UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# GEOPHYSICS ADVISOR EXPERT SYSTEM VERSION 2.0

by

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U.S. Geological Survey preliminary computer program for Geophysics Advisor Expert System. Written in True BASIC 2.01 to run under Microsoft MS-DOS 2.0 or later on IBM-PC or true compatible computers with 640k or greater memory available to the program. No source code is available.

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**Geophysics Advisor Expert System Version 2.0**

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This expert system 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. It is written to run on any IBM MS-DOS compatible computer and to be very simple to use. This is version 2.0 of the program.

Version 1.0 of the program was published as Olhoeft (1988), and asks questions about a site and the contamination problem. Then, based upon the answers given, it recommends what types of geophysics will most likely be useful at the site to solve problems such as contaminant location and hydrogeological characterization of the site. It also annotates why various geophysical techniques will likely work or not work at the site. The questions and their allowable answers are tightly focused to decide on the use of geophysics to locate contaminants and acquire hydrogeological information about the site.

Version 2.0 improves upon version 1.0 by adding a database of the physical and chemical properties of the top Superfund organic contaminants. Version 1.0 asks questions about the properties of the contaminants, such as "Are the organics miscible with water?" Version 2.0 presents a list of contaminants to select from (such as benzene). For the top Superfund organic contaminants, it will know the answers to most questions. For other contaminants, it will still ask the questions about properties. For some organic contaminants, the answers are not known as the physical properties of the contaminants are unknown. The database on which the answers are based is found in Lucius and others (1992).

To run this program, place the floppy diskette in drive A:, type 'A:' (without the quotes) 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' (hold down the 'control' key and press 'break' key at same time) to exit the program without saving at any point (this is not recommended when the program is writing to the disk), or press 'Alt-S' (hold down the 'Alt' key and press 'S' at the same time) to exit and save a partial session. During a session, questions may be answered and later changed by backing up with the 'Esc' (escape) key, or by using the F10 key at the end when the recommendations are made. After answering the questions posed by the program, it will recommend the types of geophysics to use, then the session may be saved to disk (for later 'what if?' scenarios) and printed. The appendix lists a typical session printout. As version 2.0 contains more questions and allows the saving of partial sessions, old files created with version 1.0 are incompatible with version 2.0 -- old sessions must be repeated starting from NEWFILE.

Quality Assurance requirements mandate that the program only be available in compiled form and that datafiles be encrypted. However, the program and datafiles are not copy protected and may be freely copied and distributed for no more than the cost of copying. This program is not subject to U.S. Copyright Law. The program (EXPERT.EXE) and datafiles (NEWFILE.EPA and DATABASE.ORG) may be copied and run from a hard disk drive.

## References

Olhoeft, G. R., 1988, Geophysics advisor expert system: U.S. Geological Survey Open File Report 88-399, 2p. + floppy disk (also available as U.S. EPA EMSL/LV Report EPA/600/4-89/023).

Lucius, J. E., Olhoeft, G. R., Hill, P. L., and Duke, S. K., 1992, Properties and hazards of 108 selected substances - 1992 edition: U.S. Geological Survey Open File Report 92-527, 554p.

**APPENDIX 1: List of Chemicals in Database**

| Organic Contaminant | Chemical Abstract Service Registry Number |
|---|---|
| Acetic acid | 64-19-7 |
| Acetone | 67-64-1 |
| Acrolein | 107-02-8 |
| Acrylonitrile | 107-13-1 |
| Aldrin | 309-00-2 |
| Ammonia | 7664-41-7 |
| Aniline | 62-53-3 |
| Aroclor 1260 (PCB 1260) | 11096-82-5 |
| Benz(e)acephenanthrylene | 205-99-2 |
| Benz[a]anthracene | 56-55-3 |
| Benzene | 71-43-2 |
| Benzidine | 92-87-5 |
| Benzoic acid | 65-85-0 |
| Benzo[a]pyrene | 50-32-8 |
| Bis(2-chloroethyl) ether | 111-44-4 |
| Bis(chloromethyl) ether | 542-88-1 |
| Bis(2-ethylhexyl) phthalate | 117-81-7 |
| Bromoform | 75-25-2 |
| Bromomethane | 74-83-9 |
| 2-Butanone | 78-93-3 |
| Carbon tetrachloride | 56-23-5 |
| Chlordane | 57-74-9 |
| Chlorobenzene | 108-90-7 |
| 6-Chloro-m-cresol | 59-50-7 |
| Chloroethane | 75-00-3 |
| Chloroform | 67-66-3 |
| Chloromethane | 74-87-3 |
| Chrysene | 218-01-9 |
| o-Cresol | 95-48-7 |
| Cyclohexane | 110-82-7 |
| DDT | 50-29-3 |
| Dibenz[a,h]anthracene | 53-70-3 |
| Dibromochloromethane | 124-48-1 |
| 1,2-Dibromoethane | 106-93-4 |
| Dibutyl phthalate | 84-74-2 |
| 1,2-Dichlorobenzene | 95-50-1 |
| 1,3-Dichlorobenzene | 541-73-1 |
| 1,4-Dichlorobenzene | 106-46-7 |
| Dichlorodifluoromethane | 75-71-8 |
| 1,1-Dichloroethane | 75-34-3 |
| 1,2-Dichloroethane | 107-06-2 |
| 1,1-Dichloroethene | 75-35-4 |
| trans-1,2-Dichloroethene | 156-60-5 |
| Dichloromethane | 75-09-2 |
| 2,4-Dichlorophenol | 120-83-2 |
| 1,2-Dichloropropane | 78-87-5 |

| Organic Contaminant | Chemical Abstract Service Registry Number |
|---|---|
| Dieldrin | 60-57-1 |
| Diethyl phthalate | 84-66-2 |
| Dimethyl phthalate | 131-11-3 |
| Dimethyl sulfoxide | 67-68-5 |
| 2,4-Dinitrophenol | 51-28-5 |
| 2,4-Dinitrotoluene | 121-14-2 |
| 2,6-Dinitrotoluene | 606-20-2 |
| 1,4-Dioxane | 123-91-1 |
| Dioxins (TCDD) | 1746-01-6 |
| DNAPL (Generic chlorinated solvent) | |
| Endrin | 72-20-8 |
| Ethanol | 64-17-5 |
| Ethylbenzene | 100-41-4 |
| Ethylene glycol | 107-21-1 |
| Ethylene oxide | 75-21-8 |
| Fluoranthene | 206-44-0 |
| Heptachlor | 76-44-8 |
| Hexachlorobenzene | 118-74-1 |
| Hexachlorobutadiene | 87-68-3 |
| c-Hexachlorocyclohexane (Lindane) | 58-89-9 |
| Hexachloroethane | 67-72-1 |
| Hydrocarbon (Generic gasoline, diesel, etc.) | |
| Hydrogen cyanide | 74-90-8 |
| Isophorone | 78-59-1 |
| Methanol | 67-56-1 |
| 4-Methyl-2-pentanone | 108-10-1 |
| Naphthalene | 91-20-3 |
| Nitrobenzene | 98-95-3 |
| N-Nitrosodiphenylamine | 86-30-6 |
| Pentachlorophenol | 87-86-5 |
| Phenanthrene | 85-01-8 |
| Phenol | 108-95-2 |
| Potassium cyanide | 151-50-8 |
| Quinoline | 91-22-5 |
| Sodium cyanide | 143-33-9 |
| 1,1,2,2-Tetrachloroethane | 79-34-5 |
| Tetrachloroethene | 127-18-40 |
| Toluene | 108-88-30 |
| Toxaphene | 8001-35-20 |
| 1,2,4-Trichlorobenzene | 120-82-10 |
| 1,1,1-Trichloroethane | 71-55-60 |
| 1,1,2-Trichloroethane | 79-00-50 |
| Trichloroethene | 79-01-60 |
| Trichlorofluoromethane | 75-69-40 |
| 2,4,6-Trichlorophenol | 88-06-20 |
| Vinyl chloride | 75-01-40 |
| Xylene | 108-38-30 |
| 2,4-Xylenol | 105-67-90 |
| NONE OF THE ABOVE | |

**APPENDIX 2: Typical session printout.**

Disclaimer:

NOTICE

The information in this program has been funded wholly or in part by the United States Environmental Protection Agency under interagency agreement DW14934976 to the United States Geological Survey. It has been subject 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.

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SITE NAME: Test Example

This is a test example session.

EXPLANATION: (This is the first question.)
'Continuous leak (fixed)' means it is no longer leaking.
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, leaking surface tank or pipe, 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. '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

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-----

QUESTION: What is the urgency of the site investigation?
ANSWERS:
Unknown
Emergency Response (Hours)
Days
Weeks
Months
------Years-----

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: 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

----------------------------------------------------------------

DATABASE CHOICE: Hydrocarbon (Generic gasoline, diesel, etc.)
FROM: Lucius, J. E., Olhoeft, G. R., Hill, P. L., and Duke, S. K., 1992, Properties and hazards of 108 selected substances - 1992 edition: U. S. Geological Survey Open File Report 92-527, 554p. (Order from: Books and Open File Reports Section, Branch of Distribution, U. S. Geological Survey, P.O. Box 25425 DFC, Denver, CO 80225, 303-236-7476)

----------------------------------------------------------------

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. Most silicate soils prefer to be water wet.
Many carbonates prefer to be organic-wet.
(But the detailed chemistry can make it go either way.)
QUESTION: Are the soils preferentially water-wet or organic-wet?
ANSWERS:

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

EXPLANATION: (Aqueous means in the water.) (NAPL is NonAqueous Phase Liquid)
QUESTION: Are the organics mostly in the water phase, adsorbed on soil solids, in a separate organic phase, or in the gas phase?
ANSWERS:

Unknown
Aqueous
Soil
Gas
Separate Phase (NAPL)
------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: Are bacteria or other biological activity changing the chemistry of the contaminants?
QUESTION: Is biodegradation of the organics occurring?
ANSWERS:
Unknown
No
Maybe
------Yes-----

EXPLANATION: For example, toluene is catalyzed on the surface of montmorillonite to polymerize into bibenzyl.
QUESTION: Is catalysis of the organics occurring?
ANSWERS:
Unknown
No
------Maybe-----
Yes

QUESTION: Is adsorption of the organics occurring?
ANSWERS:
Unknown
No
Maybe
------Yes-----

EXPLANATION: Volatile means they produce a gaseous vapor at room temperature. (typically that means they may smell.)
Consider the time of year the data are to be acquired.
QUESTION: Is volatilization of the organics occurring?
ANSWERS:
Unknown
No
Maybe
------Yes-----

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: Are the volatile organics present at the surface the same organics as the contaminants?
ANSWERS:
Unknown
No
Maybe
------Yes-----

QUESTION: How old is the organic/hydrocarbon contamination?
ANSWERS:
Unknown
Hours
Days
Weeks
Months
------Years-----

EXPLANATION: k' = relative dielectric permittivity (dielectric constant)
QUESTION: Are the organics good dielectrics?
ANSWERS:
Unknown
------k'<10-----
k'>10

QUESTION: What is the electrical resistivity of the organics?
ANSWERS:
Unknown
------>100 ohm-m (insulator)-----
<100 ohm-m

QUESTION: Are the organics known to react with clay minerals?
ANSWERS:
Unknown
No
Maybe
------Yes-----

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

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 flat-----
1-3m 3-10ft
3-10m 10-30ft
>10m >30ft

EXPLANATION: (Indications either from Karst geology or human activities like trenches or fluid withdrawals.)
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 <0.03 acres
100-1,000 0.03-0.3
------1,000-10,000 0.3-3.-----
>10,000 sq-m >3. 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
Need to know

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

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: 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]-----

QUESTION: How far away from the site is the nearest saltwater (ocean, bay, etc.)?
ANSWERS:
Unknown
------>1000m >3000ft-----
100-1000m 300-3000ft
<100m <300ft

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 (not mineralogy).
QUESTION: What is the dominant soil type at the site?
ANSWERS:

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

EXPLANATION: Lacustrine means soils derived from old lake beds.
Fluvial means old rivers or streams.
Glacial means the leftovers after glacial retreat.
Aeolian means airborne particle deposition.
Colluvial means soils derived from degrading cliffs, and avalanche or landslide debris. Diluvial means deposited by floods.
Deltaic soils are formed at the mouth of a river.
(Alluvial is the 'modern' version of several of these.)
QUESTION: What is the origin of the dominant soil type at the site?
ANSWERS:

Unknown
Lacustrine
Fluvial
------Glacial-----
Aeolian
Colluvial
Diluvial
Deltaic
Marine
Volcanic

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 Example
0026 Ground penetrating radar methods recommended.
0007 Soil gas methods recommended.
0007 Electromagnetic induction methods recommended.
0007 Complex Resistivity methods recommended.
0000 Gravity methods not recommended.
-001 Seismic effectiveness is uncertain.
-001 Magnetic methods not recommended.
-010 Radiometric methods not recommended.

SITE: Test Example
Site specific comments: 0007 Electromagnetic induction methods recommended.
Use time domain EM for deep sounding.
EM techniques are better for areal searches.
EM induction may detect organics that displace water from soil surfaces.
EM induction methods can sometimes (but rarely) find some organic insulators.
Bedrock is too deep to see with shallow frequency-domain EM.
Use time-domain EM to find deep bedrock.
0007 Electromagnetic induction methods recommended. EMI are electromagnetic techniques that induce currents in the earth. They measure the secondary magnetic field generated by the induced currents. The electrical conductivity of the earth is proportional to the secondary magnetic field. 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, rebar, 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: 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., 1990, Use of electromagnetic methods for groundwater studies: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.191-218.
Nabighian, M. N., 1987, Electromagnetic methods in applied geophysics -- theory, vol.1: Soc. Explor. Geophys., Tulsa, OK, 513p.
Nabighian, M. N., 1991, Electromagnetic methods in applied geophysics -- applications, vol.2: Soc. Explor. Geophys., Tulsa, OK, 972p. SITE: Test Example

Site specific comments: 0026 Ground penetrating radar methods recommended.
Radar can detect some kinds of organics.
Radar can find some insoluble organics.
Radar can detect some immiscible organics.
Radar can detect some organics that float on the water table (but not the aqueous plume).
Radar can detect pooled DNAPL sources (but not the aqueous plume).
Radar can detect soil texture scattering changes from organic wet soils.
Radar can find some organic dielectrics.
Radar can find some organic insulators.
Perform radar during winter to exploit high resistivity of frozen ground.
Bedrock is too deep to see with radar.
Radar may determine the depth to the water table.
Ground (fresh) water resistivity is good for mapping hydrogeology with radar.
Radar may determine the depth to the clay.
High resistivity is good for mapping hydrogeology with radar.
0026 Ground penetrating radar methods recommended. GPR measures changes in the propagation of electromagnetic energy in the ground. Such changes are power law sensitive to 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., 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. Proc. of the Four Int'l. Conf. on GPR: Tifton, GA (1986), Gainesville, FL (1988), Lakewood, CO (1990), Rovaniemi, Finland (1992).

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Lucius, J. E., Olhoeft, G. R., and Duke, S. K., 1990, Third International Conference on Ground Penetrating Radar, abstracts of the technical conference, May 14-18, 1990, Lakewood, CO, USA: U.S. Geological Survey Open File Report 90-414, 94p.
Powers, M. H., Duke, S. K., Huffman III, A. C., and Olhoeft, G. R., 1992, GPRMODEL: One-dimensional full waveform modeling of ground penetrating radar data: U. S. Geological Survey Open File Report 92-532, 22p + floppy disk.
Sander, K. A., Olhoeft, G. R., and Lucius, J. E., 1992, Surface and borehole radar monitoring of a DNAPL spill in 3D versus frequency, look angle and time: in Proc. of the Symp. on the Application of Geophysics to Engineering and Ground Water Problems, R. S. Bell, ed., Soc. of Engineering and Mineral Geophysicists, Golden, CO, p. 455-469.

SITE: Test Example
Site specific comments: 0007 Complex Resistivity methods recommended.
DC resistivity techniques are better for depth searches.
DC resistivity may detect organics that displace water from soil surfaces.
0007 Complex Resistivity methods recommended. 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, rebar, telephone cables, and other metallic interferences, and may be difficult to do through concrete or asphalt. 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. 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, expensive, and not readily available commercially. For further information, see: Ward, S.H., 1990, Resistivity and induced polarization methods: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.147-190. Olhoeft, G.R., 1992, Geophysical detection of hydrocarbon and organic chemical contamination: in Proc.of the Symp.on the Appl.of Geophys.to Engrg. and Environ.Problems, R.S.Bell, ed., Oakbrook, IL, Soc. Engrg. & Min.Explor.Geophys., Golden, CO, p.587-595.

SITE: Test Example
Site specific comments: -001 Seismic effectiveness is uncertain.
Seismic methods are difficult to employ in loose soils.
-001 Seismic effectiveness is uncertain. Seismic techniques measure changes in the propagation of elastic compressional or shear waves in the ground. They may be operated in reflection or refraction modes. They are linearly 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: 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. Lankston, R.W., 1990, High resolution refraction data acquisition and interpretation: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.45-74. Steeples, D.W. and Miller, R.D., 1990, Seismic reflection methods applied to engineering, environmental and groundwater problems: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.1-30. Hasbrouck, W. P., 1991, Four shallow-depth, shear wave feasibility studies: Geophysics, v.56, p.1875-1885. 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.

SITE: Test Example
Site specific comments: -001 Magnetic methods not recommended. No magnetic materials were identified at the site.
-001 Magnetic methods not 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., 1990, The role of gravity and magnetic methods in engineering and environmental studies: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.75-126. Roberts, R.L., Hinze, W.J., and Leap, D.I., 1990, Data enhancement procedures on magnetic data from landfill investigations: in Geotechnical and Environmental Geophysics, v.II, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.261-266. Gilkeson, R.H., Gorin, S.R., and Laymon, D.E., 1992, Application of magnetic and electromagnetic methods to metal detection: in Proc.of the Symp.on the Appl.of Geophys.to Engrg. and Environ.Problems, R.S.Bell, ed., Oakbrook, IL, Soc. Engrg. & Min.Explor.Geophys., Golden, CO, p.309-328.

SITE: Test Example
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., 1990, The role of gravity and magnetic methods in engineering and environmental studies: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.75-126. Richard, B.H. and Wolfe, P.J., 1990, Gravity as a tool to delineate buried valleys: in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Golden, CO, Soc.Engr.& Min.Explor.Geophys., p.59-106. Butler, D. K., 1991, Engineering and environmental applications of microgravity: in Proc.Symp.Appl.Geophys.Engr.& Environ.Probl., Knoxville, TN, Soc.Engr.& Min.Explor.Geophys., p.139-246.

SITE: Test Example
Site specific comments: -010 Radiometric methods not recommended.
There are no radioactive materials present.
-010 Radiometric methods not recommended. Radiometric techniques measure the radiation emitted 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 and of the covering soil). 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. Gregg, L.T. and Holmes, J.J., 1990, Radon detection and measurement in soil and groundwater: in Geotechnical and Environmental Geophysics, v.I, S.H.Ward, ed., Tulsa, Soc.Explor.Geophys., p.251-262.

SITE: Test Example
Site specific comments: 0007 Soil gas methods recommended.
Contaminants on the surface may interfere with soil gas.
Soil gas can detect volatile organics. Soil gas detects volatile organics.
Soil gas may detect the products of organic biodegradation.
Soil gas may detect the products of organic catalytic reaction.
Surface contamination will interfere with soil gas (requires deep soil gas probing). Older organic contamination is more likely degraded.
Soil gas probes should sample below depth of freeze in winter.
0007 Soil gas methods recommended. Soil gas techniques measure the variation in concentration of subsurface gases. The sampling zone may be at or within a few meters of the surface. The collected gases are analyzed by portable gas chromatographs and/or mass spectrometers to identify particular compounds of interest. Airborne or near surface contamination may bias interpretation of underground contaminants. Permeability variations at the site from utility corridors, clay layers, or fractures will modify the apparent contaminant patterns at the surface, requiring careful interpretation. Driving gas sampling probes into the ground to avoid surface or airborne contamination may pose a safety hazard if utilities or near-surface barrels are punctured. Soil gas is insensitive to non-volatile organics and cannot detect inorganics.
Basic references include: Lappala, E. and G.Thompson, 1984, Detection of ground water contamination by shallow soil gas sampling in the vadose zone: theory and applications, in Proc. of the 5th National Conf.on Manag. of Uncontrolled Hazardous Waste Sites, HMCRI, Silver Springs, MD, p.20-28; Kerfoot, H. and Mayer, C., 1986, The use of industrial hygiene samplers for soil-gas surveying: Ground Water Monitoring Review, v.6, n.4, p.74-78; Marrin, D.L. and G.M. Thompson, 1987, Gaseous behavior of TCE overlying a contaminated aquifer, Ground Water, v.25, n.1, p.21-27. Marks, B.J. and Singh, M., 1990, Comparison of soil-gas, soil, and groundwater contaminant levels of benzene and toluene: Hazardous Materials Control, v.3, n.6, p.40-46. Godoy, F.E. and Naleid, D.S., 1990, Optimizing the use of soil gas surveys: Hazardous Materials Control, v.3, n.5, p.23-29.
Devitt, D. A., Evans, R. B., Jury, W. A., Starks, T. H., Eklund, B., and Ghalsan, A., 1987, Soil gas sensing for detection and mapping of volatile organics: USEPA EMSL, Las Vegas, NV, EPA/600/8-87/036, 265p.