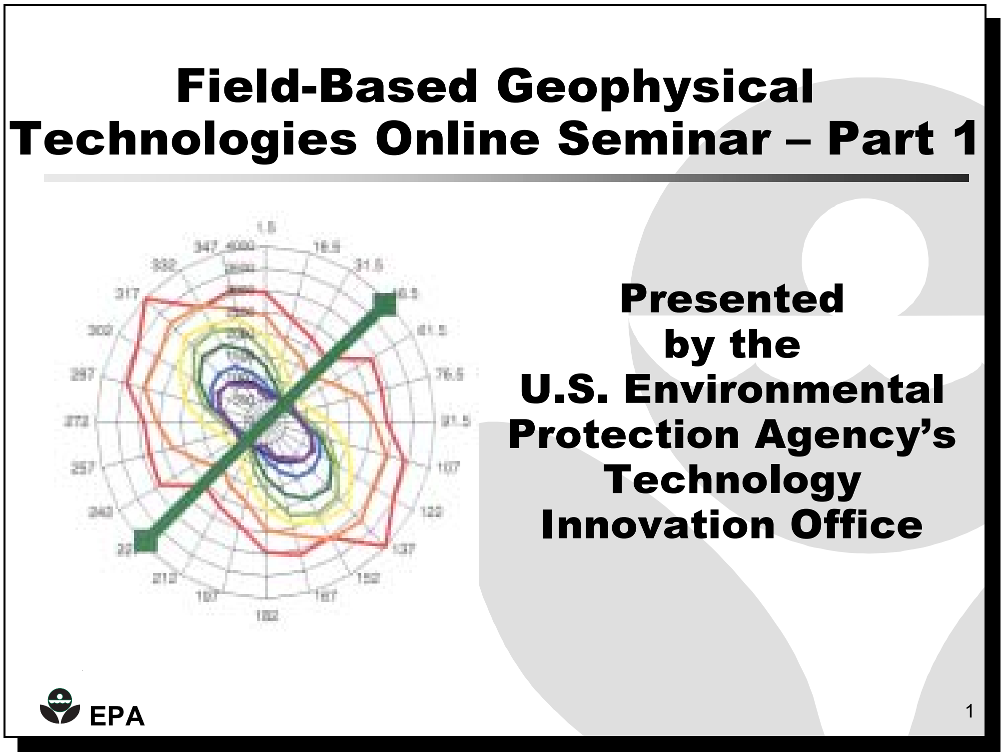
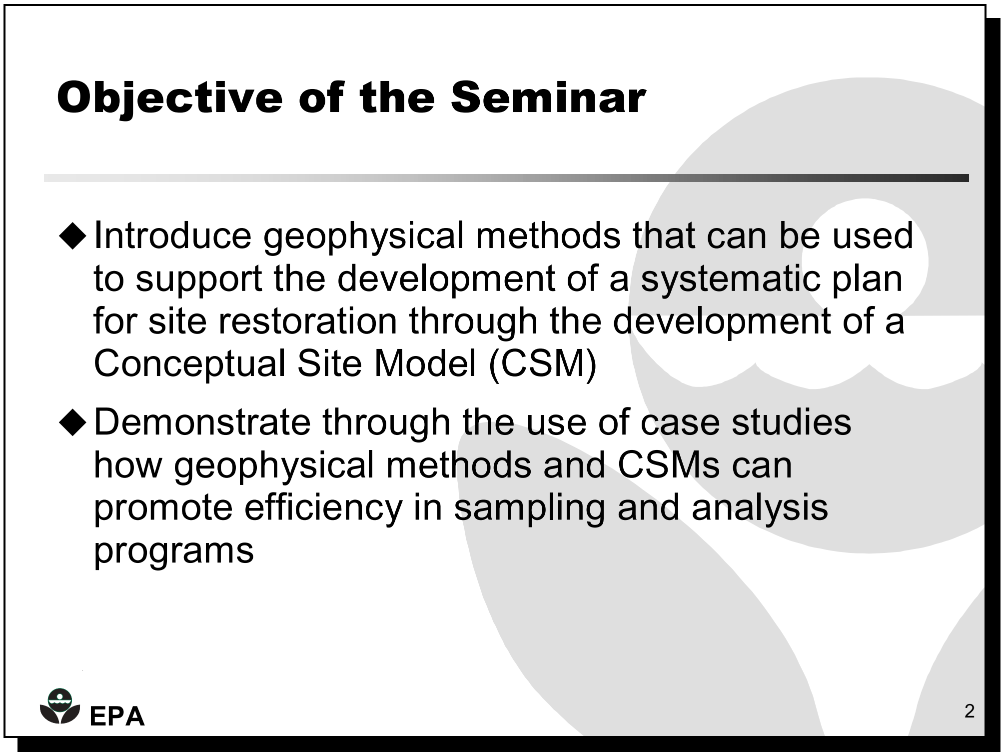


Notes:

- The following seminar is presented by the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). The course is designed for technical project leads and technical project managers. Other types of environmental site managers, and environmental professionals that are interested in the applications of geophysical technologies may also find the seminar informative.

- This seminar is part 1 of a two-part Series. Geophysical techniques discussed in this seminar include: resistivity, electromagnetics, magnetometry, and borehole. Ground penetrating radar (GPR) and seismic techniques will be discussed in part 2 of the seminar, which will be delivered at a different time.



Notes:

- 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 conceptual site models (CSM) for use during systematic planning. Systematic planning is essential to projects implemented using the Triad approach. The Triad is an integrated approach to streamlining environmental problem solving through the use of systematic planning, dynamic work plan strategies and real-time measurements. The Triad emphasizes the need for identifying and managing principle sources of uncertainty management. Geophysical methods help project teams limit cost and focus sampling efforts.

- During the online presentation, several case studies will be presented to demonstrate how certain geophysical methods can be used collaboratively to refine project CSMs and focus sampling and analysis efforts. The complete case studies are available through the links to additional resources section at the beginning and end of the seminar.

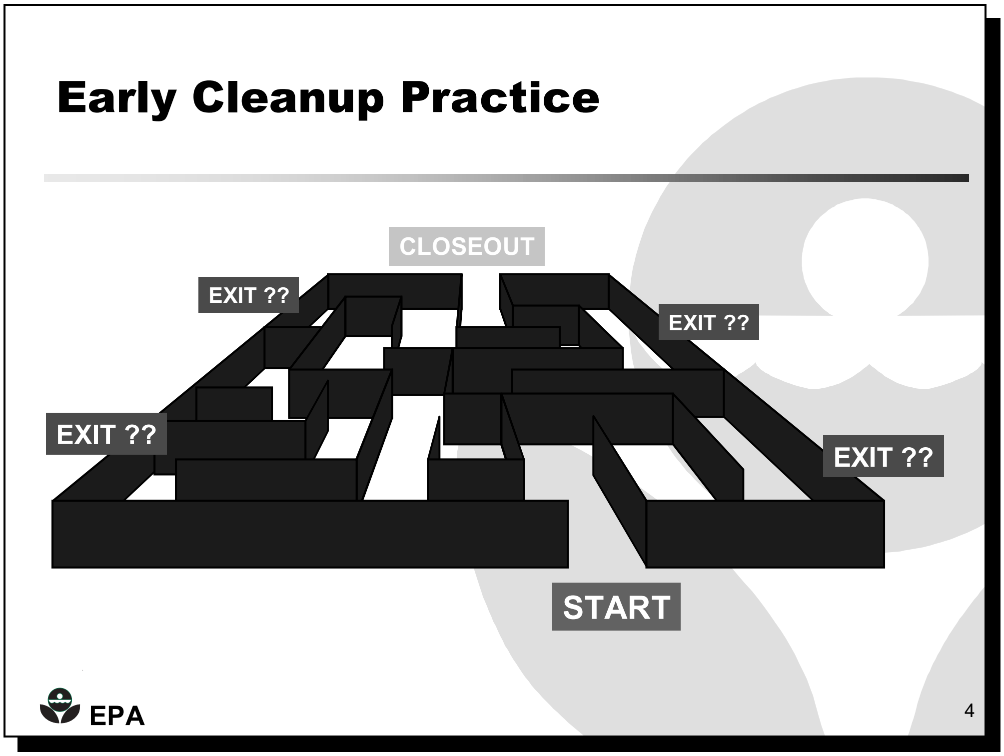
Historical Perspective of Site Characterization

- Investigative and analytical techniques and capabilities were under development
- The knowledge base was limited
- Prescriptive approaches were used because we did not understand how to manage uncertainty
- Advancements in technology and approaches are allowing us to identify and manage sources of uncertainty related to environmental decision making

EPA 3

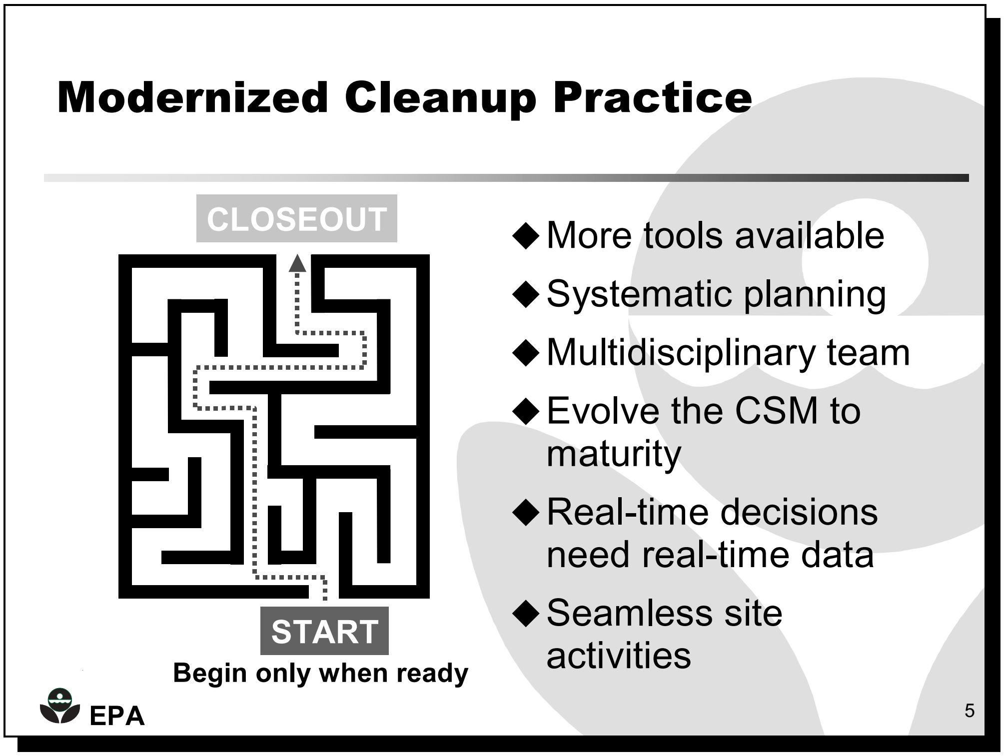
Notes:

- New management tools and approaches are being developed. Case studies are being published to assist project planners in identifying tools that could potentially apply to a particular problem.
- List software and other resources and web sites relative to Geophysics here.



Notes:

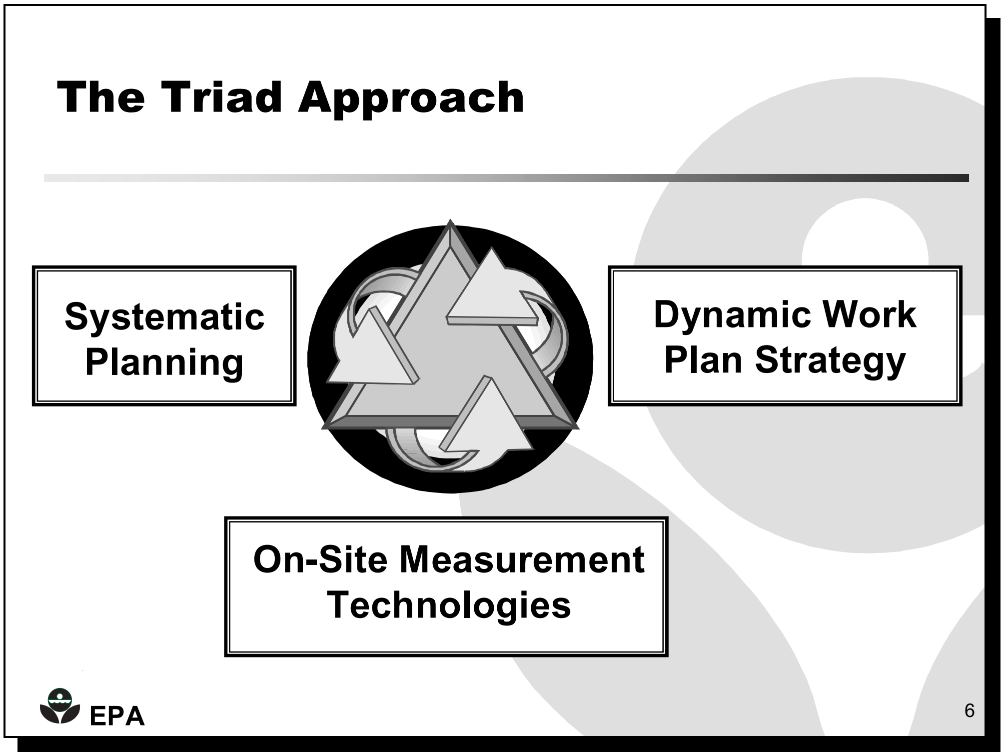
- During initial stages of project identification and characterization, the most logical exit strategy may not be obvious. Through systematic planning and the use of non-intrusive geophysical techniques, the scope and locations of potential contaminant sources can begin to be isolated. Geological information can be obtained and critical site features located. Once the problem has been well defined, the economic and practical factors can be weighed and viable exit strategies identified.



Notes:

- Early in the planning process a multidisciplinary team should be identified. This will aid technical project leads during the selection process for geophysical and other monitoring and measurement devices.

- As data is collected, a real-time data processing and analysis approach should be in place to evolve the CSM (understanding of site constraints) such that the approach or tool performance can be optimized. A chain-of-command should be established such that changes in approach can be made seamlessly with the approval of stakeholders, as necessary.



Notes:

The Triad approach:

Systematic Planning

- Take the time to clarify decision-specific issues with stakeholders
- Articulate clear project goals and tolerable decision errors uncertainties
- Chart best course to reach project goals using conceptual site models (CSMs)
- Use multi-disciplinary technical team for planning and implementation

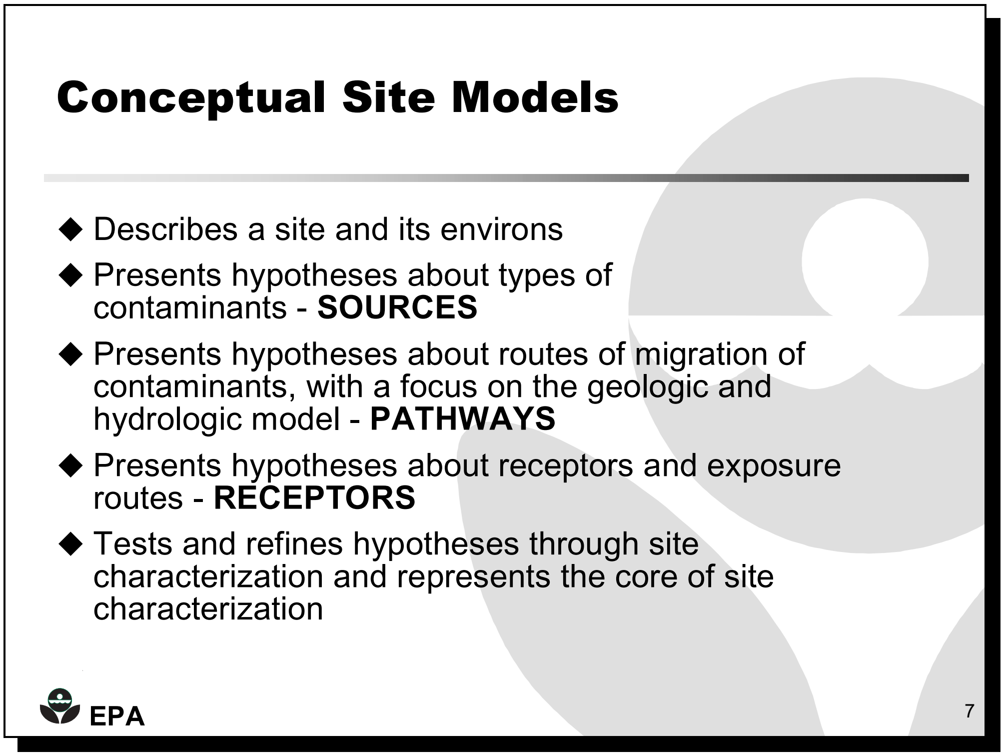
Dynamic Work Plans

- Real-time decision-making in the field allows for a seamless flow of site activities = fewer mobilizations
- Regulator-approved decision trees guide data gathering to support evolving the CSM to maturity
- On-site data compilation, processing, and analysis

Real-time Measurements

- Sample support
- Manage sampling uncertainty
- Method/technology selection
- QC design based on data as it is collected and analyzed
- Methods to meet specific needs (e.g., improve weight of evidence by using collaborative methods and data)

For more details, see paper "Improving the Cost-Effectiveness of Hazardous Waste Site Characterization and Monitoring" available at http://cluin.org/tiopersp/.



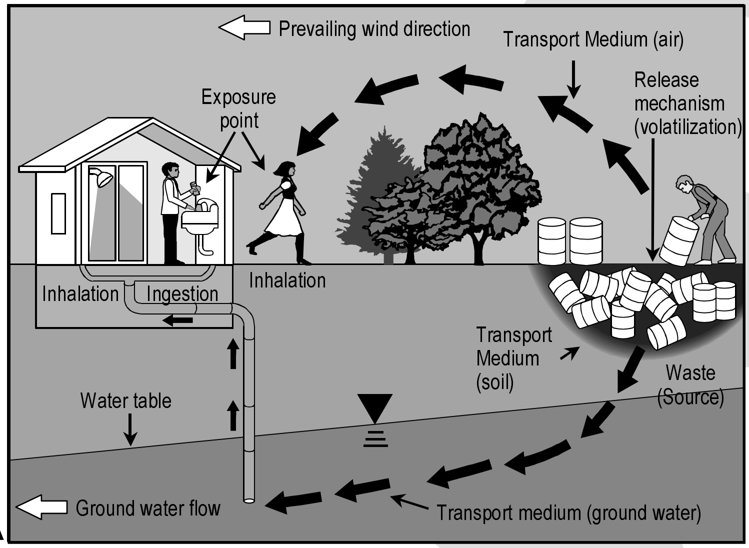
Notes:

- Some sources can be identified using geophysical tools, particularly metal objects. The effectiveness of the applicable methods will depend heavily on the physical characteristics of the target and surrounding geologic media.

- Pathway definition is one of the major benefits of using geophysical methods early in the life of a project. Collaborative use of geophysical methods and data collected considering geologic and hydrogeologic constraints will yield the best results.

- Assuring that the scope of an investigation is well defined using geophysics will assure a protective solution for all potential receptors.

Overview — Graphical Illustration



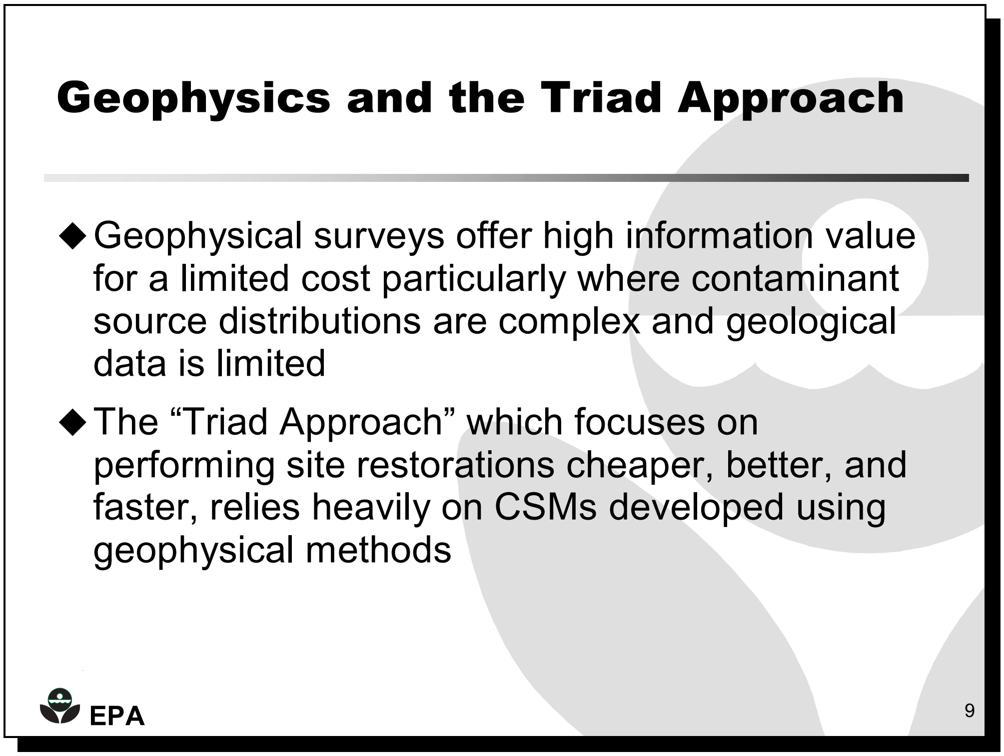
EPA

8

Notes:

- Physical characteristics such as:
  - Magnetic properties
  - Conductivity/resistivity
  - Dielectric properties
  - Acoustic velocities
  - Geologic complexity
  - Target size
  - Target composition
  - Depth of burial
  - Geographic location/geophysical

  will influence the geophysical tools selected and the data collection strategy array design.



Notes:

- 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 <u>fractured</u> media, preferred pathways can go undetected when standard drilling methods are used. Geophysical surveys can assist in such cases to assure that preferred pathways are identified and wells and other monitoring and measurement methods are focused where needed.

- Early in a project’s life, geophysical methods can assure that funds allotted for monitoring and measurement activities are expended wisely. Pincushion sampling sufficient to identify preferred pathways at complex sites are usually not possible because of economic constraints. Geophysical techniques offer an alternative approach that will provide extensive site coverage to ensure that decisions are defensible.

Systematic Plan Using the Triad Approach and Geophysical Surveys

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

EPA

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Notes:

- When using the Triad approach it is recommended that project technical leads and 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.

- 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.

Geophysical Methods Overview

- Geophysical methods that will be reviewed include:
  - » Direct Current Resistivity
  - » Electromagnetic
  - » Magnetometer
  - » Borehole

EPA 11

Notes:

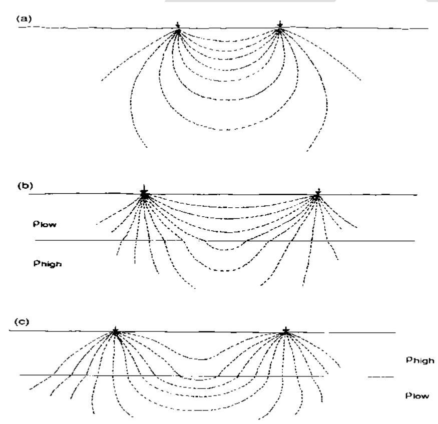
- In this seminar, we will focus on several of the commonly used methods that can assist project managers in developing systematic plans for site restorations.

- The material in this module provides a practical viewpoint in the use of various geophysical methods. There are a variety of geophysical techniques that are available for environmental site characterization. In most cases it is important to assess available site information prior to selection of a geophysical method or methods to assist in analysis of the subsurface. It is important to understand your site objectives, the advantages and limitations of the geophysical methods, and the costs that may impact the project budget.

- We will discuss in the following presentation, the applications, advantages and limitations, costs, and provide 2 case histories for site assessment using geophysical methods.

Electrical Resistivity

- Direct Current (DC) applied into the ground
- Several types of measurements
- Apparent resistivity of the subsurface is derived
- Modeling of data to infer geology



EPA

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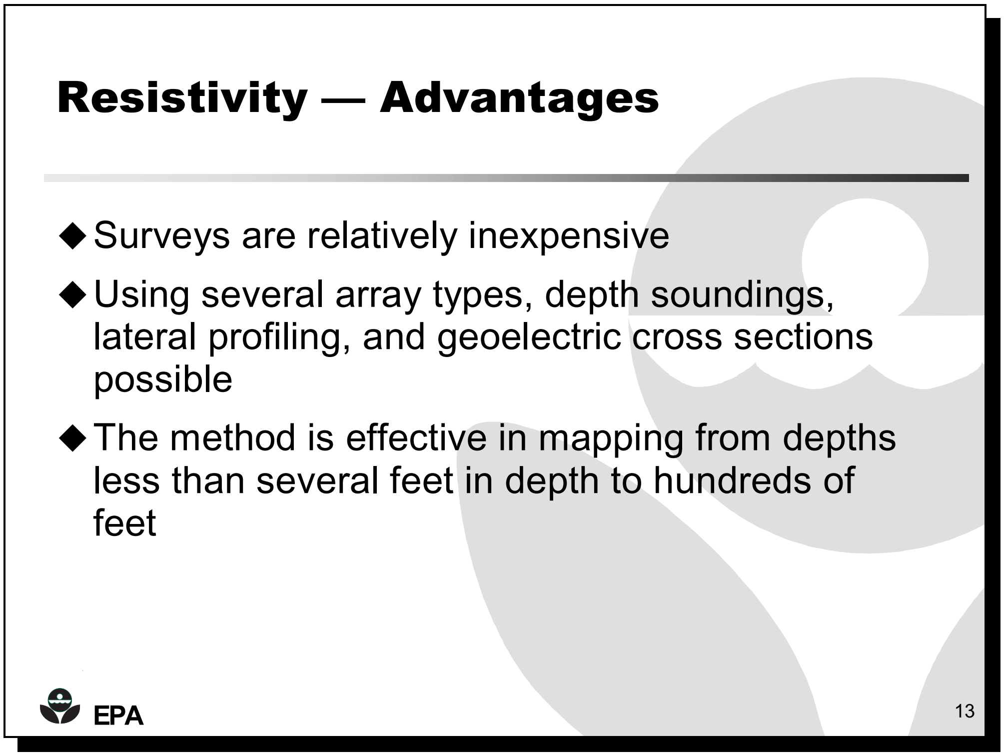
Notes:

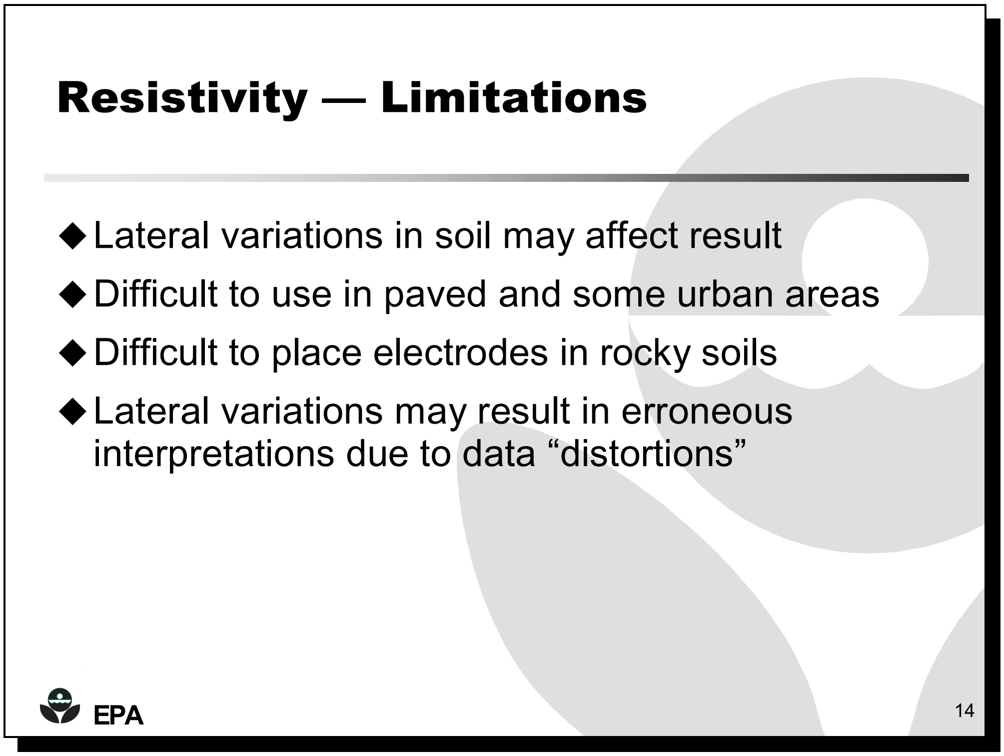
- Electrical resistivity is one of the most traditional geophysical methods. The method uses direct current applied to the ground through electrode pairs. A second pair of electrodes are used to measure the resultant voltage from the applied current. Several types of measurements can be used depending upon the objective of the survey.
- 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.
- The following slides discuss the DC resistivity method.



Notes:

- Equipment for electrical resistivity measurements can be fairly inexpensive of shallow (less than 50 feet) investigations. Commonly known as the DC resistivity method, a variety of electrode configurations can be used depending upon the type of subsurface information required. Sounding arrays determine the vertical stratification, profiling provides information about a specific depth, or multiple depths that provide a "geo-electrical cross-section" of the subsurface.

- Although the equipment is inexpensive, there are several limitations using this method. When used for vertical electrical soundings (VES) the data can be "distorted" over lateral variations in geologic structure. This may result in erroneous information about the vertical stratification. The method requires sufficient room in order to conduct the survey, and adequate contact with the ground in order to apply sufficient current or receive voltage measurements.



Notes:

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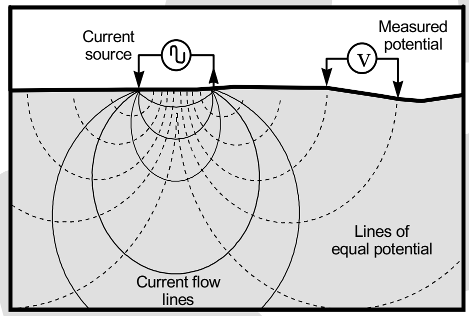
Resistivity — Physical Basis

- Electrodes are placed in the ground
- Applied direct current into subsurface
- Measured resultant voltage
- Calculation of apparent resistivity of the subsurface



EPA

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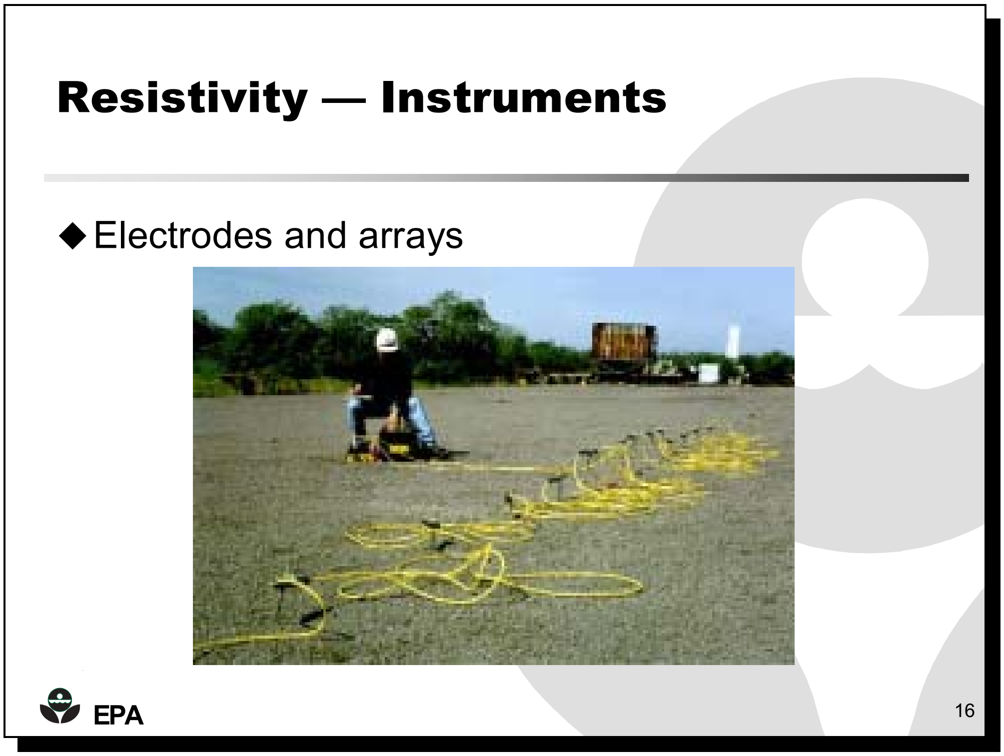
Notes:

- The current in a conductor is generally equal to the voltage applied across it divided by a constant. This constant is the resistance. 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. The reciprocal quantity is conductivity, measured in units of mhos per meter.

- The resistivity of a rock is roughly equal to the resistivity of the pore fluid divided by the fractional porosity. Clays typically have resistivities of less than 10^2 ohm-meters; loose sands typically between 10^2 and 10^3 ohm-meters. Using this basic information, the geologic materials can be inferred from the measurements.

- When passing current between a pair of grounded electrodes and measuring the resistivity between them, problems related to contact resistances (which are often on the order of 10^3 ohms) arise. Because of this, a second pair of electrodes with virtually no current flowing between them are used to measure resistivity.



Notes:

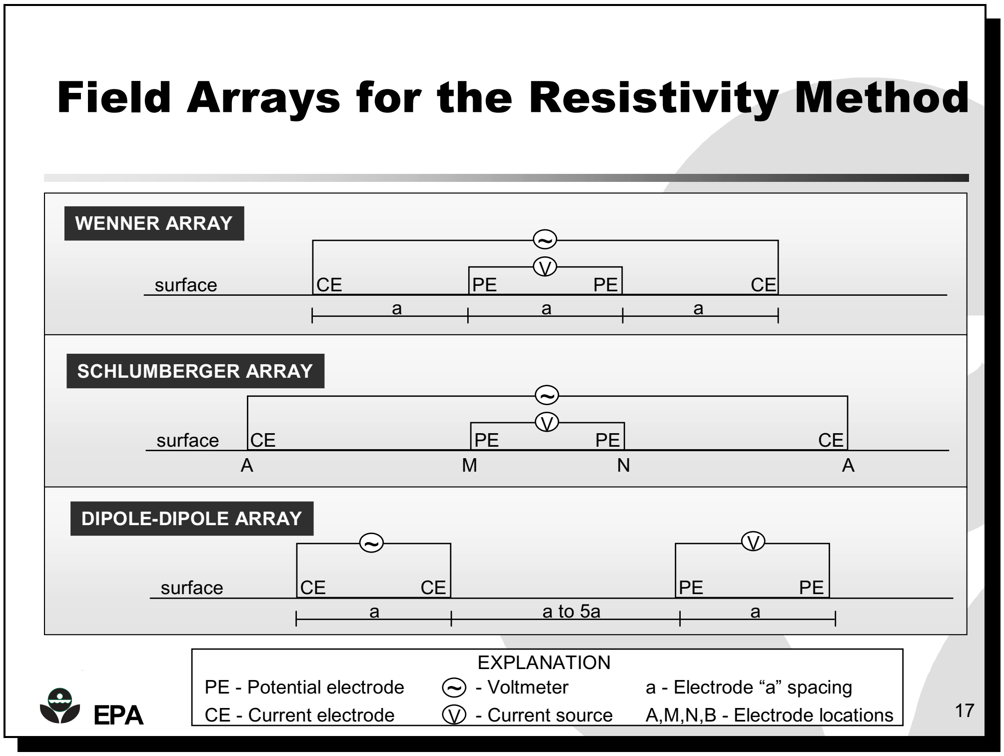
- This slide shows a basic layout of electrodes for a DC resistivity survey. In this case, the operator has lain out a series of electrodes, has the transmitter and receiver in place, and conducts the survey using only one person. In most cases, 3 person crews are used to conduct the survey, an operator, and 2 persons manning the electrode movements.

- Current electrodes are typically metal stakes. Voltage electrodes can be metal, but are sometimes a potential (called a "pot") containing 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 via the solution which leaks through the base of the pot. Electrodes are placed in well-defined geometric patterns known as arrays. Commonly used arrays include the Schlumberger, Gradient, Dipole-dipole, and Wenner.

- Resistivity cables are typically single core, multistrand copper wires that are insulated with polyvinyl chloride. Nearly all resistivity work involves at least four cables, two of which are relatively long.

- The device that controls and measures current in a resistivity survey is known as the transmitter. Transmitters are usually designed to reverse the direction of current with a cycle time of between 0.5 and 2 seconds. This helps minimize electrode polarization effects. Power is provided by a dry battery or a generator.

- Voltage measuring units are often referred to as receivers or detectors. Recently manufactured instruments generally place the transmitter and receiver equipment in a single housing unit with microprocessor control.

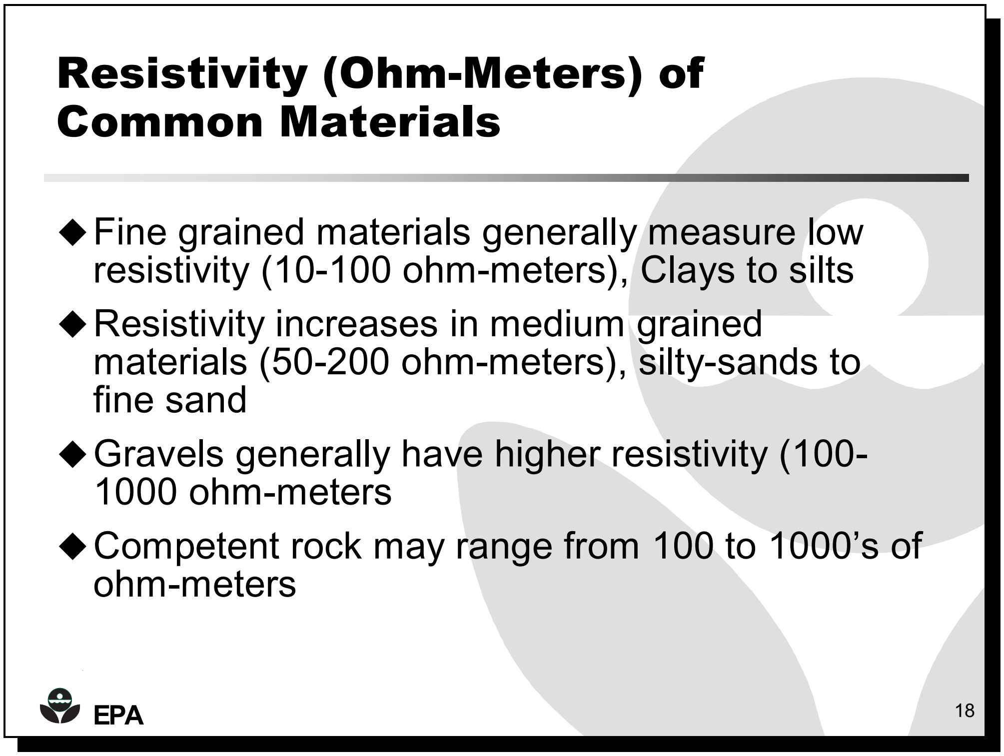


Notes:

- Several types of electrode arrays are used in DC resistivity surveys. The Wenner, Schlumberger and Dipole-Dipole Arrays are the most commonly used. Each method has it advantages and limitations, either in terms of resolution or in survey logistics. They all accomplish generally the same objective. That is a weighted average of the earth’s resistivity to a specified depth depending upon the size of the electrode array.

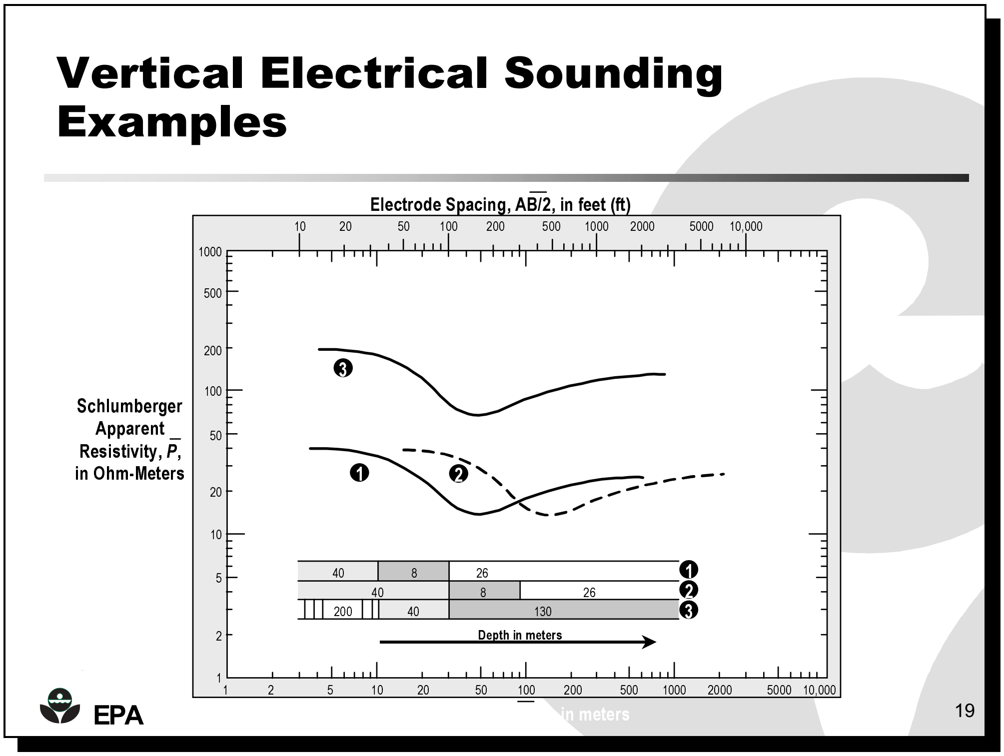
- The Wenner Array uses equidistant current and voltage electrodes. The array is spread equal distances for each measurement until the measured voltage is below the acceptable system measurement level. The Schlumberger Array uses a similar approach, however, the voltage electrodes remain at a fixed position while the current electrodes are moved out at logarithmic distances until the required depth objective is met, or the signal received at the potential electrodes is below acceptable values. The dipole-dipole array used current electrodes and potential electrodes at a fixed spacing. The separation of the current electrodes to potential electrodes are moved out at intervals equal to the spacing, at increasing intervals until the signal is no longer measurable or valid. Then, the current electrodes are moved, and the move out process of the potential electrodes occurs again. This procedure is repeated until the profile over the area of interest is achieved.

- Wenner and Schlumberger Arrays usually produce a vertical electrical sounding, while the Dipole-Dipole array results in a “geoelectrical cross section” of the area surveyed.



Notes:

- Using the DC resistivity method, measured voltages and calculated apparent resistivity can assist in inferring an interpretation of the type of soil and rock within a study area. Tables are usually available using the uniform soil classification, and published data about the ranges of resistivity of common soils and rock. There are overlaps in the ranges from each general type of soil or rock. The resistivity varies depending upon the moisture content, competency and type of minerals present in the measured unit. It is useful to have some site information when interpreting the results of resistivity surveys. This may include general geologic information, available borehole information and data obtained during the initial site survey.



Notes:

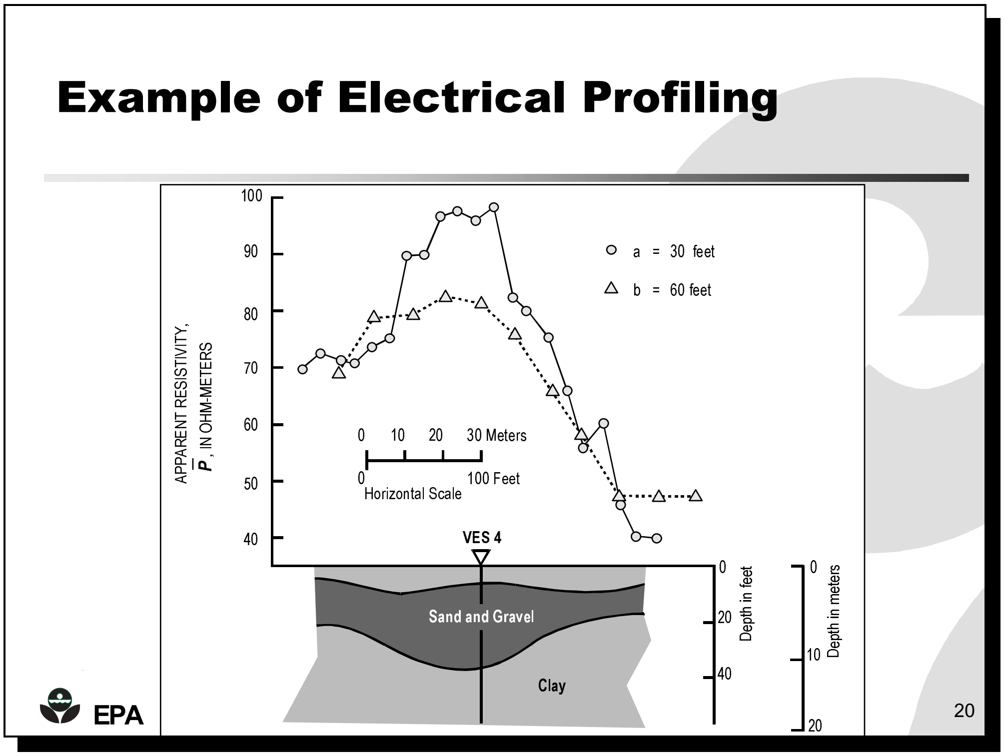
- This simple example shows three vertical electrical sounding apparent resistivity curves. Using available modeling software, the measured voltages, geometric electrode placement information, and some geophysical experience, an interpretation can be derived from the sounding data. In this case a model of 3 horizontal layers has been modeled for each curve.

- Observing apparent resistivity curves it can be noted based upon the character and position of the curves within the graphs indicate the approximate layering and resistivity of the subsurface. In each case, a 3 layer subsurface in modeled.

- In general curve 3 is higher in resistivity. This is evident in the vertical position on the graph and position with respect to the calculated apparent resistivity and the electrode spacing.

- Curves 1 and 2 are similar, however curve 2 is shifted right laterally, indicating that the upper layer is similar, but has a greater thickness.

- Vertical electrical sounding are principally used to derive information about the layering of the geologic formation or the depth to bedrock at a site. This method may be used in combination with other information including borehole information to evaluate a site using the less costly geophysical measurement to infer the geologic information about a site.



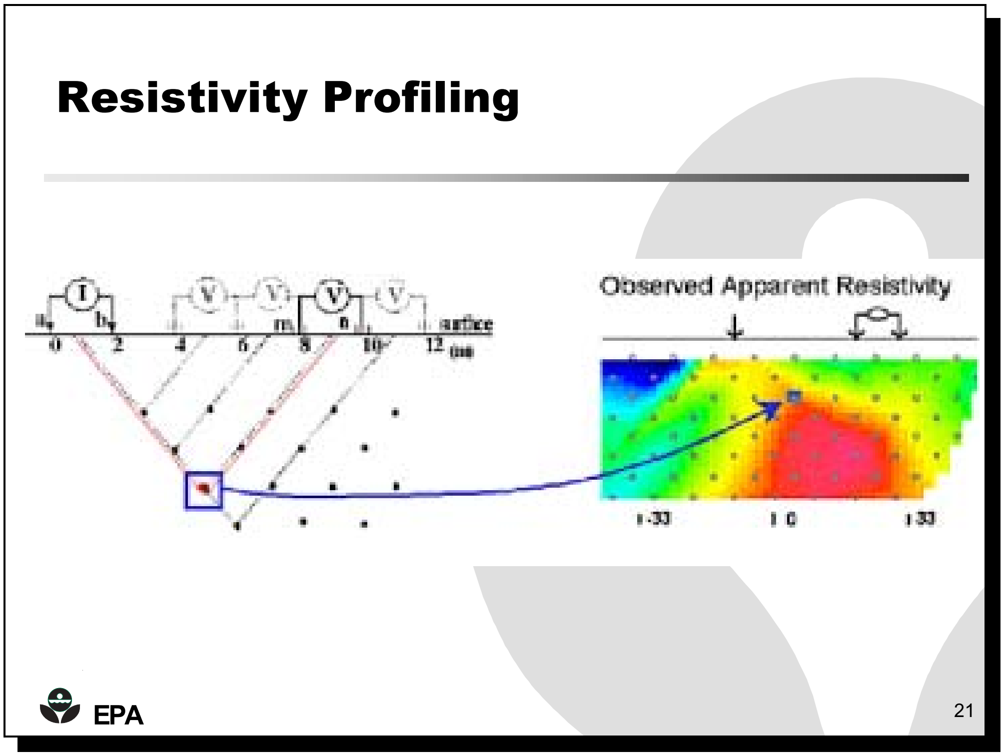
Notes:

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

- Vertical resolution of geologic formations varies depending on the conducting environment. As a rule of thumb, it is difficult to resolve a layer that is thinner that the depth to its upper surface.

- Lateral resolution is limited by the spacing at the voltage (potential) electrodes as well as the current electrodes.

- 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.

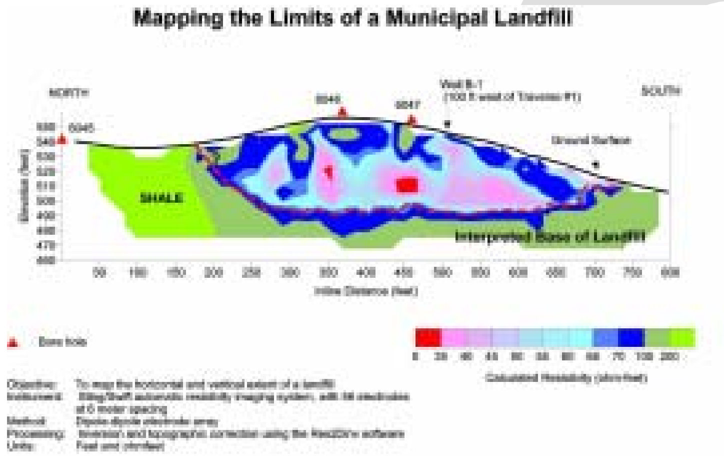


Notes:

- Resistivity profiling is a technique where transects are used to detect lateral changes in subsurface resistivity. Array parameters are varied by separating the voltage electrode pair (V) from the current electrodes (I). The depth of penetration, therefore, varies with changes in electrode pair separation and with the changes in subsurface materials, layering, and so forth.

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

Resistivity Cross Section



EPA

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Notes:

- Resistivity profiling is a technique where transects are used to detect lateral changes in subsurface resistivity. Array parameters are kept constant and the depth of penetration, therefore, varies only with changes in subsurface materials, layering, and so forth.

- This cross-sectional view was created using a dipole-dipole resistivity array. The data were processed using software developed for use with DC Resistivity data. 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. The interpretor or geophysicist usually provides initial estimates into the program of the number of layers, thicknesses, and resistivities. The program then shifts the initial estimate to match the field calculated data resulting in a model that represents the measured field data.

- In this survey, several pieces of information were desired. This includes the depth of fill and its lateral extent. In many landfill investigations, it is difficult to determine the volume of material in a landfill because the thickness of fill is often not measureable geophysically. In this case, both objectives were met by conducting a series of profile lines over the landfill area.

- Other methods may be more cost effective for the determination of landfill boundaries. We will discuss one method later in this seminar, the electromagnetic induction “terrain conductivity” method.

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.

EPA 23

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.

Resistivity — Summary

- Determine lateral variations of resistivity
- Determine depth of fill material
- Determine depth to bedrock
- Obtain cross-sectional interpretation of site
- Assist in determining fracture patterns in bedrock
- Intrusive technique that may require decon

EPA 24

Notes:

- Direct current resistivity can be a useful tool for mapping lateral variations of earth resistivity for characterization of geologic features such as less permeable clay layers or stream channels that can be conduits for contaminant migration.

- The method is useful for determining depth of fill and depth to bedrock in certain geologic and site environments. The most successful areas where depth of fill or depth to bedrock can be derived is in an area where the target geologic unit has a lower resistivity, or a resistivity contrast that is significantly different than the material above it. (For example, a conductive landfill underlain by a very resistive bedrock, or a bedrock that is primarily clayey material that is much less resistive than the overlying sands and gravels). In some cases, a method called azimuthal resistivity may be used to determine fracture orientations, particularly in shallow bedrock environments.

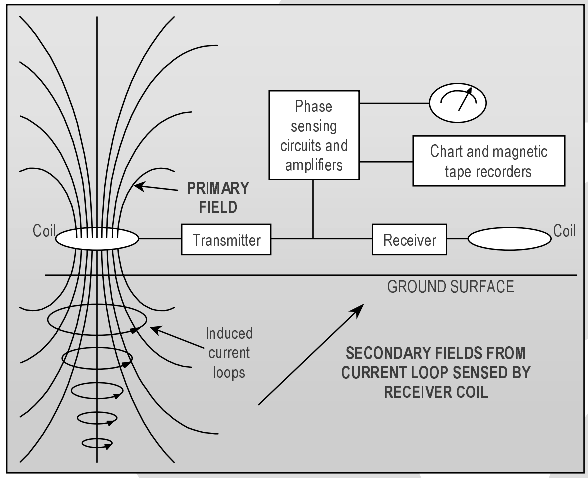
- Direct current resistivity may be better suited than seismic refraction for determining depth of fill. Seismic survey often have difficulty in a fill area because of the unconsolidated nature and lack of compaction of materials. This results in poor energy transfer of the acoustic waves needed to provide refraction off of bedrock material.

- 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. Multiple surveys in orthogonal directions may be necessary to determine validity of a data set. If a sounding result is greatly different when obtained over a point in a North-South orientation versus an East-West orientation, the data location may be problematic.

- Ground contact in contaminated sites may be a concern. This may require cleaning of electrodes prior to placing them in the ground at another location (“decon”).

Electromagnetic Conductivity Surveys

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



EPA

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Notes:

- Conductivity methods use a transmitter coil to generate an alternating electromagnetic field which induces electric current flows in the earth. The induced currents generate a secondary electromagnetic field in the subsurface. This electromagnetic field creates what are called eddy currents in the subsurface that are sensed by a receiver coil. The character and magnitude of the secondary field are governed by the frequency of the transmitted current, the transmitter-receiver separation and the distribution and magnitude of the electrical properties in the nearby subsurface.

- The electromagnetic energy transmitted into the ground undergoes attenuation and phase shift as it propagates. The attenuation is generally inversely proportional to the conductivity of the nearby subsurface. Therefore, it is typically more useful to measure the out-of-phase signal at the receiver, which is more proportional to subsurface conductivity. However, in certain cases where the subsurface conductivity is very high (an area of dense metallic disposal, for example) the attenuation is minimal and in-phase measurements tend to be more proportional to subsurface conductivity.

- Conductivity methods also are known as active electromagnetic induction techniques, and can be used to detect both ferrous and nonferrous metallic objects and detect conductivity variations in soils.

- Profiling is accomplished by making fixed-depth measurements along a traverse line. This is done by maintaining the transmitter-receiver coil separation, and moving across the surface either by continuously measuring the conductivity or by obtaining measurements at fixed points along a survey line.

- 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. Soundings are not typically done, but can be accomplished using the EM31 and EM34 instrumentation, the most commonly used instruments for this type of survey.

Electromagnetic Conductivity — Advantages

- ◆ Determine lateral variations in soil and rock
- ◆ Map landfills, placement of wells and soil sampling
- ◆ Surveys can be conducted rapidly and interpreted quickly
- ◆ Techniques available for shallow and moderate depth

EPA 26

Notes:

- The electromagnetic apparent conductivity measurement technique has been widely used for environmental investigations. The EM31 is a rapid technique to determine the lateral extent of landfills, trenches and waste pits. The EM34 has variable depth capabilities to potentially map sites with a greater depth that may require characterization. Both techniques can be conducted reasonably quickly without causing soil disturbance.

Electromagnetic Conductivity — Limitations

- Surveys provide only a bulk conductivity measurement
- The equipment is somewhat cumbersome
- Survey data may be affected by utilities
- Resolution of subsurface soil units decrease with increased depth of investigation

EPA

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Notes:

- Using increased coil separations for greater depth information decreased resolution. A "bulk conductivity" measurement is obtained with this method. In other words, the conductivity measurement is an average conductivity of the subsurface within the transmitting and receiving distance of the system, resulting in decreased resolution.

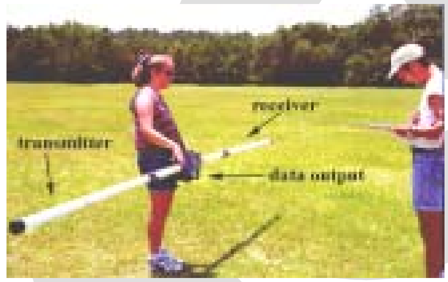
- The equipment is somewhat cumbersome due to batteries, coils and coil booms. The operator may require more frequent rest periods.

- It is important to obtain the location of subsurface utilities and metallic objects. This will assist in interpretation of the electromagnetic data. In some cases, it may be useful to conduct these types of surveys to determine the location of unknown subsurface utilities and structures. This may assist in the interpretation of other site geophysical survey data.

- In the vicinity of utilities, the equipment may be ineffective, as with many other geophysical methods.

Electromagnetic (EM) Conductivity Surveys

- The EM method provides a means of measuring the electrical conductivity of subsurface soil and rock



EM31

EPA 28

Notes:

- This slide shows 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, about 4 meters apart. 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 (6 meters) in depth in the standard vertical dipole position. A bulk conductivity measurement to about 7.5 (about 3 meters) ft can be obtained by rotating the instrument such that the transmitter and receiver coils are in the horizontal dipole position. Advantages of using the horizontal dipole mode are the more detailed conductivity measurement of the near surface, less than 7.5 feet (3 meters). The horizontal mode is not commonly used because of the need to rotate the instrument.

Conductivity Surveys — Survey Practice

- Data acquisition
- Conductivity is influenced by soil and rock properties
- Effects of cultural features
- Variable depth investigations

EM34

EPA

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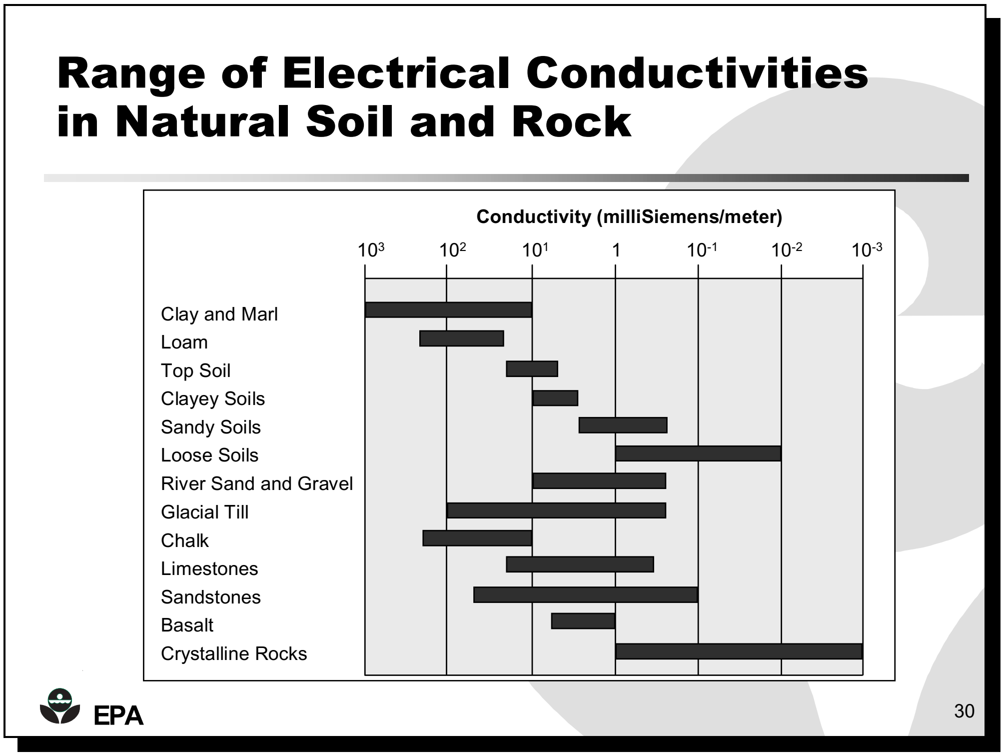
Note:

- Profiles are continuously or station-based conductivity measurements obtained along a transect. Measurements may be obtained along a grid of transects to support contouring of the data. Multiple measurements at different coil spacings may be made with variable geometry instruments (typically the Geonics EM34) at a single station to support depth-dependent conductivity relationships. Data are typically recorded in a data logger and transferred to a computer for processing.

- The measured apparent conductivity from the electromagnetic instrument can be used to infer the type of soil and rock within a survey area. Using information about known ranges of conductivity will assist in the data interpretation.

- The presence of surface conductors (for example, rail road tracks) must be carefully noted in the survey log because of the influence in data collection. Underground utilities and overhead power may cause interferences in the data. Often, the underground utilities may be one of the objectives of detecting with the survey.



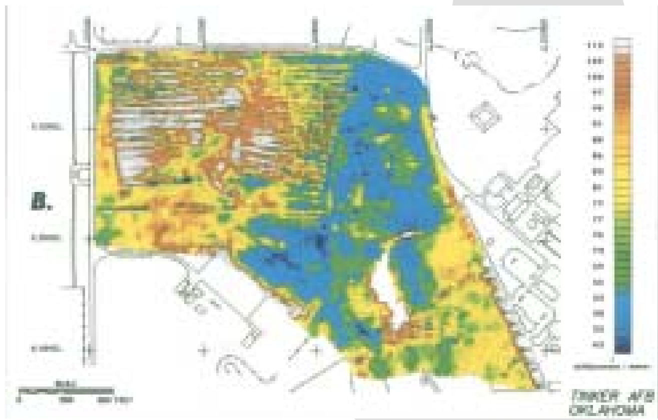
Notes:

- 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:

- 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.

- Apparent conductivity measurements show variations due to trenches, lateral variations in soil, and possibly due to utilities, roadways and other cultural features. The objective has been met over this site of determining the location of disturbed soil due to trench and fill operations.

EM Conductivity Survey — Costs

- Daily rental rate = $50-$70/day
- Shipping Weight = 75-100 pounds
- Contractor crews and equipment = $1,350 per day
- Productivity = 1 to 3 line miles per day (EM34)
- Productivity = 4 to 8 line miles per day (EM31)

EPA

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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 EM31, and other conductivity instrument equipment, are about $50 to $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. Productivity varies from up to 8 miles per day with the EM31 and down to about 1 to 4 line miles per day for the EM34.

Electromagnetic Conductivity Summary

- Key Uses
  - » EM31 surveys are useful in determining lateral variations in soil conductivity
  - » Mapping limits of landfills, trenches and waste pits
  - » Has some capability of metal detection
  - » EM34 has variable and greater exploration depth, up to 30 meters
  - » The EM34 resolution decreased with increased coil separation

(continued)

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Notes:

- Electromagnetic conductivity measurement surveys are usually a cost effective method for a first look at an environmental site. The method is highly successful in determining lateral variations in soil conductivity. The method is highly successful in many cases at determining the lateral limits of landfills, trenches and waste pits.

- In some instances the method may be useful in metal detection, however, there are other methods that are a better choice for metal detection.

- Using the fixed and variable coil separation methods can result in determining some information at various depths at a site. The EM34 can be effective to depths up to about 30 meters, although sacrificing resolution of intermediate layers between the surface and the depth of exploration.

Electromagnetic Conductivity Summary

- Considerations
  - » Site conditions, such as access, vegetation, topography and man made features are critical to the success of the method
  - » Understanding the objective of the investigation
  - » These methods can be highly effective in site characterization

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Notes:

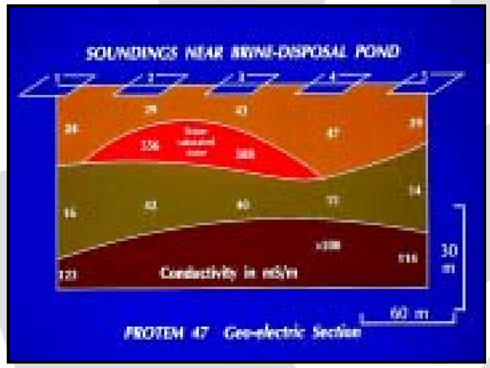
- When determining the use of electromagnetic conductivity surveys for site assessment, is necessary to evaluate site conditions to determine the access, vegetation, topography and cultural (man-made) features that may be critical to the success and cost effectiveness of the survey. It is necessary to determine if a geophysical survey can be accomplished at the site, or what measures may be necessary to conduct the survey.

- The objective of the investigation is important. Although the electromagnetic conductivity method is widely used in site assessment, there are some applications where another instrument may be more appropriate to meet the objective.

- The electromagnetic conductivity method speaks for itself. It measures variations in ground conductivity as it relates to changes in soil type and rock type or in some limited cases to a contaminant type. It is most successful in mapping lateral variations in soil types, limits of landfills and other disturbed areas, and in certain instances, metal detection or utility locations.

Time Domain Electromagnetic (TDEM) Surveys

- Electromagnetic method using time varying signal
- Electromagnetic Induction method
- Two principle types of Surveys
- Vertical Electromagnetic Soundings
- Metal Detection



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Notes:

- The time domain electromagnetic (TDEM) method was developed initially for use in exploration for mineral deposits. Advances in computer software and electronic components has advanced this technology. The method utilizes the principle of electromagnetic induction. The difference between the time domain EM method and the electromagnetic conductivity method discussed earlier is the use of a pulsed electromagnetic signal rather than a continuous transmission. The TDEM method transmits a pulse that is emitted into the ground. The EM current is turned off in the transmitter, and secondary currents that are created in the ground are sensed in the receiver coil while the primary current is off. This minimizes the need to deal with the primary signal interference.

- The method is used for two principle surveys for environmental investigations, vertical electromagnetic soundings and at a smaller scale, metal detection.

- The figure on the right is from a survey in the vicinity of an abandoned oilfield evaporation pond. The pond was not lined. Time domain electromagnetic soundings were conducted over the area, and down gradient along profile lines. The data indicate the presence of a conductive zone, shown in red, that is interpreted to be the brine plume.

TDEM Surveys — Advantages

- Sounding method has greater lateral and vertical resolution than DC resistivity method
- Metal detection equipment has superior resolution of metal objects over other metal detection methods

EPA

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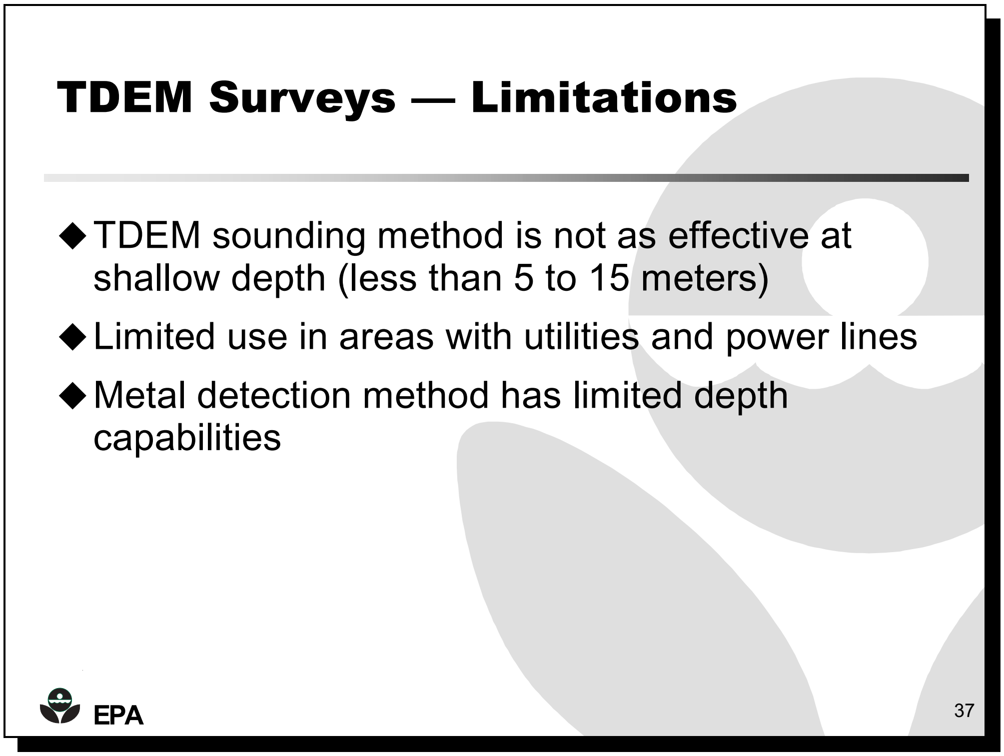
Notes:

- The TDEM sounding method is superior resolution of horizontal earth layers over the DC Resistivity method. Lateral variations in geology do not affect measurements to the degree of DC soundings. Therefore, lateral resolution of geologic formations is greater than other sounding methods.

- The TDEM sounding method does have limits of investigation. The method cannot resolve geologic information in the surface less than about 10 meters.

- The TDEM metal detectors have a high accuracy of detection and resolution of metallic targets over the magnetometer method, but has a limit of about 3-4 meters for detection depth.



Notes:

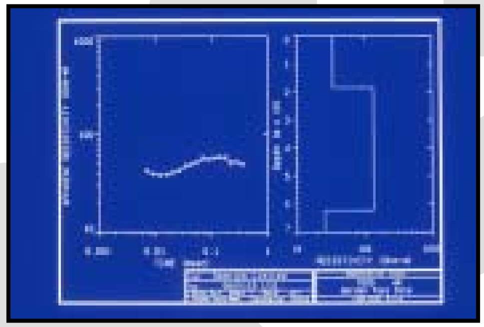
- The sounding method, because it is a time based measurement, is not effective in most applications for mapping at shallow depths. The first time measurement is "too late in time" for the shallow measurement. For shallow investigations, perhaps less than 5 to 15 meters, the direct current method may be more appropriate.

- As with other electromagnetic and magnetic methods, utilities, underground water lines and other man made structures will effect the measurements. In areas where these features are present, the seismic method may be an alternative for the investigation.

- The EM61 metal detector has a focused ability that allows the method to approach some metals from a lateral direction (automobiles for example). However, the detection of objects at depth is limited. In fact, a small object may be missed that is near the surface. The method is best suited for environmental site investigations for the detection of tanks and drums. For a single drum, keep in mind, that the survey line must be nearly over the top of the drum. A magnetometer survey may be an alternative method to use for drum detection.

TDEM Soundings

- Square transmitter loop increasing in size for increasing depth of investigation
- Lower frequencies for greater depth of exploration
- Data presented in apparent resistivity vs. time



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Notes:

- The time domain electromagnetic sounding technique uses a square transmitter loop laid out on the surface. Several systems are available. Geonics Limited of Canada produces the Protem System. This system uses 3 types of transmitting systems. The EM47 transmitter is used most commonly for environmental investigations. This system is effective using a portable transmitter for exploration to about 200-300 feet. Zonge engineering has a competitive geophysical system called the nanoTEM.

- Greater transmitter loop size and lower frequencies allow for greater depth of investigation. These systems when using large transmitter loops, and motor powered generators can be used for exploration to depths of up to about 2 kilometers when exploring for geothermal sources or other geologic targets.

- Data presentation consists of an apparent resistivity curve versus time. Modeling of the apparent resistivity curves is similar to DC resistivity processing, resulting in an interpretation of the subsurface as a vertical layering of the subsurface.

- A series of soundings can be used to produce what is called a geo-electric cross section, with an interpretation of the types of soils and rock types within the sounding data.

Electromagnetic Metal Detectors

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

EM 61

EPA

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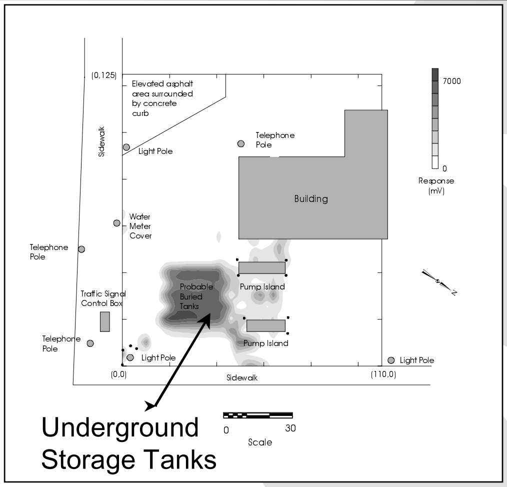
Notes:

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

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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.

EM61 — Costs

- Daily rental rate = $70
- GPS option = $50
- Shipping Weight = 130 pounds
- Contractor crews and equipment = $1,400 per day
- Productivity = 1 to 3 acres per day

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Notes:

- The EM61 is available in the original version that contains a basic data logger, and single measurement at each point. This system is good for a variety of metal detection tasks.
- The EM61 MK2 contains a data logger that readily accepts global positioning system data.
- As with all geophysical techniques, the crew and equipment rates are similar, and dependant upon crew size, usually two persons for the simple survey equipment such as the EM61.
- Productivity of the survey varies depending upon the site conditions such as terrain and topography.

Time Domain Sounding — Costs

- Daily rental rate = $200-400/day
- Shipping Weight = 150-500 pounds
- Contractor crews and equipment = $1,600 per day
- Productivity = 10 – 25 soundings per day

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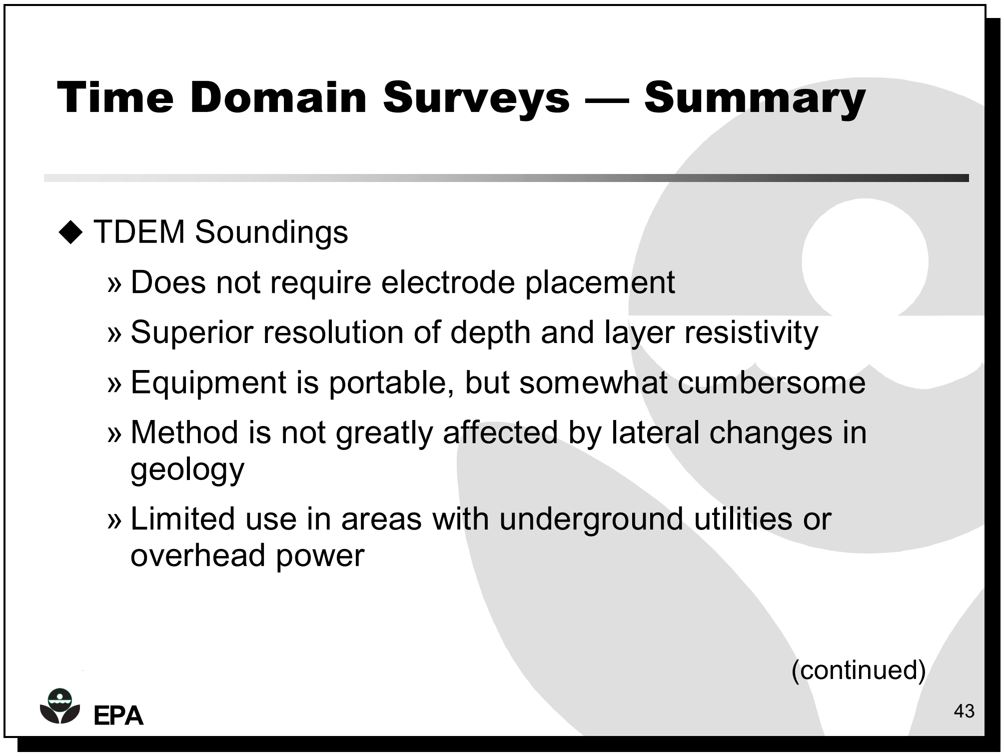
Notes:

- Time domain electromagnetic sounding equipment is available from several vendors including the manufacturer's. The weigh to the equipment for environmental investigations is about 300 pounds including a heavy receiver coil and receiver and batteries. Electrical wire is used most commonly for the transmitter, and can be purchases at an electrical supply outlet. 12 or 14 guage insulated wire is normally used. 30 meter by 30 meter transmitter loops are usually used for investigation of up to 80 meters. Smaller loops are usually multiturn that can be supplied by the rental company.

- A contractor would charge about $1,600 per day of field work, and this may include field processed data.

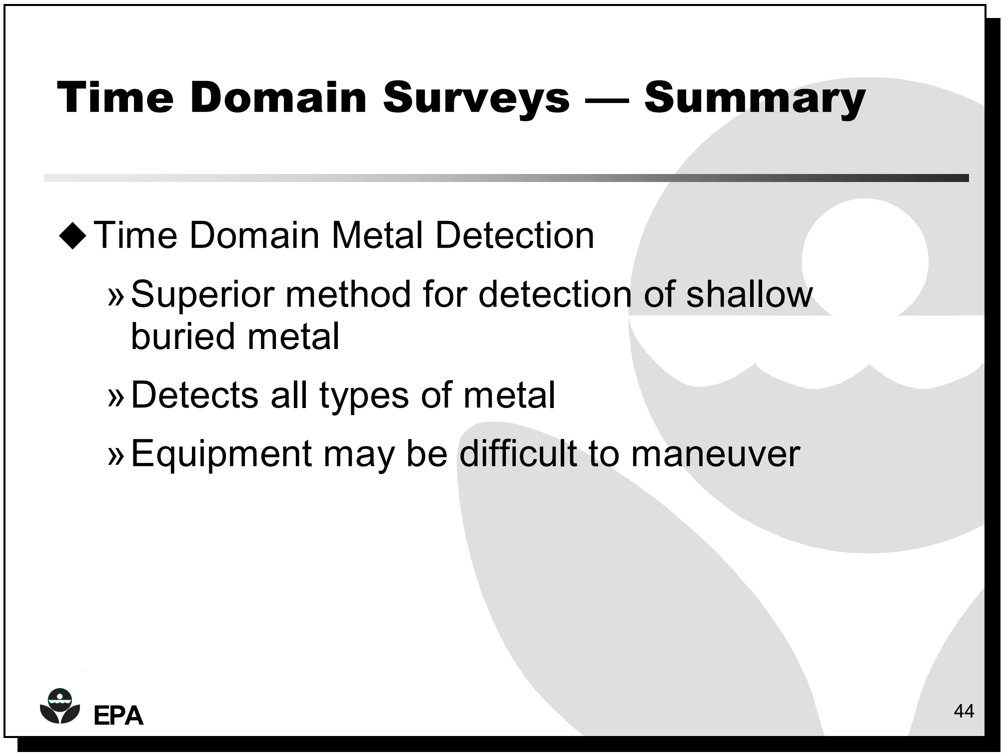
- Productivity is about 10 to 25 sounding per day depending upon terrain and other site conditions.



Notes:

- The time domain electromagnetic method has superior capabilities for mapping horizontal layering in the subsurface over the DC resistivity method. The equipment does not require intrusive probes, and can be moved fairly rapidly from location to location on a site. The method is affected by underground utilities and power lines.

- The time domain metal detectors are regarded as a superior metal detector over other methods. The detector senses all types of metals.



Notes:

- The time domain electromagnetic (TDEM) metal detection method is a superior method for detection of shallow buried metal when compared to the magnetic method. The method detects all types of metal. The method has a somewhat focused receiver, resulting in less interference from objects lateral from the system. The system is mounted on a wheeled cart that is one-half to 1 meter wide depending upon the transmitter-receiver configuration. This may be a problem in some situations where narrow pathways are present.

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

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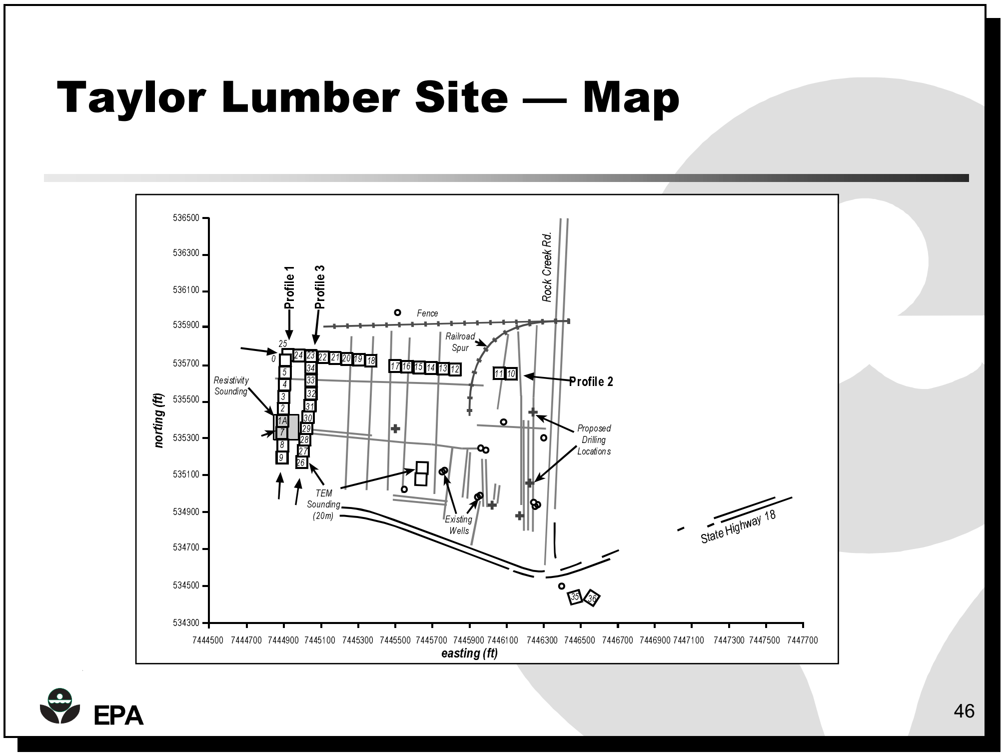
Notes:

- 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.

- The sight is underlain by up to 5 feet of fill material consisting of silty clay to gravelly clay along with road gravel. Below the fill is quaternary alluvium and lower river terrace deposits that are 10 to 20 feet thick. Underlying the aluvium is a moderately to very hard siltstone.

- Groundwater in the alluvium is semi-confined or confined by the overlying silty clay alluvium. The water table is from 4 to 20 feet below ground surface. The groundwater in the saturated portions of the is confined or semi-confined, with potentiometric levels from 2 to 8 feet below ground surface. The siltstone is massive and thought to be impermeable.

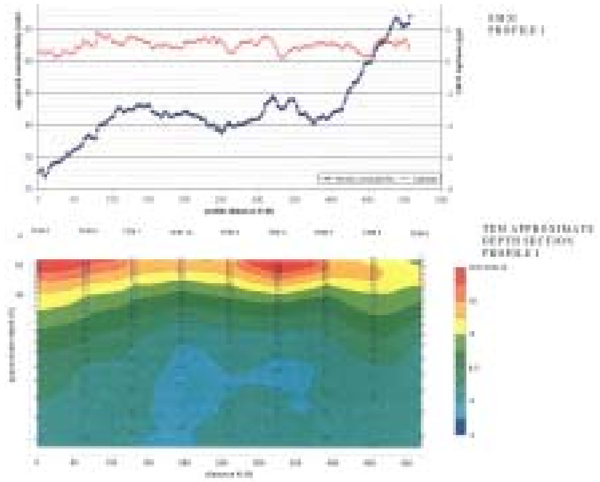


Notes:

- The slide presents a site map of the wood treatment site showing geophysical lines, TEM profiles, and sounding numbers. The squares on the map represent TEM sounding locations, and the lines represent the EM31 conductivity survey profile lines. A total of 41 EM31 profiles were obtained along with 38 – 20 meter and 1 – 40 meter sounding loops. Profiles of the data are presented on the following slides.

- The facility consists of above ground storage tanks, a retort area and drip pad, a non-contact cooling water spray pond, a laboratory, treated wood storage areas, white wood storage areas, and a shop. The treatment plant conditions and pressure-treats wood products with preservatives to prolong product life. Treating operations began in 1966, and preservatives include petroleum based creosote and pentachlorophenol (PCP) solutions.

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



EPA

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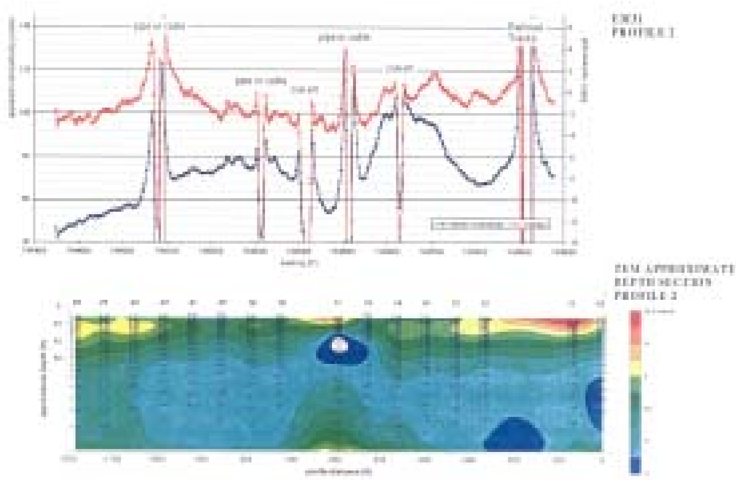
Notes:

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

- A low resistivity (interpreted to be greater than 10 ohm-meters) at the south end of the profile is shown at the south end of the profiles. This is interpreted to be a region of course grained channel type deposits in the alluvium. EM-31 terrain conductivity along this profile shows a low apparent conductivity along this interval. Another shallow high-resistivity interval occurs from 280N to 400N along PROFILE 1. Correspondingly, a terrain conductivity high occurs in the middle of this interval, but the overall region of the curve is depressed. This could be interpreted as a channel deposit where the groundwater is high in total dissolved solids (TDS). Therefore, this profile shows good correlation between TEM and EM-31 response.

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



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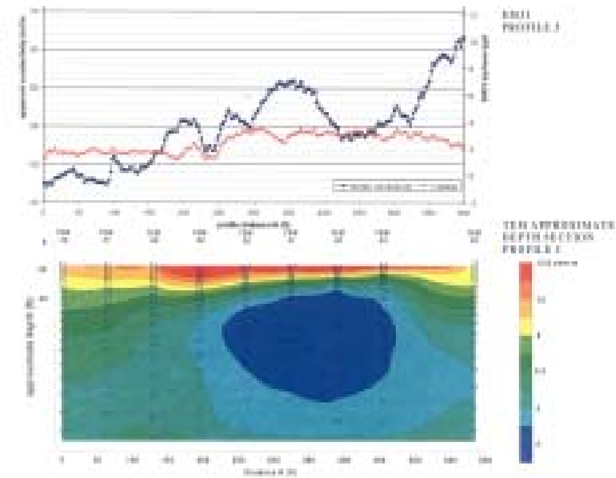
GT-48

Notes:

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

- Profile 2 shows TEM and EM31 data along a similar traverse, but note that these data are slightly offset (by as much as 130 feet). Field notes indicated steel culverts and railroad tracks and the railroad spur. Pipe responses occur at three other positions along the EM-31 traverse. TEM 17 was noted in the field notes as being contaminated by cultural noise, likely from the buried pipe indicated in the EM-31 data a short distance away. The extended spacing from TEM17 to TEM 18 occurred to avoid this metallic interference. Therefore, the anomalous response in the approximate depth section below TEM 17 should be ignored as due to metallic interference. Surficial high resistivity, indicative of channel deposits occurs at the west end of the profile, correlating with a region of low apparent conductivity in the EM-31 response. Another surficial high resistivity (channel deposit) occurs at the east end of the profile. Again, this correlates with a broad apparent conductivity low in the EM-31 data (except for the railroad track response).

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



EPA

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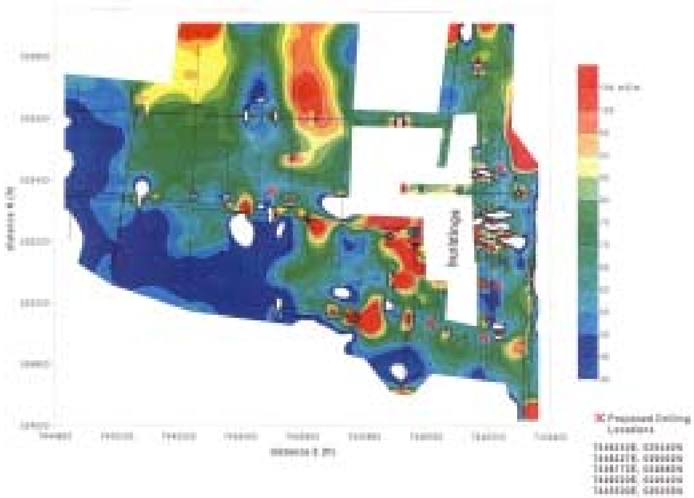
Notes:

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

- PROFILE 3 has no correlation between TEM and EM-31 response. This lack of correlation is due to cultural interference in the TEM response. During data collection, a buried pipeline was discovered running along the length of the traverse beneath the log piles. Therefore, the TEM data along this profile is responding to the pipe and not the lithology. EM-31 response along the traverse is more likely responding to the geological/hydrogeological system. Terrain conductivity lows at the south end of the traverse, and from 410 to 540 along the traverse likely correspond to channel deposits. These can be correlated to those from the parallel PROFILE 1, yielding an east-northeast trend of channels here.

Taylor Lumber Site — EM31 Conductivity Contour Plot



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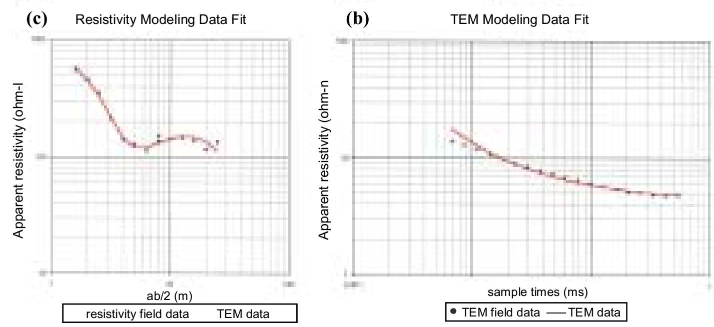
Notes:

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

- Based on the correlation between TEM and EM-31 response in PROFILE 1 and PROFILE 2, there is confidence that mapping the remainder of the site with EM-31 should yield differential lithology resulting from the paleochannel system response. Terrain conductivity lows are thought to result from coarse-grained paleochannel deposits. Proposed drill sites were also selected to sample paleochannels at their southern extent, downgradient from the drip-pad source areas, and also from the main treatment area.

Taylor Lumber Site — TEM Bedrock Modeling Results, Sounding 1A



(c) MODELING RESULTS

parameter	*final value*	*95% confidence interval* high	low
$\rho 1$ (Ω-m)	822.29	1059.18	638.38
$\rho 2$	15.83	17.22	14.55
$\rho 3$	1143.20	1733.34	753.97
$\rho 4$	4.20	4.38	4.02
$t1$(m)	1.12	1.20	1.04
$t2$	0.64	0.68	0.61
$t3$	2.02	2.99	1.36

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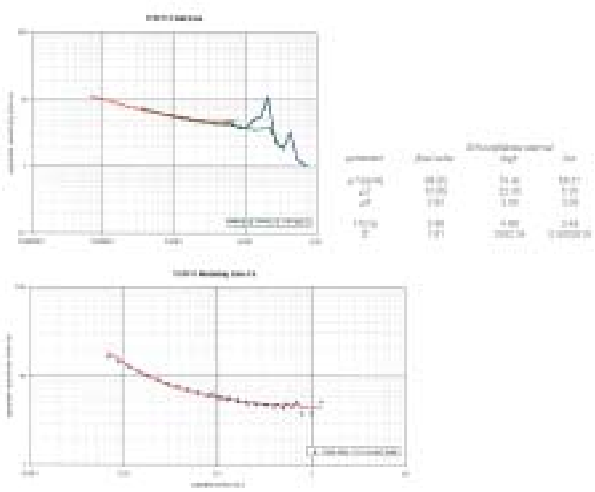
Notes:

- 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).

- An interpretation of the model is that the high-resistivity layers correspond to coarse-grained material, and the low-resistivity layers correspond to fine-grained material. The high resistivity unit shown as layer 3 of the model correlates to the gravelly unit above the bedrock surface noted in the drilling logs of several wells. The bottom layer (layer 4 of the model) correlates to the siltstone bedrock unit. Bedrock is modeled at (summing all layer thicknesses, 1.12 + 0.64 + 2.02 m = 3.9 m) 12.8 feet depth.

Taylor Lumber Site — TEM Bedrock Modeling Results, Sounding 11



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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.

- The siltstone bedrock is interpreted to be the low-resistivity bottom layer in the model (layer 3). Therefore bedrock depth is modeled at (3.48 + 1.01 = 4.49 m) 14.7 feet depth. However, resolution is not as high as for the simultaneous modeling of TEM 1A and the resistivity sounding. Parameter confidence intervals for the model show relatively tight control except for a very high confidence interval for the modeled layer 2 thickness. Therefore, the depth to bedrock is not well constrained here.

Taylor Lumber Site — Summary

- Time domain electromagnetic geoelectric sections clearly identified paleochannels
- Correlation of TEM and conductivity data provide confidence in certain areas where data could be collected that was reliable
- Boreholes were recommended downgradient based upon geophysical interpretation to optimize the sampling design
- Bedrock was found to consistently dip gently to the northeast suggesting few locations for DNAPL accumulation to occur
- Good example of collecting data in difficult area

EPA 53

Notes:

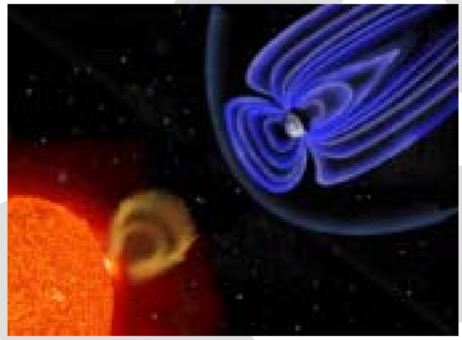
- The combined use of the two techniques employed at the site were used to focus well placements downgradient of the facility within the paleochannels on the site. Coarse grained deposits most likely to act as conduits to transport the contaminants were localized within the southeastern portions of the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

- TEM approximate depth sections clearly identified the paleochannel system in cross-section. Correlation with terrain conductivity response provided confidence in the terrain conductivity interpretation of the paleochannel system in areas where only that type of data were obtained. One resistivity sounding was collected near one of the TEM soundings in order to test the idea of improving the resolution of the electrical section interpretation. This proved valuable in delineating an electrical equivalent of the working model of the hydrogeological section based on drilling information.

- A total of 5 locations were recommended for drilling which are based on the down-gradient location of interpreted channel-type deposits in the alluvial section.

Magnetic Surveys

- Magnetometer surveys measure the magnetic field of the earth
- Ferrous metals and minerals alter the natural field



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Notes:

- A body placed in a magnetic field acquires a magnetization which is typically proportional to the field. The constant of proportionality is known as the magnetic susceptibility. Susceptibility is very small for most natural materials. However, ferromagnetic and ferrimagnetic materials have relatively large magnetic susceptibilities.

- Ferromagnetic and ferrimagnetic 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. The susceptibility of a rock typically depends only on its magnetite content. Sediments and acid igneous rocks have relatively small susceptibilities whereas basalts, gabbros, and serpentinites usually have relatively larger susceptibilities.

- The magnetic field of the Earth originates from electric currents in the liquid outer core. Earth magnetic field strengths are typically expressed in units of nanoTesla. The Earth's magnetic field varies during the day because of changes in the strength and direction of currents circulating in the ionosphere-these changes are referred to as diurnal. Sunspot and solar flare activity can create irregular disturbances in the magnetic field-these changes are referred to as magnetic storms.

- In simple terms, magnetometer surveys are used in environmental site assessment for a variety of objectives as provided in the next slide.

Magnetic Surveys — Advantages and Uses

- Underground storage tanks
- Mapping of landfills
- Geologic formations
- Detect ordnance

EPA

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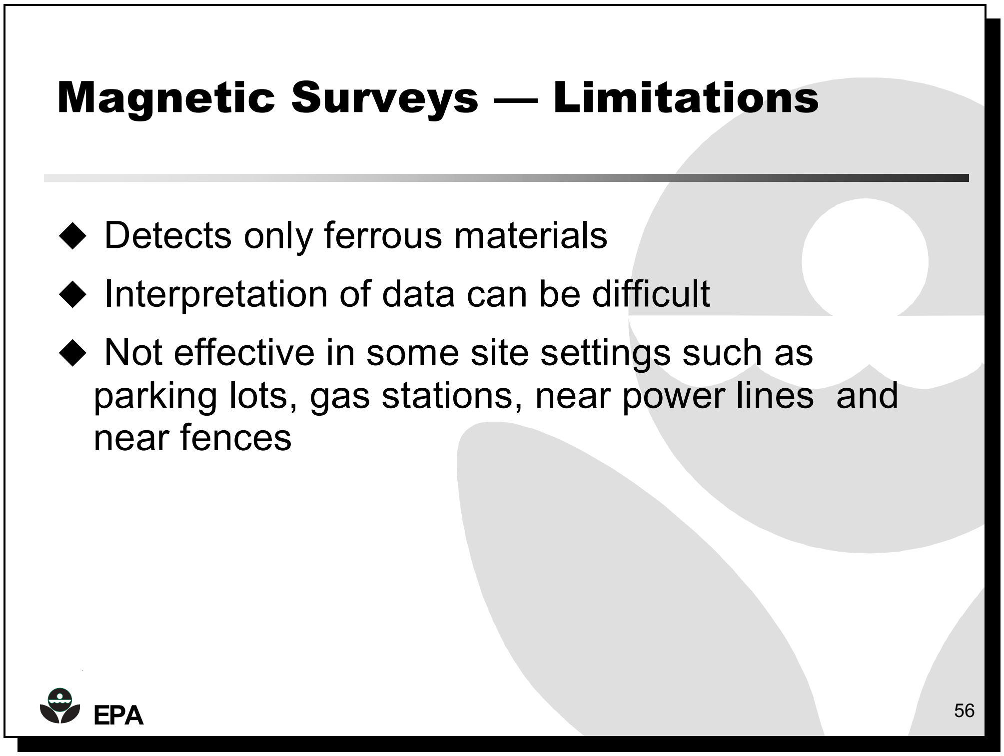
Notes:

- Magnetic surveys have become more widely used in recent years due to the increased efficiency of magnetometer systems. The most commonly used magnetometers today are called cesium vapor magnetometers. Other types of magnetometers are available, some with advanced sampling rates (such as the overhauser proton magnetometer) and the older type proton precession and fluxgate type systems. These magnetometers measure the magnetic field, in units called the nanoTesla otherwise called the gamma. Measurements can be obtained with the advanced systems at a rate of 10 times per second or more, allowing for rapid data collection.

- Magnetometers measure changes in the earth’s magnetic field caused by ferrous objects and geologic formations.

- Although there are other methods for metal detection, magnetometers are useful for a number of site objectives. These include location of underground storage tanks, assisting in assessing landfills for ferrous metal content, assisting in mapping lateral changes in geologic formations, and detection of ordnance in active and inactive military ranges. Another use for magnetometers is the detection of abandoned steel cased wells.



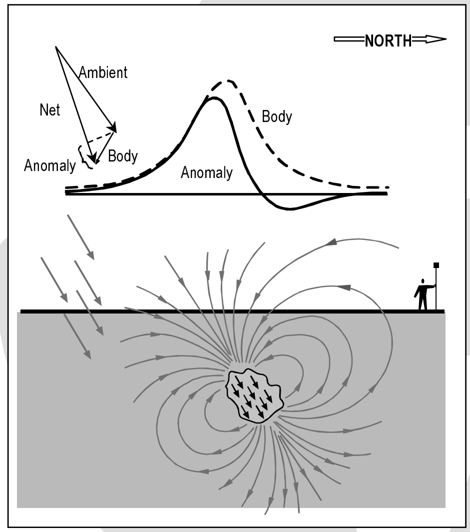
Notes:

- The principle limitation of magnetic surveys is the ability of the method to only detect ferrous materials. This includes iron and steel objects including automobiles, pipes, tanks, etc.

- Magnetometers measure changes in the earth's magnetic field caused by ferrous objects and geologic formations. These instruments do not detect non-ferrous metals such as aluminum. The measurements can be influenced by objects that are in the vicinity of the investigation site. This can include vehicles, surface objects such as gas pumps and overhead support beams, fences and electrical power. Other metal detection equipment may be an alternative in these situations.

Magnetic Field

- Naturally occurring everywhere on earth and varying
- Altered in the vicinity of a magnetic body or electrical medium that is carrying current



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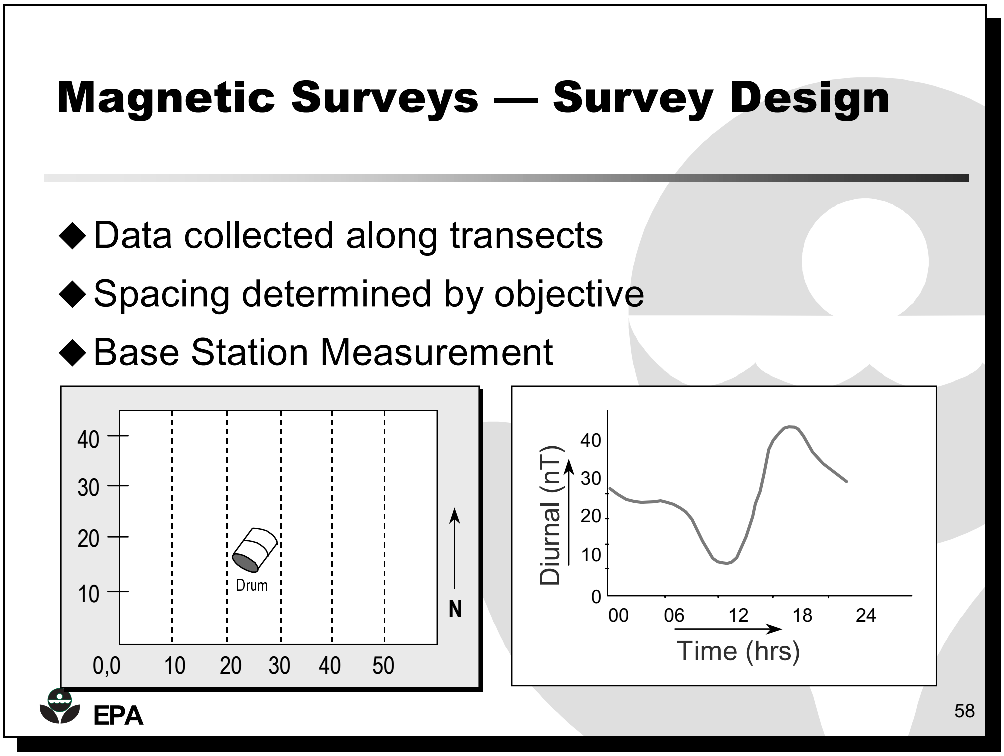
Notes:

The natural field is altered in the vicinity of a magnetic body such as a steel tank, drum, well casing, and magnetic geologic formations or rocks. The graphic depicts equipotential field lines around a static magnetized object with the passing of a magnetometer sensor along a profile over the object.

- 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.

- Note the variable spacing of the lines related to the object's geometry and the implications (gradient or flux) of making measurements in different regions around the object.



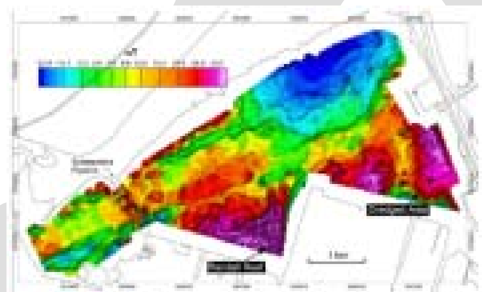
Notes:

- Most geophysical surveys are conducted along regularly spaced lines. Surveys are normally conducted along regularly spaced grid lines. Cesium vapor magnetometers are used in serpentine search or clearance patterns in addition to the grid-based data acquisition approach. Global positioning systems are used more often now to tie the geophysical measurements to ground coordinates.

- When total field measurements are being obtained, such as the case with proton and cesium vapor instruments, a separate stationary base station magnetometer should be used. The second magnetometer should be used to measure diurnal changes in the ambient magnetic field as well as possible magnetic storm effects. The next slide shows how the magnetic field varies with time during the typical day.

Magnetic Surveys

- Measure changes in field due to ferrous or magnetically susceptible objects
- Also detects geologic variations due to magnetic minerals
- Monitor of diurnal changes in the magnetic field



Marine Magnetometer Survey

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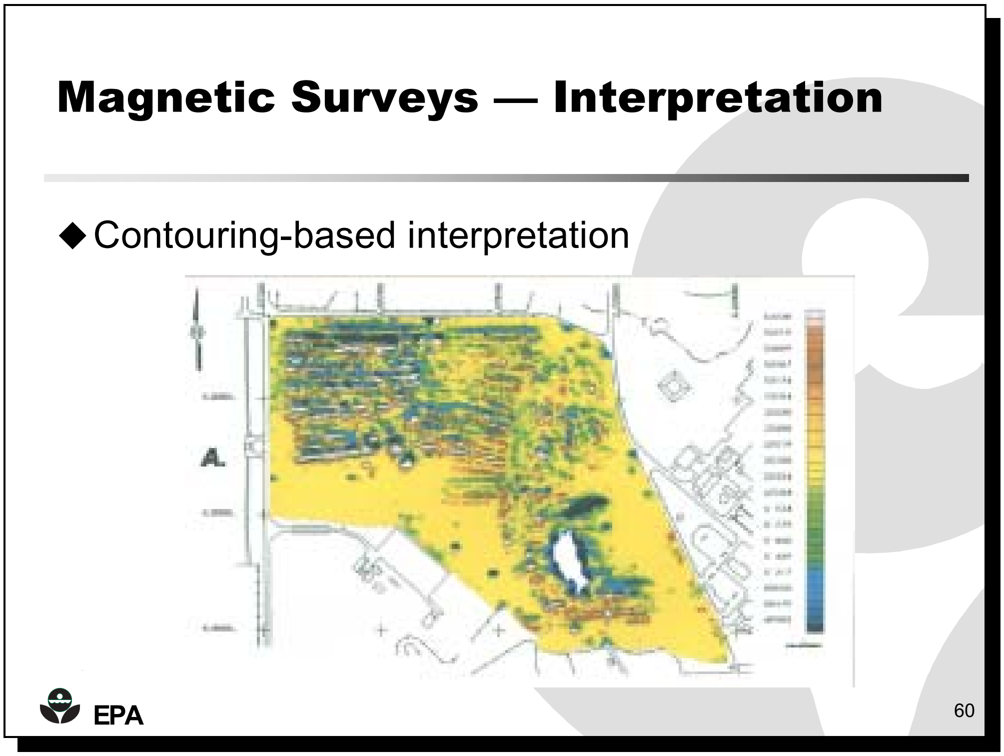
Notes:

- Magnetometers measure changes in the magnetic field due to ferrous objects, magnetic minerals in soils and rock, and also senses the variability of the natural magnetic field of the earth. This field can vary gradually during the day (10s of nanoTeslas), or can also change abruptly during magnetic storms that are related to solar events originating on the sun(up to hundreds of nanoTeslas).

- The figure on the right is a marine magnetometer map showing changes in near shore sediment magnetic susceptibility. Contaminants in this case contained measurable amounts of magnetic oxides (magnetite). Areas of high magnetite content are shown in bright colors. These sediments contained significant amounts of contaminant runoff materials from sewage treatment plants, steel mill waste and storm drain outflow sediment. This geophysical survey was conducted as a repid and cost effective method method to accurately estimate the distribution of contaminated areas in a basin, prior to the collection of core sample data. If core samples were used as the primary estimating tool to estimate sediment properties and pollutant levels, the distances between sample locations would lead to significant errors in the estimation of the distribution and total volume of sediments required for clean-up.

- The magnetic field is variable during the day requiring monitoring when a detailed magnetic survey is being conducted. An alternative to using a base station magnetometer would be to conduct a magnetic gradient survey. In this case, two sensors are used, and the difference in measurements is calculated. The measured quantity for this measure is known as the nanoTesla per meter.



Note:

- This graphic represents the common display of geophysical data when collected in either a regular spaced grid, or when using a global positioning system for positioning magnetometer data to ground coordinates.

- The data presented here are total magnetic field data from one sensor. The data were corrected for diurnal variations in the earths magnetic field. The objective in this survey was to map the lateral extent of suspected burial trenches containing mixed waste including ferrous metals. The total field data usually exhibits a slight horizontal gradient over the ground surface. Using specialized software, this gradient can be removed. The measurements shown in yellow are background values. The metal in the trench causes changes in the earths field that are caused by the ferrous metal in the trenches. In many cases apositive and a negative “dipole” anomaly is present in the data. This type of anomaly varies depending upon the type of material in the trench, its orientation, and the location on the earths surface.

- 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 were 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.

- 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. These parameters may range from defining a single tank or drum or delineating the extent of a landfill or plume.

In this case, the trenches are shown as anomalies with a positive peak to the south, and a negative peak on the north end of the trench. It is quite evident where the ferrous metal has been buried on this site. Using this information, the sampling of soils, placement of wells, and assessment of the extent of the trenching activity wasreadily determined.

Magnetic Surveys — Costs

- Daily rental rate for magnetometer = $60
- Daily rental rate for gradiometer = $90
- Base station = $20 to $60
- Shipping weight = 70 to 150 pounds
- Contractor crews and equipment = $1,450 per day
- Productivity = 3 to 6 acres per day

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Notes:

- Magnetic survey costs vary depending upon the cost of rental, the productivity of the survey team, and experience. Magnetometer equipment is generally easy to operate, but requires an understanding of proper data collection procedures. The equipment can be rented for a nominal cost. Basic software for downloading data, and observations about data quality and preliminary visual inspection of the resultant information is included in the rental. Advanced software is available from several vendors including Golden Software, Inc., Geosoft, Limited and others for data processing. The data can be displayed as either profile maps or contour maps. Usually this is the responsibility of a site or project geophysicist.

- Geophysical contractors are available that have access to the equipment, are trained to conduct a proper survey, and provide interpretations of the magnetometer data. It is highly recommended to used qualified personnel to conduct the geophysical surveys, process and interpret the geophysical data. A majority of geophysical contractors are members of the Environmental and Engineering Geophysical Society (EEGS). Links to many of these firms can be found on the EEGS website at www.eegs.org.

Magnetic Surveys — Summary

- Magnetometer surveys are useful for delineation of buried ferrous metallic objects and in some cases assist in mapping lateral or vertical variations in geologic formations and soils
- Advances in equipment and software have allowed for rapid and accurate surveys under optimum conditions

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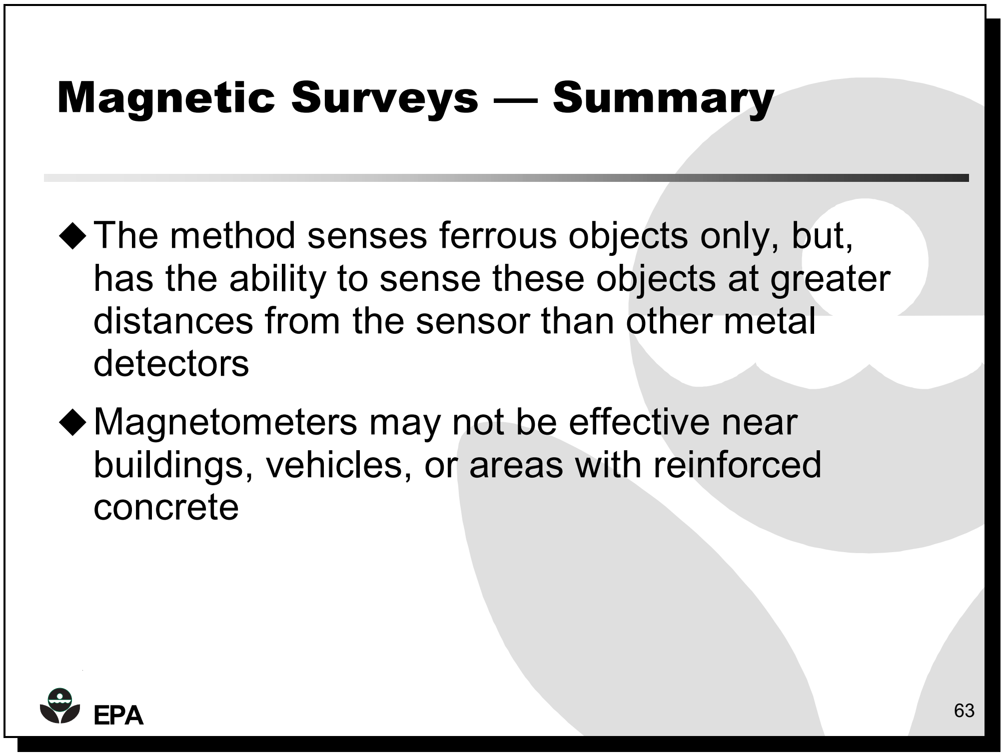
Notes:

- Magnetometers are used to detect buried ferrous metal objects such as drums, tanks and pipes.
- Magnetometers allow rapid characterization of a site.

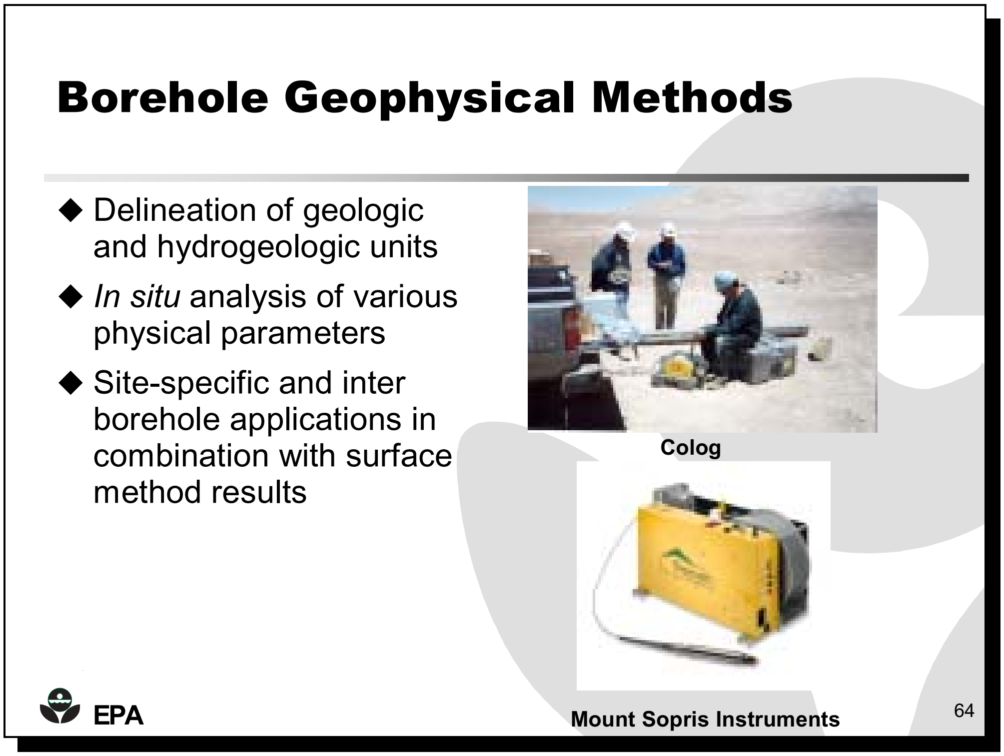


Notes:

- Magnetic surveys can detect large, deeply buried ferrous metal objects. However, smaller objects at depth may not be detected by this method. Other metal detectors, such as the EM61 (we will discuss this instrument later) cannot detect objects at great distances.

- Because magnetometers have a greater sensing distance, they may not be effective near buildings, vehicles, power lines or in areas with reinforced concrete, such as parking lots. An alternative metal detection system such as the EM61 may be an alternative choice in these types of situations.

- 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.



Notes:

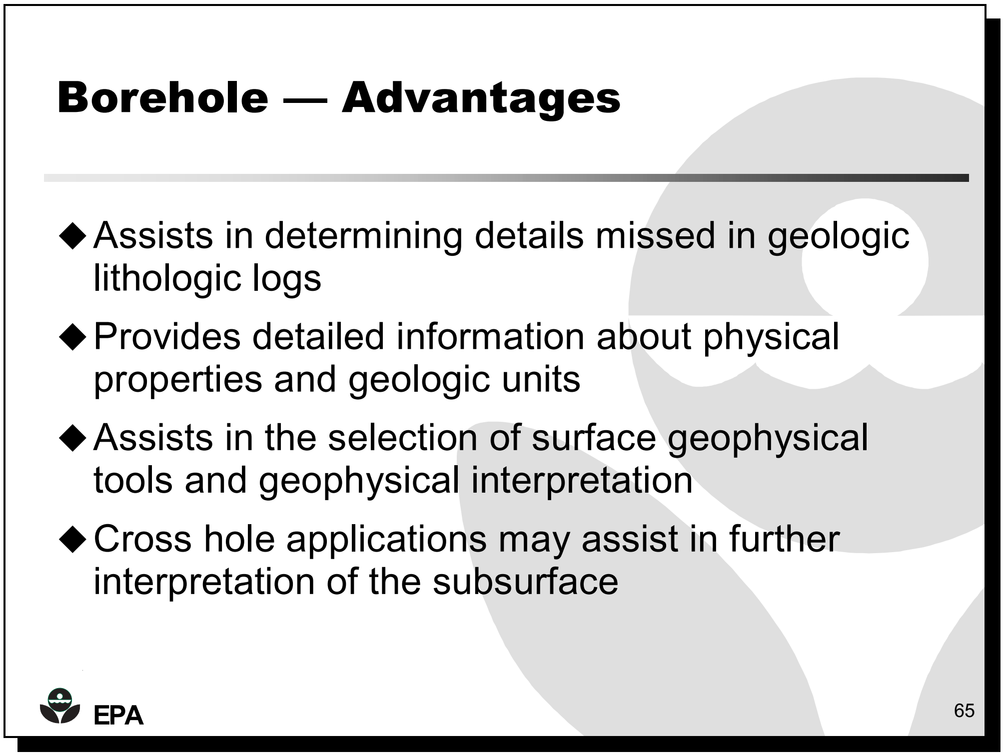
- Borehole geophysical surveys use a wide variety of physical principals to analyze the properties in test wells or monitoring wells. Probes that measure different properties are lowered into the borehole to collect a continuous data set, or in some techniques (for example, flow analysis) a point data set. These data are represented graphically as a geophysical log. Multiple logs are typically collected to take advantage of a joint analysis of the physical characteristics of the borehole.

- Measurements obtained in a borehole can provide information about the well construction, rock lithology and fractures, permeability and porosity, water quality and a number of other parameters.

- With borehole geophysical data, rapid interpretation is possible. When combined with surface geophysics, the application of borehole geophysical methods offers a three-dimensional (3-D) understanding of site 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 equipment for shallow environmental investigations is usually portable, and can be easily brought to a job site in a small van or pick-up truck.



Notes:

- Borehole geophysical surveys are useful for the determination of specific details about a geologic formation that may be missed in some borehole situations using traditional geologic or lithologic logs derived from borehole cuttings.

- 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. Polyvinyl chloride (PVC)-cased holes can be surveyed using natural gamma and electromagnetic induction conductivity. Steel-cased holes can be used by a limited number of borehole techniques.

- Cross borehole techniques such as electrical resistance and seismic tomography and cross borehole radar can be useful in expanding the interpretation of the subsurface between boreholes.

Borehole — Limitations

- ◆ Most probes can only be used in open holes
- ◆ Some probes require drilling fluid or water in the borehole
- ◆ The effective radius of measurement is within a small distance of the borehole
- ◆ Multiple boreholes are necessary to increase interpretation of an area

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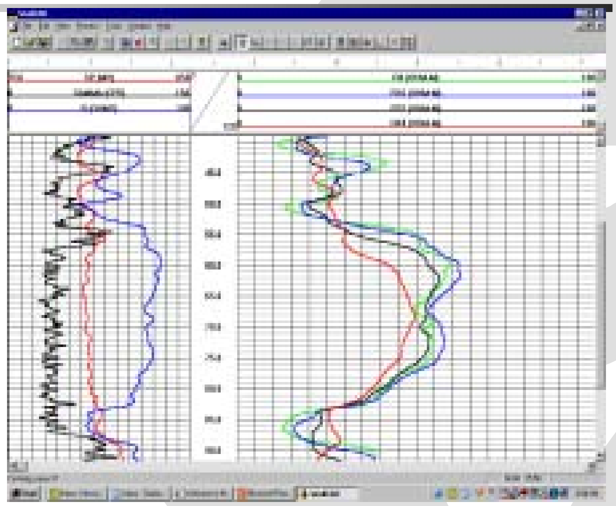
Notes:

- Limitations of borehole surveys include the necessity of a number of techniques that require an open hole for measuring the physical properties. This could result in a collapse of the hole in unconsolidated formations.
- Electrical probes require an open fluid filled hole in order to obtain information about the electrical properties of the borehole.
- The measurement of nearly all physical parameters is only within a small radius of the borehole.
- Multiple boreholes provide a better understanding of the subsurface and allow some confidence in the formations between boreholes when borehole techniques are applied.
- Borehole geophysical surveys are fairly rapid, however, these surveys result in downtime of the drilling contractor.

Borehole – Traditional Methods

- Natural gamma ray
- Single point resistance
- Spontaneous potential
- Normal resistivity
- Electromagnetic induction



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Notes:

- Traditional geophysical techniques are borehole methods that are conducted in a single borehole that are available either through a well logging service company, other geophysical survey firms, or with minimal training. Therefore, these techniques can be conducted by site personnel using rented equipment. There are other traditional techniques, a table containing most borehole techniques and a summary is provided at the end of this segment of the seminar.

- The traditional and most common borehole logs include the natural gamma, single-point resistance, and spontaneous potential. These measurements are commonly housed in one probe. Measurement of natural gamma is surveyed during one “run” up the hole, while the single point resistance and spontaneous potential (SP) are surveyed during a second run up the hole. Resistance and SP are performed in an open fluid filled hole. Measurements are usually conducted coming out of the hole in the case of potential obstructions that may be in the hole.

- Natural gamma Logs, one of several methods that can be conducted in open or cased holes record the amount of natural gamma radiation emitted by the rocks surrounding the borehole. The most significant naturally occurring sources of gamma radiation are potassium-40 and daughter products of the uranium-thorium decay series. Clay and shale bearing rocks commonly emit relatively high amounts of gamma radiation. They include weathered components of potassium feldspar and mica, and tend to concentrate uranium and thorium by ion absorption and exchange.

- Single point resistance logs measure electrical resistance of the formation rock. In general, the resistance increases with an increase in grain size and decreases with increasing borehole diameter, fracture density, and dissolved solids concentration in the water. This survey must be conducted in a water filled or drilling fluid filled hole.

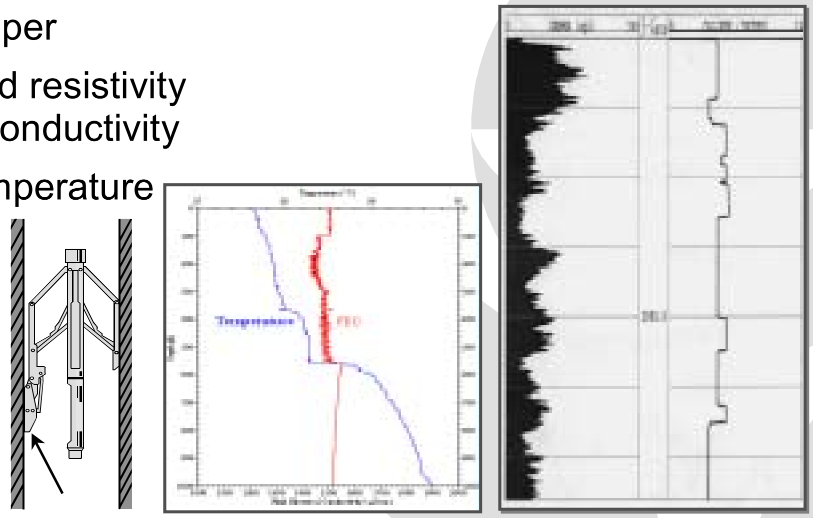
- Spontaneous potential logs record potentials (voltage) that are developed between the borehole fluid and the surrounding rock and fluids. Spontaneous potential logs can be used to determine lithology in the borehole and water quality. This survey must be conducted in a water filled or drilling fluid filled hole.

- Normal resistivity logs record the electrical resistivity of the borehole environment and surrounding rocks and water as measured by variably spaced potential electrodes on the logging probe. Typical spacing for the potential electrodes are 16 inches for "short-normal" and 64 inches for "long normal" resistivity. Normal resistivity logs are affected by bed thickness, borehole diameter and borehole fluid. These surveys must be conducted in a water filled or drilling fluid filled hole.

- Electromagnetic induction is an important technique for logging information about the conductivity of the geologic material in a borehole. This method is extremely useful because the method can be performed in uncased or PVC cased holes. In addition, it is not necessary to have fluid in the hole.

Borehole – Traditional Methods

- Caliper
- Fluid resistivity or conductivity
- Temperature



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Notes:

- Several other commonly used and important borehole techniques include the fluid conductivity method, caliper and temperature probes.

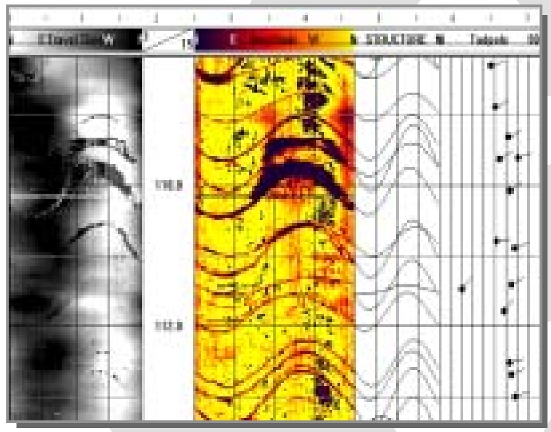
- Caliper logs record the diameter of the borehole. Changes in borehole diameter are related to well construction and are the competence of the geologic formation. The caliper survey measures the diameter of the hole mechanically. It can provide information about the geology, fracturing or caving along the borehole wall. Because borehole diameter commonly affects log response, the caliper log is useful in analysis of other geophysical logs that may be influenced by the hole diameter variations. Borehole surveys that may be affected include single point resistance and neutron.

- The Fluid conductivity probe records the electrical conductivity of the water in the borehole. Changes in conductivity reflect differences in dissolved solids concentration of water. These surveys are useful for delineating water bearing zones and identifying the vertical flow in a borehole.

- The fluid temperature log records the water temperature in the borehole. These logs are also useful for delineating water bearing zones and identifying vertical flow between zones of differing hydraulic head penetrated by wells.

Borehole – Advanced Techniques

- Acoustic televiewer
- Borehole image processing
- Full waveform sonic
- Variable density
- Borehole radar
- Flow meter
- Video camera



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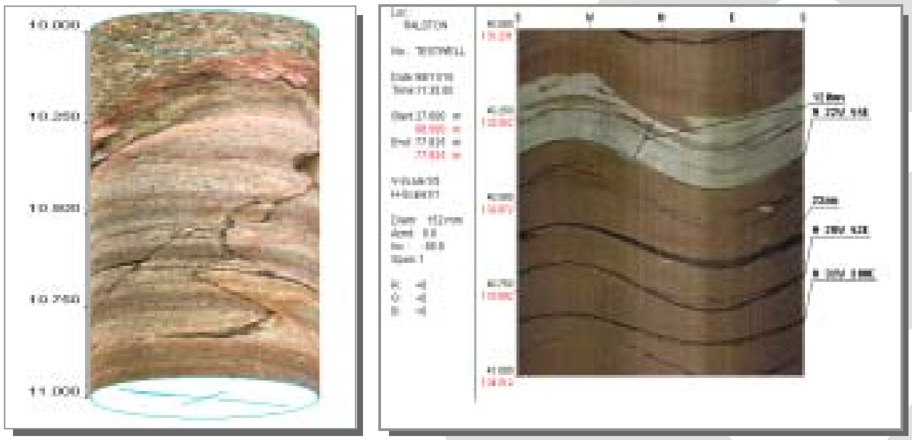
Notes:

- There are a variety of more advanced techniques that will be discussed in the next few slides. A table is provided at the end of this section that lists most of the techniques used today.
- Borehole radar, along with some of the traditional and other advanced techniques, can be used to determine lithology and fractures in the borehole. This method will be discussed later in a case history example.
- The illustration on the right is an acoustic televiewer (ATV) image. This is an ultra sonic imaging device that provides high resolution information used for measuring the orientation and distribution of borehole fractures and other features. Recent advances in computer technology have improved the quality and accuracy of ATV data and the presentation of the ATV images. The method is useful for formation evaluation, distribution and fracture orientation, and borehole inspections for casing or well bore breakouts. The optical televiewer provides a very high resolution oriented borehole image data set. This is an excellent alternative for borehole imaging where the turbidity of the well bore fluid prevents use of the higher resolution Borehole Image Processing System (BIPS) data. The ATV data can also be acquired at a faster rate that the BIPS at about 10 feet per minute. Because this is an acoustic measurement, it functions only in fluid filled portions of the borehole.

Borehole Image Processing System (BIPS)



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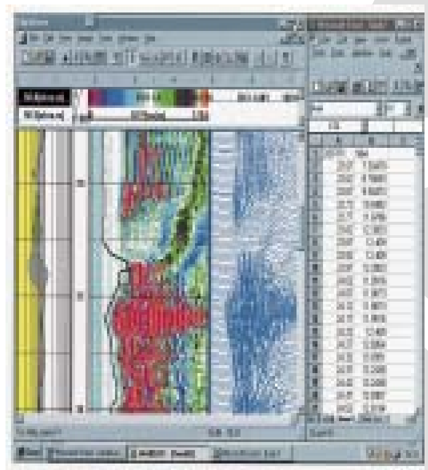
Notes:

- BIPS provides the highest resolution images of the borehole wall. The BIPS images are essentially digitized video signals and are more realistic than those provide by the ATV. Because this is an optical tool, the BIPS works only in clear fluid filled or air filled borings. The logging speed is restricted to about 2.5 feet per minute. The field deliverable for the BIPS is a VHS tape showing a color two-dimensional (2-D) waterfall display of the borehole wall.

- Data analysis and final presentation of the BIPS data includes a 3-D processed image of the borehole that can allow precise measurements of fracture and bedding orientations. Data that is provided can include the images as shown above, animated 3-D rotation, fracture tables, and statistics about fracture density.

Full Waveform Sonic Logs



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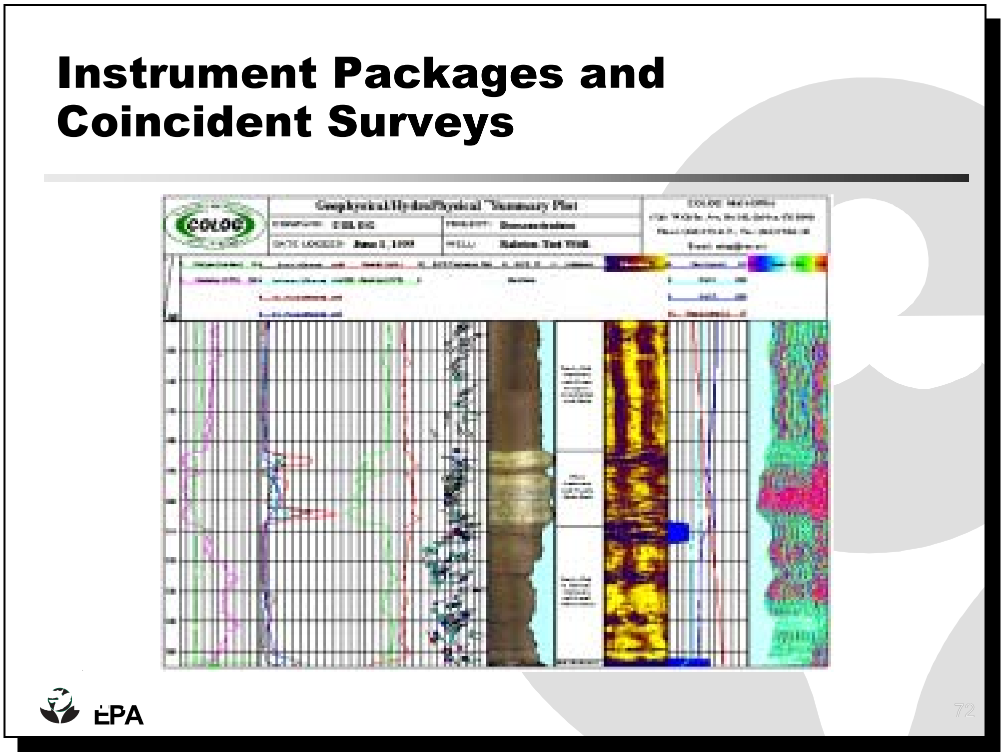
Notes:

- Full waveform sonic (FWS) logs measure sound properties in open hole, fluid filled formations. The FWS logs can be used for fracture identification, lithologic determination, waveform analysis, and rock property analysis such as porosity, permeability, competency and rock strength. The probe can also be used in the fluid filled portion of the borehole to determine if the well cement is bonding to the well casing.

- The full waveform sonic log can be used to determine amplitude and travel time (velocity) of formations, useful for assisting seismic survey interpretations.

- The graphic above is an image from an optical televiewer. 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.



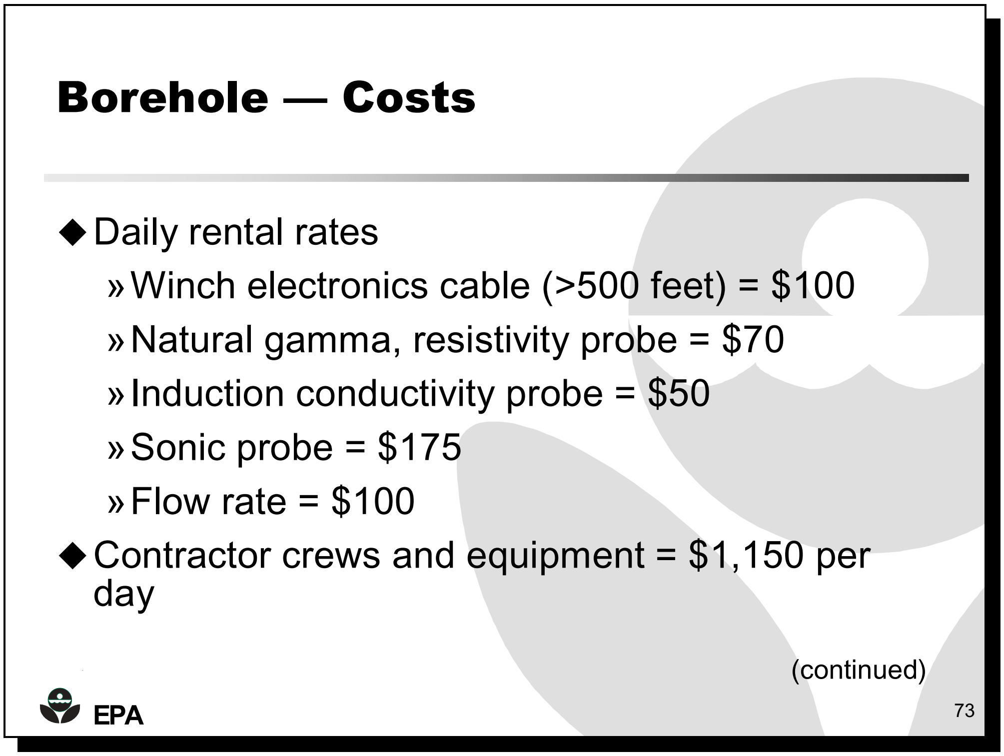
Notes:

- It is a 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 where two or more sensors may be mounted to a survey vehicle in a package format. Both downhole and surface geophysics package approaches use multiple sensors or instruments to obtain measurements during a single run or transect. Alternatively, two or more sensors may be used in the same borehole or along the same transect, but not simultaneously. This is often referred to as coincident surveying.

- In many surveys, apparently conflicting data is obtained from package or coincident surveys. A means of resolving these "conflicts" is to analyze sensor characteristics (such as signal to noise ratios) to develop error probabilities. Weightings are developed to "fuse" the data into a single interpretation. This process is sometimes done qualitatively when budgets do not allow for more rigorous, quantitative analysis.

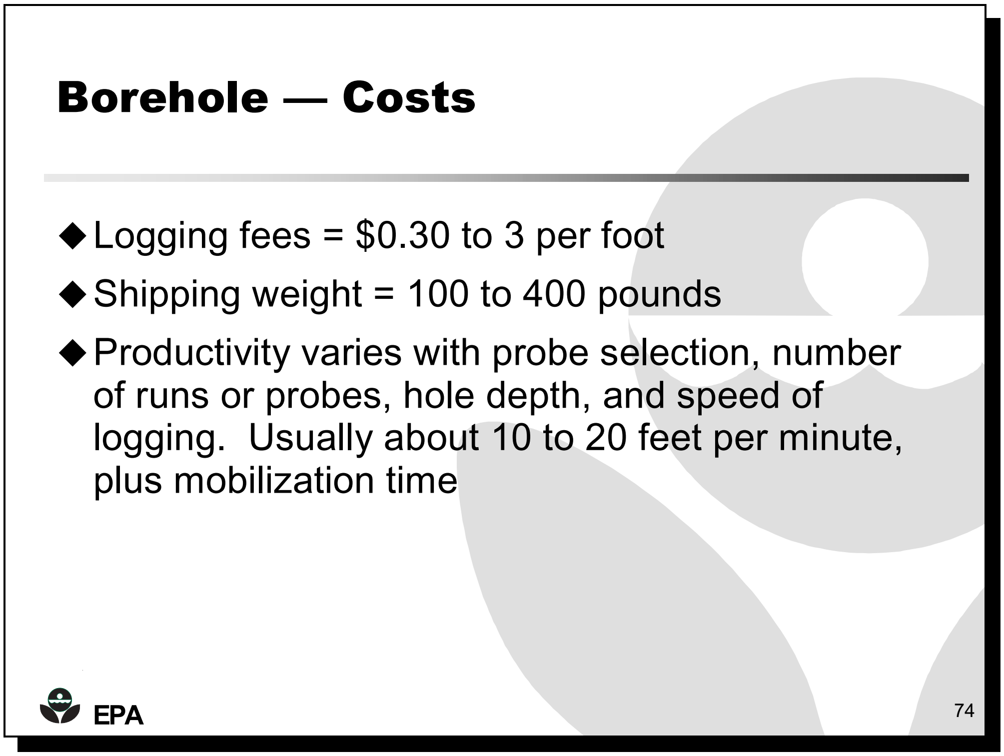
- This data presentation provides a summary of a number of the types of borehole surveys that have been discussed. By showing this type of summary plot, a better understanding of the response of the various instruments can be realized.

- Typically, this number of borehole tools are not within the budget of a project or may not be fully effective because of physical limitations at a site. This could include logging in unconsolidated formations requiring cased holes, or simply ineffective resolution of some physical parameters in the borehole.



Notes:

- 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 cost from about $50 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:

- Logging fees vary depending upon the type of borehole survey conducted. The traditional surveys, including the natural gamma, self potential, resistance and induction cost about $0.30 per foot. The advanced techniques are more expensive, require additional processing and usually are acquired at a slow rate (2-5 feet per minute). These costs can be up to about $3.00 per foot.

- The equipment is quite portable. Most probes, winches and cabling are designed to fit in containers that are compact. The shipping weight for one probe, a simple winching system and accessories can be as little as 100 pounds. Added probes will increase the weight of the shipment.

- Productivity rates vary depending upon the type of survey conducted, the number of surveys that are preformed in a hole, the hole depth and condition and the logging speed used.

- A typical logging run in a well that is about 50 to 100 feet deep will take about 20 minutes to set up, and 10 to 20 minutes to run with the simple techniques, 20 to 40 minutes with the advanced techniques.

- Total footage per day can range from several hundred to several thousand feet per day, depending upon the number of holes required to set up on. Deeper holes will result in more footage per day.

Borehole — Summary

- Provides details missed in lithologic logs
- Assists in mapping zones that may not be visible that can be interpreted to other boreholes
- Assists in providing physical data for selection of other surface geophysical techniques
- Many tools require open holes, but many can be operated in PVC cased holes, and several can be used in steel cased holes

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Notes:

- Borehole geophysical methods can be an important tool in defining important small features or unrecognizable features in boreholes that may assist in correlating information between holes that may assist in site characterization. Borehole geophysical tools are often useful in determining physical properties of the subsurface to assist in selection or interpretation of other surface geophysical methods.

- A variety of tools are available that may be used in either PVC cased ,open or steel cased holes.

Summary – Borehole Tool Applications

Borehole Technique	Application
Electrical tools	Lithology, water quality
Gamma	Lithology, clay content
Neutron	Porosity, moisture content
Televiewers	Fractures, bedding
Caliper	Hole conditions, lithology
Fluid temperature	Gradients, flow
Fluid conductivity	Fluid contamination
Borehole radar	Fractures, lithology

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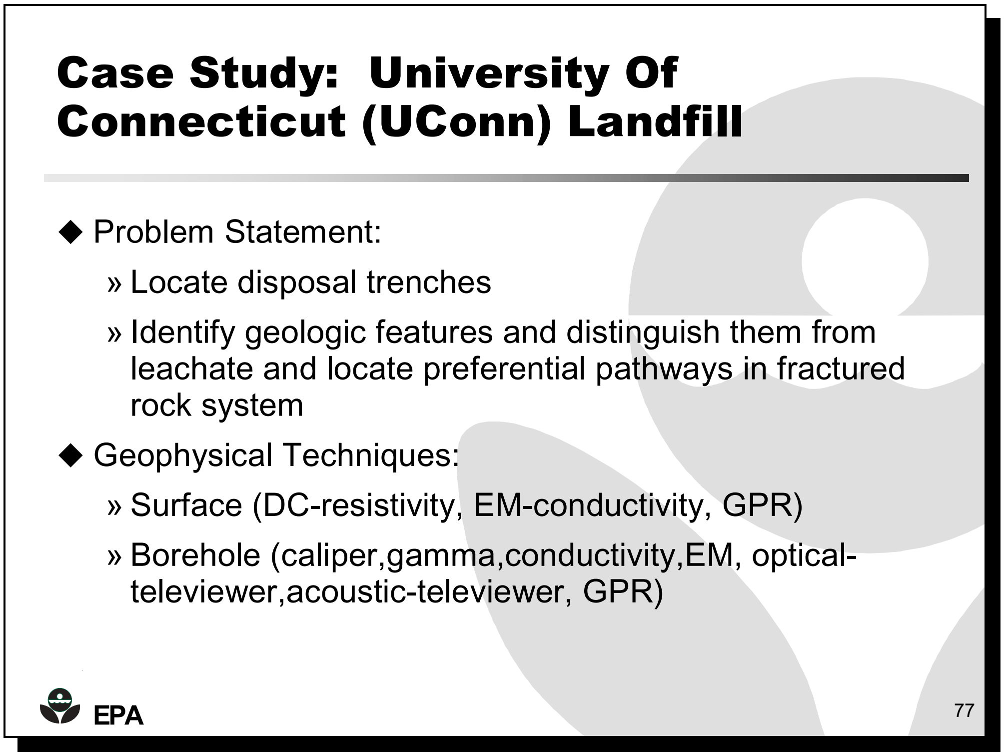
Notes:

- There are an number of borehole tools that are available, some traditional, and some that requiring special equipment, expertise, and special processing. There are too many to list in this slide. A table is provided that summarizes many of the available techniques, applications, required hole conditions and limitations. Please refer to this table, and look up the links to the literature, firms that conduct these types of surveys, and the tools that are available to conduct borehole work.

APPLICATIONS OF VARIOUS BOREHOLE GEOPHYSICAL LOGGING TOOLS

Type of Log	Properties Measured	Potential Application	Required Hole Conditions	Other Limitations
Spontaneous Potential (SP)	Electrical potential caused by salinity differences in borehole and interstitial fluids	Lithology, shale content, water quality	Open hole filled with conductive fluid	Salinity difference required between borehole and interstitial fluid
Single Point Resistance (SPR)	Resistance of rock, saturating fluid, and borehole fluid	High-resolution lithology, fracture location with differential SPR	Open hole filled with conductive fluid	Not quantitative, hole diameter effects significant
Multi-Electrode Resistivity	Resistivity, in ohm-meters of rocks and saturating fluids	Quantative data on salinity of interstitial water	Open hole filled with conductive fluid	Normal resistivity spacing must be smaller than bed thickness to measure bed accurately
Electrical Induction	Conductivity of rock and saturating fluids	Quantitative data on salinity of interstitial water, lithology	Open or non conductive casing	Skin effects for highly conductive formations
Natural Gamma, Spectral Gamma	Gamma radiation from natural or artificial radioisotopes	Lithology related to clay (silt) content and permeability. Spectral gamma identifies gamma-emitting radioisotopes	Any hole conditions, except very large, or very thick casing and cement	Very high count rates need to be corrected for dead-time
Gamma-Gamma Density	Total electron density	Bulk density, porosity, moisture content, lithology	Best results in uncased hole; qualitative through casing or drill stem	Hole diameter effects
Neutron	Hydrogen Content, Elemental spectra	Saturated porosity, moisture content, activation analysis, lithology	Best results in open hole; can be calibrated through casing	Hole diameter and chemical effects
Acoustic (Full Waveform) Velocity	Compressional, shear, & tube wave velocities	In-situ engineering properties, porosity, fracture location, & character, cement bond	open or cased fluid filled holes	Does not "see" secondary porosity
Acoustic Televiewer	Acoustic reflectivity of borehole wall	Location, orientation, & character of fractures and solution openings, strike and dip of bedding, casing inspection	Fluid filled hole	Heavy mud or mud-cake attenuates signal
Optical Televiewer	Optical borehole wall imagery	Location, orientation, & character of fractures and solution openings, strike and dip of bedding, casing inspection. Mineralogy (color and light reflectance)	Air or clear fluid	Optics diminish as hole is disturbed
Caliper	Hole or casing diameter	Hole diameter corrections to other logs, lithology, fractures, hole volume for cementing	Any conditions	Deviated holes may skew measurement
Fluid Temperature	Temperature of fluid near sensor	Geothermal gradient, in-hole flow, location of injected water, correction of other logs, curing cement	Any conditions	Best in undisturbed holes

Type of Log	Properties Measured	Potential Application	Required Hole Conditions	Other Limitations
Water Quality	Several measurements available: Fluid Conductivity., pH, Redox, Salinity, Pressure, Sulphides, Nitrates, Chlorides, Ammonia, Copper	Municipal water supply testing, environmental compliance, drinking water safety	Fluid filled hole	Some sensors require regular maintenance and / or replacement
Flow	Velocity of net flow in borehole	In-hole flow, location and apparent hydraulic conductivity of permeable interval	Fluid-filled hole	Spinners require higher velocities and centralization
Magnetic Susceptibility	Magnetic field or some derivative	Location of magnetic media	Air or fluid, non magnetic casing	Mostly qualitative, but can be calibrated if borehole diameter is known
Induced Polarization	Formation chargeability over a time or frequency domain	Location of conductive zones	Open fluid-filled hole	Best measurement requires relatively high current to be transmitted into formation
Deviation	Inclination & Bearing of borehole	Subsurface geometry, location of specific targets	Gyro required in magnetic cased holes	Surface coordinates must be known for gyro

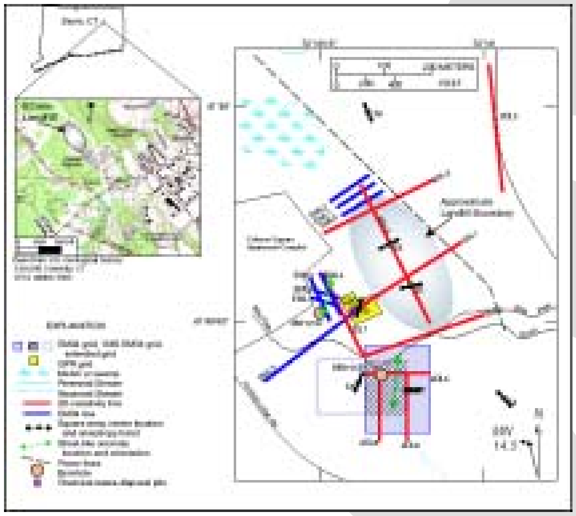


Notes:

- This Study utilized an integrated suit of geophysical methods to characterize the hygrogeology of the fractured bedrock aquifer. This was done to identify contamination or preferential pathways for contaminant migration. The site is a former 5-acre landfill at the University of Connecticut located in Storrs, Connecticut, in the northeastern part of the state.

- The USGS conducted geophysical investigations at this site where solvents have contaminated a fractured bedrock aquifer. Borehole, borehole to borehole and surface geophysical methods were used to characterize the bedrock fractures, lithologic structure, and transmissive zone hydraulic properties in 11 boreholes. The geophysical methods included conventional borehole logs, borehole imagery, borehole radar, flowmeter and azimuthal square-array dc resistivity soundings.

UConn Landfill — Survey and Borehole Locations



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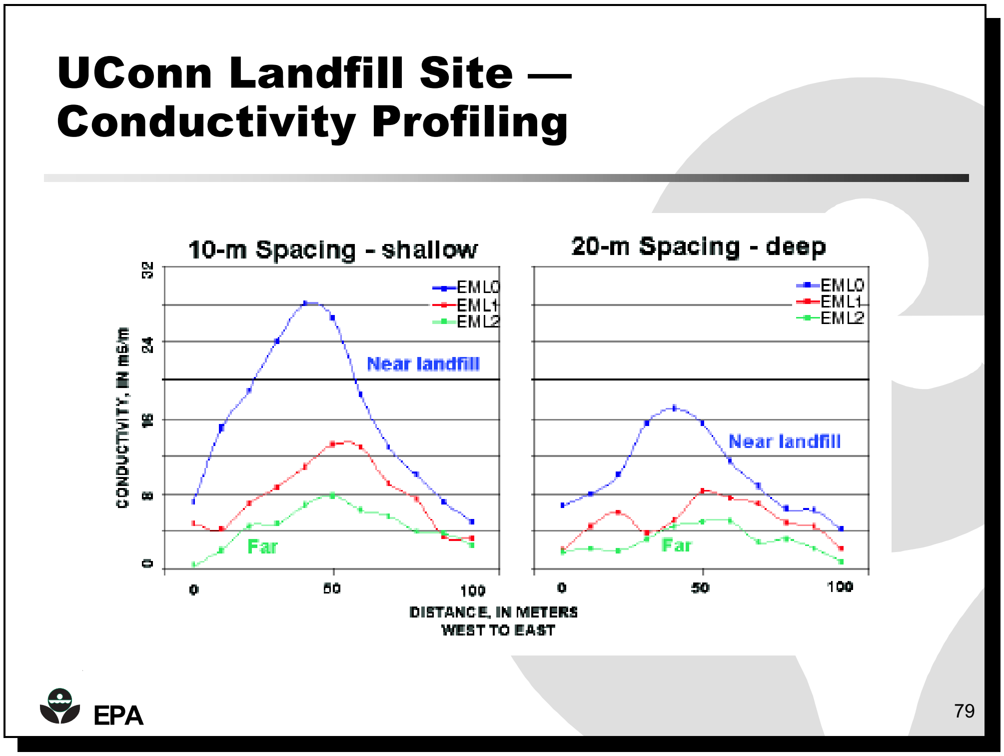
Notes:

- The UConn campus is located 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.

- The figure on the left, that can be enlarged with your viewer, shows the topographic map of the area. The figure on the right shows the geophysical survey layouts. The red lines indicate the location of the direct current resistivity survey lines. The blue lines indicate the EM34 apparent conductivity survey lines. Boreholes are shown as yellow circles. Ground penetrating radar grid areas are shown as a yellow rectangle. Also shown are the location of direct current azimuthal resistivity locations. This data is not presented in this summary, but the azimuthal surveys are used for detection of fracture orientation.



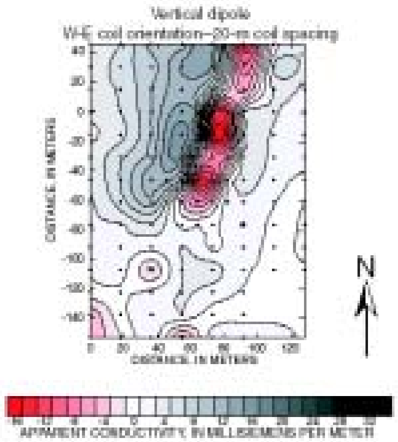
Notes:

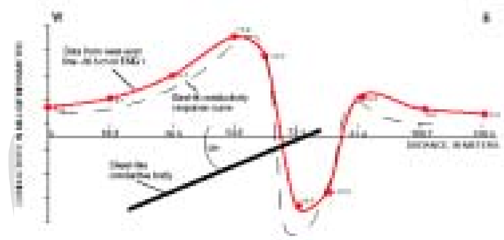
- The slide presents the inductive terrain- apparent conductivity measurements collected using the Geonics EM34 for three parallel lines at the north end of the landfill study area with 10-meter spacing on the left and 20-meter spacing on the right.

- The magnitude of the apparent conductivity anomaly decreases to almost background levels with depth and laterally at about 46 meters north of the landfill.

- Another anomaly, not shown on this slide, south of the landfill is interpreted as a shallow leachate plume that extends vertically through the overburden into the shallow bedrock and laterally along the intermittent drainage to Eagleville Brook.

UConn Landfill Site — Contoured Conductivity and Model





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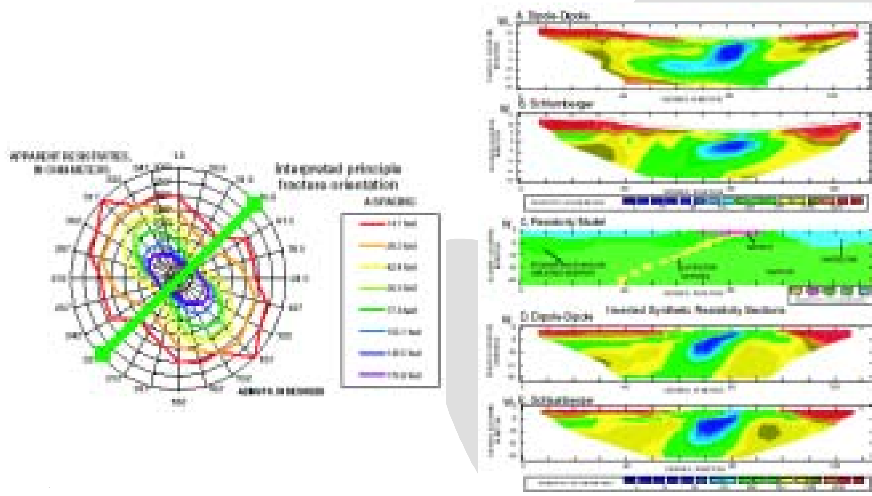
Notes:

- The slide presents the contoured terrain conductivity from the EM34 on a small grid area on the west side of the site near the former chemical waste disposal pits. This data were collected using vertical dipole orientation with 20-meter separation from the grid and lines run east-west. The figure on the right represents the conductivity response curve generated by a forward modeling program and using the data from the grid. The modeled dip and conductivity of the anomaly was estimated by comparing the observed data with forward models of conductors with known dip and conductivity.

- Another anomaly to the south of the landfill not shown here was interpreted as a shallow leachate plume that extends vertically through the overburden into the shallow bedrock and laterally along the intermittent drainage to Eagleville Brook.

UConn Landfill Site — Direct Current Resistivity Results



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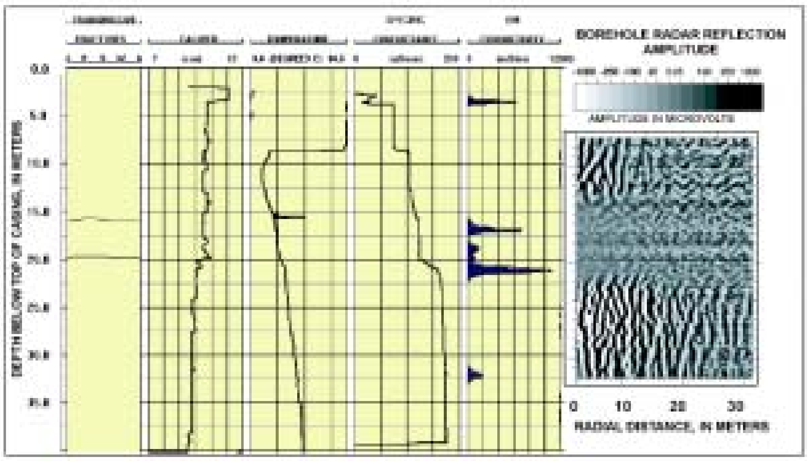
Notes:

- The figure on the right is an example of one of the azimuthal square-array direct current (dc)-resistivity soundings. These measurements measure changes in apparent resistivity (the inverse of conductivity) with direction and depth about an array center point. Apparent resistivity data measured by rotating this array over a homogeneous earth containing uniformly oriented, saturated steeply dipping fractures, will have an apparent resistivity minimum oriented parallel to the dominant fracture orientation. This is shown in green indicating that the fractures are roughly northeast to southwest. This method is usefull where electrical resistivity anisotropy is induced by bulk fracture or rock fabric orientation to estimate fracture and (or) foliation orientation trends.

- The slide on the right 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.

- Comparing the 2-D resistivity cross-section data to the EM apparent conductivity, 2 sheet like conductivity anomalies are also present. The results show that the conductive anomaly intersects the ground surface at the topographic minimum along the line. The model shows resistive bedrock underlying a conductive layer of till or weathered bedrock. The bedrock is cut by a thin dipping conductive unit. The data suggests that the anomaly observed in the field data could be induced by a conductive unit dipping about 30 degrees west, consistent with the result of the inductive terrain conductivity field data.

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



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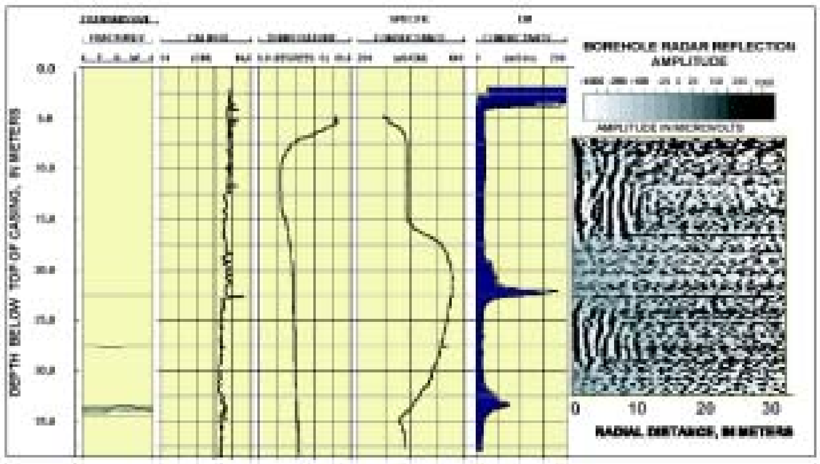
Notes:

- 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.

- Four reflectors were interpreted from the directional borehole radar reflection data shown on the far right as well as 4 zones of high radar attenuation that correlate with EM-conductivity anomalies shown directly to the left of the radar data. A spike at about 16.8 meters in the EM-conductivity data coincides with a radar reflector that is determined to be parallel with foliation. The EM-conductivity log indicates a high electrical conductivity anomaly at a depth of 21 meters. This is a sulfide mineralization observed in the optical televiewer and drilling logs. Fluids in the borehole next to the EM spikes have relatively low electrical conductivity. The low specific conductance of the fluids in the borehole support that the electrical conductivity unit detected by surface-geophysical methods, and the feature imaged in the borehole-radar log is related to a lithologic change rather than fractures.

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



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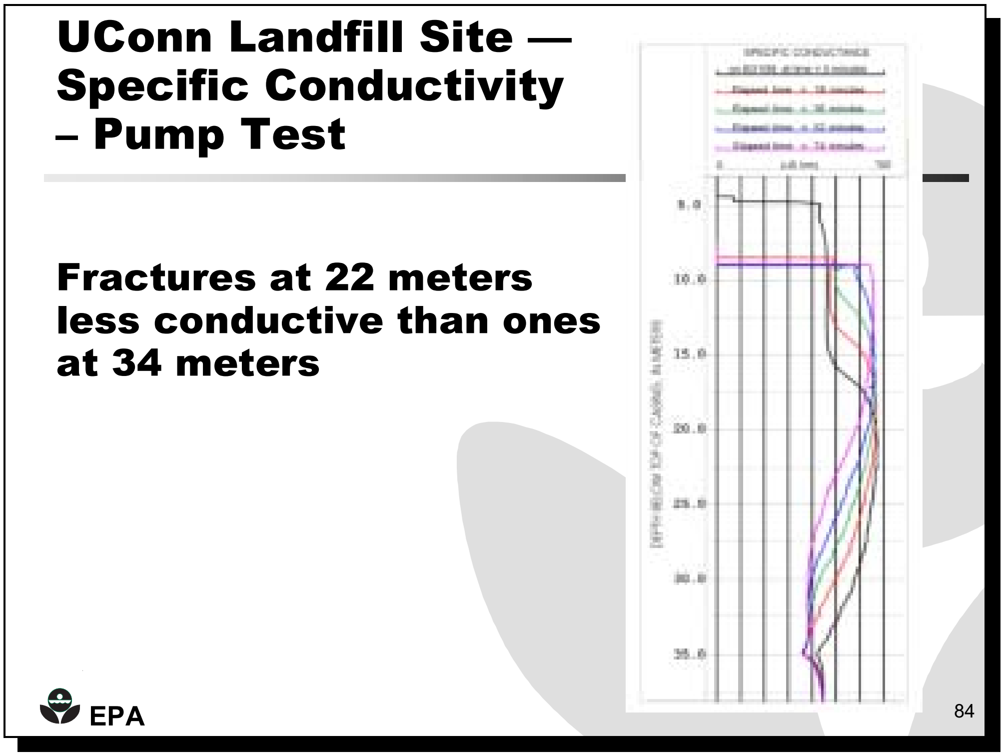
Notes:

- 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.

- Eight reflectors were interpreted from the directional borehole radar data. Seven correlate with fractures observed in the optical and accoustic televiewer logs. A south striking, westward dipping feature was identified in the radar log at 17.4 meters, which is coincident with a fracture in the ATV log. Another feature at about 22 meters was observed in the OTV, ATV and borehole-radar surveys corresponding to a logged electrical conductivity high. The location and orientation if this feature matches the anomaly interpreted from the surface geophysical data.



Notes:

- 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.

- Consecutive specific conductance logs were collected while being pumped. The logs indicate that water with a specific conductance of 370 microSiemans per centimeter entered the well at a depth of about 34 meters and displaced the more conductive water above it. After about an hour of pumping the most conductive water in the borehole that was adjacent to the fracture near 22 meters, reached the pump that was at about 10 meters. These logs indicate that the lower fracture zone at 34 meters is more transmissive that the 22 meter fracture. The logs also indicate that the water coming from the lower fracture zone is less electrically conductive than the 22 meter fracture.

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:

- 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.

- This investigation illustrates the effectiveness of geophysical surveys, both surface and borehole, for identification and evaluation of electrically conductive contaminant plumes.

Geophysical Technology Selection Summary

Environmental Problem	Geophysical Method
Metal detection	Magnetometer (ferrous metal), EM61 (all metals)
Waste pits, trenches, landfill boundaries	EM conductivity (EM31), GPR
Contaminant plumes (or preferential pathway)	EM conductivity (EM31), GPR
Depth to bedrock	DC resistivity, seismic refraction, TDEM soundings
Void detection (solution cavities, mine workings)	GPR, seismic reflection
Fault and fracture mapping	Seismic reflection, GPR, DC resistivity

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Notes:

- There are a number of geophysical technologies available for environmental site characterization. Some have dual or multiple applications. This slide provides a number of environmental problems, and a listing of geophysical methods. In many cases, there may be a multiple number of instruments that can solve the problem, but the advantages and limitations of a particular instrument may come into play when determining the geophysical method of choice. From this course, and the advantages and limitations, spend a little time and compare the methods that are listed for the problem, and determine under differing site conditions what method is the most applicable to the site. For a simple example, what metal detection system would you use to detect an aluminum container at depth? Answer: EM61 priority 1, or EM conductivity priority 1. Other methods may be applicable.

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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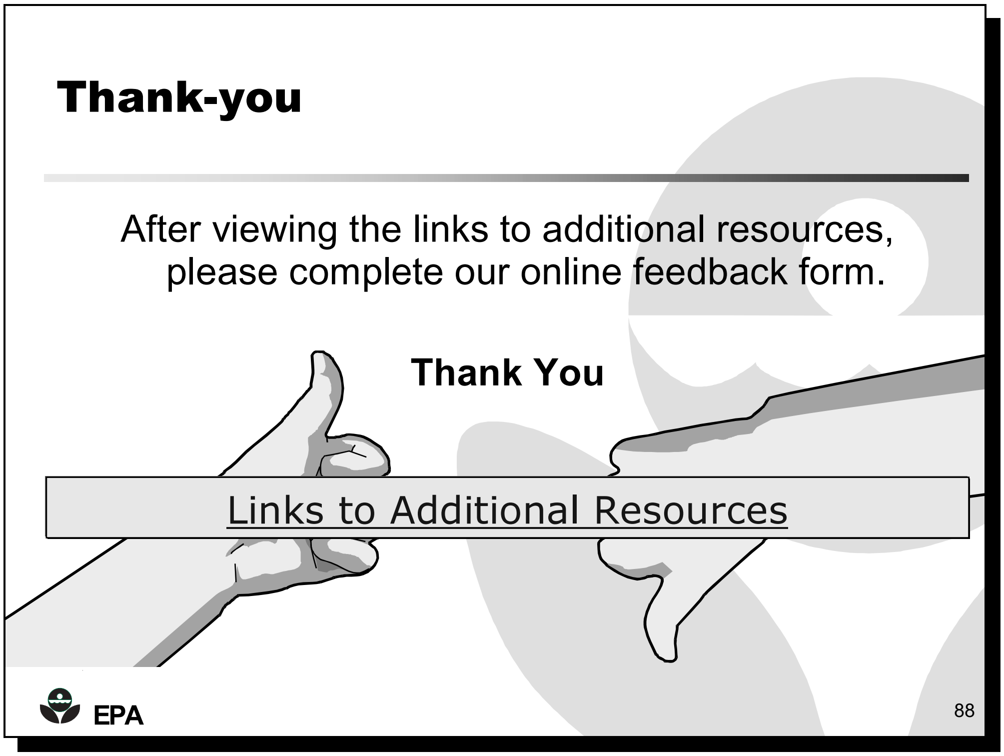
Notes:

- 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.
Thank You
Links to Additional Resources
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