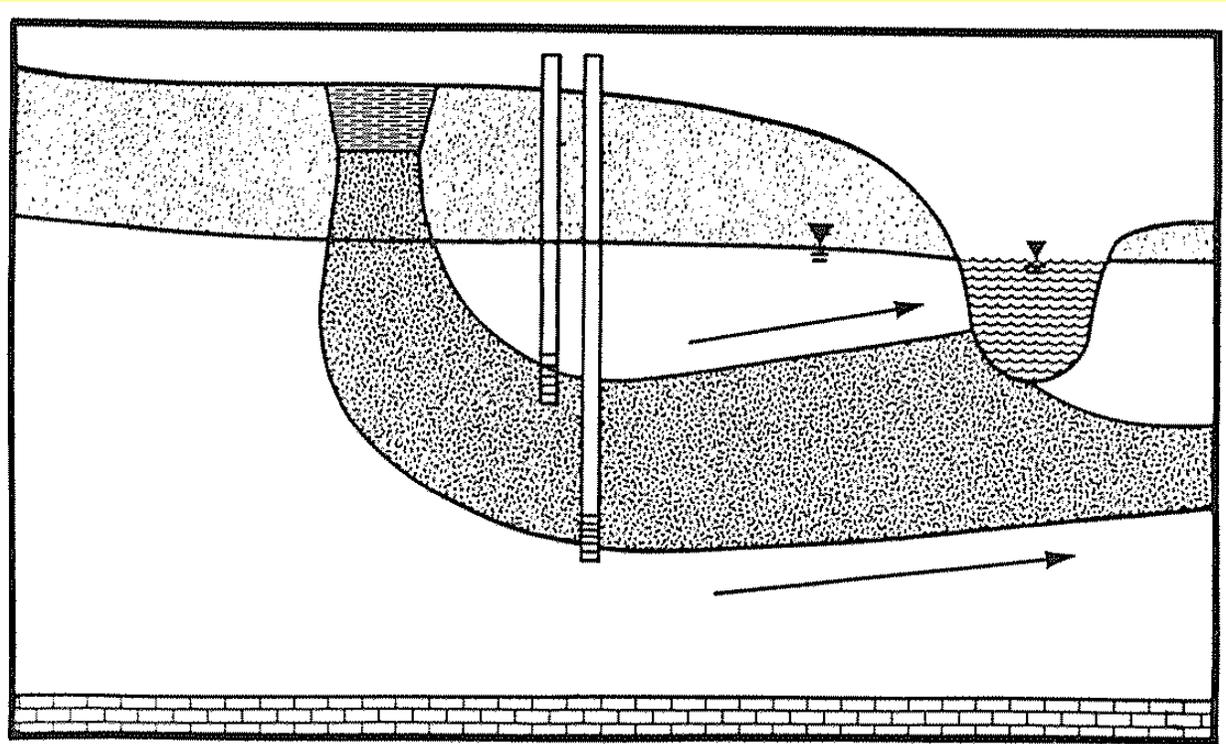


A GUIDE TO GROUNDWATER SAMPLING AND MONITORING

Idaho Department of Health and Welfare
Division of Environment
Boise, ID 83720



February 1987

WATER QUALITY REPORT NO. 69

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A GUIDE TO GROUNDWATER MONITORING AND SAMPLING

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ABSTRACT

This report presents a general set of guidelines for groundwater monitoring and sampling. Every monitoring and sampling plan should be unique and specific for the hydrogeologic setting and chemical constituents being measured. Monitoring at EPA-RCRA and CERCLA (Superfund) sites requires rigorous scrutiny and intensive site characterization, modeling, and state-of-the-art sampling techniques. Where highly reactive or volatile constituents are expected, teflon or stainless steel screen, hose, and pump materials must be used. Other situations may allow less expensive PVC materials to be utilized. Non-contaminating drilling methods such as air rotary, and good grouting and screen packing are essential to ensure that a truly representative groundwater sample is obtained.

Siting of monitoring wells is largely dependent on whether the groundwater is moving through porous materials such as sand and gravel or fractured rock such as granite or limestone. In porous media, contaminant plumes spread out more uniformly allow monitoring wells to be sited equally-distanced downgradient of the waste management unit. A 150 ft. well spacing can be used as a general "rule of thumb" until more site-specific data dictates otherwise. In fractured rock, groundwater moves primarily along discrete, linear pathways so wells should be drilled to intersect them. Locating fractures prior to drilling requires geophysical and remote sensing surveys.

Sampling for groundwater requires using a bailing or pumping method that causes minimal water disturbance so as to prevent loss of dissolved contaminants due to volatilization or precipitation. Sampling materials should be made of teflon or stainless steel when sensitive contaminants of low concentration are being measured. Sampling equipment should be thoroughly cleaned before use, and the well should have at least three well volumes pumped (or to evacuation) before sampling. All samples must be properly preserved and packed, and a record kept of their handling. A certified lab with verified quality assurance/quality control measures should always be used to ensure accuracy of the results.

Choosing existing domestic and irrigation wells for monitoring is cost-effective but can produce false results when sampling for volatiles. It is important to obtain the drillers' well logs before sampling to determine which aquifer(s) are penetrated. Also, an existing or newly created water table map must be utilized prior to sampling to determine the likely direction and orientation of the contaminant plume. It is

imperative that water levels be measured at the time of sampling. All wells should have three well volumes removed prior to sampling and the standard sampling protocol used.

A GUIDE TO GROUNDWATER MONITORING AND SAMPLING

INTRODUCTION

Groundwater is a major source of drinking water in the United States. Idaho is the fourth largest user of groundwater, and nine out of ten Idaho residents rely on this resource for their drinking water. Unfortunately, the disposal of contaminants in the ground was poorly regulated and enforced until recent years. As a result, an ever-increasing amount of groundwater contamination has been discovered. Initially, the thrust of the Environmental Protection Agency (EPA) and Idaho was towards cleaning our nation's surface waters by eliminating or significantly treating wastewater discharges. As a result, many industries and municipalities changed to land application of wastes or evaporation pond methods of waste disposal. Leakage of contaminants to the groundwater from such facilities added to the deterioration of the nation's groundwaters. Hazardous materials were indiscriminately buried in drums or released into subsurface drainfields. Municipal landfills were sited without regard to the underlying groundwater, and often were left uncovered, causing the production of leachate. Leaky underground storage tanks were unregulated and unmonitored. Monitoring for groundwater contamination was essentially unheard of.

With public awareness of groundwater contamination, came the passage of the Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 1980). These laws give EPA and states strong control over the protection and clean up of our nation's aquifers. Now there are significant civil and criminal penalties for individuals and companies that have caused groundwater contamination.

Costs for aquifer clean ups and law suits associated with adverse health effects caused by drinking contaminated water often run into the millions of dollars. As a result, it has finally become more cost-effective to prevent groundwater contamination and to construct groundwater monitoring systems around possible pollution sources. The science of hydrogeology associated with monitoring groundwater quality is relatively new and is rapidly evolving. Since the hydrogeology of the earth is highly variable and complicated, it is impossible to design a monitoring scheme that will fit all sites. Thus, the purpose of this document is to provide a general set of guidelines for developing and implementing a groundwater quality monitoring system and to present a generalized sampling protocol. This document is intended to be introductory in scope and is not intended

to replace more exhaustive reports on the subjects. The most recent and perhaps most detailed compilation of hydrogeologic considerations in siting monitoring systems is entitled RCRA Ground-water Monitoring Technical Enforcement Guidance Document (TEGD, EPA (1985)). Many of the thoughts and figures expressed in the following pages are from this manual. Four other important EPA monitoring publications are: 1) Monitoring Groundwater Quality: Monitoring Methodology by Todd et al. (1976); 2) Monitoring Groundwater Quality: Methods and Costs by Everett et al. (1976); 3) Monitoring Disposal - Well Systems by Warner (1975); and 4) Procedures Manual for Ground Water Monitoring Well Construction and Ground Water Sampling by Miller et al. (1983).

The National Water Well Association in Dublin, Ohio is the nation's largest organization of groundwater scientists. They have a large list of educational books, slide shows, videos and movies about numerous aspects of hydrology and the water well industry. They also publish three important journals that cover the more detailed aspects of hydrogeology and monitoring of groundwater. These are: 1) "Groundwater Monitoring Review;" 2) "Groundwater;" and 3) the "Water Well Journal." The NWWA also offers a referral system to aid in answering individual questions. Finally, two short summaries of groundwater monitoring methodologies include: 1) Groundwater Quality Monitoring Well Construction and Placement, (National Council of the Paper Industry for Air and Stream Improvement, 1981); and 2) Hydrogeologic Study Handbook (Michigan Department of Natural Resources, 1982).

REGULATORY CONSIDERATIONS

Widespread use of groundwater monitoring for both nonhazardous and hazardous waste disposal and storage facilities is encouraged at the state and national level due to increased public concern over groundwater contamination. In general, monitoring requirements are less stringent for the disposal of nonhazardous waste. For more detailed information on groundwater sampling techniques than is presented here, the reader is referred to the following publications: 1) Practical Guide for Groundwater Sampling by Barcelona et al. (1985); 2) Manual of Groundwater Sampling Procedures by Scalf et al. (1981); 3) A Guide to Groundwater Sampling by Unwin (1983); and 4) RCRA Groundwater Monitoring Technical Enforcement Guidance Document (EPA, 1985).

Monitoring of groundwater has been divided into three types by EPA under RCRA for facilities treating, storing or disposing of hazardous substances.

These are Detection Monitoring, Assessment Monitoring and Compliance Monitoring. A detection monitoring system is "implemented at facilities where no hazardous constituents are known to have migrated from the facility to groundwater. The objective of detection monitoring is to determine whether a facility has leaked hazardous waste into an underlying aquifer in quantities sufficient to cause a significant change in groundwater quality" (EPA, 1985). To accomplish this objective, EPA recommends a minimum of one well upgradient from the facility and three downgradient. Often times, the water table has not been mapped in sufficient detail to determine which direction the groundwater is moving beneath a site. In such cases, it is essential that small diameter piezometers are placed around the facility and accurate water level elevations are determined. Since there is usually small change in depth to the water table within the boundaries of a facility, it is important that well top elevations are accurately surveyed so the direction of groundwater flow can be determined.

To determine whether leakage has occurred, well water quality data is compared between the upgradient well(s) and the downgradient well(s). Statistically significant differences in the water quality data are determined by the Student's t-test. Four gross indicators of groundwater contamination are commonly used. These are pH, specific conductance, total organic carbon (TOC), and total organic halogen (TOX). If a facility is utilizing just a few specific compounds, it would be wise to monitor for them as well. Fecal coliform, nitrate, and chloride are common indicators of animal and human waste, for example. Leachate from a landfill will likely have high levels of heavy metals such as barium, chromium, lead and cadmium. Land application of organic waste from food processing may cause such metals as iron and manganese to become mobile and enter the groundwater. Thus, these metals should be monitored in wells around such disposal areas.

If a statistically significant change is detected, the facility should move into groundwater assessment monitoring. In groundwater assessment monitoring, the concentration, rate, and extent of contaminant migration must be determined. This usually requires additional monitoring wells and detailed analyses of samples for all possible contaminants. For RCRA sites, this requires monitoring of a wide suite of chemical parameters known as the Appendix VIII list. Once the extent of groundwater contamination is assessed, a corrective action program is initiated to clean up the aquifer to an acceptable level. Compliance monitoring then continues to ensure that leakage of hazardous constituents into the groundwater does not exceed these acceptable levels (EPA, 1985).

THE TYPICAL MONITORING WELL

A well constructed for the purpose of monitoring water quality must be made of materials durable enough to resist chemical and physical degradation, but these materials must not interfere with the quality of groundwater samples. Also, the well must be properly screened in regard to slot size and sand (filter) pack and be sealed well with cement and/or bentonite. Not all drillers have experience installing monitoring wells, so a driller must be chosen wisely.

Well Casings and Well Screens

The most commonly used construction materials for casings and screens in order of increasing cost are PVC, stainless steel, and teflon. In choosing the best material, tradeoffs must be made between durability, reactivity and cost. For example, steel casing deteriorates in corrosive environments and PVC deteriorates when in contact with ketones, esters, and aromatic hydrocarbons. Also, steel and PVC may absorb and leach chemicals which will affect the accuracy of the results (EPA, 1985). Teflon is the most inert of the three casing and screen materials, but it may lack durability. Teflon can deform under its own weight in deeper holes. Therefore, when teflon is used, the casing should be suspended from the well top. A comparison among PVC, polypropylene, teflon, kynar, mild steel, and stainless steel is presented in Table 1 (Johnson Division, 1986).

Figure 1 shows typical construction techniques for monitoring wells. To save costs, the upper casing above the water table is commonly constructed of Schedule 80 PVC. Casing lengths must be threaded together since PVC glue can add organic contaminants to the water sample. The well screen should be composed of Schedule 80 teflon or stainless steel 316 and should extend about five feet above the water table to accommodate for higher water table conditions. If water level fluctuations are known from a nearby observation well, this length can be adjusted more precisely. The bottom of the well should be capped and extend only a short distance into the underlying aquitard. It is important that the screened interval does not extend far below the aquifer since this water cannot be removed during well purging. This "dead water" in the lower screened zone will change the water chemistry as the well fills prior to sampling. Also, a single well screen should not cross two aquifers, otherwise the resultant sample will be a composite, and not representative of the upper most zone of saturation which probably will contain the highest concentration of contaminants. This also will increase the chances of cross contamination of the aquifers if the intervening seal is installed improperly or deteriorates with time. If the aquifer is thick

Table 1. Advantages and disadvantages of well casing and screen material
(Johnsons Y.O.P., 1984).

TYPE	ADVANTAGES	DISADVANTAGES
A. PVC (Polyvinylchloride)	<ul style="list-style-type: none"> *Lightweight *Excellent chemical resistance to weak alkalines, alcohols, aliphatic hydrocarbons, and oils *Good chemical resistance to strong mineral acids, concentrated oxidizing acids, and strong alkalies *Readily available *Low priced¹ <ul style="list-style-type: none"> --\$1.50 per ft. for 2-inch diameter schedule 40 pipe, plain square ends --\$1.75 per ft. for 2-inch diameter schedule 80 pipe, plain square ends --\$3.50 per ft. for 2-inch diameter schedule 40 slotted pipe, plain square ends --\$3.85 per ft. for 2-inch diameter schedule 80 slotted pipe, plain square ends --\$14.50 per ft. for 2-inch diameter wire-wound continuous slot screen 	<ul style="list-style-type: none"> *Weaker, less rigid, and more temperature sensitive than metallic materials *May adsorb some constituents from groundwater *May react with and leach some constituents into groundwater *Poor chemical resistance to ketones, esters, and aromatic hydrocarbons
B. Polypropylene	<ul style="list-style-type: none"> *Lightweight *Excellent chemical resistance to mineral acids *Good to excellent chemical resistance to alkalis, alcohols, ketones and esters *Good chemical resistance to oils *Fair chemical resistance to concentrated oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons *Low priced¹ <ul style="list-style-type: none"> --\$2.00 per ft. for 2-inch diameter scheduled 40 pipe, plain square ends --\$2.30 per ft. for 2-inch diameter scheduled 80 pipe, plain square ends 	<ul style="list-style-type: none"> *Weaker, less rigid, and more temperature sensitive than metallic materials *May react with and leach some constituents into groundwater *Poor machinability - it cannot be slotted because it melts rather than cuts

C.	Teflon (Teflon is a registered trademark of DuPont, Inc.)	<ul style="list-style-type: none"> *Lightweight *High impact strength *Outstanding resistance to chemical attack; insoluble in all organics except a few exotic fluorinated solvents 	<ul style="list-style-type: none"> *Tensile strength and wear resistance low in comparison to other engineering plastics *Expensive ¹ --\$26.00 per ft. for 2-inch diameter schedule 40 pipe, flush threaded joint --\$32.00 per ft. for 2-inch diameter schedule 40 slotted pipe, flush threaded joint
D.	Kynar	<ul style="list-style-type: none"> *Greater strength and water resistance than Teflon *Resistant to most chemicals and solvents *Lower priced than Teflon ¹ --\$13.95 per ft. for 2-inch diameter schedule 40 pipe, plain square ends --\$18.70 per ft. for 2-inch diameter schedule 80 pipe, plain square ends 	<ul style="list-style-type: none"> *Not readily available *Poor chemical resistance to ketones, acetone
E.	Mild Steel	<ul style="list-style-type: none"> *Strong, rigid, temperature sensitivity not a problem *Readily available *Low price ¹ --\$2.50 per ft. for 2-inch diameter schedule 40 pipe, plain square ends --\$17.75 per ft. for 2-inch diameter wire-wound continuous-slot screen 	<ul style="list-style-type: none"> *Heavier than the plastics *May react with and leach some constituents into groundwater
F.	Stainless Steel	<ul style="list-style-type: none"> *High strength at an exceedingly great range of temperatures *Excellent resistance to corrosion and oxidation *Readily available *Moderate price ¹ --\$6.00 per ft. for 2-inch diameter special monitoring pipe --\$30.00 per ft. for 2-inch diameter wire-wound continuous-slot screen 	<ul style="list-style-type: none"> *Heavier than plastics *May corrode and leach some chromium in very acidic waters *May act as a catalyst in some organic reactions

¹All prices are list prices as of 1984 and may vary somewhat depending on manufacturer

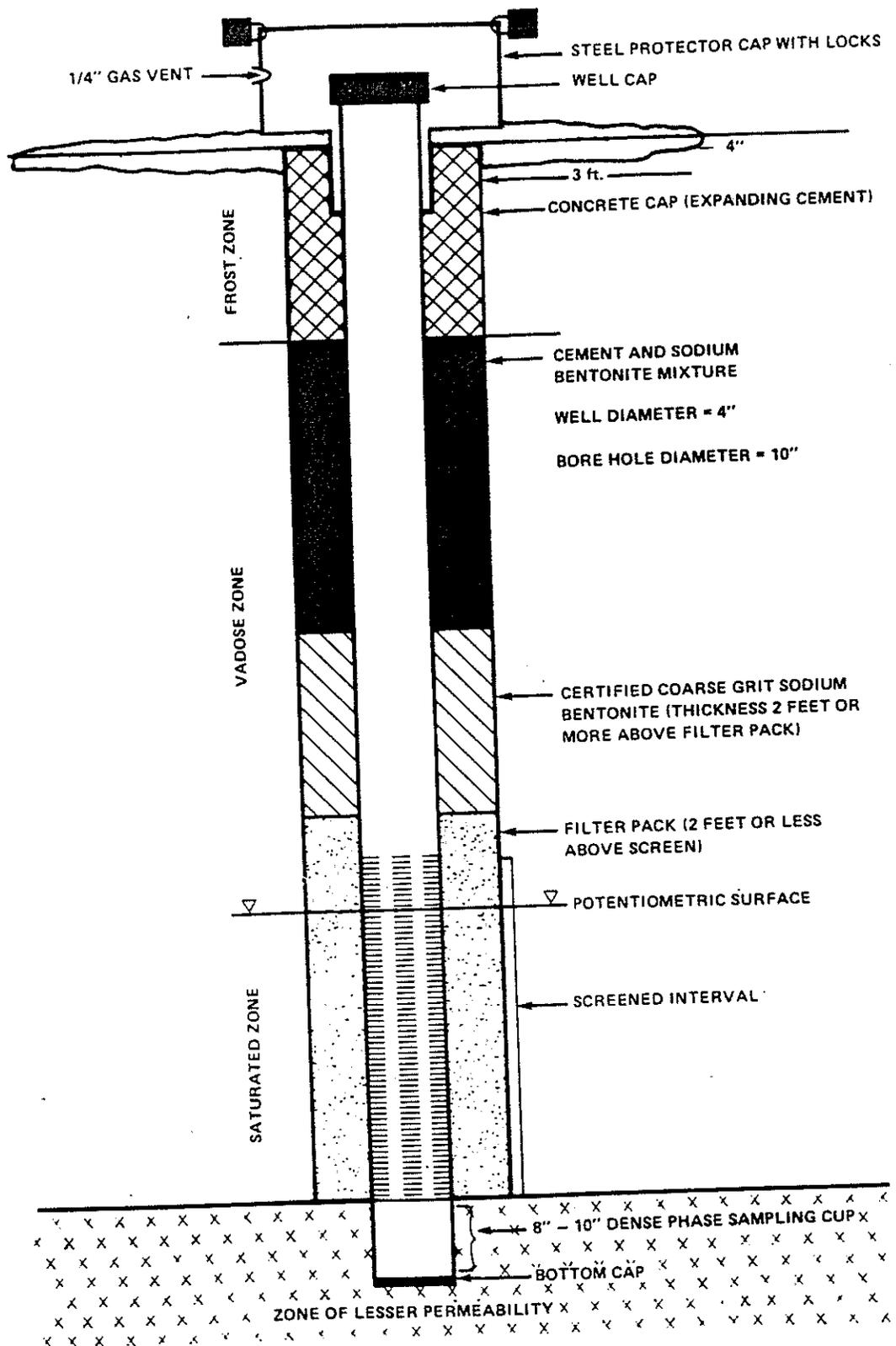


Figure 1. General monitoring well construction (EPA-TEGD, 1985)

or composed of several producing horizons, well clusters can be used (Figure 2). In some cases, multiple screens can be installed in one well and packers used during sampling to insure that samples are obtained from only one producing horizon at a time. An advantage of having well clusters is the ability to determine the vertical component of groundwater flow (Figure 3). This is important in better understanding the direction of contaminant migration and the likelihood of leakage to the underlying aquifer.

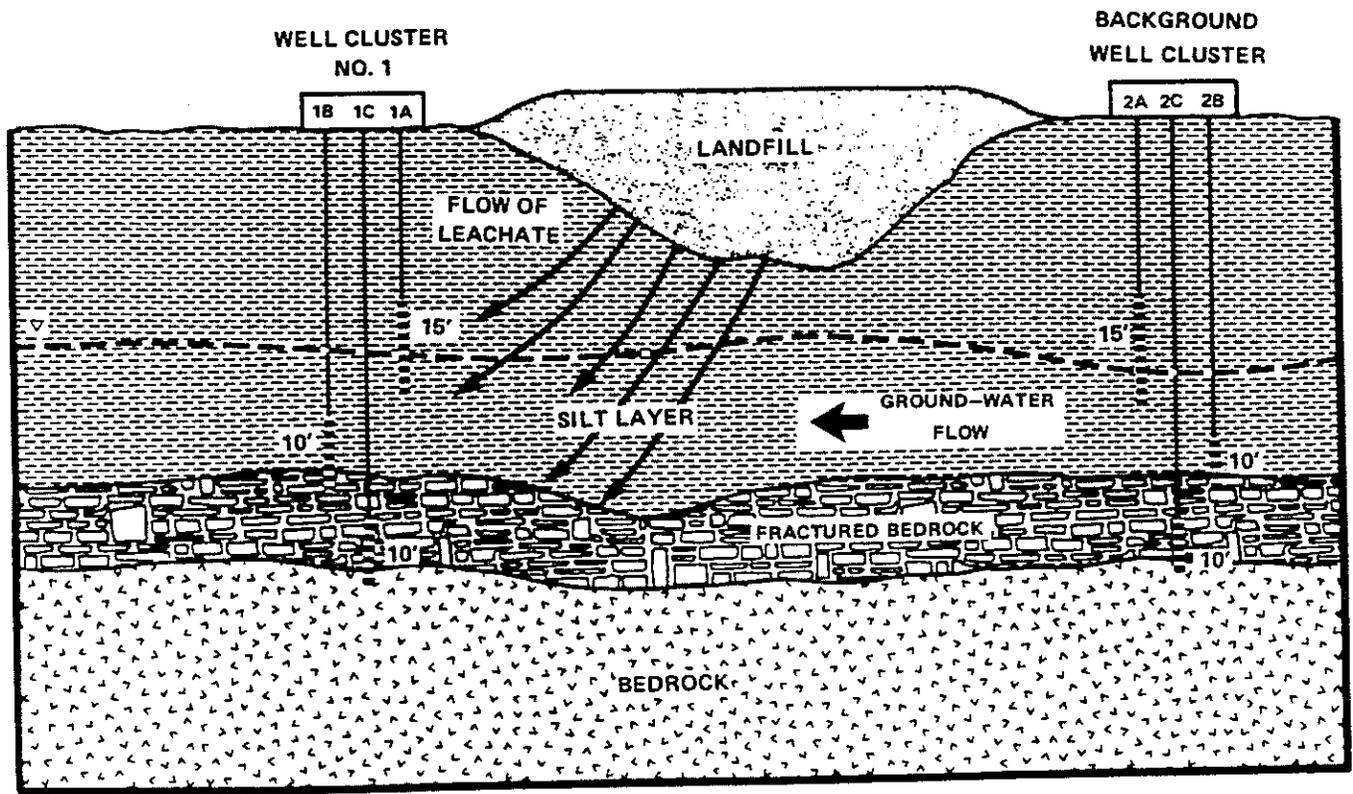
Well Screen Packing/Screen Slot Size/Grouting

A well-screen sand or gravel pack is recommended for wells in unconsolidated material. A sieve analysis of the aquifer material should be performed to determine the optimum filter pack size. Improper filter pack size may cause well turbulence and cascading that will cause a loss of volatile organic compounds. Besides loss of volatiles, improper matching of filter pack, aquifer material, and slot size will cause turbidity of the sample which interferes with chemical analyzes. Once the proper filter pack is matched, a 0.02 inch slot size is the most common, but 0.01 inch is sometimes used for fine silt-size aquifer. Monitor wells placed in bedrock generally do not need a filter pack and may not need to be screened.

Monitor wells are usually 2" or 4" in diameter, but must be drilled wider (commonly to 10") to enable the emplacement of the cement and/or bentonite grout. To ensure that space exists everywhere between the casing and borehole prior to grouting, centralizers must be placed around the casing. Centralizers have been used for many years by the oil industry to guarantee a continuous grout seal. A coarse grit sodium bentonite seal of at least 2 ft. thickness should be placed above the filter pack. A cement/bentonite pressure grout should be placed above this to the bottom of the frost zone. A concrete, expanding cement cap should be injected to the surface and cement placed around the well top to ensure that surface contaminants do not leak into the aquifer. A vented well cap should be placed on top, and this covered by a steel locking protective cap. Well caps should then be numbered or color-coded. The advantages and disadvantages of various grouting materials are presented in Table 2 (Johnson Division, 1986).

Developing Monitor Wells/Pumping (Aquifer) Tests

Prior to the use of a well for water quality monitoring, well development is needed to ensure the collection of a representative sample. Well development is performed by simply using the bailer or drill stem as a



LEGEND	
! (vertical dashed line)	WELL AND SCREEN
10' (horizontal line with arrow)	SCREEN LENGTH
▽ (inverted triangle)	WATER TABLE

Figure 2. Well placement in different hydraulically connected aquifers (EPA-TEGD, 1985)

Figure 3. Well placement based on downward and upward gradients of flows (EPA-TEGD, 1985)

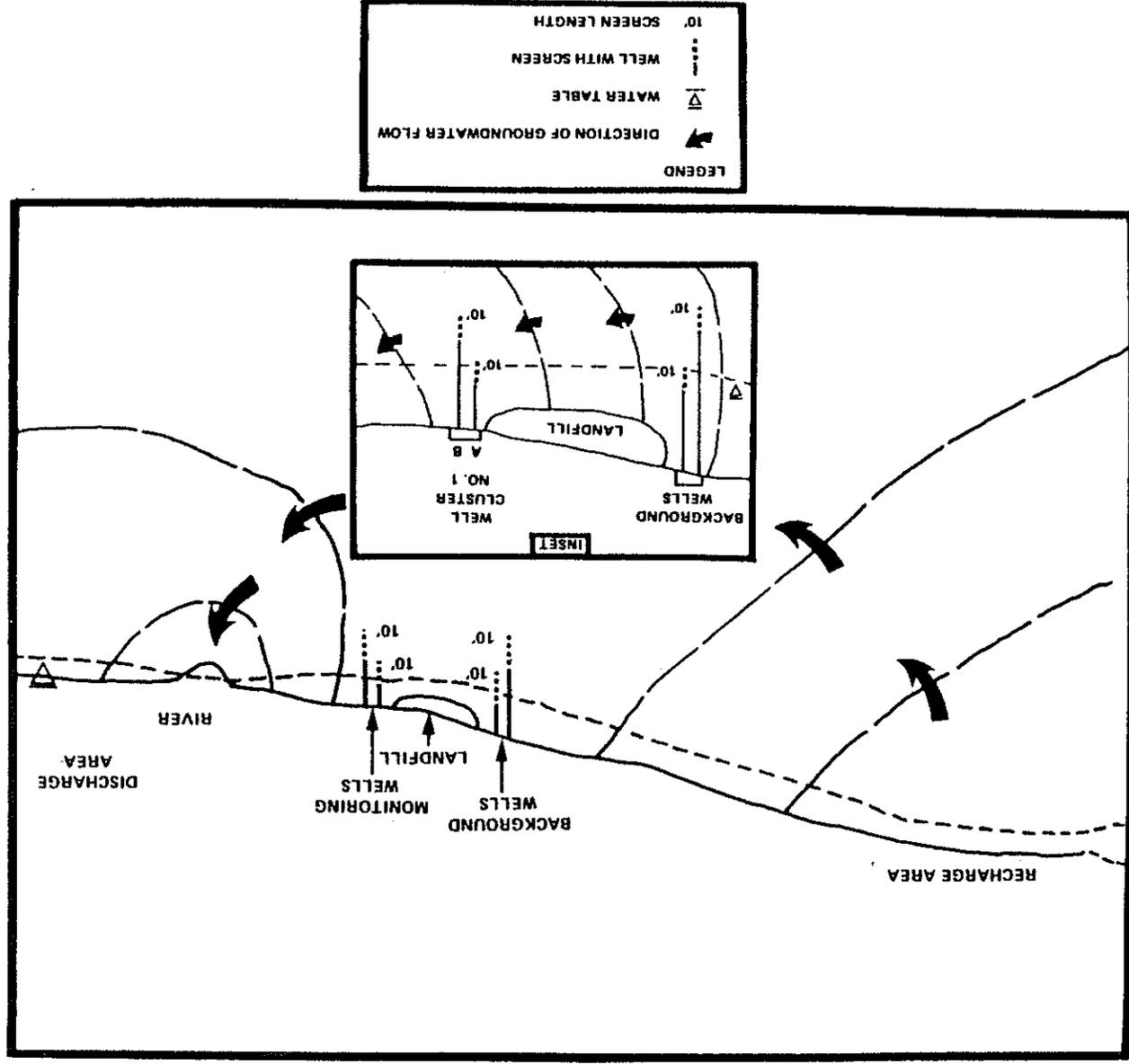


Table 2. Advantages and disadvantages of grouting materials for monitoring wells
(Johnsons VOP, Inc., 1984)

TYPE	ADVANTAGES	DISADVANTAGES
A. Bentonite	<ul style="list-style-type: none"> *Readily available *Inexpensive (about \$6 per 50 lb.) 	<ul style="list-style-type: none"> *May cause constituent interference due to ionic exchange *May not give complete seal --There is a limit to the amount of solids that can be pumped in a slurry (can't pump when percent of solids exceeds about 14%), so there are very little solids in the seal; theoretically should wait for liquid to bleed off so solids will settle --Pellets may bridge; they may wet and swell before reaching destination, sticking to formation or casing. --Cannot determine how effectively material has been placed --Cannot assure complete bond to casing
B. Cement	<ul style="list-style-type: none"> *Readily available *Inexpensive (about \$6 per 100 lb.) *Can use sand and/or gravel filter *Possible to determine how well cement has been placed by means of geothermal logs or sonic bond logs 	<ul style="list-style-type: none"> *May cause constituent interference *Mixer, pump, and tremie line are required; generally more cleanup therefore than with bentonite *May be problems getting the material to set up *Shrinks when it does set - complete bond to formation and casing not assured
C. Polymers	<ul style="list-style-type: none"> *Very good formation penetration and bonding *Very low permeability 	<ul style="list-style-type: none"> *May cause constituent interference *Hold a very high percentage of water (92-95%) *Very flexible and pliable below the water table, but will dry out above the water table *No assurance of complete bonding to casing *Very expensive

plunger to remove the clay size material and properly arrange the filter pack. Well development to remove fines can also be accomplished by a step-drawdown test. In such a test, pumping is initiated at a low discharge until the water clears. Well discharge is then increased to a higher level or step, and pumping continued until the water once again clears. This is usually continued for up to four or more pumping or step levels. If drawdown measurements are taken simultaneously, it is possible to calculate the specific capacity (gpd/ft) of the well and coefficient of transmissibility of the aquifer. With this information, it is then possible to determine the optimum pumping rate prior to sampling to ensure a representative groundwater sample. In general, it is recommended that at least three well volumes be removed prior to sampling or the well is evacuated to dryness.

Specialized Well Design for Immiscible Liquids

In certain cases, the liquid contaminant may not dissolve significantly in water and will either float on the top of the water table or sink to the bottom of the aquifer. Figures 4 and 5 show monitor well cross-sections for sampling light phase and dense phase immiscible layers, respectively. For light phase immiscible layers, both the outer casing and subcasing should be screened where floaters are expected. "The subcasing should extend to within a couple of inches of the bottom of the dense phase sampling cap to permit bailer sampling of the denser phase immiscible layer." (EPA, 1985). An alternative to this is to design a cluster of wells of various depths and depth to screening.

Documentation of Well Design and Construction

It is very important that all aspects of the monitor well drilling program, including well design and construction, be accurately documented. This could save the facility much time and expense, particularly if a later enforcement action is taken by a state or federal environmental agency. Also, remember that a water analysis is only as good as the well design and construction and the sampling procedures used. Costs for taking and analyzing a single sample for the Appendix VIII pollutants can cost over \$2000. A monitor well can cost anywhere between \$1000 to \$20,000. Therefore, it is important to do things right the first time!

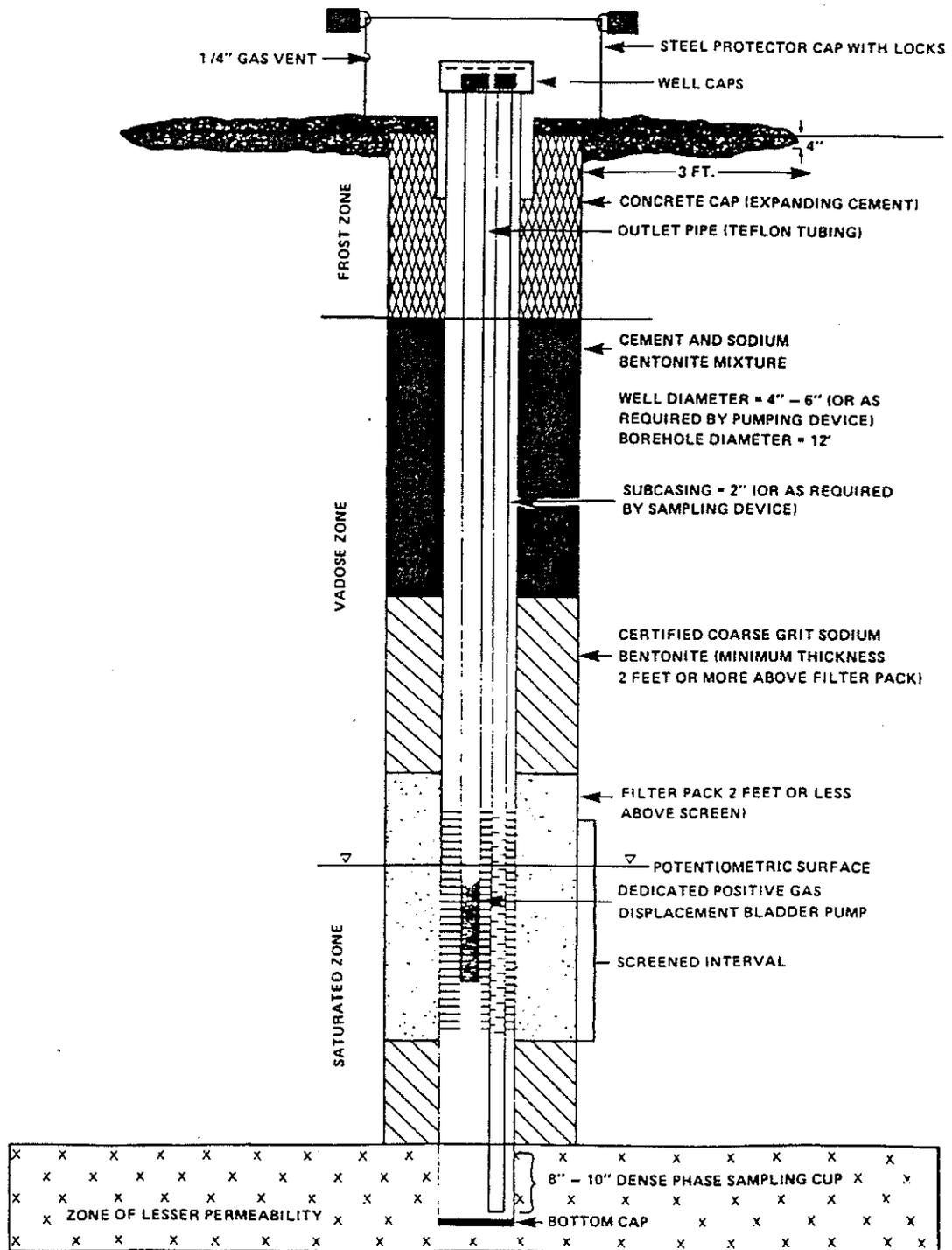


Figure 4. Monitoring well cross-section designed for sampling of light phase immiscible layers (EPA-TEGD, 1985)

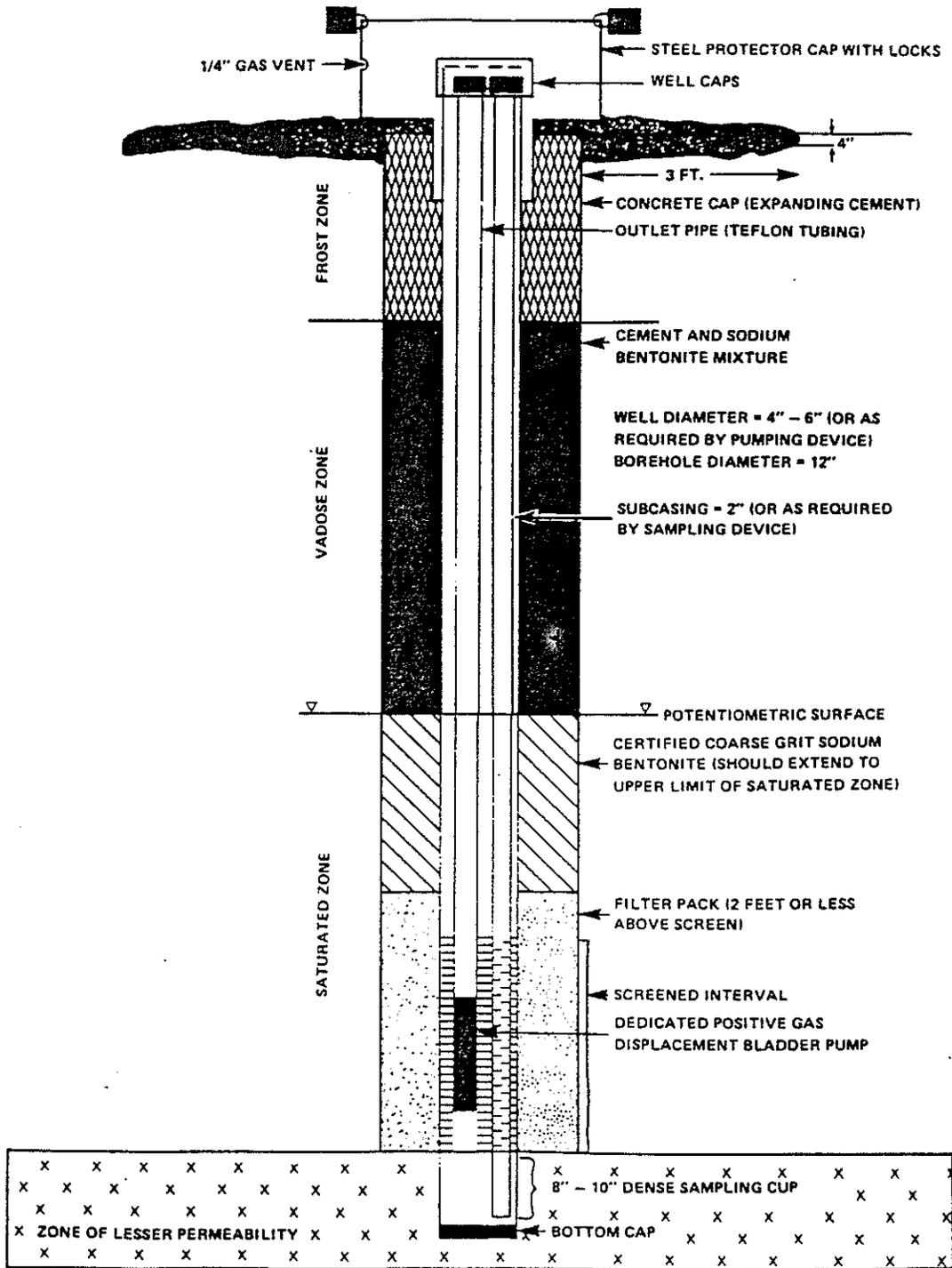


Figure 5. Monitoring well cross-section designed for sampling of dense phase immiscible layers (EPA-TEGD, 1985)

HYDROGEOLOGIC CONSIDERATIONS IN PLACEMENT OF MONITORING WELLS

Introduction

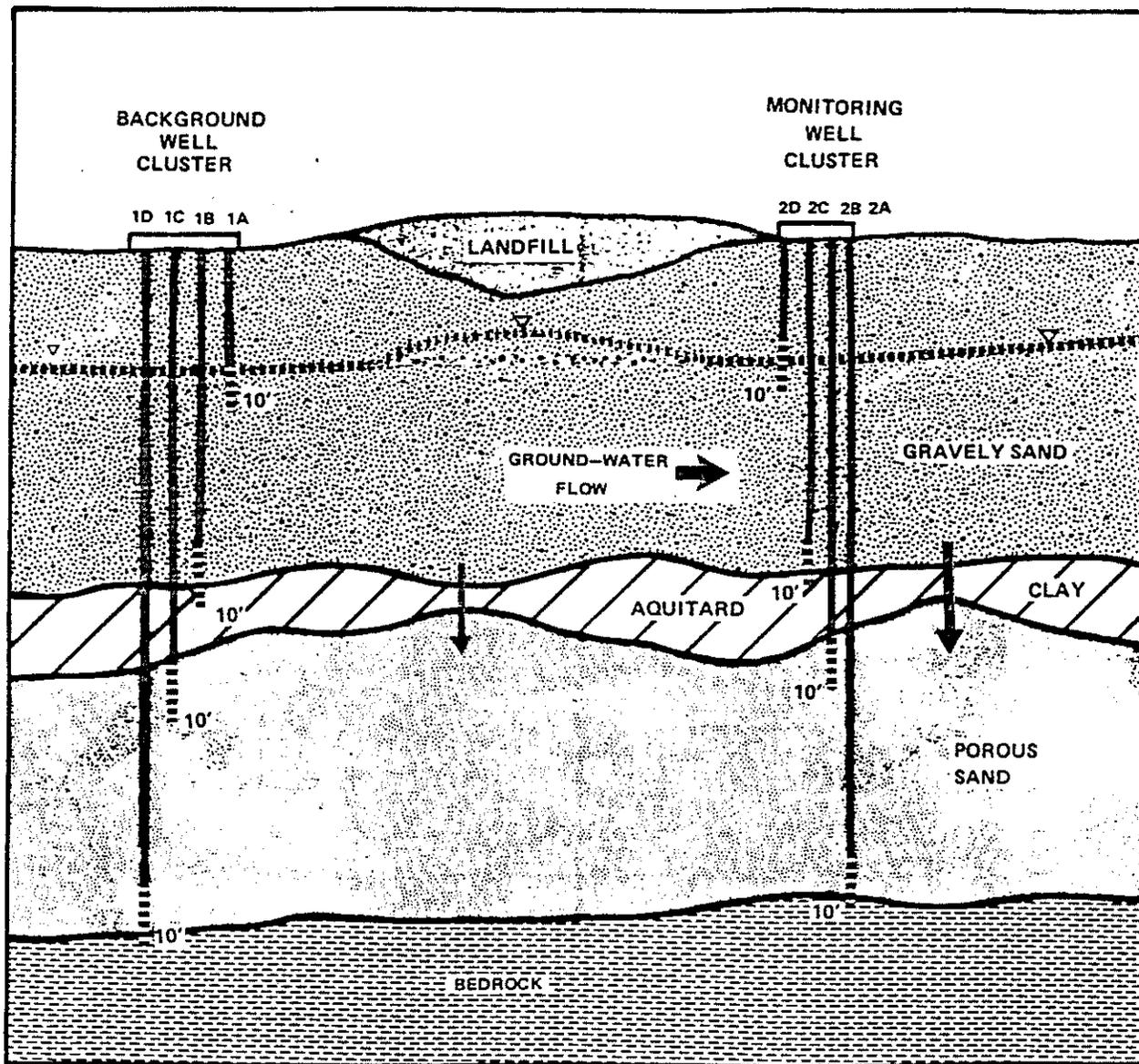
Designing a monitoring system is dependent on a large array of interacting factors. The depth to water, net recharge, aquifer material, soil characteristics, topography, thickness and lithology of the vadose zone, and hydraulic conductivity (permeability) of the aquifer are all important in determining pollution potential of an aquifer and the spacing and depth of monitoring wells (Aller et al., 1985). As previously mentioned, RCRA rules dictate that a minimum of one upgradient and three downgradient monitoring wells are installed around a hazardous waste management unit. Although non-hazardous waste disposal sites such as landfills and land waste application sites are not held to such requirements, the hydrogeology is commonly too complex to guarantee that a migrating contaminant will be found in even these few wells. RCRA also suggests a minimum spacing of downgradient wells of 150 feet. Therefore, the purpose of the rest of this next section is to demonstrate different hydrogeologic situations that affect the placement and spacing of monitoring wells.

Upgradient Wells

Upgradient wells are utilized as a means of comparing background aquifer quality to that of the downgradient wells. Gradient direction is first established by drilling small diameter piezometers and accurately measuring water table elevations. Once the direction is known, upgradient wells should be placed beyond the upgradient extent of contamination and beyond the influence of water table mounding. Figure 6 demonstrates how a mound may form beneath a leaky waste disposal site.

Downgradient Wells

A common misconception among people untrained in hydrogeology is that soil and rock layers are flat and continuous beneath the earth, and that formations are everywhere uniform in regard to water bearing properties (i.e., homogeneous and isotropic). This is rarely the case. Therefore, a detailed geologic investigation of a site must be made before monitoring wells are drilled. Figure 7 is an example of hydraulic interconnection between water-bearing units. With just the information provided from the three wells, it might incorrectly be assumed that the clay unit is continuous, separating a water table aquifer from an artesian aquifer. Since the clay is not continuous, groundwater must be monitored both above and below the impermeable clay. Figure 8 shows an example of clay



LEGEND	
! ! !	WELL AND SCREEN
10'	SCREEN LENGTH
-----▽-----	WATER TABLE

Figure 6. Monitoring wells placed in two different aquifers separated by a leaky confining aquitard. A groundwater mound has formed beneath the landfill (EPA-TEGD, 1985)

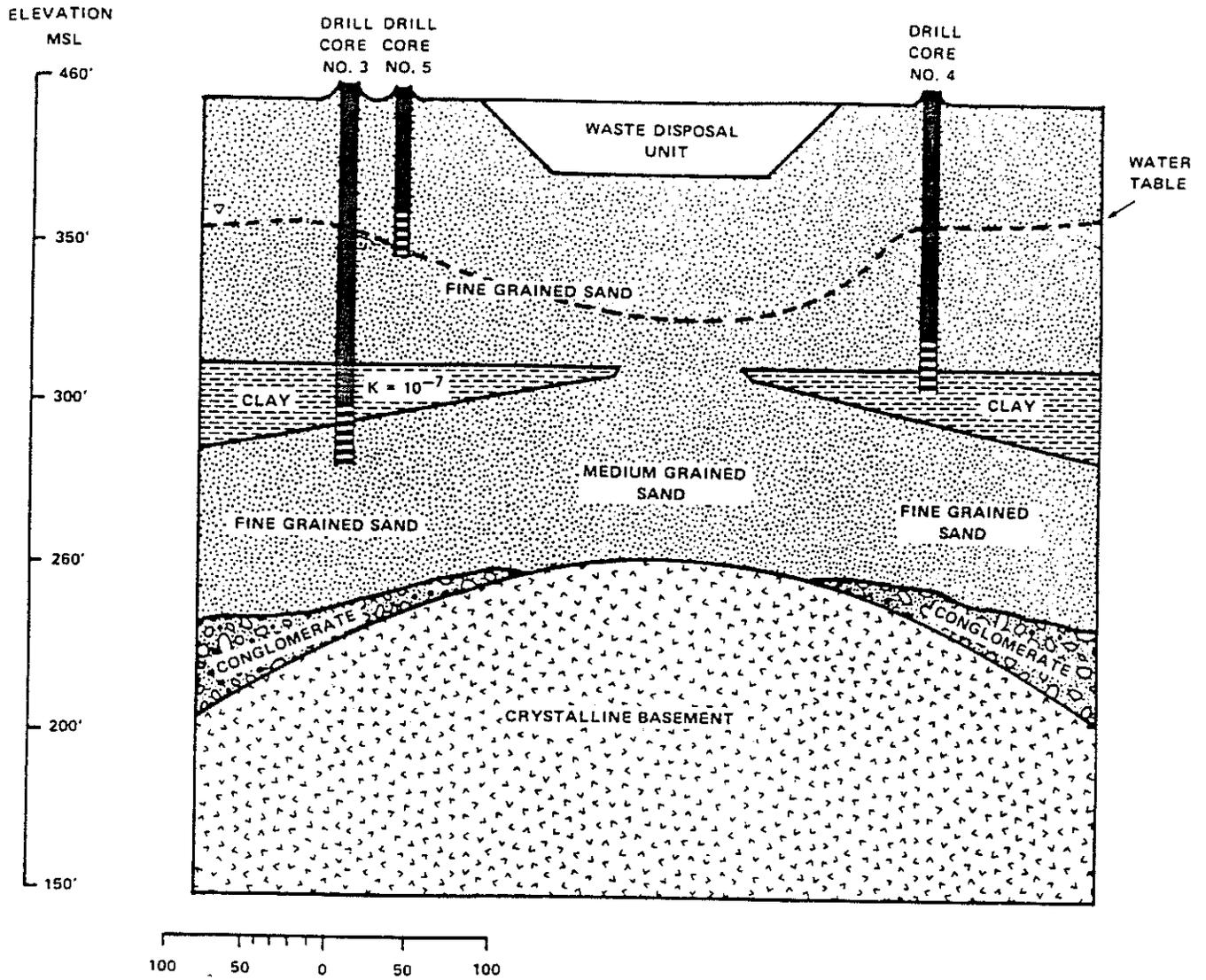


Figure 7. Example of hydraulic interconnection between water-bearing units (EPA-TEGD, 1985)

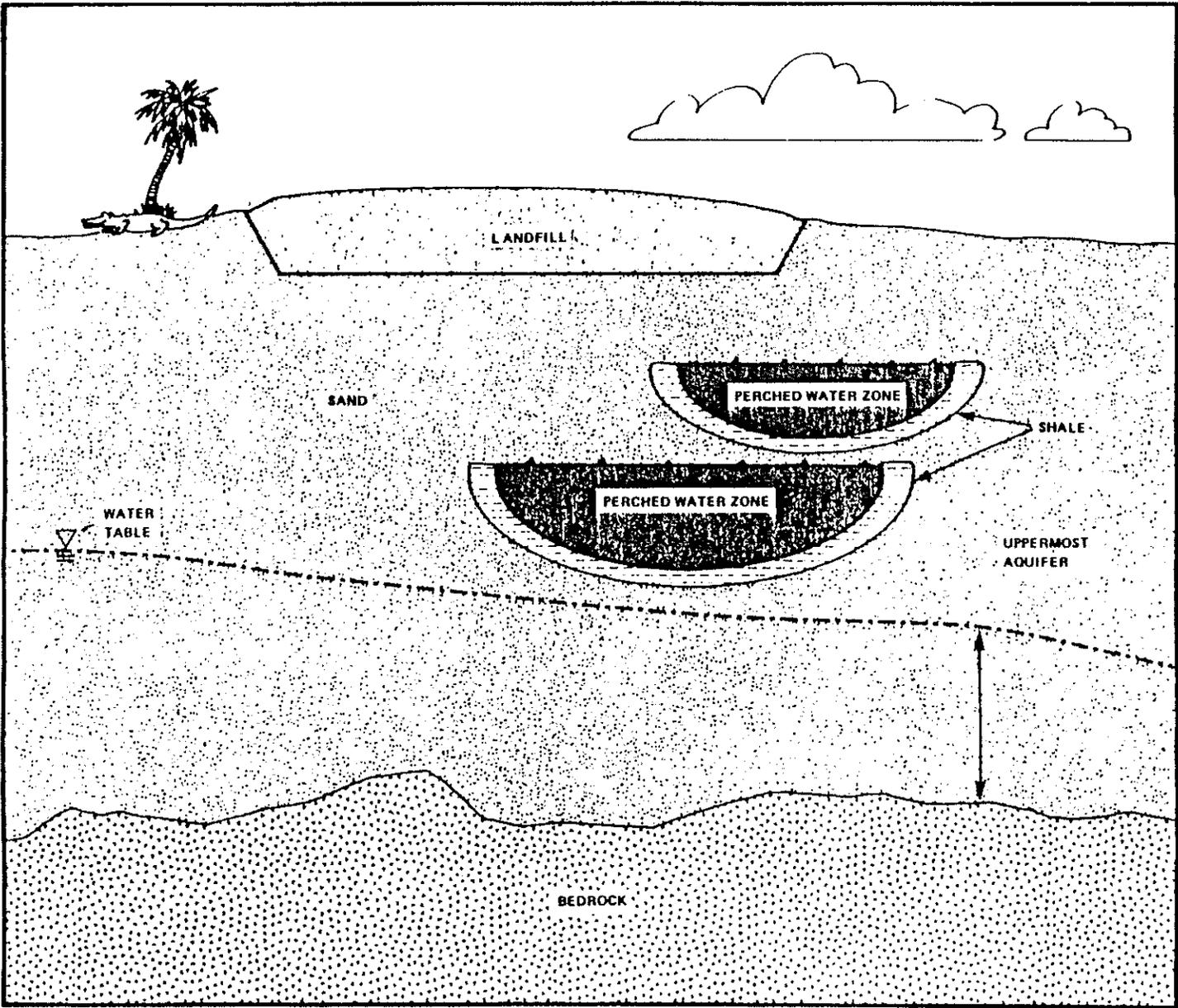


Figure 8. Perched water zones over an underlying continuous water table (EPA-TEGD, 1985)

lenses perching water locally above the true water table. This is a common situation in river alluvium deposits. Figure 9 demonstrates how fracturing in a dense limestone aquitard can cause hydraulic interconnection between an upper unconfined aquifer in unconsolidated gravelly silt and a deeper sandstone rock aquifer. In this example, monitor wells should be placed both in the upper and lower aquifer as well as along the fracture zones in the limestone. Fractures can often be located using lineament analysis on aerial photographs and electrical resistivity geophysical techniques (Ogden and Eddy, 1984). Straight lines on aerial photographs are often topographic or tonal expressions of underlying fractures. In some cases, the clay formation below the upper zone of saturation is only semi-permeable (Figure 6). If the hydrostatic pressure of the upper aquifer is greater than the underlying aquifer, contaminants may leak through. This is particularly likely if the clay is thin or if a nearby well field producing from the lower aquifer causes further reduction of the pressure with time.

Figure 10 shows how two initial borings suggests that a continuous, horizontal sandstone of low permeability occurs beneath an overlying unconfined sandy unit. In reality, there is a buried anticlinal structure beneath the unconsolidated sand, and the aquifer is in hydraulic continuity with the underlying, folded and permeable dolomite. An adequate monitoring system would demand monitoring wells be located along the crest of the anticline and others downdip on both limbs of the structure. Finally, Figure 11 shows an example of lateral changes in permeability. Such examples are relatively common near present and ancient coastal areas. In the example shown in this figure, the two monitor wells do not indicate the existence of the permeable sandstone which is in hydraulic continuity with the water in the overlying sandy gravel. To properly monitor this system, deeper wells should also be drilled into the sandstone.

Spacing of Monitoring Wells

The spacing and number of monitoring wells is largely a function of the geology, and to some extent the nature of the waste. For hazardous waste, it is paramount that waste constituents be detected immediately upon moving from the waste management unit. It must be assumed that all liners, both of natural and synthetic material, will leak in time. The purpose of the monitoring system is to ensure rapid detection so the problem can be remedied before substantial aquifer damage has occurred. To this end, EPA recommends a minimum spacing for downgradient wells of 150 ft. at hazardous waste disposal sites. Well spacing can be greater

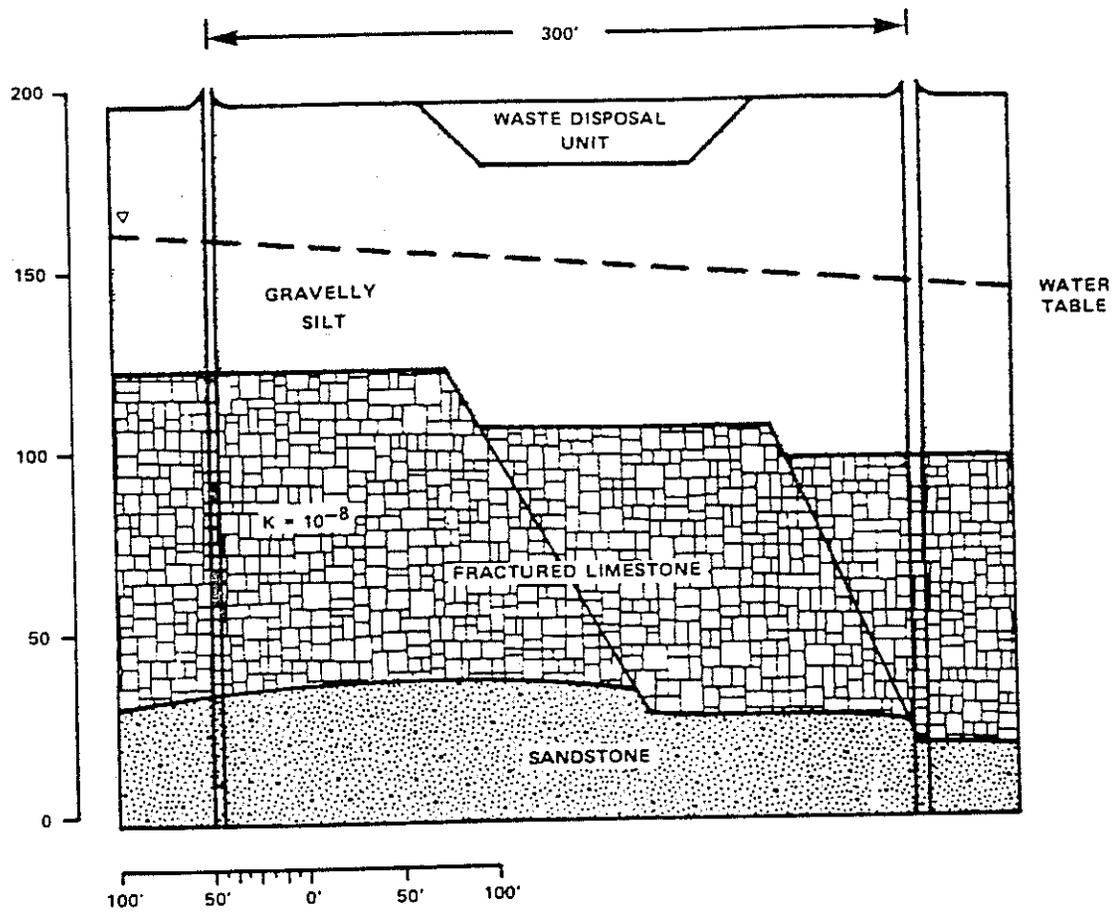


Figure 9. An example of hydraulic interconnection caused by fracturing (EPA-TEGD, 1985)

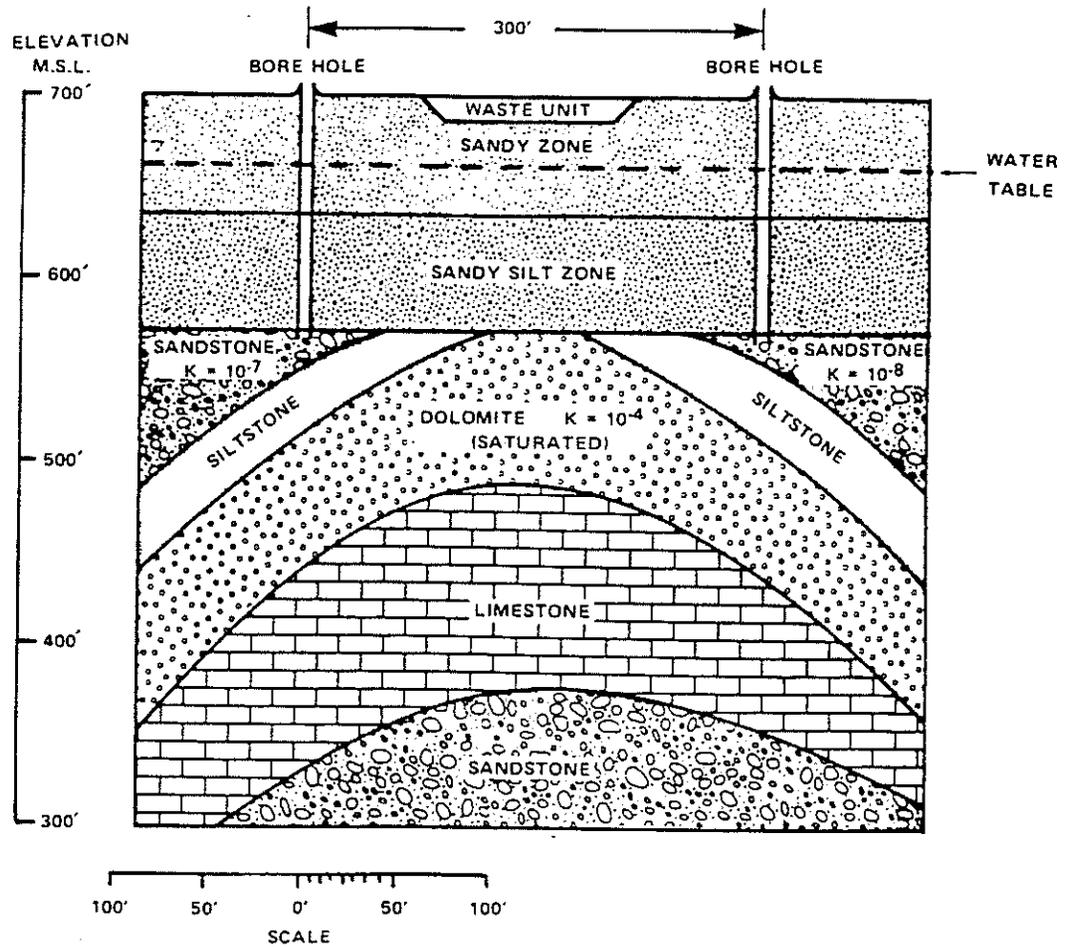


Figure 10. An example of an undetected, structurally complex uppermost aquifer (EPA-TEGD, 1985)

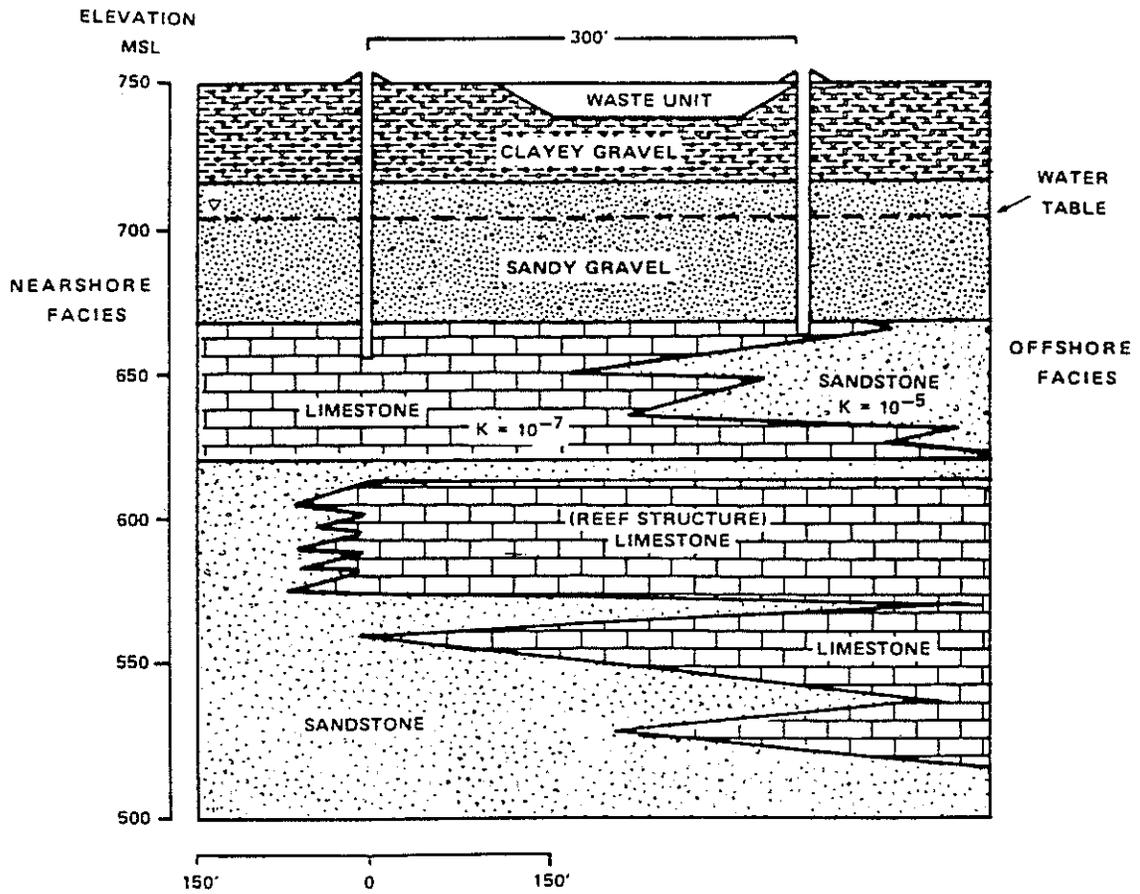


Figure 11. An example of lateral changes in permeability due to facies changes associated with time-migration of coastal environments (EPA-TEGD, 1985)

if: 1) the waste is not liquid; 2) the geology is simple (i.e., no faults, fractures, folds or caves); 3) the aquifer is homogeneous in regard to lithology and hydraulic conductivity (permeability); 4) the water table gradient is low; 5) the site is new; and/or 6) the waste is non-hazardous. The geology affects the amount of waste dispersion in the aquifer, and thus the width of the contaminant plume. Well spacing may be greater in formations such as clay-silt which are characterized by low hydraulic conductivities and higher diffusivities, thus causing wider plumes. Likewise, a leak in a synthetic liner will cause a more narrow plume than liquid wastes leaking from an unlined pond, or from solids in a landfill. This is shown in Figure 12 where monitoring wells are spaced 225 feet around the landfill because of simple and homogeneous site geology and the lack of liquid waste disposal. Monitoring wells, around the impoundment containing hazardous liquid waste are spaced 75 feet apart since there is greater chance of a narrow plume forming from a leak in the liner.

Figure 13 illustrates the placement of wells based on surficial geology. Monitoring wells should be placed closer in the gravelly sand than the clay-silt because of the greater potential of a rapid-moving, narrow plume forming in the gravel seams. In Figure 14, a groundwater mound is expected, so wells are placed entirely around the landfill, but are wider spaced in the upgradient direction. Wells are spaced only 75 feet apart in the gravelly sand because of the risk of contaminating the swamp area (a discharge zone) and the likelihood of the plume being narrow due to the lower diffusivity expected for the aquifer material. Finally, Figure 15 demonstrates that close spacing of monitoring wells is essential in fractured rock. In fractured rock, there are numerous discrete pathways that a potential contaminant may take. Thus, the plume may be very narrow. It is very difficult to locate all the fractures even using sophisticated geophysical techniques. Therefore, wells must be closely spaced to ensure detection. In general, waste should not be disposed of on top of fractured or cavernous rock unless there is a substantial thickness of overlying, low permeable material.

DRILLING METHODS FOR MONITORING WELLS

There are four basic drilling methods for monitor wells. These are: 1) hollow stem auger; 2) mud rotary; 3) air rotary; and 4) cable tool. In choosing the drilling method, several factors must be considered. These include: 1) the type of material to be drilled through; 2) depth and diameter of the hole; 3) speed of drilling; 4) ability to collect representative rock and water samples during drilling; 5) possible water sample contamination from drilling fluids; and 6) costs. The advantages

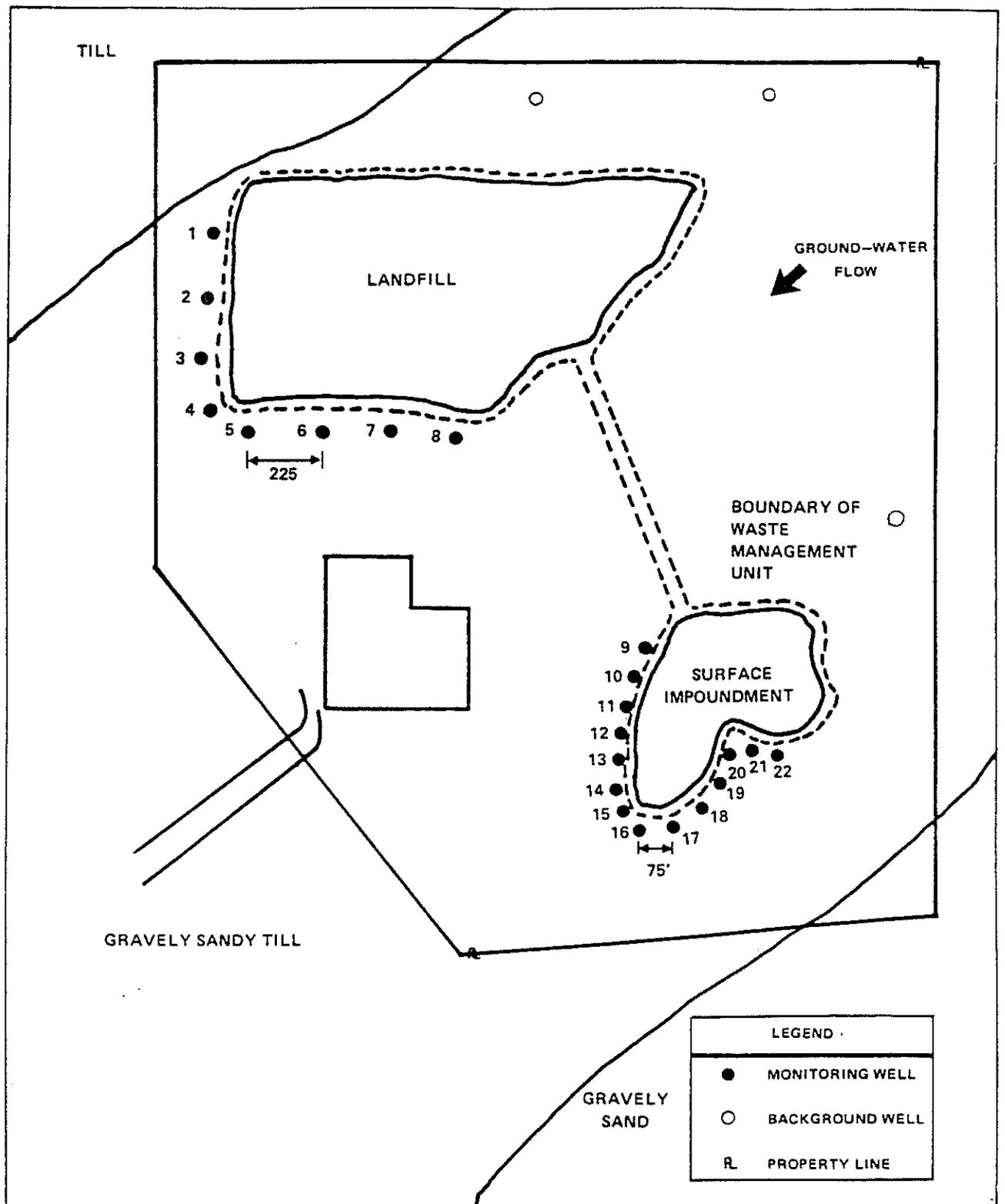
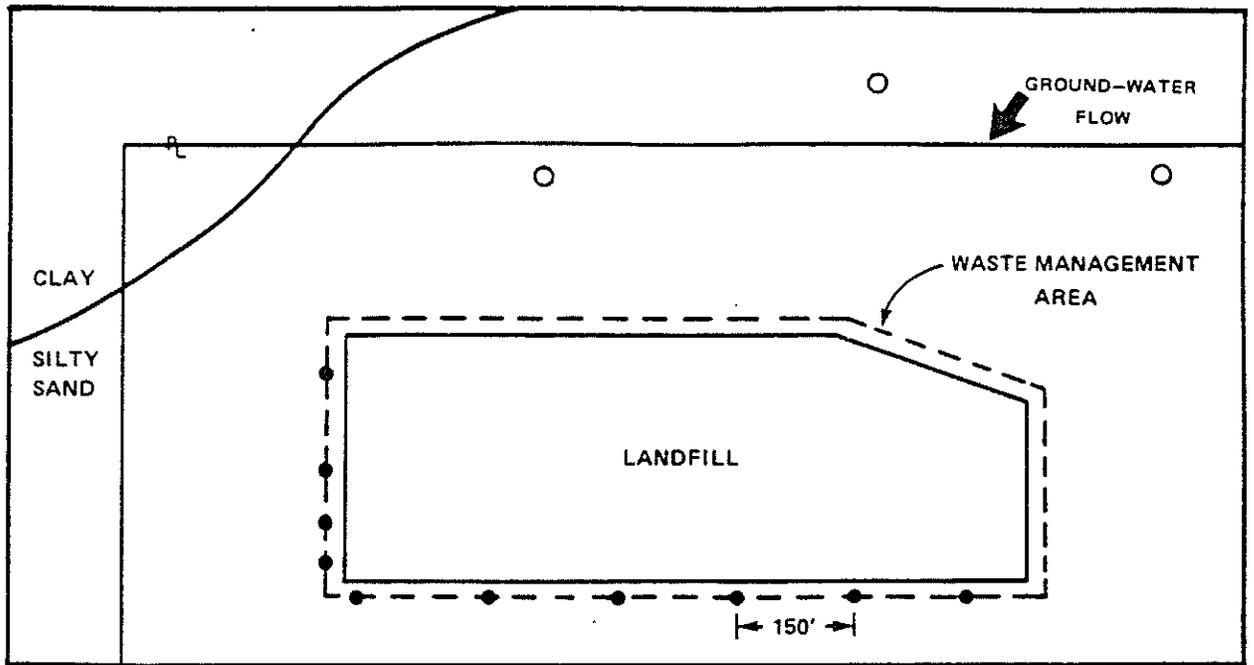
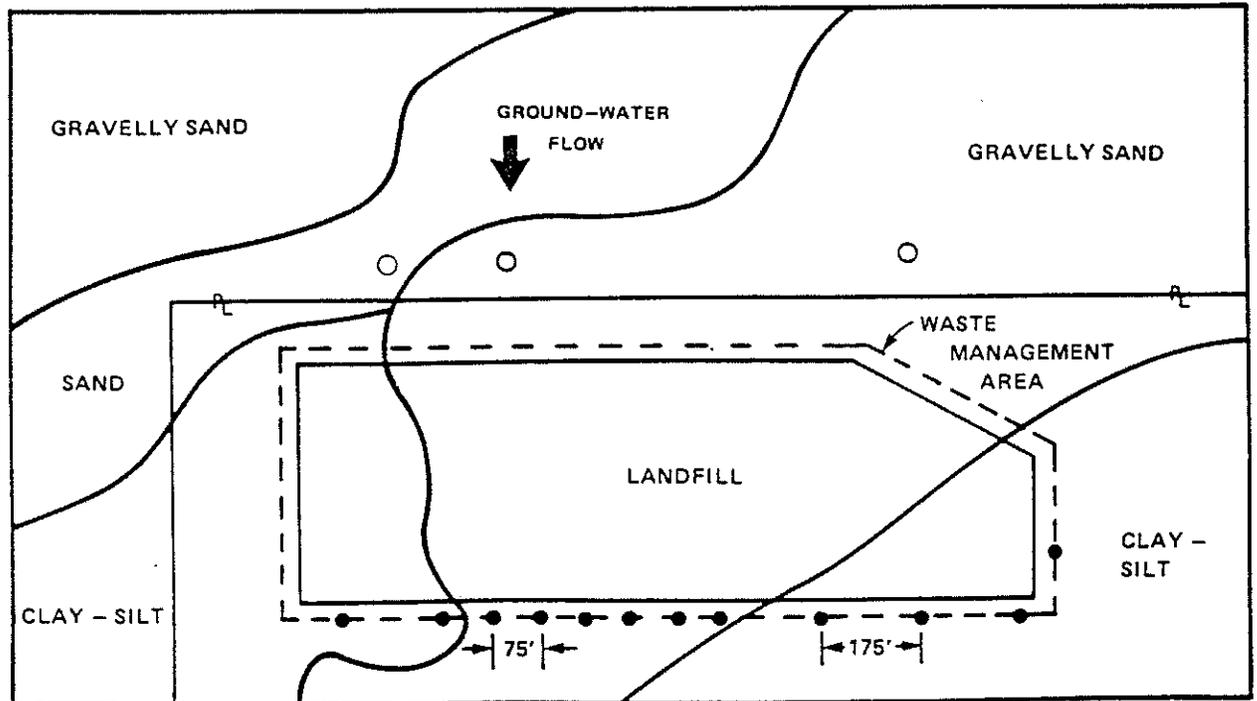


Figure 12. Monitoring well spacing based on waste character (EPA-TEGD, 1985)



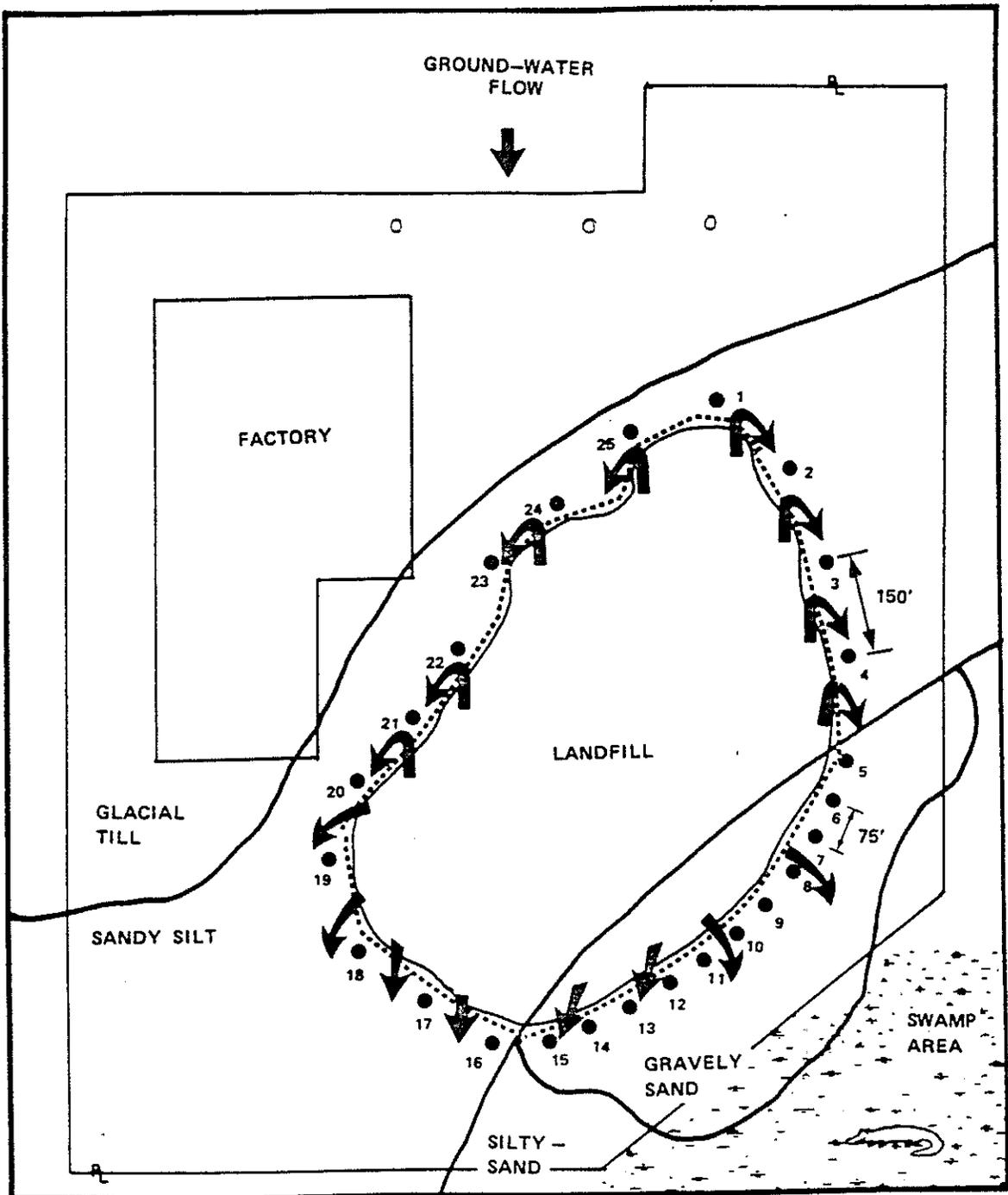
A



B

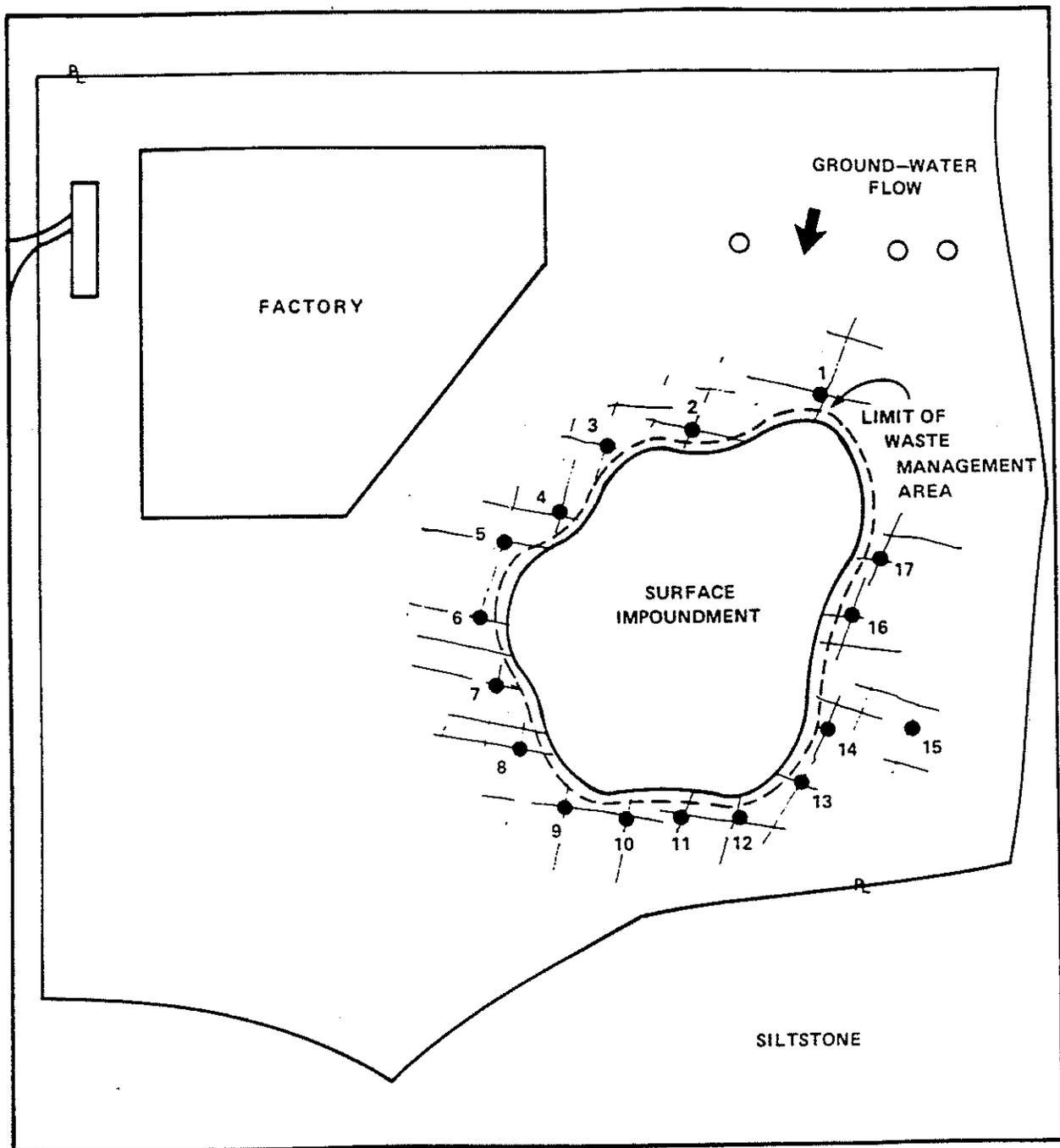
LEGEND	
●	MONITORING WELLS
○	BACKGROUND WELLS
PL	PROPERTY LINE

Figure 13. Spacing of monitoring wells based on changes in site geology (EPA-TEGD, 1985)



LEGEND	
●	MONITORING WELLS
○	BACKGROUND WELLS
—	PROPERTY LINE

Figure 14. Well placement based on changes in site geology, the presence of a groundwater mound, and groundwater flow direction (EPA-TEGD, 1985)



LEGEND	
○	BACKGROUND WELL
●	MONITORING WELL
RL	PROPERTY LINE

Figure 15. Close well spacing based upon fractures in the rock (EPA-TEGD, 1985)

and disadvantages of the four drilling methods are presented in Table 3 (Johnson Division, 1986).

SAMPLING PROTOCOL

Objectives and Problems

Once a groundwater monitoring network has been installed, a detailed sampling plan must be devised to ensure that the chemical results are truly accurate. Problems faced in achieving accuracy can be classified as either physical or chemical. Physical factors include: 1) insufficient number of well evacuations prior to sampling; 2) improper cleaning of sampling equipment; 3) poor chain-of-custody procedures; and 4) improper preservation and handling. Factors that can change the chemistry due to reactivity include: 1) sampling equipment materials that can alter the chemical constituents; 2) sampling techniques that alter water composition such as stripping of volatiles; and 3) air bubbles left in the sample container.

Sampling equipment should be constructed with materials that are least likely to affect the sample. Glass is the best with teflon a close second and stainless steel a likely third. The worst is rubber with various plastics falling in between. All materials touching the sample must be considered. This includes pump components, samplers, discharge lines, storage containers, and well casings. A compounding problem is pump lubricants and joint compounds (Scalf et al., 1981). Threaded joints should be used in all cases in which organic compounds are suspected contaminants. This is not as important for wells designed to sample for inorganics. Equally important for obtaining a representative sample is choosing an EPA approved laboratory that follows strict quality assurance (QA) and quality control (QC) procedures.

The costs of resampling and having another suite of analyses performed are of such magnitude that it is vitally important that the sampling protocol is strictly followed. The following steps are therefore suggested:

1. Characterize the Pollutants

Before sampling, it is important to determine the types and sources of potential pollutants. If there is likely to be just one or a few pollutants, and these are known, then the costs of sampling and analysis can be greatly reduced. Likewise, if the pollutants are relatively stable then less expensive and commonly more rapid

Table 3. Advantages and disadvantage of drilling methods for monitoring wells (Johnsons VOP, Inc., 1984)

TYPE	ADVANTAGES	DISADVANTAGES
A. Hollow Stem Auger	<ul style="list-style-type: none"> *No drilling fluid is used, minimizing contamination problems *Formation waters can be sampled during drilling by using a screened lead auger or advancing a well point ahead of the augers *Natural gamma-ray logging can be done inside the in-place augers *Hole caving can be overcome by implacing screen and casing before augers are removed *Fast *High mobility rigs can reach most sites *Equipment generally readily available throughout the U.S. *Usually less expensive than rotary or cable tool drilling 	<ul style="list-style-type: none"> *Can be used only in unconsolidated materials *Limited to depths of 100-150 ft. *Formation samples may not be completely accurate, depending upon how they are taken *Possible problems in heaving sand situations
B. Mud Rotary	<ul style="list-style-type: none"> *Can be used in both unconsolidated and consolidated formations *Capable of drilling to any depth *Core samples can be collected *Can run a complete suite of geophysical logs in the open hole *Casing not required during drilling *Flexibility in well construction *Fast *Smaller rigs can reach most sites *Equipment generally readily available throughout the U.S. *Relatively inexpensive 	<ul style="list-style-type: none"> *Drilling fluid is required <ul style="list-style-type: none"> -contaminants are circulated with the fluid -the fluid mixes with the formation water and invades the formation, making it very difficult to remove -Bentonite fluids may absorb metals and may interfere with some other parameters -organic fluids may interfere with bacterial analyses and/or organic related parameters *No information on location of the water table and only limited information on water-producing zones, is directly available during drilling *Formation samples may not be accurate
C. Air Rotary	<ul style="list-style-type: none"> *No drilling fluid is used, minimizing contamination problems 	<ul style="list-style-type: none"> *Casing is required to keep the hole open when drilling in soft, caving formations below water table

Air Rotary
(Continued)

*Can be used in both unconsolidated and consolidated formations

*Capable of drilling to any depth

*Formation sampling ranges from excellent in hard, dry formations to nothing when circulation is lost in formations with cavities

*Formation water is blown out of the hole along with cuttings making it possible to determine when the first water-bearing zone is encountered

*Collection and field analysis of water blown from the hole can provide enough information regarding changes in water quality for parameters such as chlorides for which only large concentration changes are significant

*Fast

*Equipment available throughout most of the U.S.

*When more than one water-bearing zone is encountered and hydrostatic pressures are different, flow between zones occurs between the time drilling is completed and the hole can be properly cased and grouted off

*May not be economical for small jobs

D. Cable Tool

*Only small amounts of drilling fluid (generally water with no additives) are required

*Can be used in both unconsolidated and consolidated formations; well suited for caving, large gravel type formations with large cavities above the water table

*Wide depth range

*Formation samples can be excellent with a skilled driller

*When water is encountered, changes in piezometric levels are observable

*Relative permeabilities of different zones penetrated can be obtained by skilled operators

*Good seal between casing and formation if flush jointed casing is used

*Rigs can reach most sites

*Equipment readily available throughout the U.S.

*Relatively inexpensive

*Relatively large diameters are required (minimum 4-inch casing)

*Steel drive pipe must be used

*Usually a screen must be set before a water sample can be taken

*Potential difficulty in pulling casing back

*Slow

sampling equipment can be used. In cases where there are numerous suspected contaminants and/or the contaminant can be easily altered by such processes as precipitation, volatilization, or oxidation, totally non-reactive sampling processes must be utilized. Volatile organic compounds such as trichloroethylene (TCE) can be rapidly lost if the sample is agitated. Also some materials such as PVC can absorb some organics. When concentrations are in the low ppb range, these interference factors can be significant.

2. Measurement of Static Water Level

Collection of water level elevations is best performed by a continuous recorder mounted above the wellhead. In most cases, the water level is simply measured by a portable device prior to well purging since low producing wells often take hours to days to completely recover. Replotting a water level measurement from each sampling period determines whether outside factors are changing the horizontal and vertical flow gradients. Examples could be the onset of irrigation (recharge) or heavy summer municipal pumping (discharge). If such effects significantly change the flow directions, a new monitoring plan may need to be developed. It is important to remember that water levels from wells screened at different elevations within the same aquifer may not necessarily represent the top of the water table. Hydraulic head (potential) can change at different depths in an aquifer, particularly in discharge and recharge areas (Figure 3).

The most commonly used water level measuring devices are a steel tape or an electric water level indicator. When using a steel tape, it is first coated with chalk at some distance near the lower end. The length between the ground and the wetted (washed off) portion of the tape is the depth to groundwater. Steel tapes are very accurate, but kinks or curls caused by age will lessen the accuracy. Cloth or fiberglass tapes can be used for shallow wells, but stretching can be a problem for depths over 100 feet. In some cases, it is possible that the chalk will contaminate the sample although purging before sampling usually takes care of this problem.

An electric water level indicator consists of a spool of wire usually marked in five foot intervals, a battery, and a milliamp meter. A weighted probe at the end consists of two separated wire ends. The circuit is completed when these wires hit the water surface; this is noted by a deflection on the milliamp meter. Electric water level meters are quick and easy to use but some stretch can occur in deep

wells. Also probe malfunction due to cascading water or water along the casing is relatively common. This problem is not as significant for monitoring wells versus older domestic and municipal wells.

Other water level measuring techniques employ sonar devices and manometer (air pressure) devices. These are usually too bulky or expensive compared to the first two methods described.

3. Detection of Immiscible Layers

Some organic compounds are immiscible with water and will either float on the water table or sink to the bottom of the aquifer depending on their density. "Floaters" such as gasoline will spread across the top of the water table surface while "sinkers" such as TCE will accumulate above an aquitard. These immiscible fluids will not be indicated by steel tape and electric probe methods or obtaining water levels. Therefore, an interface probe should be utilized to determine the air/floater, floater/water, and water/sinker boundaries. This provides a measurement of the thickness of the immiscible layer. Before using this probe, the air in the well should be tested for organic vapors to determine the potential for fire, explosion, and/or toxic effects on workers. Sampling of the immiscible fluid should then be performed prior to well evacuation (EPA, 1985).

4. Well Evacuation

When water enters a well, it experiences a pressure reduction which causes degasing. As a result, volatiles are lost and/or minerals are precipitated. Therefore, the standing water must be completely evacuated prior to sampling. For low yielding wells, purging is usually done to dryness once. As the well slowly recovers, samples are first taken for volatilization-sensitive or pH-change sensitive parameters. Less sensitive parameters are subsequently sampled. Purging should not be so rapid as to cause ground cascading through the well screen since this will cause loss of volatiles.

For higher yielding wells, a number of well volumes should be removed prior to sampling. The exact number of well volumes to be removed is dependent on the aquifer and well construction. EPA (1985) and National Council ASI (1983) recommend removing three well volumes. One method of estimating this is to monitor the temperature, conductivity, and pH of the water during purging. When these parameters stabilize, enough water has probably been removed.

Purging equipment should not introduce contaminants into the well or change the water chemistry in any way. If the contaminants are stable and not volatile, PVC bailers or submersible pumps can probably be used for purging. For more sensitive contaminants, positive gas-displacement, teflon bladder pumps, or teflon and stainless steel bailers are recommended. If purging equipment is reused, it must be thoroughly cleaned. The advantages and disadvantages of various water quality sampling devices for monitoring wells are presented in Table 4 (Johnson Division, 1984).

5. Sample Withdrawal

Once a well is purged, a sample must be withdrawn so as not to change the concentrations of contaminants being measured. Teflon or stainless steel (316) sampling devices are best, but PVC materials can be used when it can be assured not to affect water chemistry. Equipment made of neoprene, tygon, silicon rubber, polyethylene, and vitron may change the concentration of certain organic compounds. If the sampling mechanism is reused, it must be thoroughly cleaned. For higher producing wells, purging is often performed with a portable submersible pump and then sampling is done with a bailer. A bailer should be lowered and raised gently so as not to agitate the sample. Also the line used to lower the bailer should be made of teflon-coated wire, single strain stainless steel wire, or monofilament. Braided and laid lines are too difficult to decontaminate. Transfer of the sample to a bottle must be done gently to minimize aeration and volatilization.

6. Field Analyses

Some parameters are physically or chemically unstable and must be tested immediately after sampling. These include pH, redox potential, chlorine, dissolved oxygen, and temperature (EPA, 1985). It is also recommended that specific conductivity and alkalinity be measured as soon as possible. It is important that all field testing equipment is "warmed up" and calibrated before use and cleaned thoroughly between samples.

7. Sample Preservation, Handling, Containers and Blanks

Many parameters are unstable and will change with time if not properly preserved. Preservation is commonly accomplished through the addition of an acid and keeping the sample chilled. EPA has recommended procedures for preservation and analysis for a large

Table 4. Advantages and disadvantages of water quality sampling devices for monitoring wells
(Johnsons VOP, Inc., 1984)

TYPE	ADVANTAGES	DISADVANTAGES
A. Bailer	<ul style="list-style-type: none"> *Can be constructed in a wide variety of diameters *Can be constructed from a variety of materials *No external power source required *Extremely portable *Low surface area to volume ratio, resulting in a very small amount of outgassing of volatile organics while sample is contained in bailer *Easy to clean *Readily available *Inexpensive 	<ul style="list-style-type: none"> *Time consuming sampling; sometimes impractical to properly evacuate casing before taking actual samples *Transfer of water to sample bottle may result in aeration
B. Suction Lift Pump	<ul style="list-style-type: none"> *Relatively portable *Readily available *Inexpensive 	<ul style="list-style-type: none"> *Sampling is limited to situations where water levels are within about 20 ft. from ground surface *Vacuum effect can cause the water to lose some dissolved gas
C. Air Lift Samplers	<ul style="list-style-type: none"> *Relatively portable *Readily available *Inexpensive *Very suitable for well development 	<ul style="list-style-type: none"> *Not an appropriate method for acquisition of water samples for detailed chemical studies owing to degassing *Changes in CO₂ concentrations make this method unsuitable for sampling for pH sensitive parameters *Oxygenation is impossible to avoid unless elaborate precautions are taken (only a very small amount of oxygen is required to cause a water sample to attain saturation with respect to oxygen)
D. Gas-Operated	<ul style="list-style-type: none"> *Can be constructed in diameters as small as one inch *Can be constructed from a wide variety of materials 	<ul style="list-style-type: none"> *Gas source required *Large gas volumes and long cycles are necessary for deep operation *Pumping rates are not as great as with suction or jet pumps

Gas-Operated (Continued)	<ul style="list-style-type: none"> *Relatively portable *Fair range in pumping rates as possible *Driving gas does not contact water sample, eliminating possible contamination or gas stripping 	<ul style="list-style-type: none"> *Commercial units are relatively expensive--about \$2,500 for a fully equipped unit
E. Submersible Pumps	<ul style="list-style-type: none"> *Wide range in diameters *Various materials are available *Fairly portable *Depending upon size of pump and pumping depths, relatively large pumping rates are possible *Readily available 	<ul style="list-style-type: none"> *Most submersible pumps are small enough in diameter for use in 2-inch wells *Conventional units are unable to pump sediment-laden water without incurring damage to the pump
F. Johnson-Keck Submersible Pump	<ul style="list-style-type: none"> *1.75 inch outside diameter allows sampling of 2 inch wells *Construction materials are adequate for sampling sensitive chemical parameters *Highly portable; powered by 12-volt rechargeable battery pack *Rotor and stator construction permits pumping of fine-grained materials without damage to the pump *Easily cleaned 	<ul style="list-style-type: none"> *Delivers low pumping rates at high heads *Relatively expensive--about \$3,500 for a fully equipped unit

number of chemical parameters. These can be found in Methods for Chemical Analysis of Water and Wastes (EPA, 1979) and Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater (EPA, 1982) and subsequent updates. Samples to be analyzed for metals should be placed in polyethylene containers. When the samples are collected for analysis of organics, it is best to use glass bottles with teflon-lined caps. Sample bottles should only be reused after proper cleaning by an EPA-approved procedure. Samples requiring analysis for organics should not be filtered and no air space should be left in the bottle. Samples tested for metals should be split; one filtered for dissolved metals and the other left unfiltered for total metals.

Blanks should be used to verify cleanliness of the sample container, environment of the sampling site, and sampling equipment. For each sampling event, a trip blank containing deionized water should be prepared for each type of sample bottle. After being cleaned, sampling equipment should be filled or pumped through with deionized water and this sample tested in the laboratory.

8. Chain of Custody

It is very important to keep a record of all personnel who have handled the samples from field collection to laboratory analysis. This is essential if the information is likely to be used later in court. Samples should be carefully labeled by a method that will not fall off the bottle or be dissolved by water. A field logbook should be kept during the sampling, and all comments regarding field conditions, procedures, and abnormal occurrences should be recorded. Also included in the logbook should be information about the well, ID number, date and time of sampling, and name of collector.

9. Field and Laboratory Quality Assurance/Quality Control

Commonly contaminants in groundwater are at very low concentrations. Many laboratories cannot provide the reliability to assure accurate measurements. Since the information may be used in court or in designing a remedial action program, it is absolutely essential that a laboratory be chosen with a demonstrated quality assurance/quality control program. Therefore, only certified laboratories should be used.

MONITORING USING EXISTING DOMESTIC AND IRRIGATION WELLS

In the previous section, monitoring design and sampling methods were described primarily for those involved with EPA-RCRA regulated sites. Often sampling is performed to determine if groundwater contamination has occurred from such activities as agricultural practices, highway spills, or municipal landfills. Sometimes water well sampling is conducted to ascertain ambient groundwater quality conditions. In such cases, existing wells are used as monitoring wells. Careful consideration is required when choosing wells to sample. If a point source of contamination is being investigated, the direction of groundwater flow must be determined either from existing water table maps or by making a new water table map. To make an accurate water table map, surveying is required to determine exact well top elevations from which depths to water measurements are subtracted. Most household wells have a small vent hole on the cap through which a water level measuring device can be lowered. When making such measurements, it is important that the pump is not running. Experience has shown that most household wells, even in low producing aquifers, will fully recover to their static water level within an hour after the pump has shut off. In high producing aquifers, such as the Snake Plain and Rathdrum Prairie aquifers, domestic wells seldom cause significant drawdown, and thus fully recover in minutes after pumping ceases.

Commonly, there is insufficient money or time to determine accurate well top elevations. If the area to be sampled is sufficiently large (greater than a square mile) or the slope of the water table in a small area is greater than about 20 ft/mile, then an approximate water table map can be made using elevations determined from USGS 7 1/2 minute topographic maps. Plotting well locations on the map while in the field usually enables elevation to be determined within ± 3 feet. Therefore, where the hydraulic gradient is relatively steep, a reasonably accurate determination of groundwater flow directions can be made. Even if a water table map is not being made, the depth to water should be determined as a tool in accessing pollution susceptibility.

Once the water table map is made or obtained from some governmental agency, a range of approximate groundwater velocities can be determined by using the equation:

$$V=KI$$

where:

V= groundwater velocity

K= hydraulic conductivity (permeability)

I= hydraulic gradient (slope of the water table)

From hydrogeology textbooks, a range for hydraulic conductivity values for various aquifer materials can be estimated if exact numbers have not previously been determined through aquifer pumping tests (Figure 16). Let's say a spill occurs at Point A on Figure 17. In this example, an approximate water table map is quickly made and theoretical flowlines are drawn perpendicular to the water table contour lines (equipotential lines). The hydraulic gradient is then determined from the spill point to an arbitrary point down gradient (Point B). In this example, the hydraulic gradient is 20 ft/mile or 0.00038 ft/ft. If the aquifer material is a fine to coarse sand, hydraulic conductivity values from the table in Figure 16 range from 10^{-2} to 10^{-3} m/day. Placing these values into the equation, the range in velocity is 0.00004 to 3.8 m/day. This range demonstrates the crude estimation of velocity obtained by using table values, but it does provide a means of determining a worst case scenario. Using this range for hydraulic conductivity and estimates of porosity, it is also possible to predict the approximate width of the contaminant plume using modeling methods. In many cases, neither the time nor trained personnel are available to perform the modeling, so field sampling must be done based on the flow paths suggested by the water table map and the worst case groundwater velocity.

For unconsolidated aquifer materials such as sand and gravel, determining sampling locations is not as difficult as for rock. In sandstone, granite, or basalt, for example, the velocity and volume of contaminant transport along fractures and faults can greatly exceed that which is flowing through the pores. Faults are commonly shown on geologic maps published by the Idaho Geologic Survey. If faults cross the plume, wells located on or near the faults should be sampled. Fractures are more difficult to locate without utilizing geophysical techniques. One method for locating major fractures and faults is through a photo-lineament analysis. A photo-lineament is defined as a natural linear feature expressed on aerial photographs such as a straight stream segment, or soil tone and vegetation alignments (Lattman and Parizek, 1964). Stereo, black and white, 1:20,000 aerial photographs are most useful in delineating photo-lineaments and can be readily obtained through the Soil Conservation Service and the Idaho Department of Transportation. Wells located on such linear features should be included in the sampling plan.

A very important consideration in choosing existing domestic and irrigation wells as monitoring sites is knowing the depth and rock strata from which water is being obtained. It would be useless to sample wells in a confined aquifer, for example. Depth of wells and position of the screening can be obtained from well logs on file at the Idaho Department

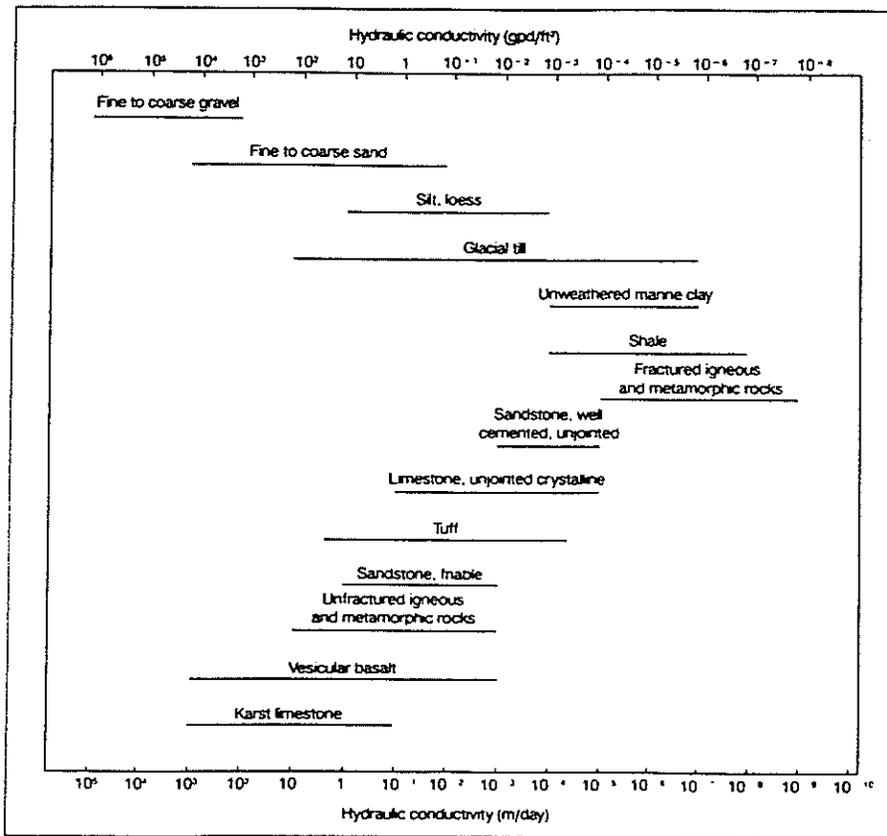


Figure 16. Typical K values for consolidated and unconsolidated aquifers (after Freeze and Cherry, 1979)

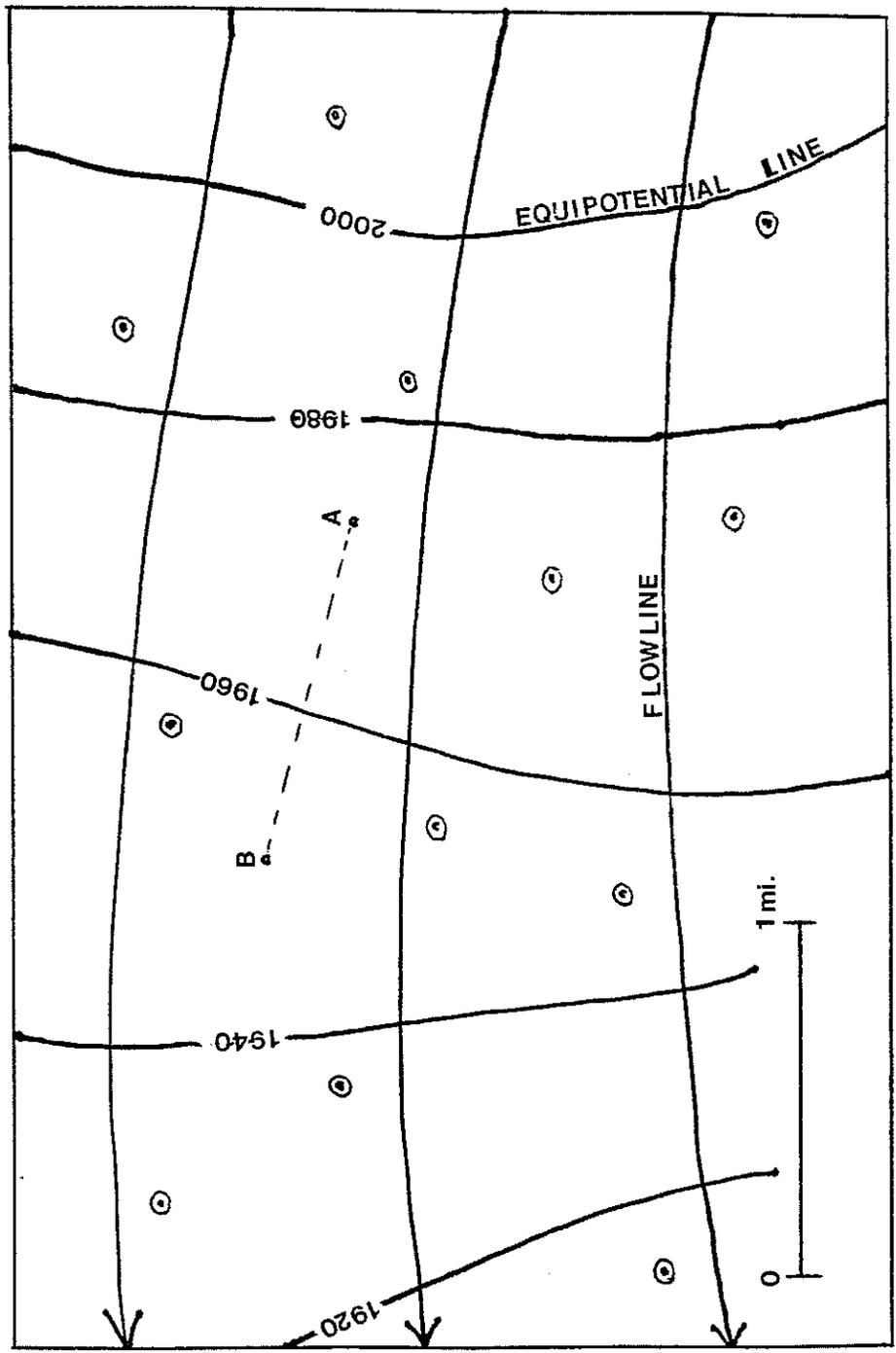


Figure 17. Hypothetical spill and water table map

of Water Resources. These logs also contain useful information such as static water level, aquifer and vadose zone materials, and estimated well yields. In some circumstances, short pumping tests are performed by the driller and reported on the logs. From this data, the specific capacity (C) of the well can be determined. The specific capacity (C) is defined as:

$$C = \frac{Q}{s}$$

where:

C= specific capacity (gpm/ft)

Q= average pumping rate (gpm)

s= total drawdown (ft)

To have an accurate measurement of specific capacity the well should totally penetrate the aquifer, and the test should be run until drawdown ceases. Many times these conditions are not met. Regardless, this estimate of the specific capacity can be used to determine the approximate hydraulic conductivity (K) using an analytical program on file at the Idaho Department of Water Resources (Bradbury and Rothschild, 1985). Using this calculated K value will give a much more accurate estimate of groundwater velocity than simply using K values from tables.

Once the wells are chosen for sampling, consideration must be made for choosing the sample location within the plumbing system. It is best to obtain a sample as close to the well head as possible. Be certain to ask the owner whether any type of water treatment unit is in use between the well head and sampling spigot. If possible, use abandoned wells in which a bailer can be lowered down the borehole. Submersible pumps will drive off volatile organics and possibly change chemical constituents affected by redox reactions. Also, a floating immiscible fluid, such as gasoline will likely not be detected when sampling with a submersible pump. Whether the well is bailed or pumped, it is essential that at least three well volumes are removed before sampling. EPA recommends removing three volumes or pumping the well to dryness. A six inch diameter well casing will contain approximately 1.5 gallons of water per foot of well casing. Therefore, if there is 100 ft of standing water in the well, at least 450 gallons of water should be removed before sampling. Figure 18 demonstrates how water chemistry can change as the well is pumped.

If there is no way to determine how much water is standing in the well, simple parameters such as pH, conductivity, and temperature can be monitored as the well is pumped. When these parameters stabilize, it is a

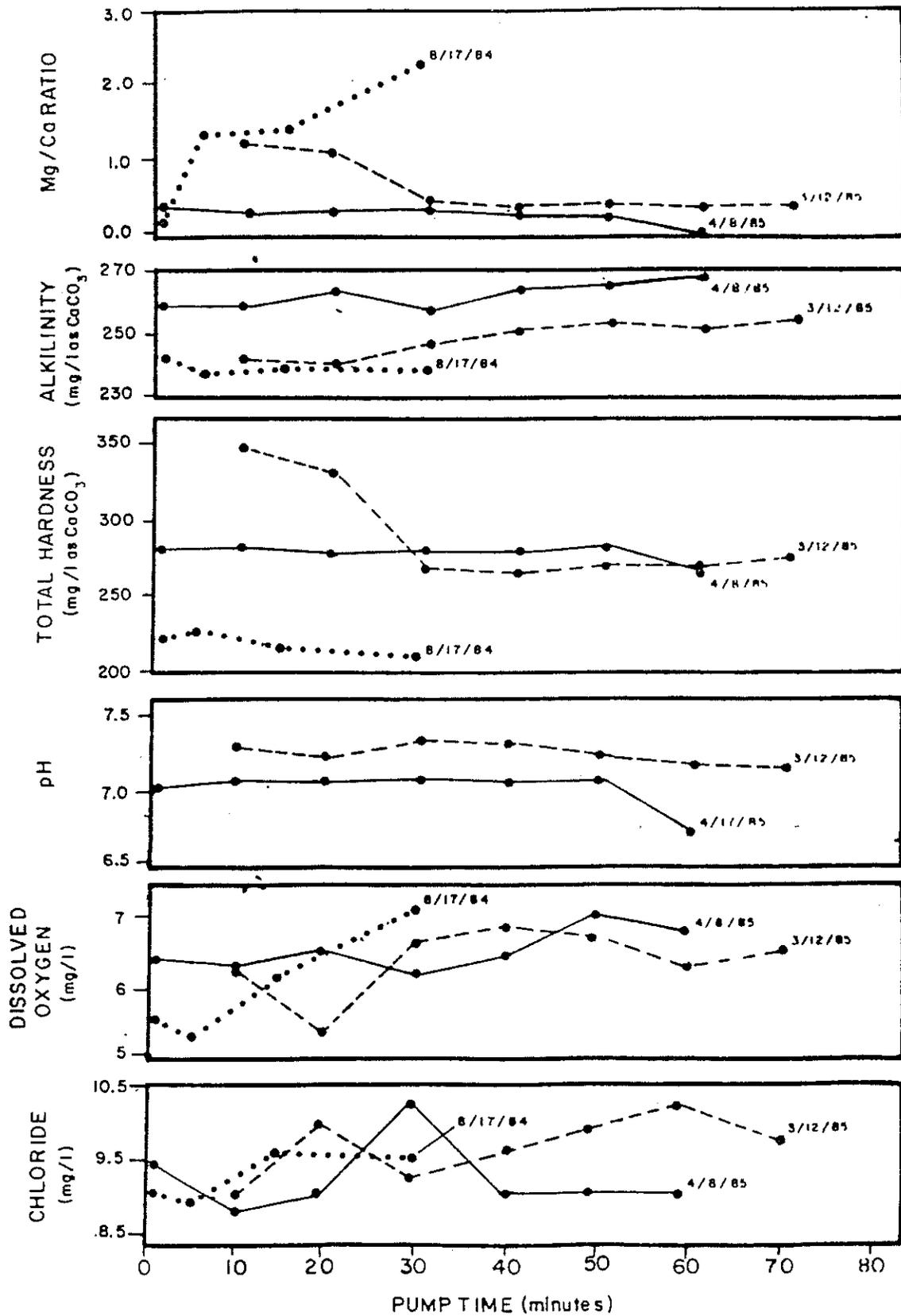


Figure 18. Chemical changes with pumping time for three test periods for Well No. 174 (from Ogden et al., 1986)

good indication that the water stored in the borehole and pressure tank has been removed and fresh aquifer water is emerging at the discharge point.

In all cases, it is important that an accurate field record is made during sampling and that the proper sample container and preservative is used. Table 5 presents a list of specific chemical parameters and the required container type and preservative. Be certain that all equipment such as the pH probe and water level indicator are thoroughly cleaned between sampling sites to eliminate cross-contamination. As mentioned previously, it is very important to keep a proper chain of custody and be certain to label all sample containers with indelible labels which are certain not to fall off.

Usually, more rounds of sampling are required to determine changes in the concentration of contaminants with time. Both seasonal and recharge factors can significantly affect the water chemistry of wells and springs. Notice how some of the wells in Figure 19 show significant changes in conductivity related to recharge events, rise in the water table, and the growing season (Ogden et al., 1986). Figure 20 shows how the water chemistry of a limestone spring changes dramatically as discharge rises during storms. Figure 21 shows how storms markedly affected the water chemistry of the same spring during low flow conditions even though little change in discharge occurred (Rothermel and Ogden, 1987). Wells located near recharge points can show similar changes in water chemistry during storms. Leaky irrigation ditches can likewise affect water chemistry in wells and cause changes in static water levels. In the Boise Valley, for example, significant amounts of leaked petroleum product from a tank farm are found on top of the water table only during the winter months when irrigation ceases and groundwater levels are lower.

The aerial distribution of chemical constituents in an aquifer may also be highly variable due to changes in hydrogeologic conditions, flow velocities and lithology. Figure 22 shows the aerial distribution of hardness in the Rathdrum Prairie sole source aquifer (Thompson, 1987). Figure 23 shows how in the Edwards Limestone Aquifer, groundwater increases in sulfate concentration as it moves in a southern direction dissolving more gypsum. Anomalously high sulfate values are related to native sulfur deposits in the rock and to zones of slow circulation (Ogden et al., 1986). Therefore, to properly determine ambient water quality conditions, temporal and aerial factors must be considered.

Table 5. Sampling and preservation procedures for detection monitoring
(from EPA-TEGD, 1985)

Parameter	Recommended Container ^b	Preservative	Maximum Holding Time	Minimum Volume Required for Analysis
<u>Indicators of Ground-Water Contamination^c</u>				
pH	T, P, G	Field determined	2 hours	25 ml
Specific conductance	T, P, G	Field determined	None	100 ml
TOC	G, Teflon-lined cap	Cool 4°C, HCl to pH <2	28 days	4 x 15 ml
TOX	G, amber, Teflon-lined cap	Cool 4°C, add 1 ml of 1.1M sodium sulfite	7 days	4 x 15 ml
<u>Ground-Water Quality Characteristics</u>				
Chloride	T, P, G	4°C	28 days	50 ml
Iron	T, P	Field Acidified ^d to pH <2 with HNO ₃	6 months	200 ml
Manganese				
Sodium				
Phenols	G	4°C/H ₂ SO ₄ to pH <2	28 days	500 ml
Sulfate	T, P, G	Cool, 4°C	28 days	50 ml
<u>EPA Interim Drinking Water Characteristics</u>				
Arsenic	T, P	<u>Total Metals</u>	6 months	1,000 ml
Barium		Field acidified to		
Cadmium		pH <2 with HNO ₃	6 months	1,000 ml
Chromium				
Lead		<u>Dissolved Metals</u>		
Mercury		1. Field filtration		
Selenium		(0.45 micron)		
Silver		2. Acidify to pH <2 with HNO ₃		
Fluoride	T, P	Field acidified to pH <2 with HNO ₃	28 days	300 ml
Nitrate	T, P, G	4°C ^e	48 hours	1,000 ml

(Continued)

Table 5. (Continued)

Parameter	Recommended Container ^b	Preservative	Maximum Holding Time	Minimum Volume Required for Analysis
Endrin Lindane Methoxychlor Toxaphene 2,4 D 2,4,5 TP Silvex	T, G	Field acidified to pH <2 with HNO ₃	24 hours	1,000 ml
Radium Gross Alpha Gross Beta	P, G	Field acidified to pH <2 with HNO ₃	6 months	1 gallon
Coliform bacteria	PP, G (sterilized)	Cool, 4°C	6 hours	200 ml
<u>Other Ground-Water Characteristics of Interest</u>				
Cyanide	P, G	Cool, 4°C, NaOH to pH >12	14 days	500 ml
Oil and Grease	G only	Cool, 4°C H ₂ SO ₄ to pH <2	28 days	100 ml
Hazardous constituents (§261, Appendix VIII)	G only	Cool, 4°C	7 days	1 gallon ^f

^aReferences: Test Methods for Evaluating Solid Waste - Physical/Chemical Methods, SW-846 (2nd edition, 1982).
Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.
Standard Methods for the Examination of Water and Wastewater, 16th edition (1985).

^bContainer Types:
P = Plastic (polyethylene)
G = Glass
T = Teflon
PP = Polypropylene

^cBased on the requirements for detection monitoring (§265.93), the owner/operator must collect a sufficient volume of ground water to allow for the analysis of four separate replicates.

^dIn the event that HNO₃ cannot be used because of shipping restrictions, the sample should be refrigerated to 4°C, shipped immediately, and acidified on receipt at the laboratory.

^eFor samples from nonchlorinated drinking water supplies concentrated H₂SO₄ should be added to lower sample pH to less than 2. The sample should be analyzed before 14 days.

^fOr as required by the procedures (SW-846) for the specific hazardous constituents being assessed.

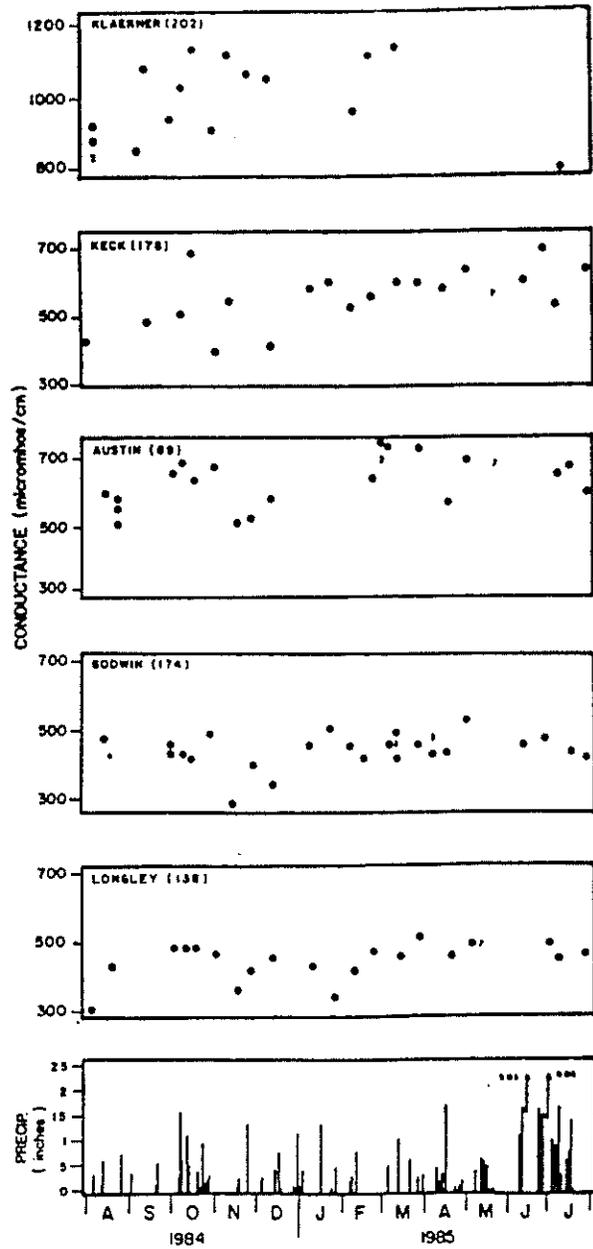


Figure 19. Time series plot of specific conductance concentrations between August, 1984 and July, 1985 for five monitor wells in the Edwards Limestone Aquifer - Texas (from Ogden et al., 1986)

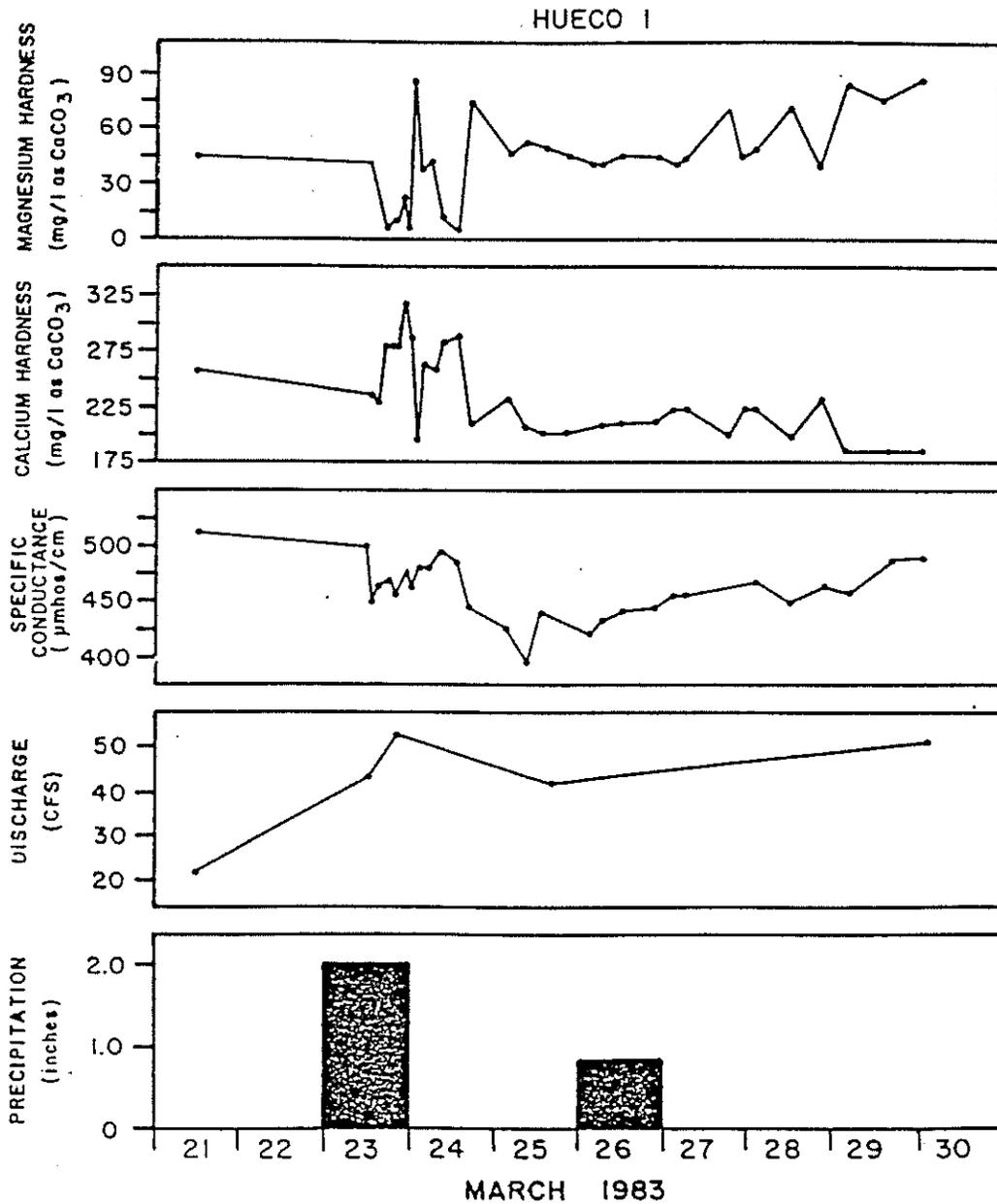


Figure 20. Plot of magnesium hardness, calcium hardness, specific conductance and discharge surrounding a March, 1983 storm event at Hueco Springs, Texas (from Rothermel and Ogden, 1987)

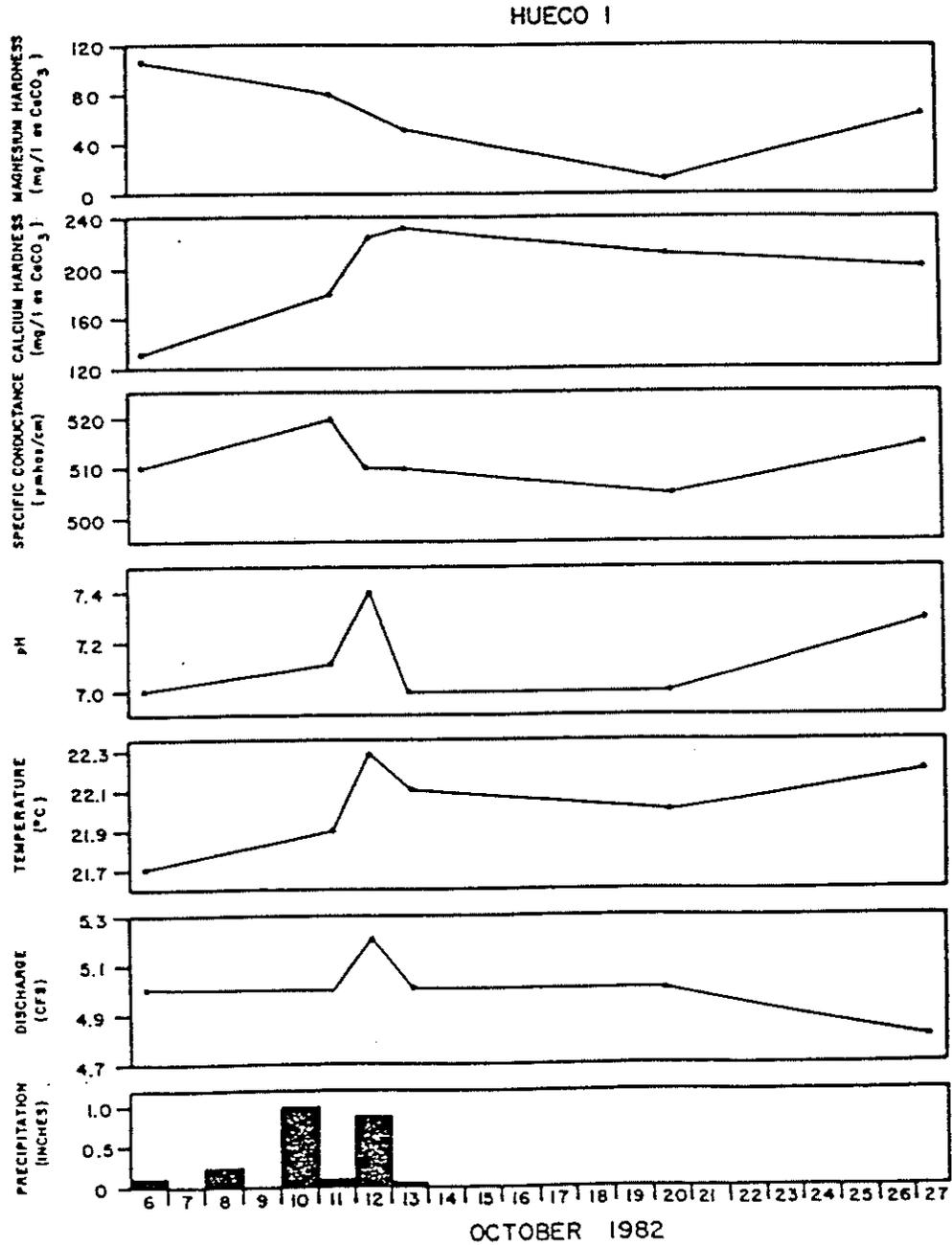


Figure 21. Plot of magnesium hardness, calcium hardness, specific conductance, pH, temperature, and discharge surrounding October, 1982 storm events at Hueco Springs, Texas (from Rothermel and Ogden, 1987)

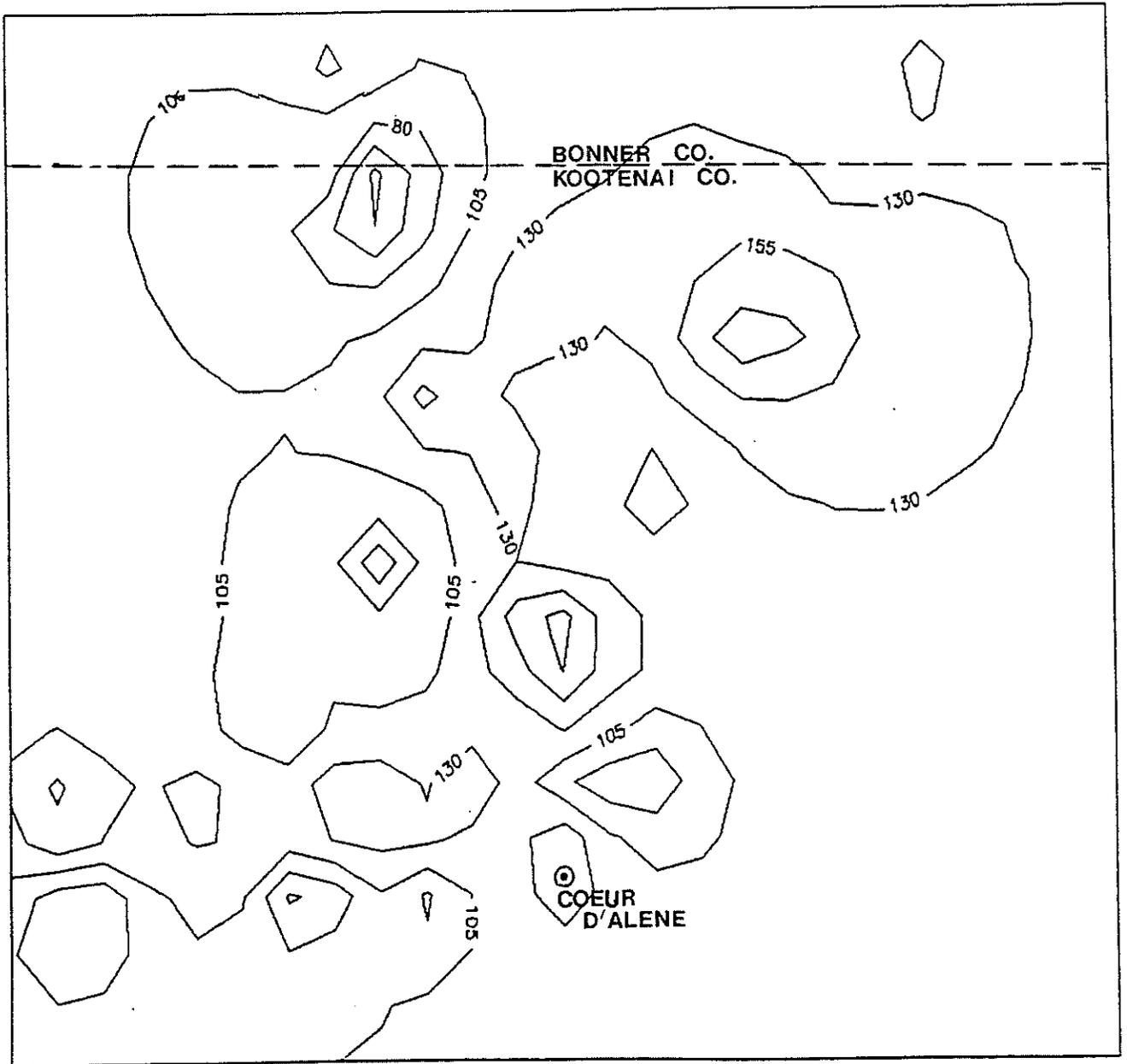


Figure 22. Hardness concentration contours for the Rathdrum Prairie Aquifer (from Thompson, 1987)

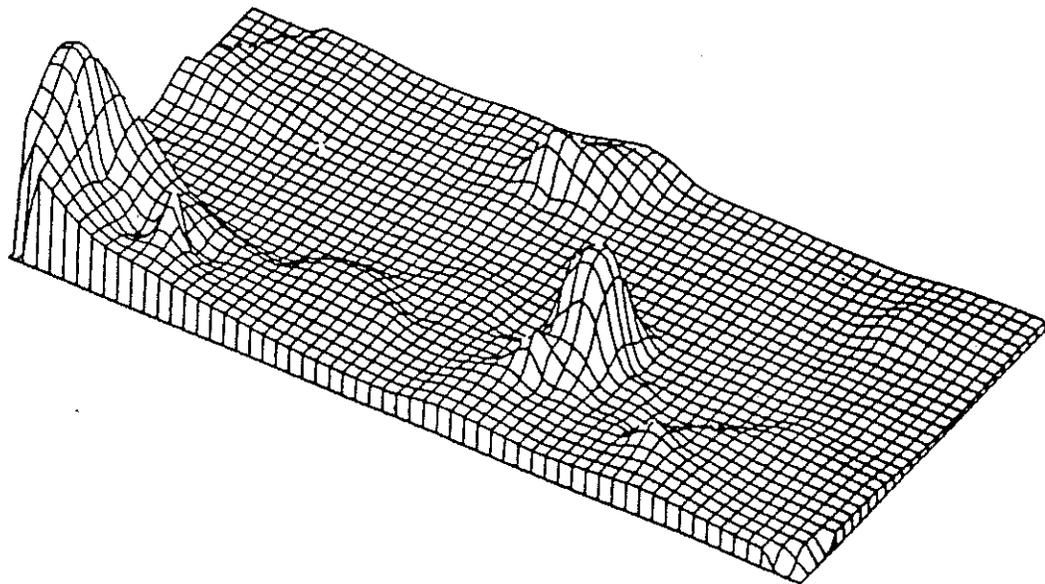
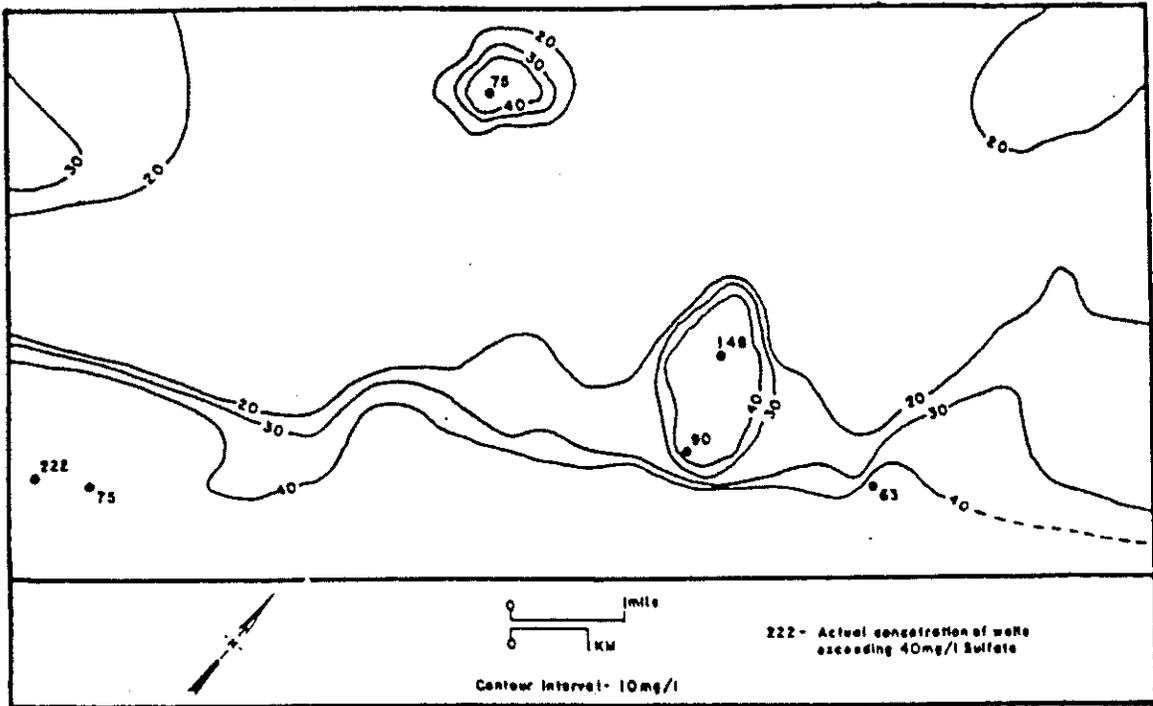


Figure 23. Isocon and fishnet maps of sulfate concentrations in the Edwards Aquifer around San Marcos, Texas (from Ogden et al., 1986)

In summary, perform the following when using existing wells for monitoring:

1. Determine the depth to water at the time of sampling.
2. Obtain well logs and sample primarily those wells with logs.
3. Map the water table or obtain a published water table map to determine approximate groundwater flow directions.
4. Estimate the groundwater velocity from the water table map and published or measured values of hydraulic conductivity.
5. Obtain geology maps to locate faults, and sample wells located on or near the faults.
6. Map photo-lineaments from aerial photographs and sample wells located on or near the lineaments.
7. Sample the wells as close to the well head as possible.
8. Remove at least three well volumes prior to sampling.
9. Repeat sampling throughout a longer period (preferable at least a year) to determine the effects on water quality changes from recharge and seasonal factors.
10. Determine "normal" changes of water chemistry aurally within the aquifer that are related to natural changes within the aquifer.
11. Keep accurate field records and keep a proper chain of custody.
12. Thoroughly clean all reusable sampling devices prior to sampling.
13. Use the proper sample container and preservative.

SUMMARY AND CONCLUSIONS

This report was prepared as a general set of guidelines for groundwater monitoring and sampling. These guidelines are not meant to be site-specific. Each monitoring and sampling plan should be designed to fit the hydrogeologic setting of the site. Equally important considerations are the chemical species being sampled for and which governmental agency (if any) the monitoring plan must satisfy. Monitoring dictated by EPA under RCRA and CERCLA (Superfund) often requires the use of non-reactive substances such as teflon and stainless steel for screening and pump materials, especially when sampling for volatile organic constituents of low concentration. Non-contaminating drilling methods such as air rotary and good grouting and screen packing are essential to ensure that a sample is truly representative of the groundwater. If there are only a few suspected contaminants, and they are of low reactivity, then less costly materials for well construction, such as PVC, can be used.

To site monitoring wells, the groundwater flow direction and aquifer material must be known. Porous materials such as sand and gravel are characterized by relatively uniform contaminant plumes. The placement and number of monitoring wells in a function of the size and shape of the plume. In general, at least one upgradient and three downgradient wells are needed. A 150 ft well spacing can be used as a general "rule-of-thumb" when there is no existing information on aquifer characteristics. When the aquifer is fractured rock, the wells should be sited on the fractures where most of the water is moving. Locating these fractures requires a geophysical and remote sensing survey of the site prior to drilling.

The efforts to install good monitoring wells can be negated if samples are not taken properly. It is paramount that all sampling equipment be properly cleaned before reuse. If sampling is for volatiles, then the pump materials and hosing must not contaminate the sample through absorption or leaching, and the sample must not be stirred or mixed. All samples must be properly preserved and packed, and traced throughout their route to the lab.

Costs for monitoring well construction and sample analysis are continually increasing. Poor construction and sampling techniques commonly yield inaccurate and meaningless measurements that may result in even more costly well replacement and resampling. Every site is unique, and a well thought out monitoring plan prior to drilling and sampling is essential for keeping costs down and preserving the quality of our aquifers.

REFERENCES

- Aller, L., T. Bennett, J.H. Lehr, and R.J. Petty, 1985, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings: Office of Research and Development, R.S. Kerr Environmental Research Lab., EPA/600/2-85/018, Ada, OK 74820, 103 p.
- Barcelona, M.J., J.P. Gibb, J.A. Helfrich, and E.E. Garske, 1985, Practical Guide for Ground-Water Sampling: Office of Research and Development, R.S. Kerr Environmental Research Lab., EPA/600/2-85/104, Ada, OK 74820, 169 p.
- Bradbury, K. and E. Rothschild, 1985, A program to estimate aquifer transmissivity and hydraulic conductivity from specific capacity tests: Ground Water, V. 23, No. 2, p. 240-246.
- Environmental Protection Agency, 1979, Methods for Chemical Analysis of Water and Wastes: EPA-600/4-79-020, Environmental Monitoring and Support Laboratory, Office of Research and Development, Cincinnati, OH 45268.
- Environmental Protection Agency, 1982, Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater: J.E. Longbottom and J.J. Lichtenberg, Editors, EPA-600/4-82-057, Environmental Monitoring and Support Laboratory, Office of Research and Development, Cincinnati, OH 45268.
- Environmental Protection Agency, 1985, RCRA Ground-Water Monitoring Enforcement Guidance/Technical Enforcement Guidance Document (TEGD): Office of Waste Programs Enforcement, Cincinnati, OH.
- Everett, L.G., K.D. Schmidt, R.M. Tinlin, D.K. Todd, 1976, Monitoring Groundwater Quality: Methods and Costs: Office of Research and Development, Environmental Monitoring and Support Lab, EPA-600/4-7-023, Las Vegas, NV 89114, 140 p.
- Fenn, D., E. Coccozza, J. Isbister, O. Braids, B. Yare, and P. Roux, 1980, Procedures Manual for Ground-Water Monitoring at Solid Waste Disposal Facilities: Environmental Protection Agency, SW-611, Solid Waste Information Distribution Office, Cincinnati, OH, 269 p.

- Freeze, R.A. and J.A. Cherry, 1979, Groundwater: Prentice-Hall, Inc., Englewood Cliffs, NJ 07632, 604 p.
- Hampton, N.F., 1976, Monitoring Groundwater Quality: Data Management: Office of Research and Development, Environmental Monitoring and Support Lab, EPA-600/4-76-019, Las Vegas, NV 89114, 62 p.
- Johnson Division, 1986, Ground Water and Wells: F.G. Driscoll, Principal Author and Editor, Johnson Division, St. Paul, MN 55112, 1108 p.
- Knox, R., B. Schick McDonough, and E.T. Dohn, 1986, RCRA Orientation Manual: Office of Solid Waste, EPA/530-SW-86-001, 401 M Street SW, Washington, DC 20460.
- Lattman, L.H. and R.R. Parizek, 1964, Relationship between fracture traces and the occurrence of ground water in carbonate rocks: Jour. Hydrol., V. 2, p. 73-91.
- Michigan Department of Natural Resources - Water Quality Division, 1982, Hydrogeologic Study Handbook: Task 7 of Ground Water Management Strategy for Michigan, Lansing, MI, 50 p.
- Miller, R.A., M. Barcelona, and J.P. Gibb, 1983, A Guide to the Selection of Materials for Monitoring Well Construction and Ground Water Sampling: National Water Well Association, Dublin, OH 43017, 78 p.
- Moss, R., 1982, A Guide to Water Well Casing and Screen Selection, National Water Well Association, Dublin, OH 43017, 76 p.
- National Council of the Paper Industry for Air and Stream Improvement, Inc., 1981, Groundwater Quality Monitoring Well Construction and Placement: Technical Bulletin No. 342, 260 Madison Avenue, New York, NY, 37 p.
- Ogden, A.E. and P. Eddy, 1984, The use of tri-potential resistivity to locate fractures and caves for siting high yield water wells: Proc. Nat. Wat. Well Assoc. Conf. on "Surface and Borehole Geophysical Methods in Ground Water Investigations", p. 130-149.
- Ogden, A.E., R.A. Quick, S.R. Rothermel and D.L. Lunsford, 1986, Hydrogeological and hydrochemical investigation of the Edwards Aquifer in the San Marcos area, Hays Co., Texas: Edwards Aquifer Research and Data Center Publ. No. R1-86, San Marcos, Texas, 364 p.

- Rothermel, S.R. and A.E. Ogden, 1987, Hydrochemical Investigation of Comal and Hueco spring systems, Comal County, Texas: Edwards Aquifer Research and Data Center Publ. No. R1-87, San Marcos, Texas, 181 p.
- Scaif, M.R., J.F. McNabb, W.J. Dunlap, R.L. Cosby, and J.S. Fryberger, 1981, Manual of Groundwater Quality Sampling Procedures: National Water Well Association/EPA Series, Dublin, OH 43017, 93 p.
- Thompson, S.D., 1987, Factors affecting spatial and temporal water quality changes in the Spokane-Rathdrum Prairie Sole Source Aquifer in Idaho, MS thesis, University of Arkansas, in preparation.
- Todd, D.K., R.M. Tinlin, K.D. Schmidt, and L.G. Everett, 1976, Monitoring Groundwater Quality: Monitoring Methodology: Office of Research and Development, Environmental Monitoring and Support Lab, EPA-600/4-76-026, Las Vegas, NV 89114, 154 p.
- Unwin, J.P., 1982, A guide to ground-water sampling: National Council of the Paper Industry for Air and Stream Improvement, Inc., Technical Bulletin No. 362, 260 Madison Avenue, New York, NY, 67 p.
- Warner, D.L., 1975, Monitoring Disposal-Well Systems: Office of Research and Development, Environmental Monitoring and Support Lab, EPA-680/4-75-008, Las Vegas, NV 89114, 99 p.