

TAKING THE MYSTERY OUT OF GROUND WATER MONITORING



Ground water -- the unseen, the ubiquitous, the mysterious vehicle which gives life to plants and trees, but which has fragile qualities - that which is easily contaminated and must be protected at almost any cost.

What is really happening when someone accuses you of contaminating the town's drinking water supply three miles away? How do you prove that you're really not at fault - or are you? What are those strange geologist doing driving over your plant towing a downward looking Radar unit, pounding stakes in the ground and drilling all those expensive ground-water monitoring wells.

Today, we will attempt to answer some of those questions -- and take some of the mystery out of a very complex and seemingly mysterious subject. We will look at the reasons for monitoring the ground water, how it moves, how contaminants move in it, what tools the geologists use to investigate it, and finally the management of a ground-water monitoring program.

PURPOSE IN MONITORING

Why are you interested in developing information about the ground water? Several purposes come to mind.

Ground-water monitoring may only be an incidental requirement of an environmental program, or it may be the focus of one

whose's purpose is to define the extent of ground-water contamination.

RCRA ground-water monitoring is required by Subpart F of 40 CFR parts 264 and 265. This monitoring relates to the operation or closure of a surface impoundment, a landfill, or other hazardous waste disposal activities.

A whole new class of ground-water monitoring requirements are about to be imposed upon industry in the form of the LUST Regulations -- (Leaking Underground Storage Tank). Leaks from underground storage tanks maybe difficult to detect. Very small leaks are almost impossible to detect by conventional tank testing methods but may be detected by monitoring the ground water. An underground tank which has been tested by conventional methods and which has been found not to be leaking can still lose up to 1.2 gallons per day of its contents; this leak could easily contaminate an entire aquifer leading to several hundred thousands of dollars in cleanup costs. Ground-water monitoring around underground storage tanks may be the early warning system which prevents big costs later.

In addition to the Federal requirements, several states have passed or are passing ground-water monitoring and leaking underground storage tank laws. In California, for example, the Katz bill requires a hydro-geologic assessment to be performed on all surface impoundments -- regardless of whether or not they contain Hazardous Wastes. The Sher bill, another California law addresses the LUST issue by requiring monitoring and testing of all underground tanks.

Defensive ground-water monitoring is sometimes performed to establish background or existing conditions. It can be important in real estate acquisition or new plant construction, as part of the environmental impact statement filings, or for the purpose of aquifer development to supply cooling or drinking water to a processing plant.

In real estate transactions the rule of law still is caveat emptor - "let the buyer beware". With the purchase of the property comes the assumption of the responsibility for any contamination which may be underneath the property and the assumption of the liability for site cleanup, if required. Law Environmental Services routinely receives calls to examine properties to determine whether old underground fuel tanks were properly removed or whether the buried septic tank could be causing a ground water problem.

Corporations are becoming aware of the need to monitor the ground water to establish their innocence against potential charges of ground-water pollution. In some cases, a demand for good corporate citizenship creates a desire to discover what may be down in the ground water so that preventive actions can be initiated before the plant has bigger environmental problems.

GROUND-WATER MOVEMENT-- A BRIEF PRIMER

Ground water always flows in the direction of decreasing hydraulic gradient or downhill. That is the easy part of ground-water movement. Determining the extent and travel speed of ground-water contaminants is considerably harder. The ground-water movement is controlled by geologic characteristics and some

of the conditions which influence the movement of ground water or its' pollutants include clay layering, non-isotropic conditions in the soil, fracturing in the rock, and reactive conditions between the contaminants and the soils. The seasonal fluctuation of the ground water will also influence the direction and speed of groundwater and contaminant travel. Pumping wells, lakes, rivers, and streams can significantly influence the direction and speed of the ground-water movement also.

GROUND WATER AND CONTAMINANT MOVEMENT

The basic equation governing ground-water movement is Darcy's Law:

$$V = -K \, dh/ds$$

V= velocity

K= coefficient of hydraulic conductivity, and

dh/ds= hydraulic head gradient

Darcy's law can be developed from the Bernoulli equation by neglecting the velocity term because it is so very small. In ground water, flow regimens are laminar, usually with Reynolds numbers much much less than 1. Darcy's equation, when combined with continuity principle, leads to the relationship shown on Figure 1.

Ground water flow is not constant with time or with direction in the ground. A more general description of the flow regimen is the LaPlace Equation:

$$\nabla^2 h = \frac{S}{T} \frac{\partial h}{\partial t} \quad \text{or} \quad \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S}{T} \frac{\partial h}{\partial t} \quad \text{eg. \#2}$$

h = hydraulic head

S = storage coefficient of the aquifer,

T = transmissivity of the aquifer $=Kb$,

b = thickness of the aquifer, and

K = hydraulic conductivity

When this equation has been transformed to cylindrical coordinates and integrated, the equation takes the familiar forms as shown in Figure 1.

Contaminants in the ground water may or may not move at the same rate as the ground water, and they may interact with soil or rock, changing form or chemical composition as they move along, or they may disappear entirely.

Figure 2 illustrates the complexity of trying to predict the movement and behavior of chemical contaminants in the ground water. In this relatively simple case, the ground water is in a confined layer moving through a porous medium -- sand - at a small velocity v_x . The initial concentration of the contaminant is C_0 , and at some point in the direction of the flow -- downstream -- the concentration C is zero.

Before we leave this subject entirely, two more points should be made. A model is just one of the tools used by geologists in trying to predict and understand the movement of the contaminants. In using the models, the data constraints can be very very great and sometimes the best models cannot accurately approximate the physical situation because enough information is not available.

THE ROOFTOP MODEL

The following analogy frequently helps explain some of the problems associated with conducting a subsurface investigation:

Let us suppose that you are located on the roof of an apartment or an office building in a large city trying to find out what is going on in the building. The roof has its own terrain, and may be flat, irregular, or have terraces, gables, and steeply sloping areas where it might be prohibitive to stand or drive.

A second requirement is that your funds are somewhat limited, and you cannot, or do not want to rip up the entire roof to see what is going on below. You can take all the subsurface measurements you like and can drill holes to the limit of your budget.

Your subroof exploration will yield greatly different results, depending upon how deep you go and where on the roof you are. The kitchen in one level may be a den or bathroom on another level, and an equipment room or a broom closet on still another level. As you explore the building, you might even find the elevator shaft or the swimming pool-- big discontinuities which, if taken by themselves, could lead to false conclusions about the contents or activity within the building.

Locating and describing the subsurface activity and geology can be just as tough as describing what is going on below the roofline.

Geologists and geophysicists have developed a variety of instruments which can reduce the overall cost of subsurface

exploration, and while not always a substitute for a bore hole, these techniques can provide some interesting information about what is underground.

NEAR SUBSURFACE EXPLORATION BY INDIRECT TECHNIQUES-- RADAR, ELECTRICAL RESISTIVITY, AND SEISMIC

Many of the surface exploration tools measure the change in electrical properties of the soils. Where the soils are high in salt content or where the contaminant plumes do not change the electrical properties of the ground water, the surface geophysical methods may be of limited use.

GROUND PENETRATING RADAR

Figure 3 shows a typical towed ground penetrating radar unit. It works much the same as airborne radar, only the signals in the ground travel at slower rate, depending upon the dielectric properties of the soils. Typical dielectric values of soils and radar groundwave propagation speeds are shown in Table 1. The depth that a radar can probe the ground and the resolution of the image is also dependent upon the frequency of the radar. Most commercial units operate at 3 or more frequencies, commonly 120 MHz, 350 MHz and 700 MHz. The commercial radars commonly used can "see" into the ground several feet in wet clays to a hundred feet or more in dry sand. On a stationary set up, a radar unit can survey up to 90,000 square feet; on a profiling assignment it can be used to profile several kilometers per day.

Ideal uses for ground penetrating radar include locating buried tanks, trenches, pits, pipes, and the top of shallow rock

or ground water. Ground Penetrating Radar can also be used to find voids beneath concrete slabs, provided the reinforcing bar does not interfere with the signal. A typical radar profile looks like that shown in Figure 4.

Ground Penetrating Radar is blind in highly conductive soils and salt water. In one instance, in Bayonne, New Jersey, a radar survey, conducted by others, failed to find buried drums because they were near the high water line where the salt water intrusion created highly conductive subsurface layers.

ELECTROMAGNETIC SURVEYS AND ELECTRICAL SURVEYS

Electromagnetic surveys and electrical surveys both measure the electrical properties of the soil. The electromagnetic equipment (EM) measures relative conductivity by measuring the differences in a soil induced electromagnetic field. Because the EM equipment does not require direct contact with the ground, it can generate subsurface profiles very quickly. The EM survey equipment is useful in locating drums, metallic objects, and other buried objects up to a distance of about 10 meters or 30 feet - or deeper if power lines, chain link fences and other objects do not interfere.

Electrical resistivity surveys take longer to conduct because they require conductive spikes to be driven into the ground before the measurements are made. In an electrical survey a current is impressed between two points on the ground and the voltage difference between two points is measured. Varying the electrode spacing and strength of the applied electrical field will permit deeper "soundings" of the subsurface to be developed.

The resistivity measurements can also be used for profiling. Two typical types of subsurface data are shown in Figures 5 and 6.

SEISMIC PROFILING

One of the most familiar subsurface exploration techniques is seismic profiling. It is usually thought of in connection with deep subsurface exploration used by oil companies, but it can be used for shallow exploration as well.

The seismic techniques use an array of geophones to measure the ground vibration from an acoustic source which does not always need to be an explosion, but for shallow work can be a mallet strike. The sound travels outward from the source and is reflected and refracted at various interfaces and returned to the surface where the geophones record the time and frequency of the wave. A typical seismic array and profile are shown in Figure 7.

Obviously in a plant area where heavy machinery is used, or where ground vibration is a factor, the use of seismic profiling may be quite restricted. Seismic techniques are not suited for locating buried drums or for defining plumes of contaminated ground water, but they can provide a lot of useful information about the depth and location of major subterranean features including the ground-water tables.

DRILLED WELL EXPLORATION TECHNIQUES

A drilled borehole, properly logged, can tell a geologist quite a bit about subsurface conditions beneath your site. In addition to the borehole, the geologist uses a number of instruments to log the well and provide further information about the

geology. The porosity and permeability and density of the soil and rock layers are often indicators of the way in which water and pollutants will move through an area.

The borehole has the disadvantages that it is expensive to drill, and that it provides information about only a very small area -- just like our rooftop analogy.

ELECTRICAL RESISTIVITY

Electrical Resistivity measurements are made on wet uncased holes, using a meter and a portable generator which generates alternating and direct current. By comparing the direct current Specific Potential with the alternating current Resistivity, a picture of the subsurface lithology and an estimate of ground water quality can be obtained. A typical profile and plot of Specific Potential and Resistivity is shown in Figure 8.

NUCLEAR LOGGING

Measurement of Gamma Rays or Neutrons generated naturally from natural sources artificial sources within the logging tool are used to obtain data on subsurface porosity and density and mineralogical formations. Gamma or neutron logging can be used in a cased or uncased well. When used in combination with other techniques and with core samples, these logs can provide fairly accurate information about the subsurface lithology.

Gamma ray logging is useful in locating clay layers, because clays contain much higher concentrations of naturally occurring Potassium 40 than do rock formations.

Backscattered Gamma Ray logging can be used to determine the

density and porosity of the soil or rock near the well. Backscattered Neutron logging is used primarily to measure the porosity of the subsurface formations.

GROUND-WATER WELLS

A drilled well is one of the most common methods of getting water out of the ground. Just as people are different, so are wells. Law Engineering uses 3 types of well and each is appropriate to specific use and geologic conditions. The three types of wells are shown in Figure 9.

The Type I well is the simplest to construct and is generally small diameter because it is used primarily to determine the depth of the ground water in a shallow formation. The backfill around the well casing is usually soil or, occasionally, a bentonite clay.

Type II wells are more expensive to drill. The Type II well is grouted around the casing to prevent vertical contaminant migration between distinct lithologic zones -- such as between the soil and the underlying rock formations.

Type III wells are the most expensive wells to drill because they are double drilled to prevent contamination from an upper zone from going into a lower zone. Using this technique, a larger diameter well is first drilled, cased and grouted through the contaminated zone(s). A second well is then drilled inside the casing of the first well to insure that the chance of pollution migration is minimized.

Development of a good monitoring or pilot well is an art. It may look easy, but it requires the services of a well driller

and a geologist with experience in soil and rock conditions similar to that found at your site. An improperly constructed monitoring or pumping well can permit cross aquifer contamination, allowing dirty water to pollute clean formations, indicating the existence of a problem where none exists, or creating a new and bigger ground water problem.

Contrary to the EPA's opinion, a monitoring well does not need to be made from Teflon and Stainless Steel, especially when PVC or polyethylene is satisfactory. The materials used in monitoring wells have to be carefully selected. PVC is occasionally subject to chemical attack, especially from aromatic organic compounds and solvents; polyethylene may absorb certain organics; and iron pipe may be suitable for some monitoring applications. Galvanized steel pipe's coatings may dissolve in acidic waters releasing Zinc and Cadmium, which may contaminate the water samples.

Small monitoring wells which are used for water level measurements are usually 2" diameter and cased with PVC pipe. These wells are generally used for ground water sampling because they are inexpensive to drill.

The four inch diameter well is the most common for low volume ground water pumping. Well yields depend upon the size of the well and the porosity and permeability of the formation.

SETTING UP A SAMPLING AND ANALYSIS PROGRAM

After you have several monitoring wells around your plant you will be facing one of the most difficult challenges -- setting up a sampling program. The sampling program can literally

make or break your facility. The results of your sampling probably will become public knowledge, and the program and analysis will receive high level scrutiny from within your company.

The keys to setting up a good monitoring program are political and technical. You must know why you are monitoring, what results must be reported, and to whom they must be reported before the first sample is taken.

Currently, there are at least 3 separate series of analysis run on ground water - the RCRA pollutants, (including Appendix VIII compounds) the Priority Pollutants and analyses for the Drinking Water Standards; it is not uncommon to find laboratory analytical fees ranging from \$800 per sample for Priority Pollutant analyses to around \$3000 for RCRA Appendix VIII analyses. The Drinking Water Standards analysis may run to as much as \$200 per sample. Unfortunately, it is too common to find an incomplete analysis -- incomplete or suspect because of poor sampling techniques, or lack of planning.

POLITICAL CONSIDERATIONS

The sampling and analysis program should be set up with the idea that all data generated will become public knowledge and will, in turn, be scrutinized by the press, the public, and the regulatory agencies. Unfavorable publicity may cause other regulatory investigations of the plant, and, in the extreme cases, may lead to an Securities and Exchange Commission investigation of the environmental liabilities in the company's Annual Report.

The unfavorable publicity can only be dealt with in a straight forward and honest manner. Employing an outside public relations consultant may be of benefit, provided the proclamations made to the public match the actions taken by the company, and provided the company can maintain image of its credibility with the press and public, and the regulatory community.

The company undertaking a ground-water sampling program must be prepared to deal with unpleasant results and must be committed to spending the money necessary to resolve or correct the problem.

DETECTION LIMITS

What does "BDL" or "ND" mean on a laboratory sheet? Indications that a compound is either not detected or that it may be present below detection limits do not mean the same thing. The compound may not be detected, or it may not be present.

New extraction and concentration techniques and new analytic detection equipment have lowered the detection threshold several thousandfold over the past 10 years. A compound not detected 10 years ago can be measured to three significant places. Consequently, an "ND" or "BDL" indication on an analysis is meaningless -- unless it is referenced to a specific method, an detection limit, and a specific piece of analytical apparatus.

SELECTING A LABORATORY

Look carefully at the credentials of your laboratory -- as

well as at their price list. Are they a Certified Laboratory? Have they routinely done, or are they doing, the type of analysis you want, or are you their guinea pig? Inspect the laboratory or have someone who is qualified inspect it for you. Obtain a copy of the Quality Control and Quality Assurance Program, and determine in advance whether or not it meets minimum EPA and State requirements. Discuss the types of samples which will be sent and clearly state your objectives and expectations from the laboratory. Agree in advance how the sample is to be handled, what analyses are to be performed, and how the results are to be reported.

Typical laboratory analysis reporting form which Law Environmental Services uses are shown in Figure 10. There is nothing sacred about the form or format but note that all the data are in one place.

Decide in advance whether or not you want all the calculations or just the data summaries, and obtain definite commitments on when the results are to be delivered. Laboratories performing the RCRA analysis for Appendix VIII compounds may have a 3 month backlog.

CHAIN OF CUSTODY

The concept of a chain of custody of a sample for analysis has been developed from legal considerations and from a need for regulatory agencies to prove that the sample collected was really the one obtained from Company X.

The chain of custody protocols must be followed, even if special arrangements have to be made for the sample trans-

portation. Industry is often too lax about the chain of custody protocols, but a Federal Express or other airbill will be sufficient to establish custody, provided the samples arrive intact and the laboratory logs them in.

As part of the overall chain of custody, you will want to know how the samples will be disposed of when the analyses are completed. Law Environmental Services is strict about returning samples to the client who generated them. Other companies routinely dispose of hazardous waste samples in various ways. Practices of sample disposal vary from company to company and from State to State.

THE WELL SAMPLING

Planning a sampling campaign can require all the logistics and planning that go into a military battle. Each sample has preservation and holding requirements which may require rapid transport and analysis. Typical sample preservation requirements are shown in Table 2; these figures represent maximum holding times for a water sample.

Some of the measurements need to be made in the field. Temperature, atmospheric pressure, the concentration of dissolved gasses and pH can all change by the time the sample is received at the laboratory; e.g., the release of dissolved CO₂ will change the pH of a sample by the time it reaches the laboratory.

In the field, the well is bailed -- a process which should remove at least 5 well volumes before the actual sample is collected. Well bailers can be dedicated or portable. Typical bailers are shown in Figure 11. The bailer must be carefully

decontaminated between well samplings. Use of a dirty bailer will show up in the laboratory in a contaminated sample, and with routine laboratory sensitivities, low levels of residual contamination will show up in the analyses.

Before you dip the bailer down the well -- stop and think. Are sufficient containers and sample bottles on hand? Are sufficient bailer decontamination supplies available? Have you obtained the water level measurements from the well? How will you dispose of the water you are bailing from the well? Finally, check all protective and safety equipment to prevent a contractor's or your people from being exposed to harmful substances.

SUMMING IT UP

Successful ground water monitoring requires a variety of skills and talents. From the geologist who determines where to drill the well and supervises its installation, to the geophysicist who explores the subsurface properties, to the analyst who analyzes the sample. All of these people represent skills which can make the difference between a successful and an unsuccessful sampling program. If you are about to become involved in a major sampling effort, I would suggest that a team approach should be considered.

The three key people on your team should be your Attorney, your Environmental Consultant, and your Environmental Project Manager. The attorney will handle legal matters and can receive data under a seal of attorney-client privilege. The Environmental Project Manager will help set up and run the program,

controlling costs and coordinating management details, and the Environmental Consultant will help you design data collection program and then assist you in interpreting the results.

**TABLE 1 DIELECTRIC VALUES FOR
GROUND PENETRATING RADAR**

SUBSTANCE	DIELECTRIC CONSTANT	RADARWAVE VELOCITY ft/nanosec.	WAVELENGTH AT 100 MHz ft.
AIR	1.0	1.0	10.0
SNOW	3.0	0.58	5.7
ICE	3.2	0.56	5.5
DRY SAND	3.0	0.58	5.7
SANDSTONE	4.0	0.3	4.9
LIMESTONE	6.0	0.41	4.0
GRANITE	9.0	0.33	3.3
WET SOIL	16.0	0.25	2.5
WATER	80.0	0.11	1.1

SOURCE: LAW ENVIRONMENTAL SERVICES, MARIETTA, GEORGIA
GEOPHYSICS TECHNICAL NOTE #3, DEC. 1983.

TABLE 2

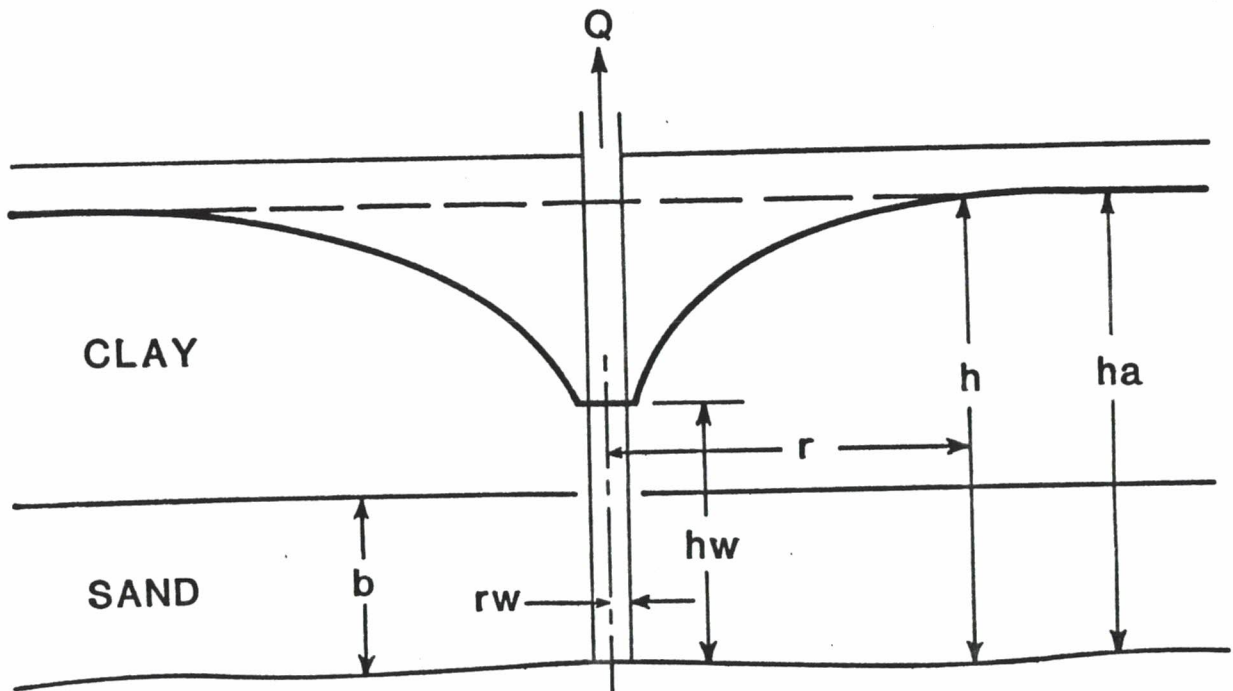
**RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES
AND SAMPLE HOLDING TIMES. (40 CFR 136)**

Parameter No /name	Container ¹	Preservation ^{2, 3}	Maximum holding time ⁴
Table IA—Bacterial Tests:			
1-4 Coliform, fecal and total	P, G	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵	6 hours.
5 Fecal streptococci	P, G	do	Do.
Table IB—Inorganic Tests:			
1. Acidity	P, G	Cool, 4°C	14 days.
2. Alkalinity	P, G	do	Do.
4. Ammonia	P, G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
9. Biochemical oxygen demand	P, G	Cool, 4°C	48 hours.
11. Bromide	P, G	None required	28 days.
14. Biochemical oxygen demand, carbonaceous	P, G	Cool, 4°C	48 hours.
15. Chemical oxygen demand	P, G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
16. Chloride	P, G	None required	Do.
17. Chlorine, total residual	P, G	do	Analyze immediately.
21. Color	P, G	Cool, 4°C	48 hours.
23-24 Cyanide, total and amenable to chlorination	P, G	Cool, 4°C, NaOH to pH > 12, 0.6g ascorbic acid ⁵	14 days. ⁴
25. Fluoride	P	None required	28 days.
27. Hardness	P, G	HNO ₃ to pH < 2, H ₂ SO ₄ to pH < 2	6 months.
28. Hydrogen ion (pH)	P, G	None required	Analyze immediately.
31, 43. Kjeldahl and organic nitrogen	P, G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
Metals:⁷			
18. Chromium VI	P, G	Cool, 4°C	24 hours.
35. Mercury	P, G	HNO ₃ to pH < 2	28 days.
3. 5-8, 10, 12, 13, 19, 20, 22, 26, 29, 30, 32-34, 36, 37, 45, 47, 51, 52, 58-60, 62, 63, 70-72, 74, 75. Metals, except chromium VI and mercury.	P, G	do	6 months.
38. Nitrate	P, G	Cool, 4°C	48 hours.
39. Nitrate-nitrite	P, G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
40. Nitrite	P, G	Cool, 4°C	48 hours.
41. Oil and grease	G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
42. Organic carbon	P, G	Cool, 4°C, HCl or H ₂ SO ₄ to pH < 2	Do.
44. Orthophosphate	P, G	Filter immediately, Cool, 4°C	48 hours.
46. Oxygen, Dissolved Probe	G Bottle and top	None required	Analyze immediately.
47. Winkler	do	Fix on site and store in dark	8 hours.
48. Phenols	G only	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
49. Phosphorus (elemental)	G	Cool, 4°C	48 hours.
50. Phosphorus, total	P, G	Cool, 4°C, H ₂ SO ₄ to pH < 2	28 days.
53. Residue, total	P, G	Cool, 4°C	7 days.
54. Residue, Filterable	P, G	do	48 hours.
55. Residue, Nonfilterable (TSS)	P, G	do	7 days.
56. Residue, Settleable	P, G	do	48 hours.
57. Residue, volatile	P, G	do	7 days.
61. Silica	P	do	28 days.
64. Specific conductance	P, G	do	Do.
65. Sulfate	P, G	do	Do.
66. Sulfide	P, G	Cool, 4°C add zinc acetate plus sodium hydroxide to pH > 9.	7 days.
67. Sulfite	P, G	None required	Analyze immediately.
68. Surfactants	P, G	Cool, 4°C	48 hours.
69. Temperature	P, G	None required	Analyze.
73. Turbidity	P, G	Cool, 4°C	48 hours.
Table IC—Organic Tests:⁸			
13, 18-20, 22, 24-28, 34-37, 39-43, 45-47, 56, 66, 88, 89, 92-95, 97. Purgeable Halocarbons	G, Teflon-lined septum	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵	14 days.
6, 57, 90 Purgeable aromatic hydrocarbons	do	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ , HCl to pH 2 ⁹	Do.
3, 4 Acrolein and acrylonitrile	do	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ , Adjust pH to 4-5 ¹⁰	Do.
23, 30, 44, 49, 53, 67, 70, 71, 83, 85, 96. Phenols ¹¹	G, Teflon-lined cap	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵	7 days until extraction. 40 days after extraction.
7, 39. Benzidines ¹¹	do	do	7 days until extraction. ¹³
14, 17, 48, 50-52. Phthalate esters ¹¹	do	Cool, 4°C	7 days until extraction: 40 days after extraction.
72-74 Nitrosamines ^{11, 14}	do	Cool, 4°C, store in dark, 0.008% Na ₂ S ₂ O ₅ ⁵	Do.
76-82 PCBs ¹¹ acrylonitrile	do	Cool, 4°C	Do.
54, 55, 65, 69. Nitroaromatics and isophorone ¹¹	do	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵ store in dark	Do.
1, 2, 5, 8-12, 32, 33, 58, 59, 64, 68, 84, 86. Polynuclear aromatic hydrocarbons ¹¹	do	do	Do.
15, 16, 21, 31, 75. Haloethers ¹¹	do	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵	Do.
29, 35-37, 60-63, 91. Chlorinated hydrocarbons ¹¹	do	Cool, 4°C	Do.
87 TCDD ¹¹	do	Cool, 4°C, 0.008% Na ₂ S ₂ O ₅ ⁵	Do.
Table ID—Pesticides Tests:			
1-70 Pesticides ¹¹	do	Cool, 4°C, pH 5-9 ¹¹	Do.
Table IE—Radiological Tests:			
1-5. Alpha, beta and radium	P, G	HNO ₃ to pH < 2	6 months.

Table Notes

¹ Polyethylene (P) or Glass (G).

FIGURE 1 BASIC GROUNDWATER FLOW EQUATIONS



r_w = RADIUS OF WELL, K = COEFFICIENT OF PERMEABILITY

h_w = HEIGHT OF WATER IN THE WELL BEING PUMPED

b = THICKNESS OF AQUIFER

h_a = HYDRAULIC HEAD AT NON PUMPING CONDITIONS

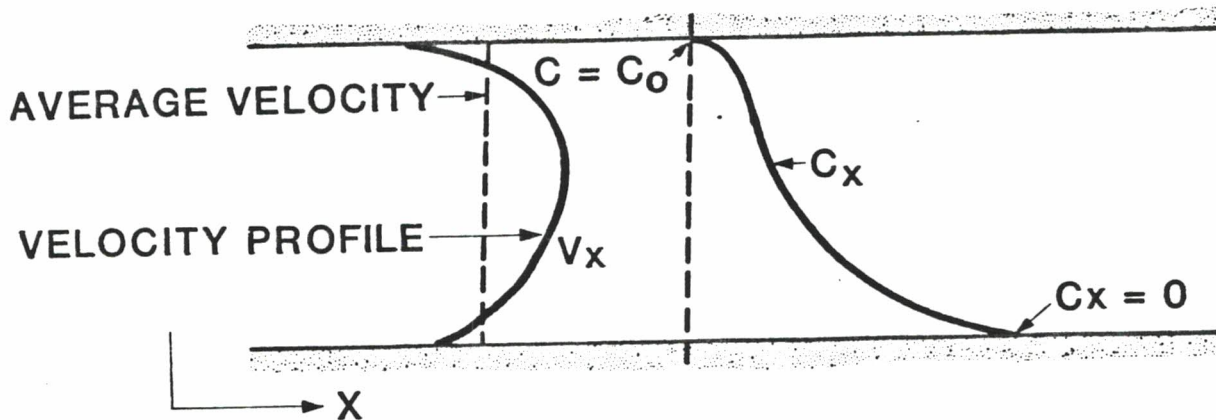
Q = PUMPING RATE

$$Q = 2 \pi r b K \frac{dh}{dr}$$

$$h - h_w = \frac{Q}{2 \pi K b} \ln \frac{r}{r_w} \quad \text{or} \quad h - h_w = \frac{Q}{2 \pi T} \ln \frac{r}{r_w}$$

FIGURE 2

MOVEMENT OF CONTAMINANTS IN GROUNDWATER



ADVECTION AND DISPERSION EQUATION

$$\frac{\partial C}{\partial t} = D \nabla^2 C - v \frac{\partial C}{\partial x}$$

D = DISPERSION COEFFICIENT [L^2/T]

C = CONCENTRATION

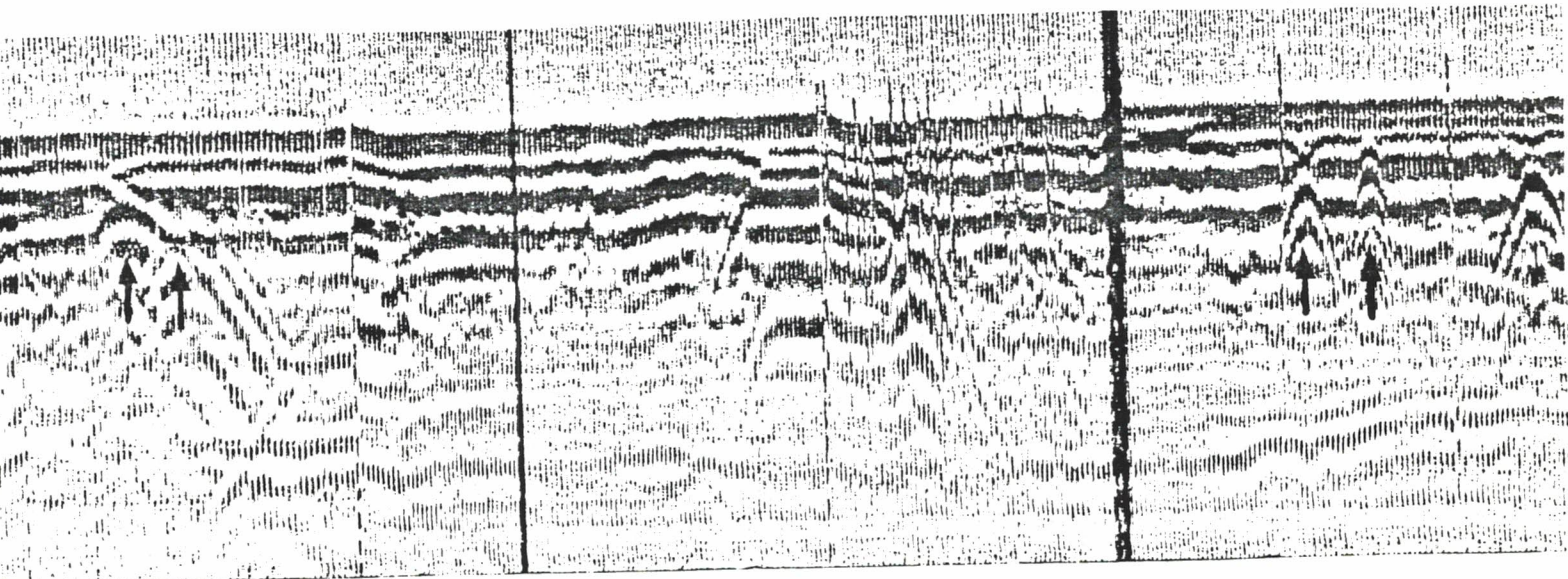
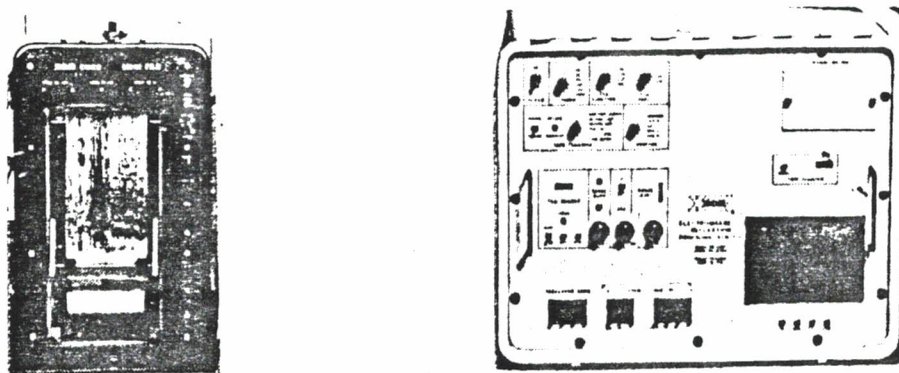
WHEN THE ABOVE EQUATION IS REARRANGED
AND SOLVED FOR THE CONCENTRATION

$$\frac{C}{C_0} = 1/2 \left[\operatorname{erfc} \left(\frac{1 - \xi}{2 \sqrt{\xi \eta}} \right) + \exp \left(\frac{1}{\eta} \right) \operatorname{erfc} \left(\frac{1 + \xi}{2 \sqrt{\xi \eta}} \right) \right]$$

WHERE $\xi = \frac{v t}{x}$ and $\eta = \frac{D}{v x}$

SOURCE: FLUID MOVEMENT IN EARTH MATERIALS, BY A. OGATA AND R.B. BANKS,
U.S. GEOLOGICAL SURVEY PAPER #411-A, 1961.

FIGURE 3 GROUND PENETRATING RADAR

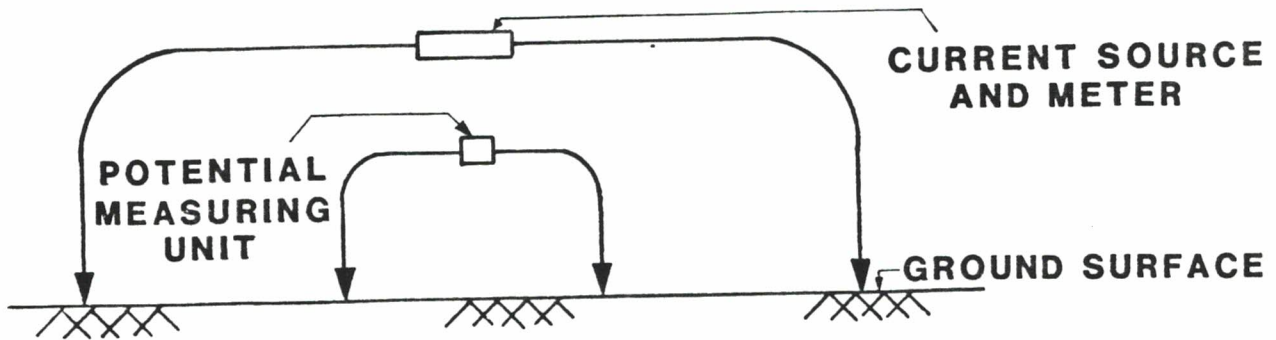


PARABOLIC PROFILES (ARROWS) INDICATE BURIED PIPES

FIGURE 4 TYPICAL RADAR PROFILES

VERTICAL RESISTIVITY SURVEY EQUIPMENT AND PROFILES

TYPICAL RESISTIVITY ARRAY (SCHLUMBERGER)



TYPICAL SOIL PROFILE

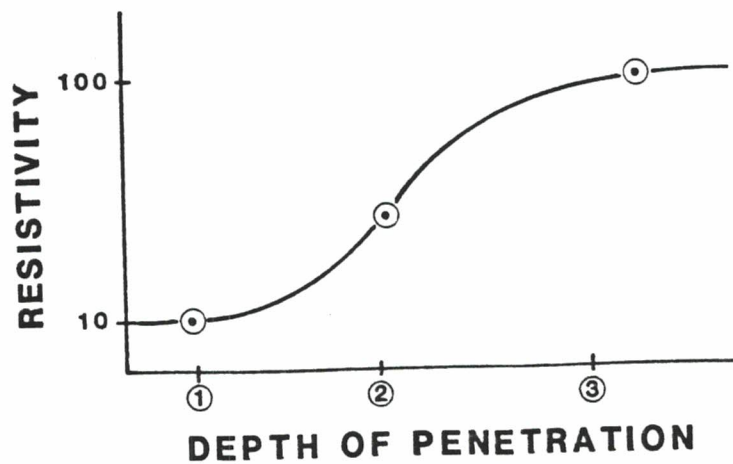
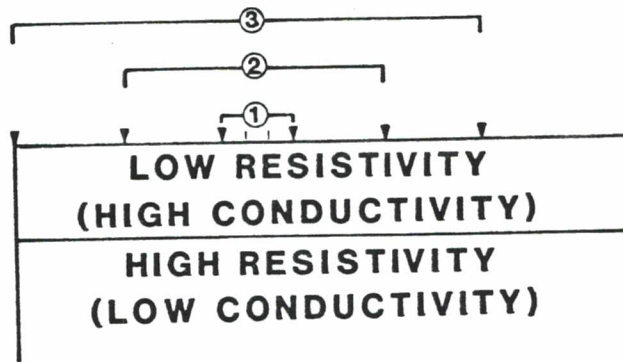


FIGURE 5

HORIZONTAL ELECTROMAGNETIC SURVEY EQUIPMENT

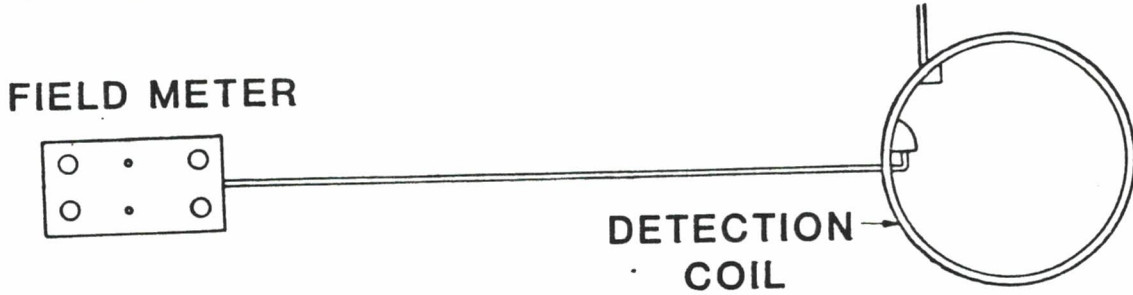


FIGURE 6A

HORIZONTAL CONDUCTIVITY PROFILING

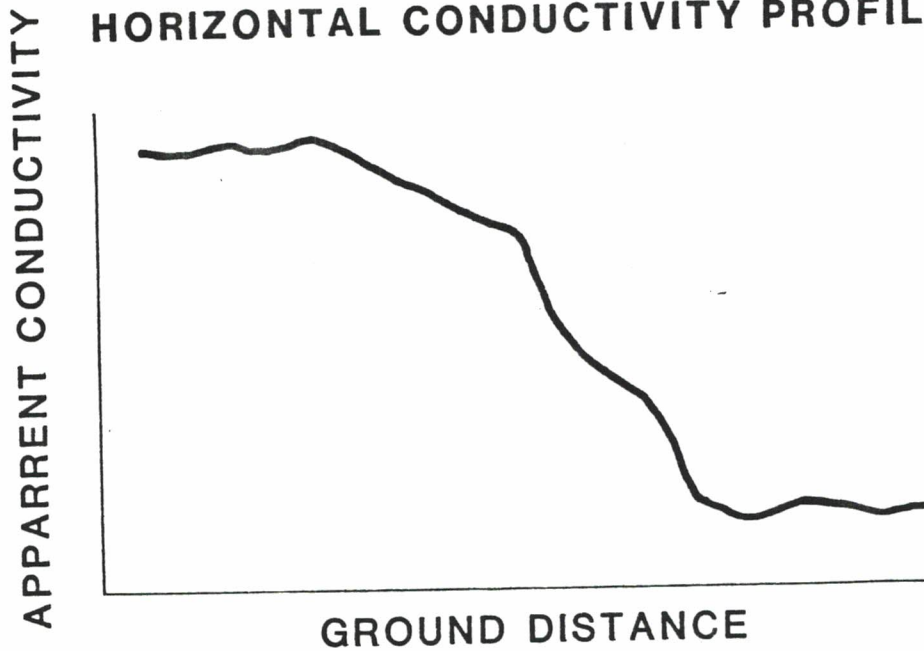
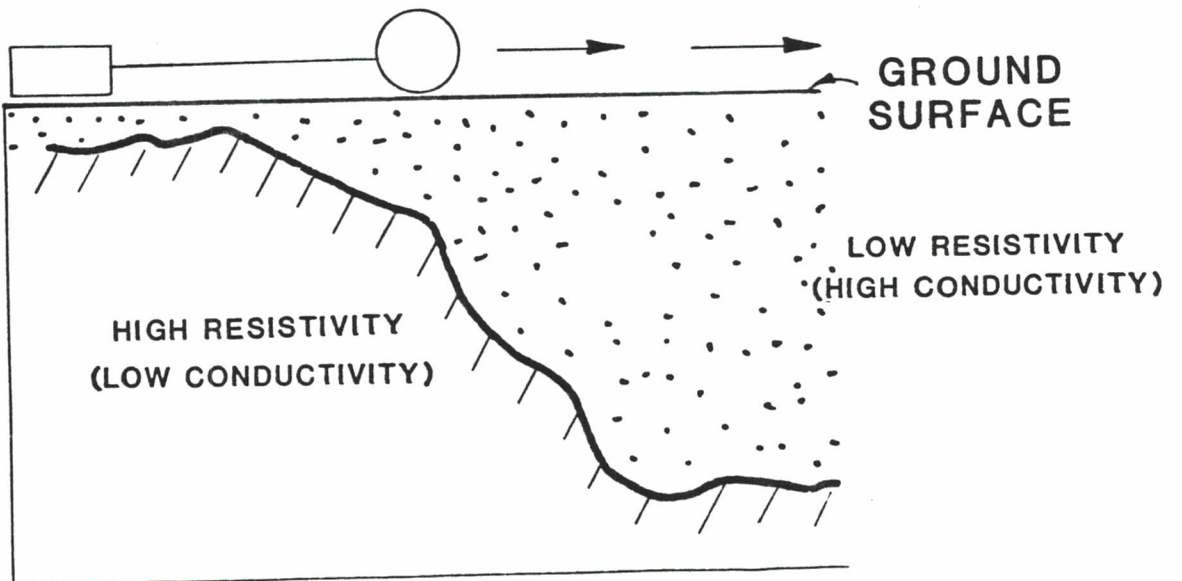
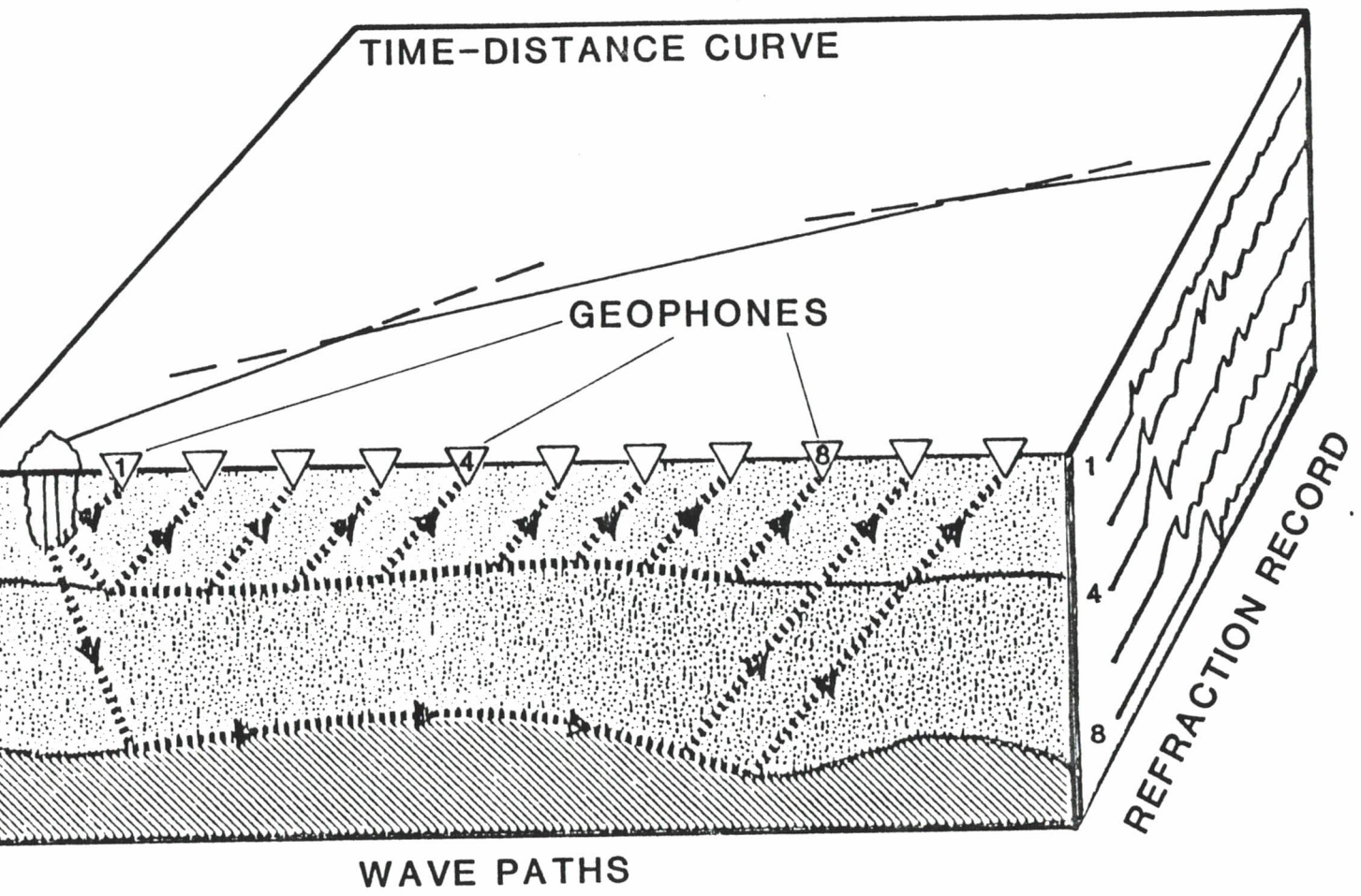


FIGURE 6B



HORIZONTAL CONDUCTIVITY PROFILING



SEISMIC EXPLORATION
 TIME-DISTANCE CURVE FROM SEISMIC PROFILE

COMPARISON OF BOREHOLE LOGGING TECHNIQUES

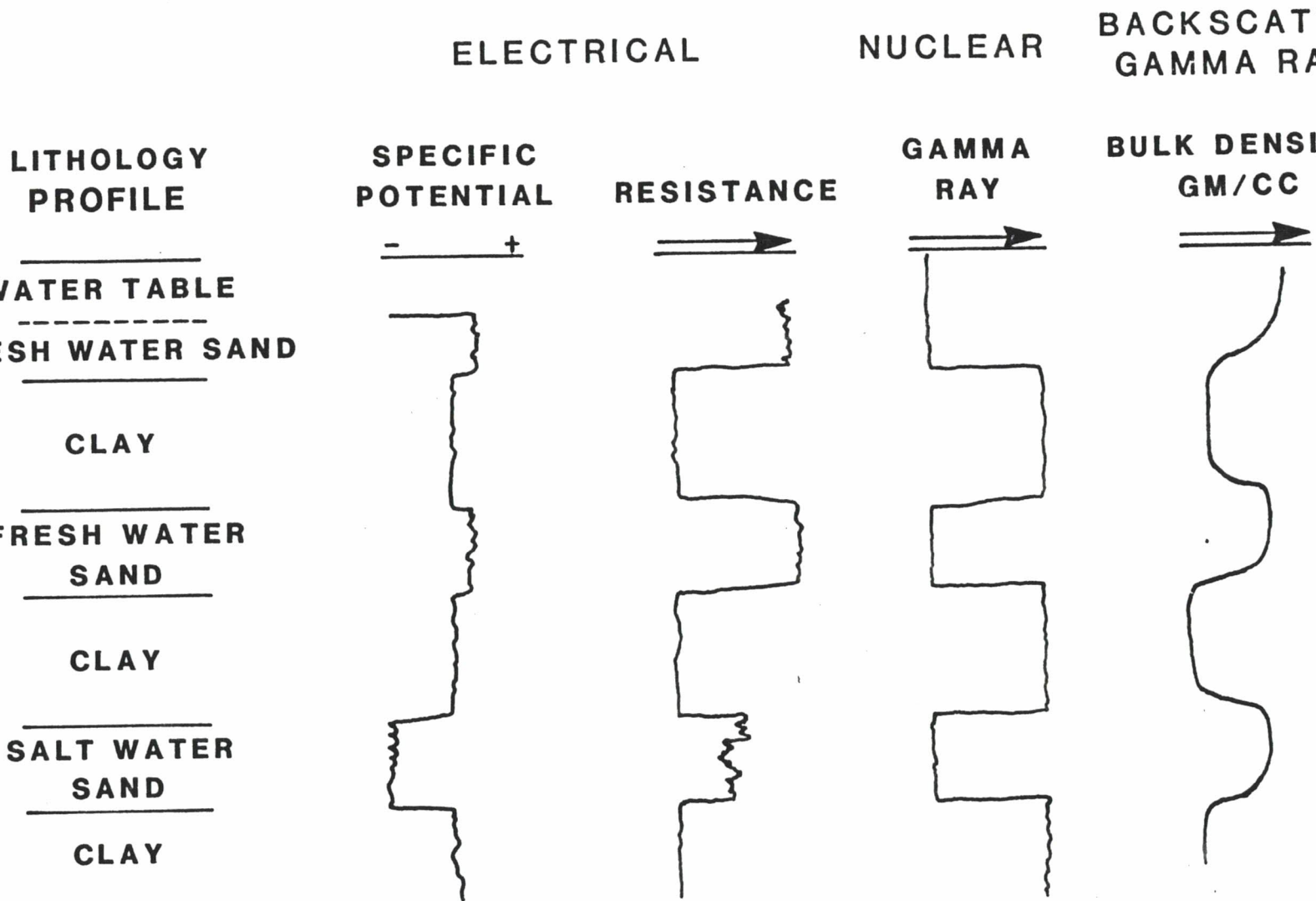
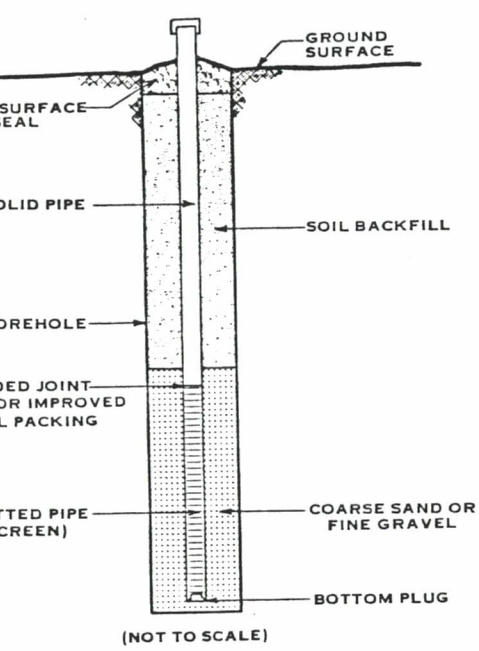


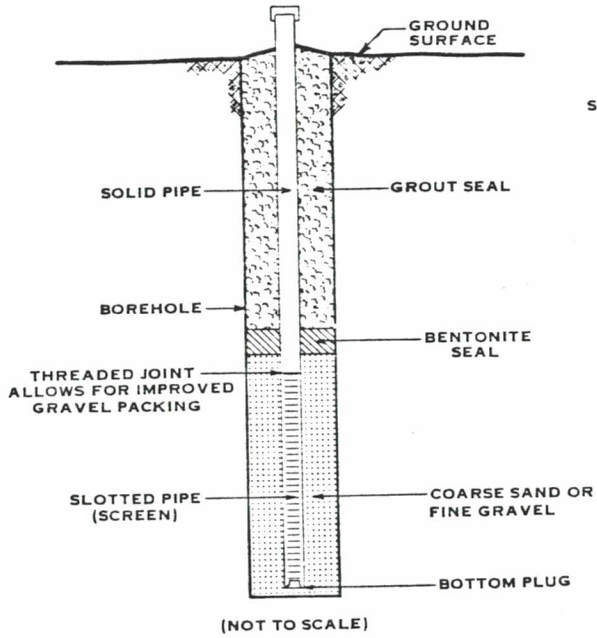
FIGURE 8

TYPE I, II, AND III WATER QUALITY MONITORING WELLS

TYPE I



TYPE II



TYPE III

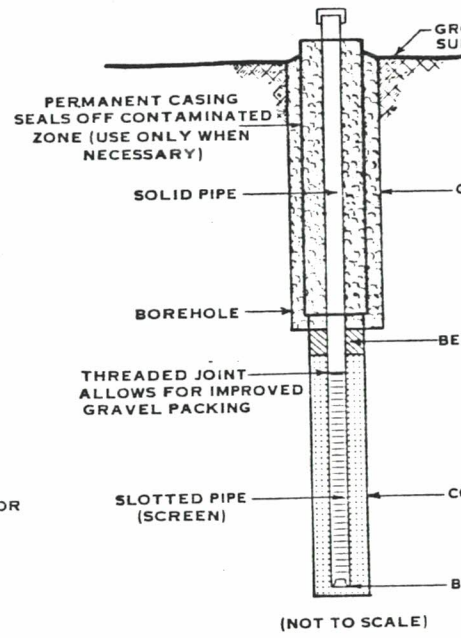
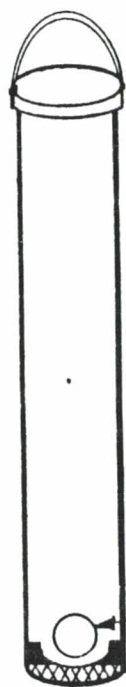


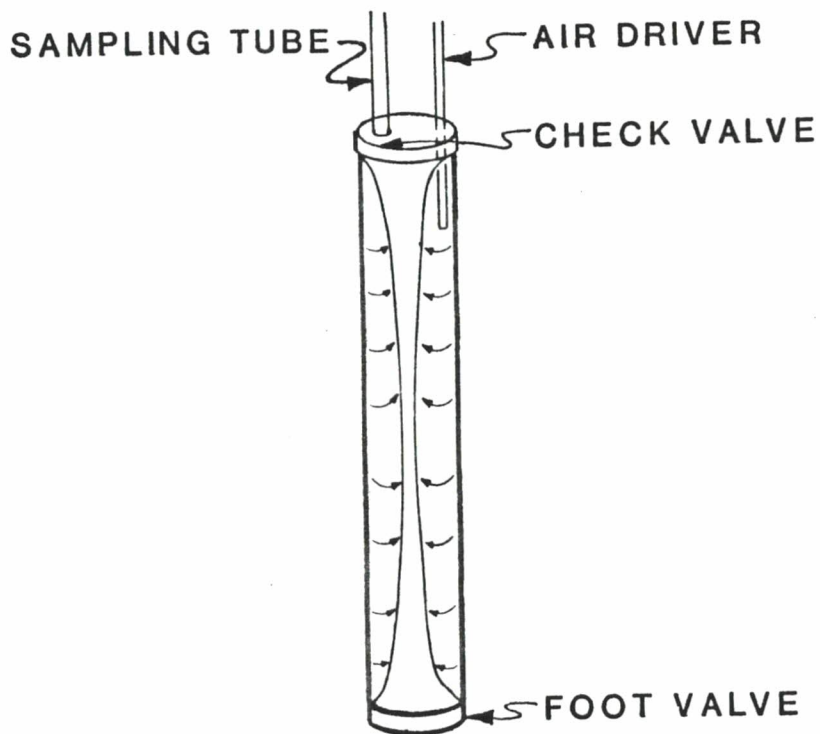
FIGURE 11 TYPICAL WELL BAILERS



GLASS MARBLE
CHECK VALVE

MANUAL

BAILER LOWERED INTO WATER
AND WITHDRAWN



**AIR ACTUATED
"WELL WIZARD"**

AIR TUBE PRESSURIZES
HOUSING FORCING SAMPLE
UP THE SAMPLING TUBE

LOG IN

LAB NN - NNNN - NN PROJECT AA NNNN DEPT/MGR NNM/AAA

CLIENT Name XYZ Corp
 Address Chemical Plant Row
 City _____ State _____ Zip _____
 Phone _____
 Contact _____

SAMPLE Station _____ Start Date/Time NNNN/NNNN
 Source _____ End Date/Time NNNN/NNNN
 Matrix Soil AA Received Date/Time NNNN/NI
 Type AAAA Received From AAA
 Total Samples NN Received by AAA
 Collector AAA Chain of Custody # NNNNN
 No. Containers NNN

Remarks Slight Oily Odor

ANALYSIS

Test Code	Test Date	Test Code	Comp Date	Test Code	Comp Date	Test Code	Comp Date
<u>NNNN</u>	<u>NNNN</u>	_____	_____	_____	_____	_____	_____
<u>1314</u>	<u>9/13</u>	_____	_____	_____	_____	_____	_____
<u>2163</u>	<u>9/13</u>	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____

DATA REPORT

LAB # LES - ML PROJ. # LL9320
 SAMPLE STATION Well #6 SAMPLE DATE/TIME _____

FIELD INORG METALS VOA EXTR ORG PEST } SERIES CODE FOR EACH SERIES

RESULTS

PARAMETER	METHOD	UNITS	CONCENTRATION/ANALYST	DATE	DETECTION LIMIT	% R
1,1,1,TCE	6020	mg/kg	123.5/WEI	9/13/85	0.2	93
Dibenzofuran	1625	mg/kg	BDL/WEI	9/13/85	0.5	110