United States
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Environmental Monitoring
Systems Laboratory
P.O. Box 93478
Las Vegas NV 89193-3478

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Geophysics Advisor Expert System

Version 1.0

GEOPHYSICS ADVISOR EXPERT SYSTEM: VERSION 1.0

by

Gary R. Olhoeft
U.S. Geological Survey
Denver, Colorado 80225

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Project Officer

Aldo T. Mazzella
Advanced Monitoring Systems Division
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada 89193-3478

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ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89193-3478

NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Interagency Agreement Number DW14932497 to the United States Geological Survey. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

This expert system computer program is designed to assist and educate non-geophysicists in the use of geophysics at hazardous waste sites. It is not meant to replace the expert advice of competent geophysicists. The program is written to run on any IBM-PC-DOS compatible computer and to be simple to use. The program asks questions about the geology at a site, the contamination problem, and cultural noise. The program considers the following geophysical methods: electromagnetic induction, d.c. resistivity, seismic, magnetic, ground penetrating radar, soil gas, gravity, and radiometric techniques. Based upon the answers given to the questions, the program recommends what types of geophysical methods will most likely be useful at the site to solve such problems as the location of the contamination and hydrogeological characterization of the site.

This report was submitted in fulfillment of Interagency Agreement Number DW14932497 by the U.S. Geological Survey under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from May 1987 to May 1989, and work was completed as of May 1989.

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INTRODUCTION

This expert system computer program was created for the U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada. The expert system is designed to assist and educate non-geophysicists in the use of geophysics at hazardous waste sites. It is not meant to replace the expert advice of competent geophysicists.

GEOPHYSICS ADVISOR EXPERT SYSTEM

The geophysics expert program asks questions about a site and the contamination problem. Questions about the types of cultural noise are also addressed. Over 90 questions are in the program. The total number of questions asked, however, varies depending upon the answers to initial questions. The program considers the following geophysical methods: electromagnetic induction, d.c. resistivity, ground penetrating radar, magnetic, seismic, soil gas, gravity, and radiometric techniques. Based upon the answers given, the program recommends what types of geophysics will most likely be useful at the site to solve such problems as the location of the contamination and hydrogeological characterization of the site. A relative numerical ranking of the various methods is produced, with the more positive number indicating the best or better methods to consider. The methods are also ranked into three general categories, with a method receiving a recommended, not recommended, or uncertain effectiveness evaluation. The program also annotates why the various geophysical techniques will likely work or not work at the site. At the end of a run the program will indicate any apparent inconsistencies in the responses to the questions. The user can go back to any specific question and change an answer. If a large number of inconsistencies are indicated, it is best to consider going back to the beginning and go through the whole program.

If a site is very complicated with many things happening, it is recommended that the site be broken down into several subsite problems, and the program should be run separately for each problem. The program is designed to give a hard copy printout of all the questions and answers on Epson compatible printers. An example of a computer output of the program is included. The output can also be stored on a computer file.

The program is written to run on any IBM-PC-DOS compatible computer and to be very simple to use. It is written in True Basic and by itself requires about 200 kilobytes of memory. About 512 kilobytes of memory is required when the overhead of a typical DOS operating system is included.

To run the program, place the floppy diskette in drive A:, type 'A:' and press the 'Enter' key, then type 'EXPERT' and press the 'Enter' key. Follow the instructions shown on the screen from that point on. Press 'Ctrl Break' to exit the program at any point (this is not recommended when the program is writing to the disk). Quality Assurance requirements mandate that the program only be available in compiled form and the datafile be encrypted. However, the program and datafile are not copy protected and may be freely copied. This program is not subject to U.S. Copyright Law.

RECOMMENDATIONS

A second version of the program (2.0) is currently under development. Version 2.0 will improve the system by adding a database of the physical and chemical properties of the top 100 chemicals on the hazardous substances list. The current version 1.0 asks questions about the properties of the contaminants, such as "Are the organics miscible with water?" Version 2.0 will present a list of contaminants to select from (such as benzene). For the top 100 contaminants, it will know the answers to the questions. For other contaminants, it will still ask the questions about the properties. Version 2.0 will be available in 1990.

The consideration of other geophysical methods, such as the self or electrokinetic potential technique, is currently being reviewed and may be added in the next version of the program.

EXAMPLE OF COMPUTER PRINTOUT

The example on the following pages is a computer printout of the program. It was based upon initial information of an actual investigation. The problem was to find buried transformers possibly containing PCB's. The advisor expert program recommended ground penetrating radar, magnetometer, and electromagnetic induction methods. In the actual field investigation, magnetometer and electromagnetic induction methods were used with good success. Ground penetrating radar equipment was not available for use at the site. Based upon the field results, it too would have worked with good success in finding the buried transformers.

An example of the computer printout of the program is shown below and on the following pages.

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U.S. Geological Survey preliminary computer program for Geophysics Advisor Expert System. Written in True BASIC 2.03 to run under Microsoft MS-DOS 2.0 or later on IBM-PC or true compatible computers with 512k or greater memory available to the program. No source code is available.

Use of brand names and model numbers is for the sake of description only, and does not constitute endorsement by the U.S. Geological Survey.

Although this program has been used by the U.S. Geological Survey, no warranty, expressed or implied, is made by the USGS as to the accuracy and functioning of the program and related program material nor shall the fact of distribution constitute any such warranty, and no responsibility is assumed by the USGS in connection herewith.
(press any key)
NOTE: You may leave this program at any time by pressing Control-Break.

SITE NAME: Test Site

This is an example of a test run with the expert advisor program. The problem was to find buried transformers possibly containing PCBs.

EXPLANATION: (This is the first question.)
QUESTION: The source of contamination was:
ANSWERS:

```
            Unknown
      ------Single event-----
            Continuous leak (fixed)
            Continuing leak
```

EXPLANATION: 'Surface spill' includes all types of contamination that start at the surface (such as an oil slick or any others than those listed separately). 'Not a spill or leak' is something like an intact, lost barrel of waste. If several sources are involved, do one session for each...
QUESTION: The contaminants originated from:
ANSWERS:

```
            Unknown
            Surface spill
            Land treatment facility
            Surface impoundment
            Leaking landfill
            Leaking underground storage tank
            Leaking underground pipeline
            Leaking trench
            Deep injection well
      ------Not a spill or leak-----
```

EXPLANATION: For 'Yes' or 'no' questions like this, 'Unknown' means you don't know and don't care. 'Maybe' is closer to 'Yes' than 'no', and 'Need to know' means you'd like to know this.
QUESTION: Did the contaminants reach the surface? (or are they on the surface?)
ANSWERS:

```
            Unknown
      ------No-----
            Maybe
            Yes
            Need to know
```

QUESTION: Are the contaminants in the unsaturated subsurface? (above the water table)
ANSWERS:

```
      ------Unknown-----
            No
            Maybe
            Yes
            Need to know
```

QUESTION: Are the contaminants in the saturated subsurface? (at or below the water table)
ANSWERS:

```
      ------Unknown-----
            No
            Maybe
            Yes
            Need to know
```

QUESTION: Do the underground sources (trenches, pipelines, barrels, wells, tanks, etc.) need to be located?
ANSWERS:

Unknown
No
Maybe
------Yes-----

EXPLANATION: Magnetic metals include iron, nickel and many (but not all) steels. Aluminum, copper, brass, plastic, wood, and glass are non-magnetic.
QUESTION: Do the underground sources (trenches, pipelines, barrels, wells, tanks, etc.) contain magnetic materials?
ANSWERS:

Unknown
No
Maybe
------Yes-----

EXPLANATION: An areal search is a search across the surface of the earth for the location of the contaminant problem.
A depth search is a search for the location of the contaminant problem versus depth.
QUESTION: Is this an areal search, a depth search, or both?
ANSWERS:

Unknown
Areal
Depth
------Both-----

EXPLANATION: 'Container' includes barrels and drums as well as pond and trench liners.
QUESTION: Are the contaminants in a plume or in a container?
ANSWERS:

Unknown
Surface plume
Subsurface plume
------Intact container-----
Leaky container
Both

QUESTION: What is the form of the container?
ANSWERS:

Unknown
Barrel
Drum
------Box-----
Pipeline
Pond liner
Trench

QUESTION: What material is the container or liner made from?
ANSWERS:

Unknown
Clay
------Magnetic metal-----
Nonmagnetic metal
Rubber
Glass
Wood
Paper
Plastic
Concrete

QUESTION: What is the condition of the container?
ANSWERS:

Unknown
Leaking
------Intact-----
Need to know

QUESTION: Do you need to locate the containers?
ANSWERS:

Unknown
No
Maybe
------Yes-----

QUESTION: Are radioactive contaminants present?
ANSWERS:

Unknown
------No-----
Maybe
Yes
Need to know

QUESTION: Are non-radioactive inorganic contaminants present?
ANSWERS:

Unknown
------No-----
Maybe
Yes
Need to know

EXPLANATION: 'Organics' includes hydrocarbons.
QUESTION: Are organics present?
ANSWERS:

Unknown
No
Maybe
------Yes-----
Need to know

EXPLANATION: Soluble or insoluble in water.
Soluble means they chemically dissolve in water (such as alcohol).
QUESTION: Are the organics water soluble or insoluble?
ANSWERS:

------Unknown-----
Insoluble
Soluble
Mixed

EXPLANATION: Immiscible means they do not physically mix with water (such as oil). Miscible means they mix with water.
QUESTION: Are the organics water miscible or immiscible?
ANSWERS:

------Unknown-----
Miscible
Immiscible
Mixed

EXPLANATION: Lighter than water means they float. Heavier than water means they sink.
QUESTION: Are the organics heavier or lighter than water?
ANSWERS:

------Unknown-----
Neither
Heavier than water
Lighter than water
Both

EXPLANATION: Anionic means they are negatively charged in water. Cationic means they are positively charged in water.
QUESTION: Are the organics polar?
ANSWERS:

------Unknown-----
Nonpolar
Anionic
Cationic
Mixed

EXPLANATION: A soil is not wet by a liquid if the liquid forms beads on the surface of the soil.
QUESTION: Are the soils preferentially water-wet or organic-wet?
ANSWERS:

------Unknown-----
Neither
Water
Organic
Both

QUESTION: Are the organics mostly in the water phase, adsorbed on soil solids, or in the gas phase?
ANSWERS:

------Unknown-----
Water
Soil
Gas
All

EXPLANATION: Modification processes include biodegradation, catalysis, volatilization, and any other reactions.
QUESTION: Are the organics being modified by any processes?
ANSWERS:

------Unknown-----
No
Maybe
Yes
Need to know

EXPLANATION: Volatile means they produce a gaseous vapor at room temperature. (typically that means they may smell.)
QUESTION: Are the organics volatile?
ANSWERS:

------Unknown-----
Non volatile
Volatile
Both

EXPLANATION: Organics present at the surface means in the air, on the ground or in leaking containers at the surface.
QUESTION: Are there volatile organics present at the surface in the area of study?
ANSWERS:

Unknown
------No-----
Maybe
Yes

QUESTION: How old is the organic/hydrocarbon contamination?
ANSWERS:

Unknown
Hours
Days
Weeks
Months
------Years-----

EXPLANATION: Empty means land with few or no manmade features of any kind.
Rural means farm country (or 2 or less houses per acre suburbs).
Suburban means 3 or more houses per acre site density.
Urban means high density center-city housing and utility density.
Industrial means setting with high building and utility density.
Landfill means low surface density, high subsurface density clutter.
Military means active military base with many interference sources.
Service station means gasoline/diesel service station or refinery.
Choose the lowest density of buildings and utilities that characterize the site itself.
QUESTION: What is the environment at the site?
ANSWERS:

Unknown
Empty
------Rural-----
Suburban
Urban
Industrial
Landfill
Military base
Service station

EXPLANATION: Metallic objects such as fences, pipelines, and electrical or telephone (above or below ground) wires will interfere with some geophysical techniques.
Small metallic objects such as pop cans are not a problem unless present in large continuous piles.
Magnetic, electrical and electromagnetic techniques are biased around metallic objects.
QUESTION: Are there any metallic objects on or near the site?

ANSWERS:

Unknown
No
Maybe
------Yes-----
Need to Know

EXPLANATION: Metallic objects such as fences, pipelines, and electrical or telephone (above or below ground) wires will interfere with some geophysical techniques.
Small metallic objects such as pop cans are not a problem unless present in large continuous piles.
Magnetic, electrical and electromagnetic techniques are biased around metallic objects.
QUESTION: What is the average horizontal spacing between metallic objects? (such as fences, pipelines or wires)
ANSWERS:

Unknown
<3m <10ft
------3-10m 10-30ft-----
10-30m 30-100ft
30-100m 100-300ft
>100m >300ft

EXPLANATION: Metallic objects such as fences, pipelines, and electrical or telephone (above or below ground) wires will interfere with some geophysical techniques.
Small metallic objects such as pop cans are not a problem unless present in large continuous piles.
Magnetic, electrical and electromagnetic techniques are biased around metallic objects.
QUESTION: How much of the areal extent of the site surface is covered by metallic objects? (such as metallic trash or metallic-sheet buildings)
ANSWERS:

Unknown
None
------<10%-----
10-25%
25-50%
50-75%
>75%

QUESTION: Are metallic well casings installed at the site?
ANSWERS:

Unknown
------No-----
Maybe
Yes

EXPLANATION: In this context, buildings means current or former buildings or their foundations.
QUESTION: How much of the site is covered by buildings?
ANSWERS:

Unknown
None
------<10%-----
10-25%
25-50%
50-75%
>75%

EXPLANATION: 'Difficult' means it is difficult to walk around the site.
'Walking' means most of the site is available to access on foot.
'ATV' means access by all terrain vehicle is possible.
'4-WD' means four-wheel drive jeeps can drive over most of the site.
'2-WD van' means two-wheel van-like vehicles can drive over most of the site.
QUESTION: What is the site access like?
ANSWERS:

Unknown
Difficult
Walking
ATV
4-WD
------2-WD van (easy access)-----

EXPLANATION: 'Inaccessible' includes site access problems due to property ownership and trespass, excessive safety hazards such as explosive hazard, and difficulties due to quicksand, swamp or other similar problems.
QUESTION: How much of the site is inaccessible?
ANSWERS:

Unknown
------None-----
<10%
10-25%
25-50%
50-75%
>75%

QUESTION: What is the annual precipitation?
ANSWERS:

Unknown
<5cm <2in
5-20cm 2-8in
20-50cm 8-20in
------>50cm >20in-----

EXPLANATION: (If so, what is the wet season?)
QUESTION: Does most precipitation occur in one season of the year?
ANSWERS:

------Unknown-----
No
Spring
Summer
Fall
Winter

QUESTION: Are there natural organics present? (from forest, jungle, farm, swamp, etc.)
ANSWERS:

Unknown
------No-----
Maybe
Yes

EXPLANATION: Radio, TV and radar transmissions may interfere with some geophysical methods.
In this context, also consider nearby active airports, police stations, and

other non-commercial radio stations.
Arc-welders in welding shops may also qualify as 'radio' transmitters.
QUESTION: Are there radio, TV or radar transmitters within 2 km of the site?
ANSWERS:

Unknown
------No-----
Maybe
Yes

EXPLANATION: Some sounds may interfere with some geophysical methods.
Sources of acoustic noise include railroads, heavily travelled roads, airport flight paths, and industrial plants.
Continuously windy sites also qualify as acoustically noisy.
QUESTION: Is the site acoustically noisy?
ANSWERS:

Unknown
------No-----
Maybe
Yes

EXPLANATION: These permeability features may modify the results of a soil gas survey.
QUESTION: Are streams (past or present), utility or other trenches, glacial scours or drains present in the site?
ANSWERS:

Unknown
No
------Maybe-----
Yes
Need to know

EXPLANATION: Concrete will interfere with some geophysical techniques.
QUESTION: How much of the areal extent of the site is surfaced by concrete?
ANSWERS:

Unknown
------None-----
<25%
25-50%
50-75%
>75%

EXPLANATION: Asphalt will interfere with some geophysical techniques.
QUESTION: How much of the areal extent of the site is surfaced by asphalt?
ANSWERS:

Unknown
------None-----
<25%
25-50%
50-75%
>75%

EXPLANATION: Some geophysical techniques require topographic correction for proper interpretation.
QUESTION: What is the range of topographic relief across the site?
ANSWERS:

Unknown
<1m <3ft
------1-3m 3-10ft-----
3-10m 10-30ft
>10m >30ft

QUESTION: Are there sinkholes or evidence of subsidence present at the site?
ANSWERS:

Unknown
------No-----
Maybe
Yes
Need to know

QUESTION: What is the approximate area of the site?
ANSWERS:

Unknown
------<100 sq-m <3 acres-----
100-1,000 3-30
1,000-10,000 30-300
>10,000 sq-m >300 acres

QUESTION: Is this a four-season site with freezing winters?
ANSWERS:

Unknown
No
Maybe
------Yes-----

QUESTION: What is the average depth of freeze?
ANSWERS:

Unknown
------<0.3m <1ft-----
0.3-1m 1-3ft
1-3m 3-10ft
>3m >10ft

QUESTION: What is the average depth to bedrock?
ANSWERS:

------Unknown-----
<3m <10ft
3-10m 10-30ft
10-30m 30-100ft
>30m >100ft

QUESTION: Do you need to determine the average depth to bedrock?
ANSWERS:

Unknown
------No-----
Maybe
Yes

QUESTION: Is the zone of interest above or below the bedrock interface?
ANSWERS:

Unknown
------Above-----
At
Below
All

QUESTION: What is the average depth to the water table?
ANSWERS:
------Unknown-----
<3m <10ft
3-10m 10-30ft
10-30m 30-100ft
>30m >100ft

QUESTION: Do you need to determine the average depth to the water table?
ANSWERS:
Unknown
------No-----
Maybe
Yes

QUESTION: Is the zone of interest above or below the water table?
ANSWERS:
Unknown
------Above-----
At
Below
All

EXPLANATION: In this context, consider lakes, rivers and other permanent surface water bodies.
QUESTION: How much of the surface areal extent of the site is covered by water?
ANSWERS:
Unknown
------None-----
<10%
10-25%
25-50%
50-75%
75-90%
>90wt%

QUESTION: How much of the surface areal extent of the site is regularly irrigated?
ANSWERS:
Unknown
------None-----
<10%
10-25%
25-50%
50-75%
75-90%
>90%

EXPLANATION: Resistivity in ohm-meters or (conductivity in millimho/meter).
QUESTION: What is the electrical resistivity of the ground water?
ANSWERS:
------Unknown-----
<30 ohm-m (>30 mmho/m) [not fresh]
>=30 ohm-m (<30 mmho/m) [fresh]

EXPLANATION: 'Brine layers' include seawater intrusions and other salty waters.
QUESTION: Are there brine layers present at the site?
ANSWERS:

Unknown
------No-----
Maybe
Yes
Need to know

EXPLANATION: Some geophysical techniques are influenced by rock and soil type. The sequence gravel to clay indicates coarse to fine particle size.
QUESTION: What is the dominant soil type at the site?
ANSWERS:

------Unknown-----
Rock - no soil
Gravel
Sand
Till
Clay

EXPLANATION: The presence of clay helps some geophysical techniques and hinders others.
Clay in this context means mineralogical clay (such as montmorillonite) not engineering-size-fraction 'clay'.
The depth penetration of ground penetrating radar in particular is strongly limited by clay.
QUESTION: Is clay present at the site? (exclude a basal clay below depths of interest)
ANSWERS:

------Unknown-----
No
Maybe
Yes
Need to know

EXPLANATION: 'Quickly' means in less than one day.
QUESTION: Does rainfall on the site surface sink in slowly or quickly?
ANSWERS:

------Unknown-----
Run off
Pond
Sink in slowly
Sink in quickly

EXPLANATION: Resistivity in ohm-meters or (conductivity in millimho/meter).
QUESTION: What is the average electrical resistivity of the site in ohm-meters?
ANSWERS:

------Unknown-----
<1 ohm-m (>1000 mmho/m)
1-10 (100-1000)
10-30 (33-100)
30-100 (10-33)
100-300 (3-10)
>300 ohm-m (<3 mmho/m)

SITE: Test Site

0014	Ground penetrating radar methods recommended.
0010	Magnetic methods recommended.
0010	Electromagnetic induction methods recommended.
0001	Resistivity effectiveness is uncertain.
0000	Soil gas effectiveness is uncertain.
0000	Seismic effectiveness is uncertain.
0000	Gravity methods not recommended.
-010	Radiometric methods not recommended.

SITE: Test Site
Site specific comments: 0010 Electromagnetic induction methods recommended. Use time domain EM for deep sounding.
EM induction methods work well in locating underground sources.
Metal detectors methods work well in locating underground sources that are less than 3 meters deep. EM techniques are better for areal searches.
EM methods may find magnetic metallic containers.
Metal detectors may find magnetic metallic containers buried less than 3 meters deep. EM methods may find metallic containers.
Metal detectors may find shallow metallic containers buried less than 3 meters deep. Metallic objects interfere with EM techniques.
Too many metallic objects for EM.
EM techniques will require topographic correction.
0010 Electromagnetic induction methods recommended. EMI are electromagnetic techniques that induce currents in the earth. They measure the magnetic field generated by the induced currents. The electrical conductivity of the earth is proportional to the magnetic field generated from the induced currents. The depth of investigation is a function of the instrument coil spacing and orientation, frequency of measurement, and the electrical conductivity of the ground. By measuring and mapping the changes in electrical conductivity, EMI techniques may directly locate plumes of inorganic contaminants, clay lenses, metallic objects such as buried drums, and inhomogeneities in geology such as fractures. EMI techniques are ineffective in areas with many fences, pipelines, telephone cables, and other metallic interferences. EMI techniques require topographic correction. EMI techniques are readily available commercially, relatively inexpensive, and require 1 or 2 man crews. EMI methods acquire data very quickly over large areas, whereas resistivity methods are preferred for sounding to acquire depth information. For further information, see: Keller, G.V. and Frischknecht,F., 1966, Electrical methods in geophysical prospecting, NY, Pergamon, 517p. Greenhouse, J. and Harris, R., 1983, Migration of contaminants in ground water at a landfill: a case study, 7. DC, VLF, and inductive resistivity surveys, J.Hydrol., v.63, p.177-197. McNeill, J.D., 1988, Advances in electromagnetic methods for groundwater studies, in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.252-348.

SITE: Test Site
Site specific comments: 0014 Ground penetrating radar methods recommended.
Radar has very high resolution for locating underground sources (trenches, barrels, tanks, pipelines, etc.). Radar may find magnetic metallic containers.
Radar has the highest resolution to find containers.
Radar can detect some kinds of organics.
Radar may require topographic correction.
Perform radar during winter to exploit high resistivity of frozen ground.
Radar may find depth to bedrock.
Radar may determine the depth to the water table.
Radar may determine the depth to the clay.
0014 Ground penetrating radar methods recommended. GPR measures changes in the propagation of electromagnetic energy in the ground. Such changes typically occur from changes in water content and bulk density. Thus, GPR is a sensitive indicator of soil stratigraphy, bedrock fracturing and an excellent way to map the water table. GPR may sometimes directly detect organic contaminants either by changes in scattering properties (the texture of the radar record) or dielectric contrast (such as oil floating on water). GPR works well in high resistivity environments such as dry or fresh-water saturated coarse sand or granite. Low resistivity salt water and clays such as montmorillonite severely limit the depth of penetration and effectiveness of GPR. In clay-free soil with resistivity above 30 ohm-m, GPR can provide vertical sections of the earth to depths of 30 meters with resolution of a few centimeters. For further information, see: Olhoeft, G.R., 1984, Applications and limitations of ground penetrating radar, in Expanded abstracts, 54th Annual Int'l. Meeting and Expo. of the Soc. of Explor.Geophys., Atlanta, p.147-148. Olhoeft, G.R., 1986, Direct detection of hydrocarbon and organic chemicals with ground penetrating radar and complex resistivity, in Proc. of the NWWA/API Conf. on Petroleum hydrocarbons and organic chemicals in ground water -- prevention, detection and restoration, Nov.12-14, Houston, p.284-304. Olhoeft, G.R., 1988, Selected bibliography on ground penetrating radar, in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.462-520.

SITE: Test Site
Site specific comments: 0001 Resistivity effectiveness is uncertain.
DC resistivity techniques are better for depth searches.
Resistivity techniques will require topographic correction.

0001 Resistivity effectiveness is uncertain. Resistivity techniques use electrodes in contact with the ground to measure electrical resistivity (reciprocal of conductivity). The depth of investigation is a function of the electrode spacing and geometry, (larger spacings see deeper). By measuring and mapping the changes in electrical resistivity, these techniques may directly locate plumes of inorganic contaminants, clay lenses, metallic objects such as buried drums, and inhomogeneities in geology such as fractures. Resistivity techniques are ineffective in areas with many fences, pipelines, telephone cables, and other metallic interferences. Resistivity techniques require topographic correction, are readily available commercially, relatively inexpensive, and require 1 or 2 man crews. Resistivity methods are preferred for sounding to acquire depth information, whereas EM induction provides easier and faster areal mapping. For further information, see: Greenhouse, J. and Harris, R., 1983, Migration of contaminants in ground water at a landfill: a case study, 7. DC, VLF, and inductive resistivity surveys, J.Hydrol., v.63, p.177-197. Complex resistivity measures resistivity as a function of frequency. It can detect organic contaminants when they react with clay minerals, but it is much more time consuming and expensive than DC resistivity. Olhoeft, G.R., 1986, Direct detection of hydrocarbon and organic chemicals with ground penetrating radar and complex resistivity, in Proc.NWWA/API Conf.Petroleum hydrocarbons and organic chemicals in ground water -- prevention, detection and restoration, Nov.12-14, Houston, p.284-304.

SITE: Test Site
Site specific comments: 0000 Seismic effectiveness is uncertain. Seismic methods may require topographic correction.
0000 Seismic effectiveness is uncertain. Seismic techniques measure changes in the propagation of elastic compressional or shear energy in the ground. They may be operated in reflection or refraction modes. They are sensitive to changes in density and water content. They are most useful in defining subsurface geological and hydrological structure. They cannot detect contaminants directly, though they may locate trenches or other disturbed burial zones in the ground. In urban environments, high noise or difficult coupling (such as through concrete or asphalt) may make their use prohibitive. Seismic and radar techniques are complementary as seismic works well in clay soils where radar does not, and radar works well in loosely compacted sandy soil where seismic does not. Basic references are: Mooney, H.M., 1973, Handbook of engineering geophysics, vol.1, seismic: Bison Instruments, Minneapolis, MN, 216p. Romig, P.R., ed., 1986, Special issue - engineering and ground water, Geophysics, v.51, p.221-323. Hasbrouck, W.P., 1987, Hammer-impact, shear-wave studies, in Shear-wave exploration, S.H.Danbom and S.N.Domenico, eds., Tulsa, SEG, p.97-121. Ensley, R.A., 1987, Classified bibliography of shear-wave seismology, in Shear-wave exploration, S.H.Danbom and S.N.Domenico, eds., Tulsa, SEG, pp.255-275. Lankston, R.W., 1988, High resolution refraction data acquisition and interpretation, in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.349-408. Steeples, D.W. and Miller, R.D., 1988, Seismic reflection methods applied to engineering, environmental and ground water problems, ibidem, p.409-461.

SITE: Test Site
Site specific comments: 0010 Magnetic methods recommended.
Magnetics are good for locating underground sources (trenches, barrels, tanks, pipelines, etc.) containing or filled with magnetic metals.
Magnetics are good at finding magnetic materials.
Too many metallic objects for magnetics.
0010 Magnetic methods recommended. Magnetic techniques measure perturbations in the earth's natural magnetic field near magnetic objects such as iron drums or barrels. Magnetic techniques cannot locate non-metallic materials nor non-magnetic metallic objects. Large concentrations of iron or steel fences, utilities, culverts, vehicles or buildings may interfere with the technique. High iron content soils (such as greensands, basalts, red hematitic soils) may be sufficiently magnetic to hide objects detectable under other soil conditions. Basic references include: Benson, R.C., Glaccum, R.A., and Noel, M.R., 1983, Geophysical techniques for sensing buried wastes and waste migration, National Water Well Association, Dublin, OH, 236p. Hinze, W.J., 1988, Gravity and magnetic methods applied to engineering and environmental problems, in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.1-108.

SITE: Test Site

Site specific comments: 0000 Gravity methods not recommended.

0000 Gravity methods not recommended. Gravity techniques measure changes in the gravitational field of the earth. These changes are interpreted in terms of changes in density and porosity in the ground. Microgravity techniques may be useful in locating trenches, voids, and incipient subsidence problems. They cannot directly detect contaminants. Gravity techniques require accurate location and topographic surveying, removal of regional gradients, and correction for tidal effects. Basic references are: Butler, D.K., 1984, Microgravimetric and gravity gradient techniques for detecting subsurface cavities, Geophysics, v.49, p.1084-1096. Rodrigues, E.B., 1987, Application of gravity and seismic methods in hydrogeological mapping at a landfill site in Ontario, in Proc. of the First National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, May 18-21, 1987, Las Vegas, NWWA, Dublin, Ohio, p.487-503. Hinze, W.J., 1988, Gravity and magnetic methods applied to engineering and environmental problems, in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.1-108.

SITE: Test Site
Site specific comments: -010 Radiometric methods not recommended. There are no radioactive materials present.
-010 Radiometric methods not recommended. Radiometric techniques measure the radiation emmitted from radioactive isotopes. Radioactive contaminants may be masked by high background levels of natural radioactivity or by roughly a meter of overlying soil cover (depending upon the type and strength of the source). These are generally only useful at radioactive waste disposal sites. However, they may be useful in locating natural radioactive hazards (such as radon gas sources), early radium processing plants, mining mill tailings, and other similar sites. Basic references are: EG&G Idaho Inc., 1983, Low-level radioactive waste management handbook series: Environmental monitoring for low-level waste-disposal sites, DOE/LLW-13Tg, available from NTIS, Springfield, VA, var.pag.; Morse, J.G., ed., 1977, Nuclear methods in mineral exploration and production, NY, Elsevier, 280p.