Surface methods were used to identify the dominant direction of fracture orientation and to locate potential leachate plumes.

## UConn Landfill — Survey and Borehole Locations



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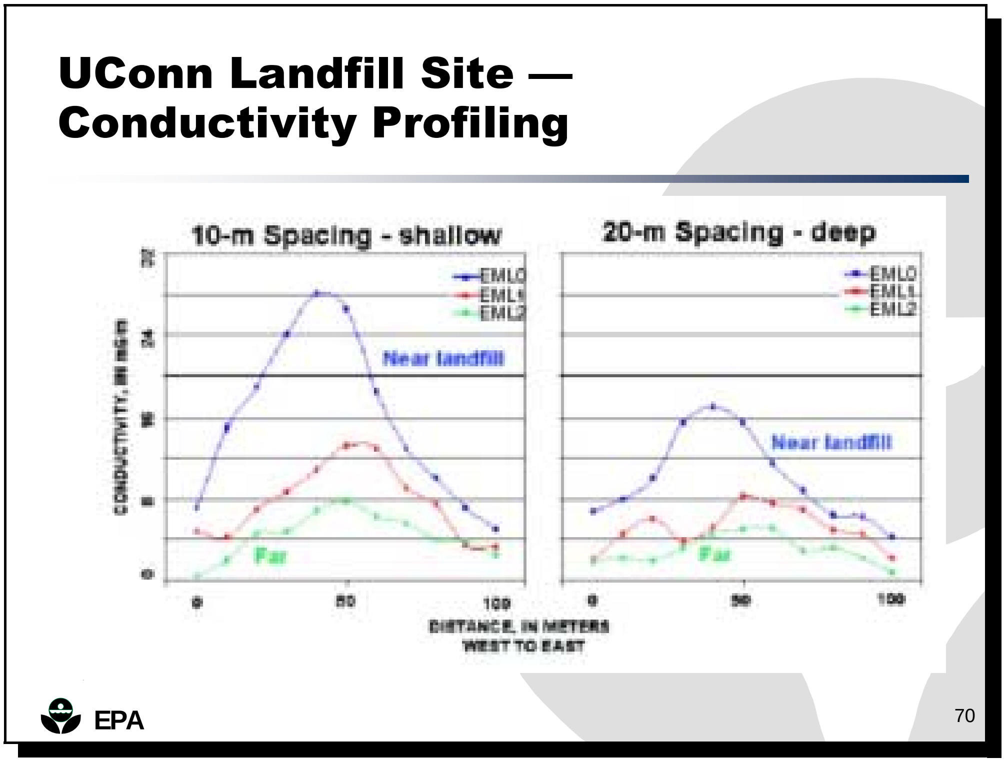
**Notes:**

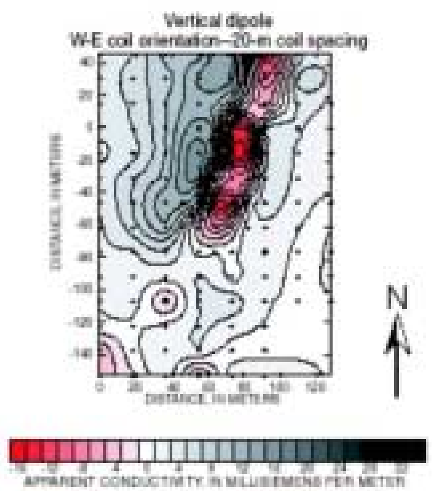
- The UConn campus is located in Storrs, Connecticut, in the northeastern part of the state. The study area occupies a north trending valley with highlands to the northeast and southwest. The 5-acre landfill is situated over a minor groundwater divide that drains to the north and south along the axis of the valley. Surface runoff flows north through a wetland towards Cedar Swamp Brook and south toward Eagleville Brook through a seasonal drainage. The study area is bounded on the east by a steep hill and on the west by minor hills. Bedrock is folded, faulted and fractured schist and gneiss with sulfide layers. The bedrock aquifer is overlain by glacial till and unconsolidated deposits from zero to six meters thick.




**Notes:**

- The slide presents the inductive terrain-conductivity measurements collected using the Geonics EM34 for three lines at the north end of the landfill study area with 10-meter spacing on the left and 20-meter spacing on the right.

## UConn Landfill Site — Contoured Conductivity and Model

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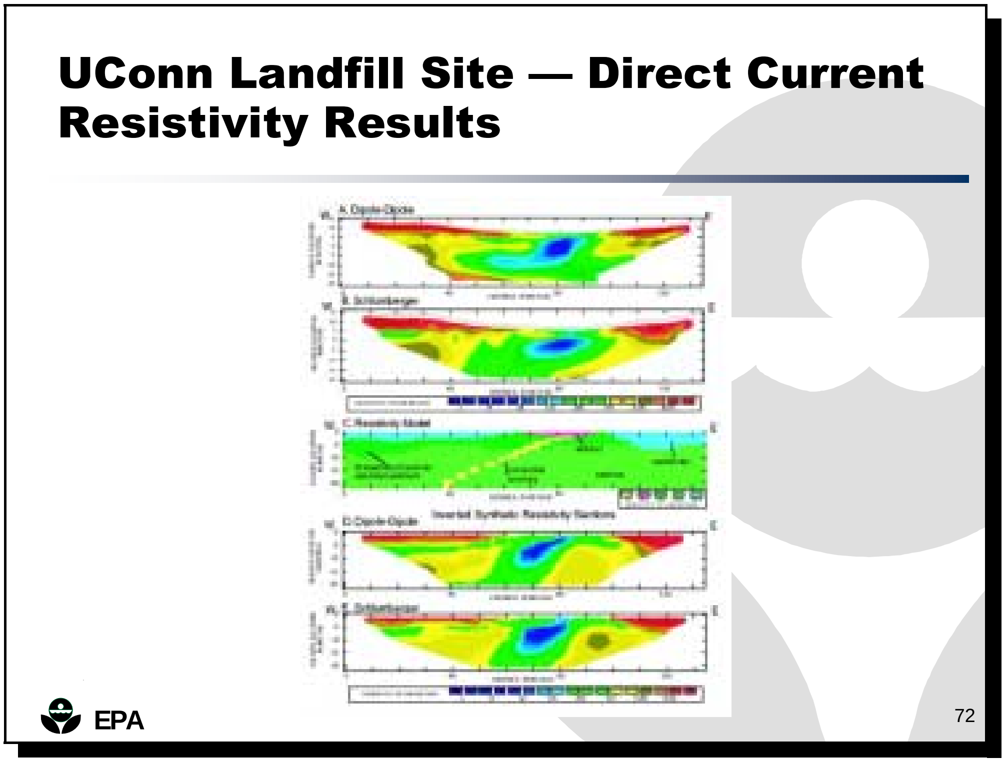
**Notes:**

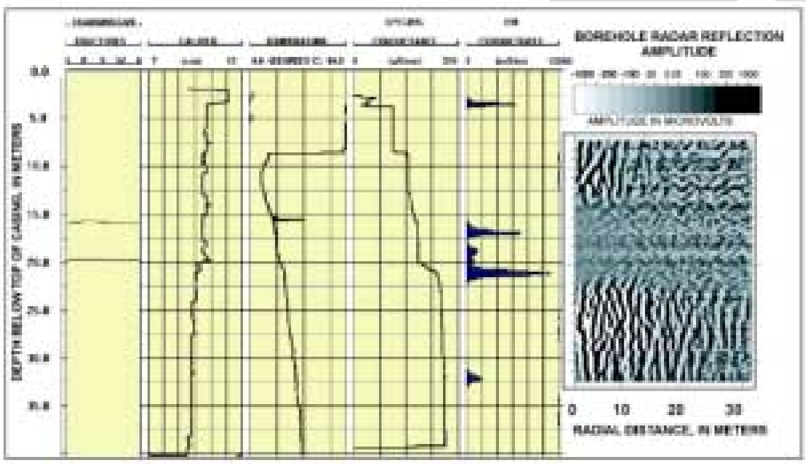
- The slide presents the contoured terrain conductivity from the EM34 using vertical dipole orientation with 20-meter separation from the grid. The bottom figure represents the conductivity response curve generated by a forward modeling program and using the data from the grid at the UConn Landfill.




**Notes:**

C The slide presents inverted resistivity sections generated from a modeling program. From top to bottom, the dipole-dipole array, schlumberger array, resistivity model, dipole-dipole array inverted synthetic resistivity sections, and the inverted schlumberger array inverted synthetic resistivity sections. Data were collected with 5-meter spacing between electrodes.

## UConn Landfill Site — Borehole Logs and Borehole Radar MW 121R




EPA

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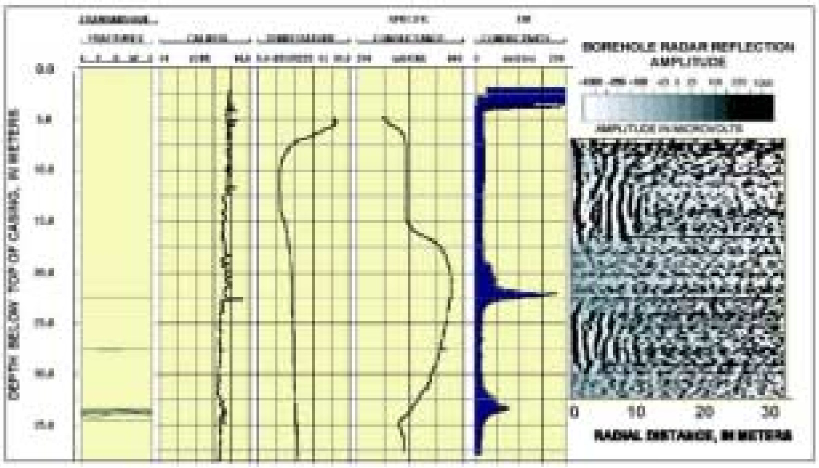
**Notes:**

- The data presented in this slide is from borehole MW121R.  It includes caliper, temperature, conductance, and conductivity information along with Transmissive Fractures on the left and borehole radar on the right.

## UConn Landfill Site — Borehole Logs and Borehole Radar MW 105R




EPA

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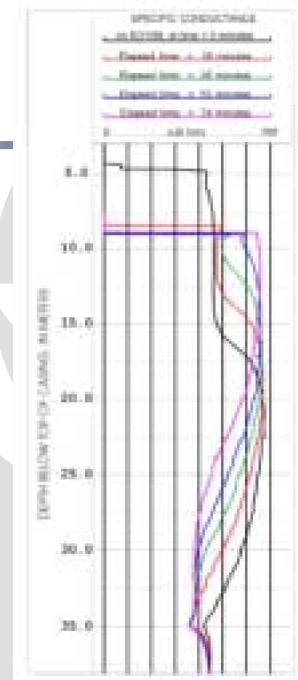
**Notes:**

- The data presented in this slide is from borehole MW105R. It includes caliper, temperature, conductance, and conductivity information along with Transmissive Fractures on the left and borehole radar on the right.

## UConn Lanfill Site — Specific Conductivity – Pump Test

**Fractures at 22 meters less conductive then ones at 34 meters**



EPA

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**Notes:**

C Shown in this slide is the specific conductivity in MW105R, in response to pumping at a rate of 3.7-liters per minute. Individual logs shown are for elapsed time in minutes from the start of the pumping.

## UConn Landfill Site — Summary of Geophysical Investigations

- Surface geophysical methods were used to identify extent of disposal trenches and most likely potential contaminant pathways for further study
- Borehole results constrain interpretations of surface methods allowing for the distinction between geologic features and leachate plumes
- Without the use of geophysical methods identification of preferred pathways would have been extremely difficult

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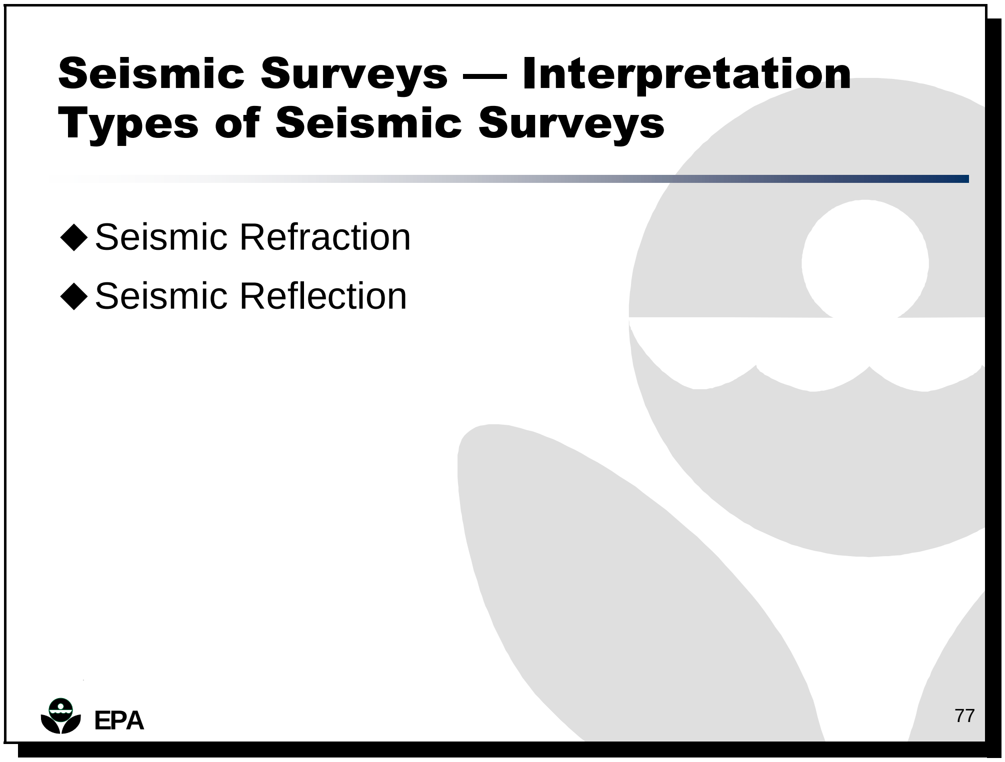
**Notes:**

C Surface geophysical surveys were used to identify potential contamination pathways at the UConn landfill using electromagnetic and electrical geophysical methods. Additional borehole geophysical tools were used to characterize hydrology of the bedrock. Measured high electrical conductivity zones confirmed the presence of sulfide-rich layers in the bedrock. Borehole results constrained the interpretation of surface investigations and the overall survey demonstrates effectiveness of combined methods to evaluate an electrically conductive fracture system that could represent a preferred pathway for the migration of chlorinated solvent known to be present at the site.



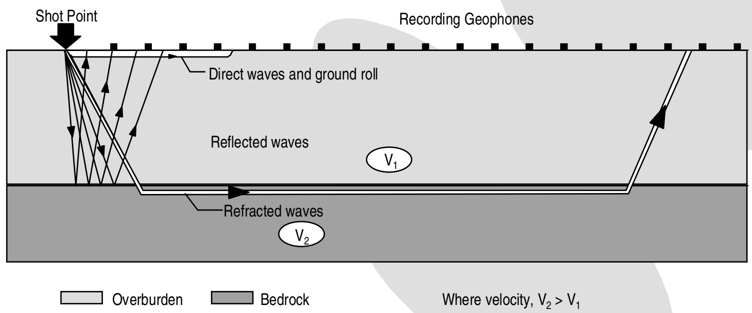

**Notes:**

C There are two types of seismic surveys employed for environmental investigations, seismic refraction and seismic reflection.

*Instructor:* *Inform the class that the next slides will discuss some basic information about the mechanics of seismic refraction and reflection followed by some example field data results.*

## Seismic Surveys — Physical Basis

- Types of elastic waves
- Seismic velocities
- Interface effects

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**Notes:**

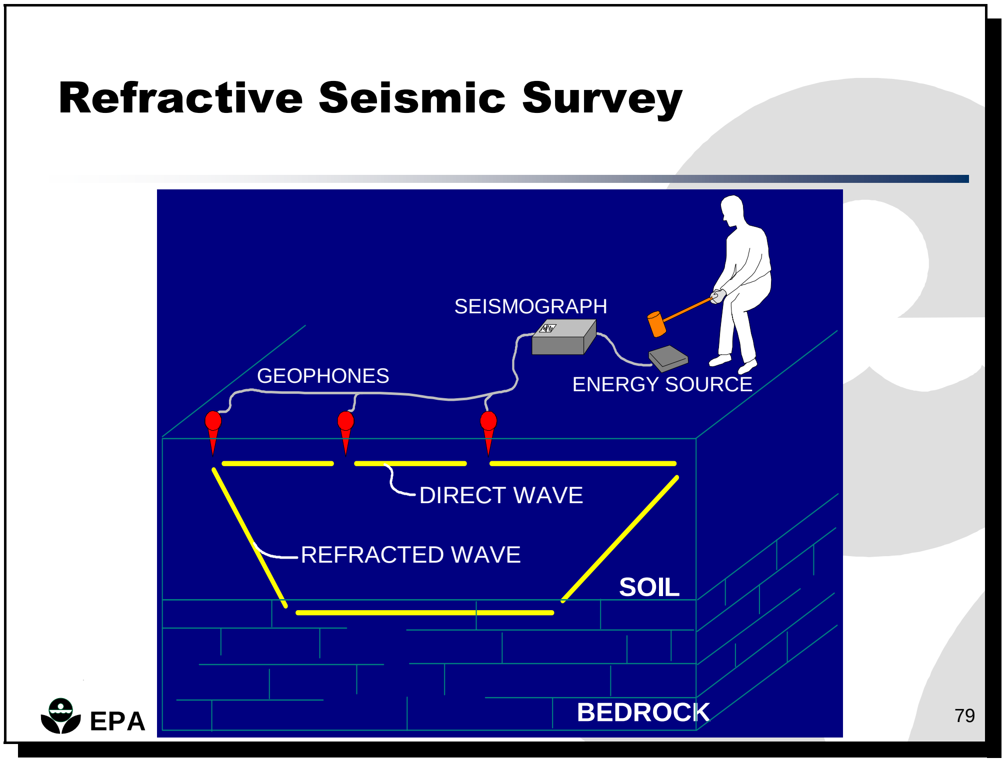
- When a sound wave travels in air, the molecules oscillate backward and forward in the direction of energy transport. This type of wave propagates as a series of compressions and expansions. It is referred to as a P-wave.

- P-waves propagate in a solid matrix as do S-waves, which are oscillations at right angles to the direction of energy transport. P and S wavefronts expand throughout the matrix and are termed body waves.

- In both refraction and reflection surveys, information about subsurface conditions is derived by evaluating the travel times of various wavepaths between sources and receivers.

- As is the case with EM and sonic waves, scattering phenomena (including refraction and reflection) and energy partitioning occur when a seismic wave encounters an interface between two different types of rock.

*Instructor:* *Explain that the graphic illustrates some of the various wave partitioning phenomena that can occur in a two-layer stratigraphic system.*

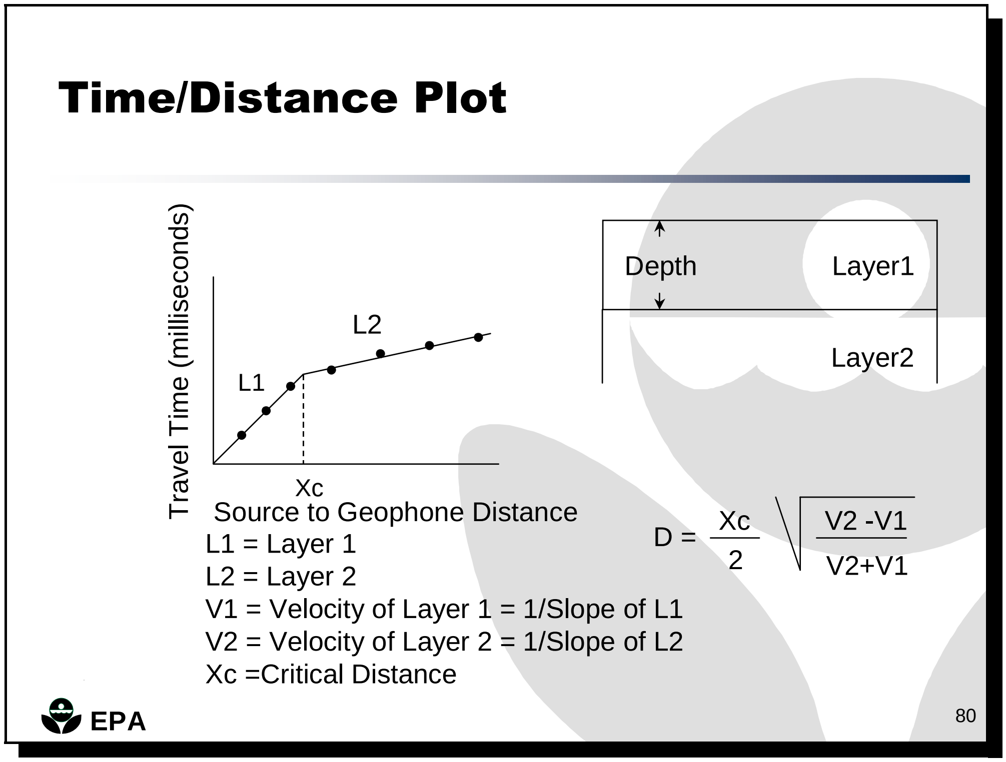



**Notes:**

- Refracted waves travel down through the overburden, are critically refracted below the interface of the overburden and the bedrock, and then travel upward through the overburden to the geophone. Along those paths, refracted waves travel at bedrock velocities below the interface of the overburden and the bedrock and at overburden velocities along the upward and downward paths.

- This slide illustrates a simplified example of refractive seismic survey.

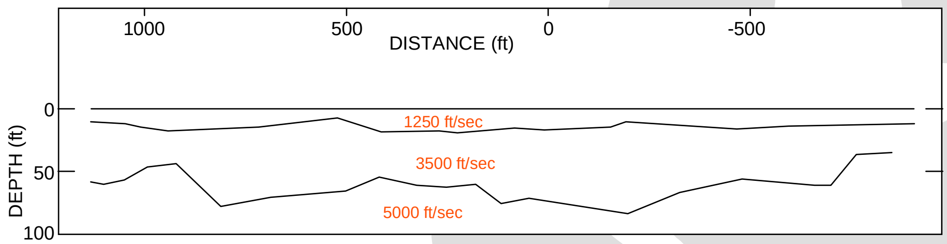
- A generalized refraction seismic survey uses 12 geophones as a minimum. Typical seismic sources include a sledge hammer, mechanical elastic wave generator or explosives.




**Notes:**

- This slide shows a graphical representation of refraction data and calculation of geologic material velocity.

## Refraction Analysis

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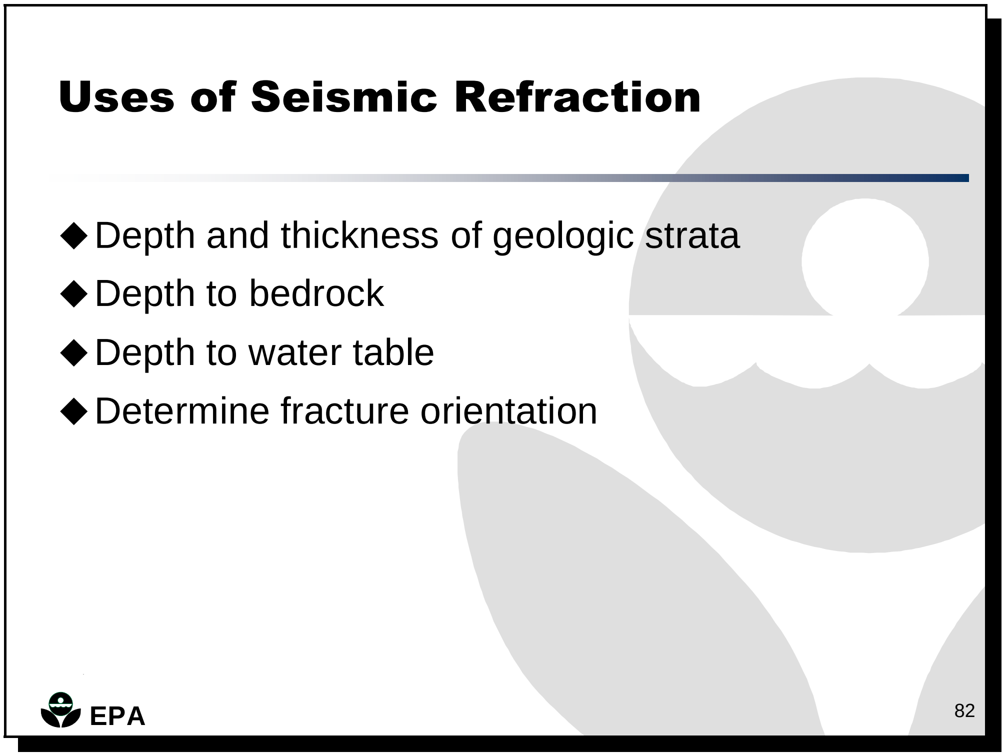
**Notes:**

- The profile shows variations in velocity among three layers. Low velocity likely represents unconsolidated sediments, while the high velocity represents bedrock.




**Notes:**

- Seismic refraction may be used to determine the depth and thickness of geologic strata, the depth to bedrock, the depth to the water table, and fracture orientation.

## Seismic Refraction — Advantages and Limitations

- Advantages
  - » Determination of depth and soil/rock velocity
  - » Infer soil competency, weathering, fractures
  - » Acquisition and processing less expensive than reflection
- Limitations
  - » Resolution less than reflection surveys
  - » Large impact source may be required
  - » Increased rock velocity with depth required
  - » "Hidden layers" may be detected, but possibly not interpreted

EPA

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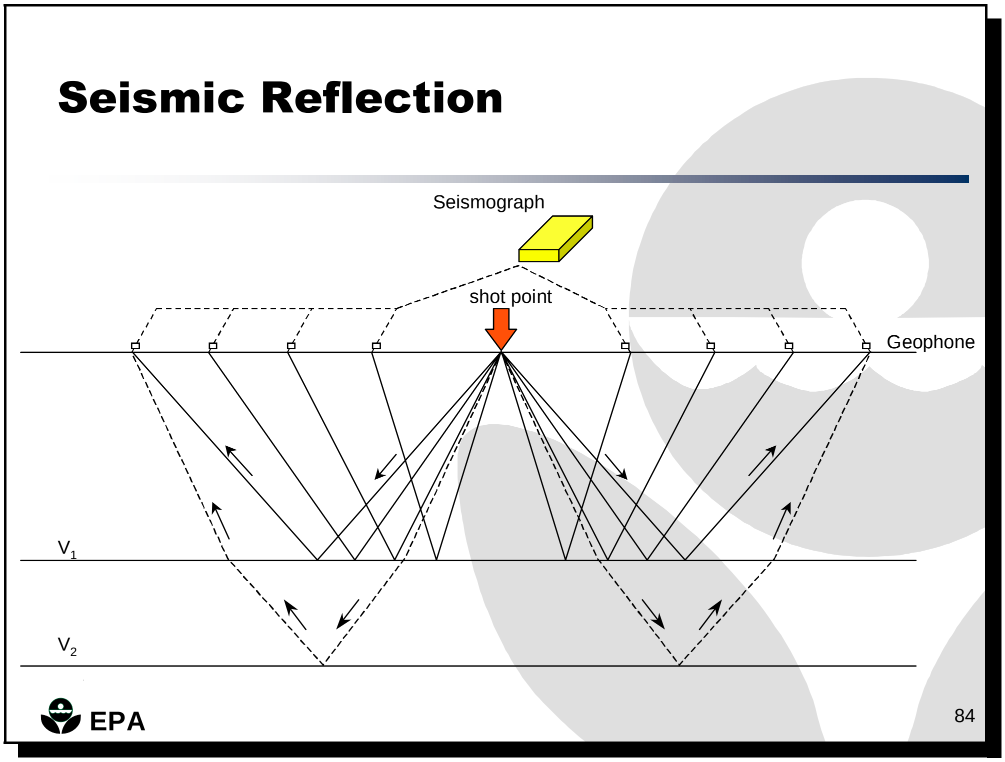
**Notes:**

C Seismic refraction surveys are less costly than reflection surveys. Many parameters about the subsurface may be derived from the data including competency, "rippability," degree of weathering and fractures. Acquisition and processing costs are less than seismic reflection surveys. The method does however require an increased soil or rock velocity with depth. Hidden layers, layers imbedded within a low velocity layer, may be hidden, within the data, but may not be defined.



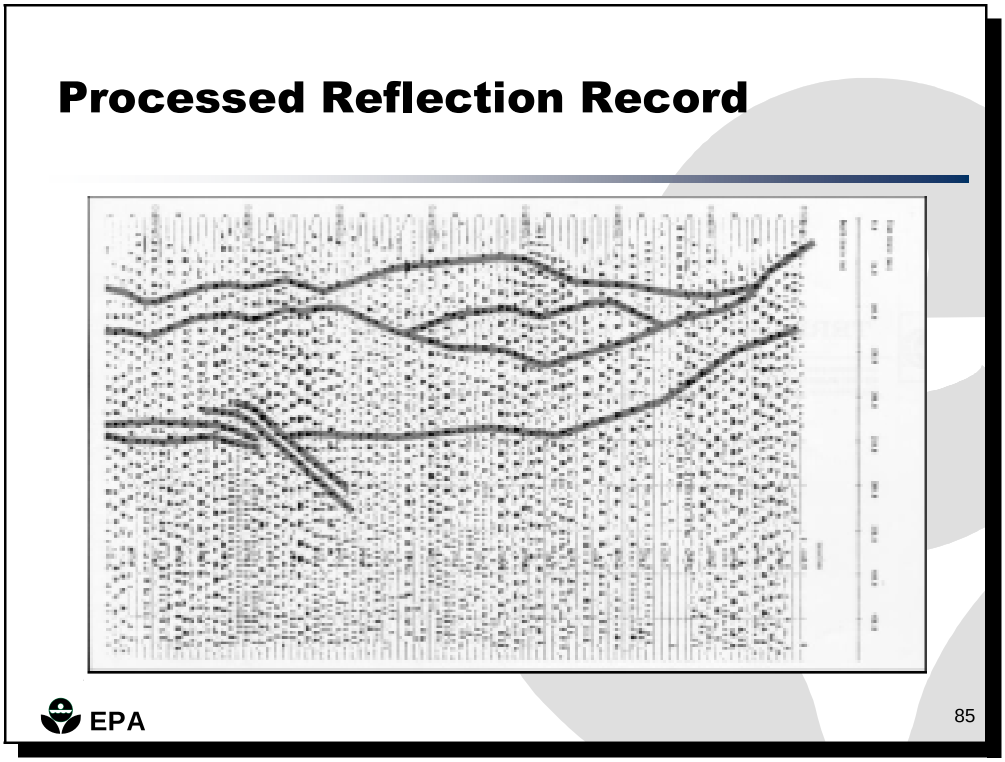

**Notes:**

C Reflected waves travel down to the interfaces of the overburden and the bedrock and are reflected back up at the same angle to the geophone. Reflected waves travel at overburden velocities along their entire paths.

*Instructor:* *Inform the class that the following slides deal with interpretation of seismic reflection and refraction data. The slide shows a recording truck on the surface. Notice the seismic record indicates early arrivals near the truck and later (apparently deeper) arrivals at a distance from the truck. This phenomenon is likely due to the source near the truck location. Also shown in the illustration is a geophone. Perhaps discuss how the geophone is designed.*

C Seismic reflection surveys usually require additional equipment including an increased number of recording geophones and a good energy source for generating signal. This may include a vibration source.

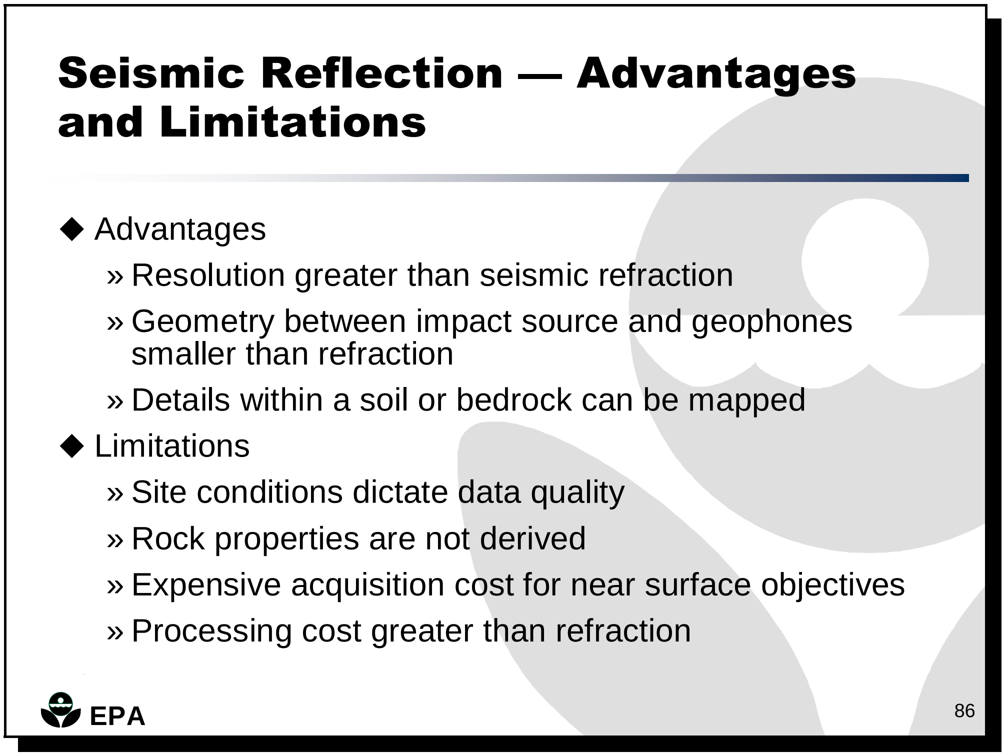
*Instructor:* *Inform the class that the following slide shows simple processing and interpretation of seismic reflection data.*




**Notes:**

C The final product of a seismic reflection survey is obtained after significant processing of data. Distance versus time plots are converted into distance versus depth plots. Often, layers or structure is plotted on the interpretation map.

*Instructor:* *Inform the class that the seismic reflection method is useful for obtaining detailed information about subsurface geologic layering and structure.*




**Notes:**

C Seismic reflection surveys can provide a great resolution of the subsurface. The method is somewhat site specific in that data quality may be in question in some situations such as urban environments, areas where the impact source has problems such as in loose soils or high water table. Acquisition and processing can be costly.

## Seismic Survey (Refraction) — Costs

- Daily rental rate = $135
- Accessories = $100 to $300
- Shipping Weight = 150 to 600 pounds
- Contractor crews and equipment = $2,000 to $2,500 per day
- Productivity varies from about 1,200 linear feet per day to several miles depending upon logistics, objectives, and depth of investigation

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**Notes:**

C Daily rental rates range from about $135 for seismograph and $100 to $300 for geophones, cables and impact source. Several vendors are available to provide equipment. Shipping weighs are a major consideration due to cost factors. A contractor crew may charge about $2,000 or more per day plus the processing and report costs. Productivity varies due to site conditions.

## Seismic Survey (Reflection) — Costs

- Daily rental rate = $150 to $300
- Accessories = $100 to $1,000
- Shipping Weight = equipment often is transported
- Contractor crews and equipment = $3,500 to $5,000 per day
- Productivity varies from about 1,200 linear feet per day to several miles depending upon logistics, objectives, and depth of investigation

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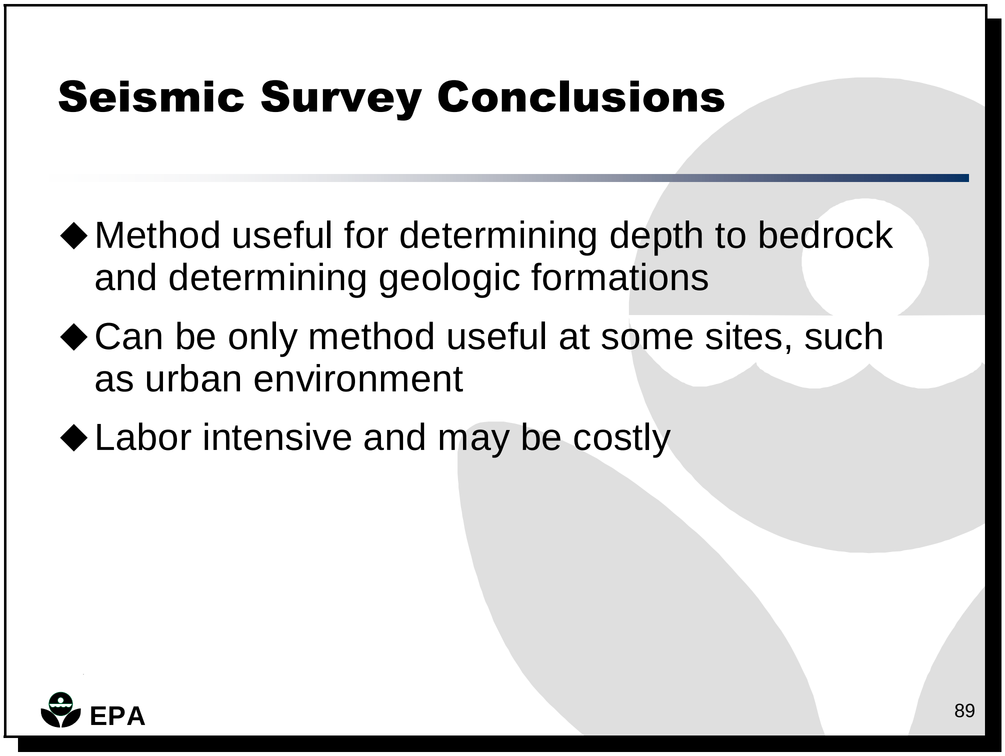
**Notes:**

- Daily rental rates range from about $150 to $300 for seismograph and $100 to $1,000 for geophones, cables and impact source, including hammer, elastic wave generator and vibrator sources. Several vendors are available to provide equipment. Shipping weighs are a major consideration due to cost factors. A contractor crew may charge about $2,000 or more per day plus the processing and report costs. Productivity varies due to site conditions.




**Notes:**

C Seismic surveys can be useful for determining depth to bedrock and mapping geologic formulations.

C The seismic method may be the only geophysical method that can provide subsurface information in some urban environments.

C The method can be relatively labor intensive and the seismic reflection method can be costly, particularly with respect to costs to mobilize equipment.

*Instructor:* *Inform the class that in urban environments, electrical power and subsurface utilities can affect electrical and electromagnetic geophysical methods. Magnetometers will be affected by ferrous objects such as automobiles and reinforced concrete. Seismic surveys are not affected as greatly by urban environments, except for vehicle motion and other vibration noise sources.*

## Case Study: Imaging DNAPL Using Seismic Refection Techniques at Two Department of Energy (DOE) Sites

- Problem Statement:
  - » Can seismic methods be used to identify the nature and extent of DNAPL?
- Methods Used:
  - » Standard high quality seismic reflection data collected
  - » Amplitude of arrival time of seismic waves versus offset (AVO) methods to detect DNAPL

EPA

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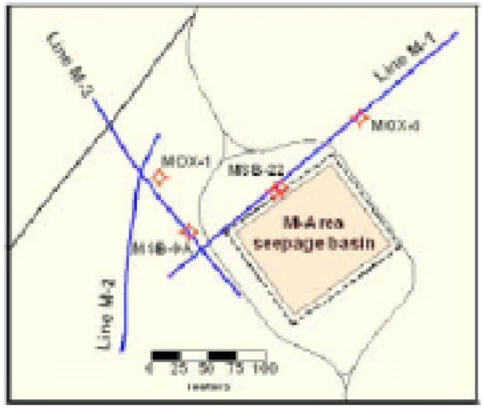
**Notes:**

C This study was conducted using data from both the Department of Energy's (DOE) Hanford, Washington Site and The Savannah River Site in South Carolina. The study used complex techniques to evaluate seismic data by modeling expected responses and using high quality seismic field data. The technique used amplitude of arrival time of seismic waves versus offset (AVO) methods to detect hydrocarbon bearing strata. This technique commonly is used in oil and gas exploration.

## Savannah River Site — Location Map of M-Area Seepage Basin




EPA

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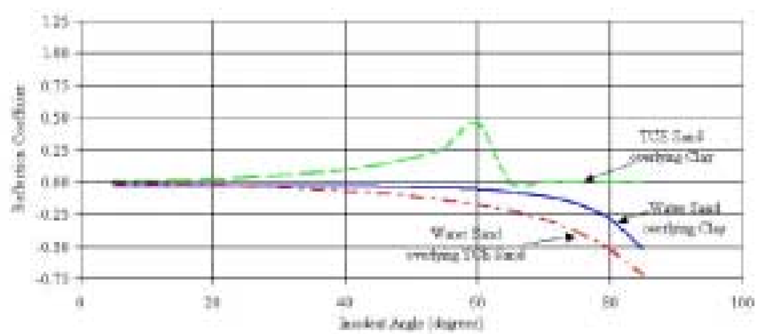
**Notes:**

- This figure shows the location of all 2-D seismic lines acquired for AVO analysis at the Savannah River Site M-Area seepage basin. Well MSB-3D is adjacent to MSB-22. Well MSB-3D has free-phase DNAPL at the bottom of the well.

## Savannah River Site — Graph of Modeled Substrata - Reflection Coefficients




EPA

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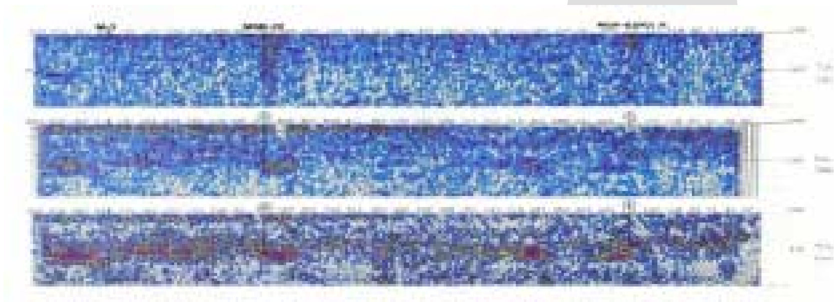
**Notes:**

- The graph shown represents reflection coefficients versus angle of incidence using the Zoeppritz equations for water saturated sand overlying TCE saturated sand. The middle graph is for water saturated sand overlying the green clay. The lower graph is the reflection coefficient versus angle of incidence for water saturated overlying the sand.

- This slide is provided to the participant to illustrate how the interpretation was derived.

## Savannah River Site — Offset Range Limited Stacks



EPA

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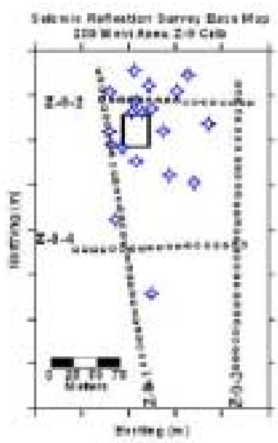
**Notes:**

- The slides shows offset range limited stacks and fluid factor stacks for profile M-1. Near the offset section (top), far offset (middle), and fluid factor (bottom). The middle section was generated by stacking offsets greater than 17.68 meters. High amplitudes that occur only at far offsets should denote presence of DNAPL. The bottom section is a fluid factor stack of M-1 Well MSB-3D that is adjacent to MSB-22. The water table occurs at a depth corresponding to approximately 100 milliseconds time. The amplitude envelope (magnitude of Hilbert transform) is displayed.

- This slide is presented to show that the fluid factor stack can provide information about the location of the contaminant bearing areas within the formation. It is not expected that a full understanding of the processes to derive this data are obtained. A highly trained seismic geophysicist is required for this type of data processing.

## Hanford Site — Location Map



EPA

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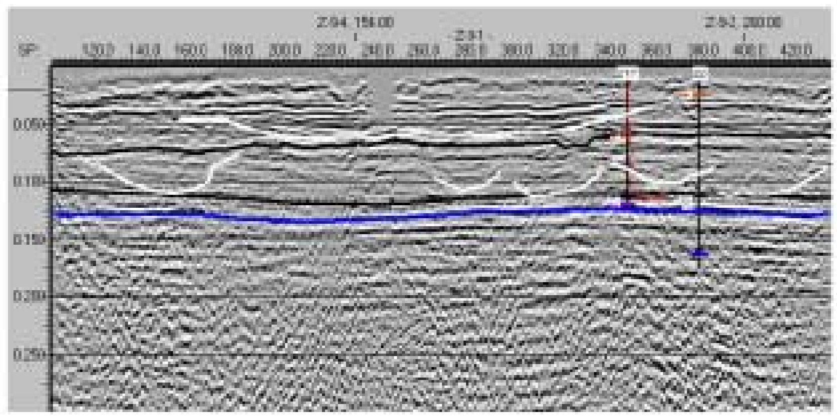
**Notes:**

- This figure shows the location of all 2-D seismic lines acquired for AVO analysis at the Hanford study area site.

## Hanford Site — Seismic Reflection Line



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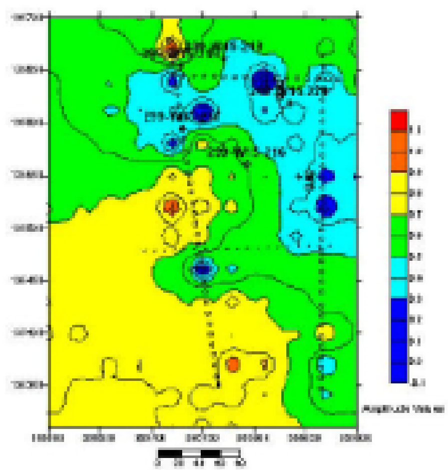
**Notes:**

C This figure shows the seismic reflection line Z-9-1 at 200 West area Hanford Site. The line direction is south to north, left to right. The upper black line is the top of the Hanford Fine. The lower black line is the top of the Plio-Pleistocent, and the blue line is the top of the caliche layer. The concave features are channels in the Hanford Formation.

## Hanford Site — Plio-Pleistocene Contour Map



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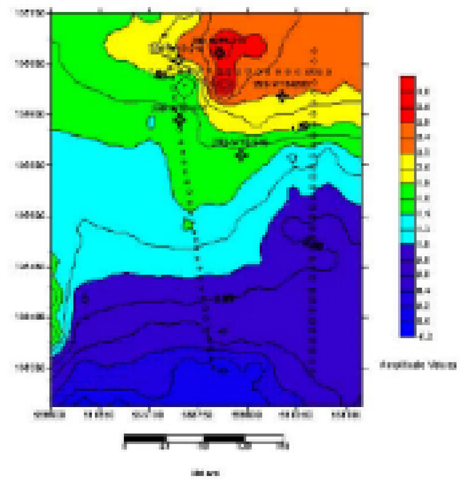
**Notes:**

- This map shows the amplitude values for the Plio-Pleistocene surface.

## Hanford Site — Caliche Contour Map



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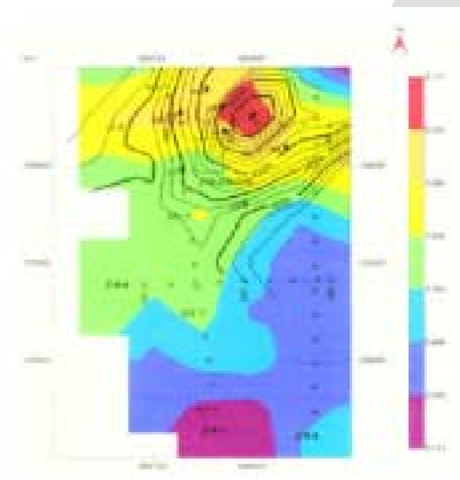
**Notes:**

- This map shows contours of amplitude values for the top of the caliche layer.

## Hanford Site — Carbon Tetrachloride Isoconcentration Map



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**Notes:**

C This map shows the carbon tetrachloride isoconcentratins at the top of the caliche layer. The contour intervals are in parts per million.

## Savannah River Site and Hanford Site — Summary

- Savannah River Site DNAPLs can be imaged using high resolution seismic data
- Hanford Site seismic modeling agree with measured amplitude anomalies
- AVO methods when modeled correctly can be used to map DNAPL
- This is a somewhat costly study and caution must be exercised in applying the technique to other sites. Site information and modeling are necessary before a seismic survey is conducted.

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**Notes:**

- This study shows that, in these two cases, DNAPL can be imaged using high resolution seismic reflection data. The Hanford site model agrees with measured amplitude anomalies. This method and study is quite costly (costs are not known as of this writing). Caution must be exercised before full seismic surveys are conducted. Site information and modeling are necessary before conducting this type of investigation.

- The participant should realize that the processing techniques used in this case study were used by a highly trained seismic geophysicist. The participant is not expected to fully understand the detailed processing, but rely on a geophysical contractor team for the data processing and interpretation.

## Seminar Summary

- In fractured or other complex geologic settings, geophysics can increase the information content available at a reasonable cost upon which a systematic plan can be established for a site
- Geophysical methods can result in substantial cost savings by helping to focus monitoring and measurement activities
- Using both surface and subsurface methods with differing capabilities is the best means for assuring the defensibility of project decisions

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**Notes:**

C When applying the Triad Approach at complex sites or where little is known about the geology and hydrogeology at a site, geophysical methods offer high information value at a reasonable cost. Intrusive sampling activities can be focused and remedial goals achieved more quickly and effectively when some information is used to guide follow-up activities. It is important to have a good handle on the potential interference that can impact the results before selecting and implementing a geophysical program to help guide systematic planning and development of a CSM. Expending more time and money during the front end-planning portions of a program and considering the use of geophysical methods will, in the long run, prove to be a wise use of time and funds.

## Thank-you

After viewing the links to additional resources, please complete our online feedback form.


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