United States
Environmental Protection
Agency

Office of
Waste Programs Enforcement
Office of Solid Waste and
Emergency Response

September 1986

Solid Waste

EPA

RCRA Ground-Water Monitoring Technical Enforcement Guidance Document

RCRA GROUND-WATER MONITORING
TECHNICAL ENFORCEMENT GUIDANCE DOCUMENT
(TEGD)

SEPTEMBER 1986

OVERVIEW

This publication, entitled the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD), describes in detail what the United States Environmental Protection Agency deems to be the essential components of a ground-water monitoring system that meets the goals of the Resource Conservation and Recovery Act. This guidance is intended to be used by enforcement officials, permit writers, field inspectors and attorneys at the federal and state levels to assist them in making informed decisions regarding the adequacy of existing or proposed ground-water monitoring systems or modifications thereto. It is not a regulation and should not be used as such. The TEGD is divided into six chapters which contain discussions on the following:

- Characterization of site hydrogeology;
- Location and number of ground-water monitoring wells;
- Design, construction and development of ground-water monitoring wells;
- Content and implementation of the sampling and analysis plan;
- Statistical analysis of ground-water monitoring data; and
- The content and implementation of the assessment plan.

The document is mainly directed towards interim status facilities. Much of the purely technical content, especially regarding site characterization, well design and construction, and assessment of contamination of ground water, is germane to permitted facilities as well as non-RCRA programs. Clearly, the spectrum of hydrogeologic regimes is great, and no single document could provide detailed, step-by-step instructions for monitoring each one. The writers of the TEGD concur and have developed a framework within which a dynamic decision-making process may be applied using a combination of national opinion and site-specific considerations.

In August 1985, the RCRA Ground-Water Monitoring Compliance Order Guide was published. It is the companion document to the TEGD and contains guidance on the use and formulation of compliance orders. It is the hope of U.S. EPA that these guidance documents will further the goal of the regulators and regulated community alike to protect human health and the environment.

The U.S. EPA fully recognizes the dynamic nature of the RCRA program. The TEGD, as it is presented, documents current policy and direction for enforcement and compliance. The TEGD can be used by technical reviewers and the regulated community toward attaining the mandate of protection of human health and the environment.

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CHAPTER ONE

CHARACTERIZATION OF SITE HYDROGEOLOGY

The adequacy of an owner/operator's ground-water monitoring program hinges, in large part, on the quality and quantity of the hydrogeologic data the owner/operator used in designing the program. Technical reviewers and permit/closure plan reviewers (hereafter permit writers), therefore, should evaluate the adequacy of an owner/operator's hydrogeologic assessment as a first step towards ascertaining the overall adequacy of the detection and/or assessment monitoring network. Clearly, if the design of the well system is based upon poor data, the system cannot fulfill its intended purpose. Because of the complexity of ground-water monitoring systems, owner/operators should discuss the intended approach initially with the State or EPA.

In performing this evaluation, technical reviewers should ask themselves two questions.

- Has the owner/operator collected enough information to: (1) identify and characterize the uppermost aquifer and potential contaminant pathways, and (2) support the placement of wells capable of determining the impact of the facility on the uppermost aquifer?

- Did the owner/operator use appropriate techniques to collect and interpret the information used to support the placement of wells?

The answer to each question will, of course, depend on site-specific factors. For example, sites with more heterogeneous subsurfaces require more hydrogeologic information to determine placement of wells that will intercept contaminant migration. Likewise, investigatory techniques that may be appropriate in one setting, given certain waste characteristics and geologic features, may be inappropriate in another.

This chapter is designed to help technical reviewers answer the above questions. It identifies various investigatory tasks that enable an owner/operator to characterize a site, and explores the factors that technical reviewers should consider when evaluating whether the particular investigatory program an owner/operator used was appropriate in a given case. Technical reviewers should also find this chapter useful when constructing compliance orders that include hydrogeologic investigations.

1.1 Investigatory Tasks for Hydrogeologic Assessments

An owner/operator should accomplish two tasks in conducting a hydrogeologic investigatory program:

1. Define the geology beneath the site area; and
2. Identify ground-water flow paths and rates.

A variety of investigatory techniques are available to achieve these goals, and technical reviewers must evaluate the success of the combination of techniques used by the owner/operator, given the site-specific factors at the facility.

There are certain investigatory techniques that all owner/operators, at a minimum, should have used to characterize their sites. Table 1-1 illustrates a number of techniques that an owner/operator may use to perform hydrogeologic investigations. Those techniques that the owner/operator, at a minimum, should have used to define the geology or identify ground-water flow paths are identified with check marks.

Table 1-1 also presents preferred methods for presentation of the data generated from a hydrogeologic assessment. An owner/operator who has performed the level of site characterization necessary to design a RCRA ground-water monitoring program will be able to supply any of the outputs (cross sections, maps, etc.) listed in the last column of Table 1-1.

The owner/operator should have reviewed the available literature on the hydrogeology of the site area prior to conducting the site-specific

TABLE 1-1

HYDROGEOLOGIC INVESTIGATORY TECHNIQUES

INVESTIGATORY TASKS	INVESTIGATORY TECHNIQUES	DATA PRESENTATION FORMATS/ ASSESSMENT OUTPUTS
Definition of Subsurface Materials [geology]	√ Survey of existing geologic information √ Soil borings • Rock corings √ Material tests (grain size analyses, standard penetration tests, etc.) • Geophysical well logs (point and lateral resistivity and/or electromagnetic conductance, gamma ray, gamma density, calipher, etc.) • Surface geophysical surveys (D.C. resistivity, E.M., seismic) • Hydraulic conductivity measurements of cores (unsaturated zone) • Aerial photography (fracture trace analysis) • Detailed lithologic/structural mapping of outcrops and trenches	√ Narrative description of geology √ Geologic cross sections √ Geologic or soil map (1" = 200') √ Boring logs or coring logs • Structure contour maps of aquifer and confining layer (plan view) • Raw data and interpretive analysis of geophysical studies √ Raw data and interpretive analysis of material tests

(Continued)

TABLE 1-1 (Continued)

HYDROGEOLOGIC INVESTIGATORY TECHNIQUES

INVESTIGATORY TASKS	INVESTIGATORY TECHNIQUES	DATA PRESENTATION FORMATS/ ASSESSMENT OUTPUTS
Identification of Ground-Water Flow Paths [hydrology]	√ Installation of piezometers; water level measurements at different depths and locations	√ Narrative description of ground water with flow patterns
		√ Water table or potentiometric maps (plan view) with flow lines (1" = 200')
Ground-water flow directions (including vertical and horizontal components of flow)	√ Slug tests and/or pump tests • Tracer studies	√ Hydrologic cross sections
Hydraulic conductivities	• Estimates based on sieve analyses	• Raw data and interpretive analysis of slug tests, pump tests, and tracer studies

√ Minimum techniques and corresponding outputs that should be used to define site hydrogeological conditions.

investigation. Such a review provides a preliminary understanding of the distribution of sediments and rock, general surface water drainage, and ground-water flow that serves to guide the site-specific investigation.

The owner/operator's site-specific investigatory program should have included direct (e.g., borings, piezometers, geochemical analysis of soil samples) methods of determining the site hydrogeology. Indirect methods (e.g., aerial photography, ground penetrating radar, resistivity), especially geophysical studies, may provide valuable sources of information that can be used to interpolate geologic data between points where measurements with direct methods were made. Information gathered by indirect methods alone, however, generally would not have provided the detailed information necessary. The owner/operator should have combined the use of direct and indirect techniques in the investigatory program to produce an efficient and complete characterization of the facility, including an identification of:

- The geology below the owner/operator's hazardous waste facility;
- The vertical and horizontal components of flow in the uppermost aquifer below the owner/operator's site;
- The hydraulic conductivity(ies) of the uppermost aquifer;
- The vertical extent of the uppermost aquifer; and
- The pertinent physical/chemical properties of the confining unit/layer relative to hazardous wastes present.

The following sections outline the basic steps an owner/operator should have followed to implement a site hydrogeologic study, and detail the methods that the owner/operator should have used to collect and present site hydrogeologic data.

1.2 Characterization of Geology Beneath the Site

In order to detail the geology beneath the site and therefore be able to identify potential pathways of contamination, the owner/operator should have collected direct information identifying the lithology and structural characteristics of the subsurface. Indirect methods of geologic investigation such as geophysical studies may be used to augment the evidence gathered by direct field methods, but should not be used as a substitute for them. Surface geophysical studies, such as resistivity, electromagnetic conductivity, seismic reflection, and seismic refraction, and borehole methods like electromagnetic conductivity, resistivity, and gamma ray may yield valuable information on the depth to the confining unit, the types of unconsolidated material(s) present, the presence of fracture zones or structural discontinuities, and the depth to the potentiometric surface. Additionally, geophysical methods may have their greatest utility in correlating the continuity of formations or strata between boreholes. The result is the efficient compilation of extensive site data without drilling an excessive number of boreholes. Geophysical methods, however, should have been used primarily to supplement information obtained from direct sources. In order to characterize the lithology, depositional environment, and geologic characteristics of the area beneath the site, the owner/operator should have used direct means. The limitations of geophysical methods should also be recognized. For instance, electrical borehole logging cannot be performed when the hollow stem auger drilling method is used.

1.2.1 Site Characterization Boring Program

The technical reviewer should determine whether an owner/operator, through the soil/rock boring program, gathered the information necessary to characterize the geology beneath the site and consequently to identify potential contaminant migration pathways. Such a program should have entailed the following:

- Initial boreholes should be installed at a density based on criteria described in Table 1-2 and sufficient to provide initial information upon which to determine the scope of a more detailed evaluation of geology and potential pathways of contaminant migration.

TABLE 1-2

FACTORS INFLUENCING DENSITY OF INITIAL BOREHOLES

FACTORS THAT MAY SUBSTANTIATE REDUCED DENSITY OF BOREHOLES	FACTORS THAT MAY SUBSTANTIATE INCREASED DENSITY OF BOREHOLES
• Simple geology (i.e., horizontal, thick, homogeneous geologic strata that are continuous across site that are unfractured and are substantiated by regional geologic information)	• Fracture zones encountered during drilling
• Use of geophysical data to correlate well log data. Preferred methods: DC resistivity, seismic reflection or seismic refraction, geophysical well logging	• Suspected pinchout zones (i.e., discontinuous units across the site)
	• Geologic formations that are tilted or folded
	• Suspected zones of high permeability that would not be defined by drilling at large intervals
	• Laterally transitional geologic units with irregular permeability (e.g., sedimentary facies changes)

- Initial boreholes should have been drilled into the first confining layer beneath the uppermost aquifer. The portion of the borehole extending into the confining layer should have been plugged properly after a sample was taken.

- Additional boreholes should be installed in numbers and locations sufficient to characterize the geology beneath the site. The number and locations of additional boreholes should have been based on data from initial borings and indirect investigation.

- Collection of samples of every significant stratigraphic contact and formation, especially the confining layer, should have been taken. Continuous cores should have been taken initially to ascertain the presence and distribution of small- and large-scale permeable layers. Once stratigraphic control was established, samples taken at regular, e.g., five-foot intervals, could have been substituted for continuous cores.

- Boreholes in which permanent wells were not constructed should have been sealed with material at least an order of magnitude less permeable than the surrounding soil/sediment/rock in order to reduce the number of potential contaminant pathways.

- Samples should have been logged in the field by a qualified professional in geology.

- Sufficient laboratory analysis should have been performed to provide information concerning petrologic variation, sorting (for unconsolidated sedimentary units), cementation (for consolidated sedimentary units), moisture content, and hydraulic conductivity of each significant geologic unit or soil zone above the confining layer/unit.

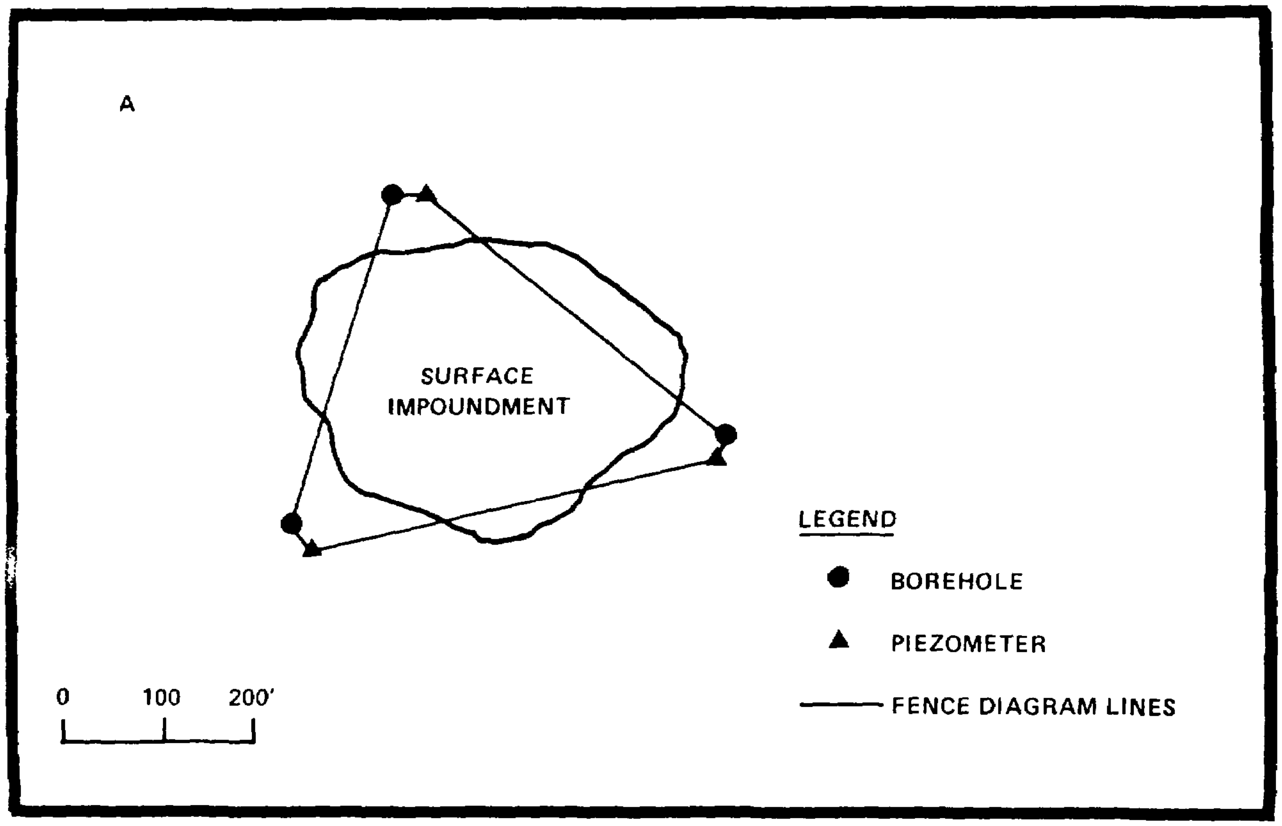
- Sufficient laboratory analysis should have been performed to describe the mineralogy (X-ray diffraction), degree of compaction, moisture content, and other pertinent characteristics of any clays or other fine-grained sediments held to be the confining unit/layer. Coupled with the examination of clay mineralogy and structural characteristics should have been a preliminary analysis of the reactivity of the confining layer in the presence of the wastes present.

At many sites a site characterization has already been done and monitoring wells installed. In evaluating the design of such systems, the technical reviewer should utilize, where appropriate, data already gathered by the owner/operator. Because of the quality of existing data, it is possible that site characterization may be complete or may only need to be supplemented by a few additional boreholes, piezometers, or monitoring wells. Some facilities, including closed facilities, may need to undertake a site characterization from the first phase.

The borehole program to elucidate site hydrogeology generally requires more than one iteration. A benefit to this technique is that data and observations derived from previous boreholes may be used to guide the placement of future ones.

It is imperative that the owner/operator research local hydrogeology before initiating a borehole program. Existing reports, maps, and research papers gathered from a variety of sources can be used to understand, in a broad sense, the hydrogeological regime in which the facility is located. Thus, such information as local stratigraphy, depositional environment, and tectonic history serves to provide an estimate of the distribution and types of geologic materials likely to be encountered. Similarly, knowledge of regional ground-water flow rate, depth, quality, and direction, local pumping, evapotranspiration rates, and surface water hydrology represents an effective first approximation of site-specific ground-water characteristics. The next phase should have been the progressive placement of boreholes based, at first, on research and, subsequently, on previous boreholes and data from research.

The number of initial boreholes should have been sufficient to provide initial information upon which to determine the scope of a more detailed evaluation of geology and potential pathways of contaminant migration. An example of a simple case is illustrated in Figure 1-1. The objective of the initial boreholes is to begin to reconcile the broad, conceptual model derived from research data with the true site-specific hydrogeologic regime. In other words, the borehole program is necessary to establish the small-scale geology of the area beneath the facility and place it in the context of the geology of the region or locale.



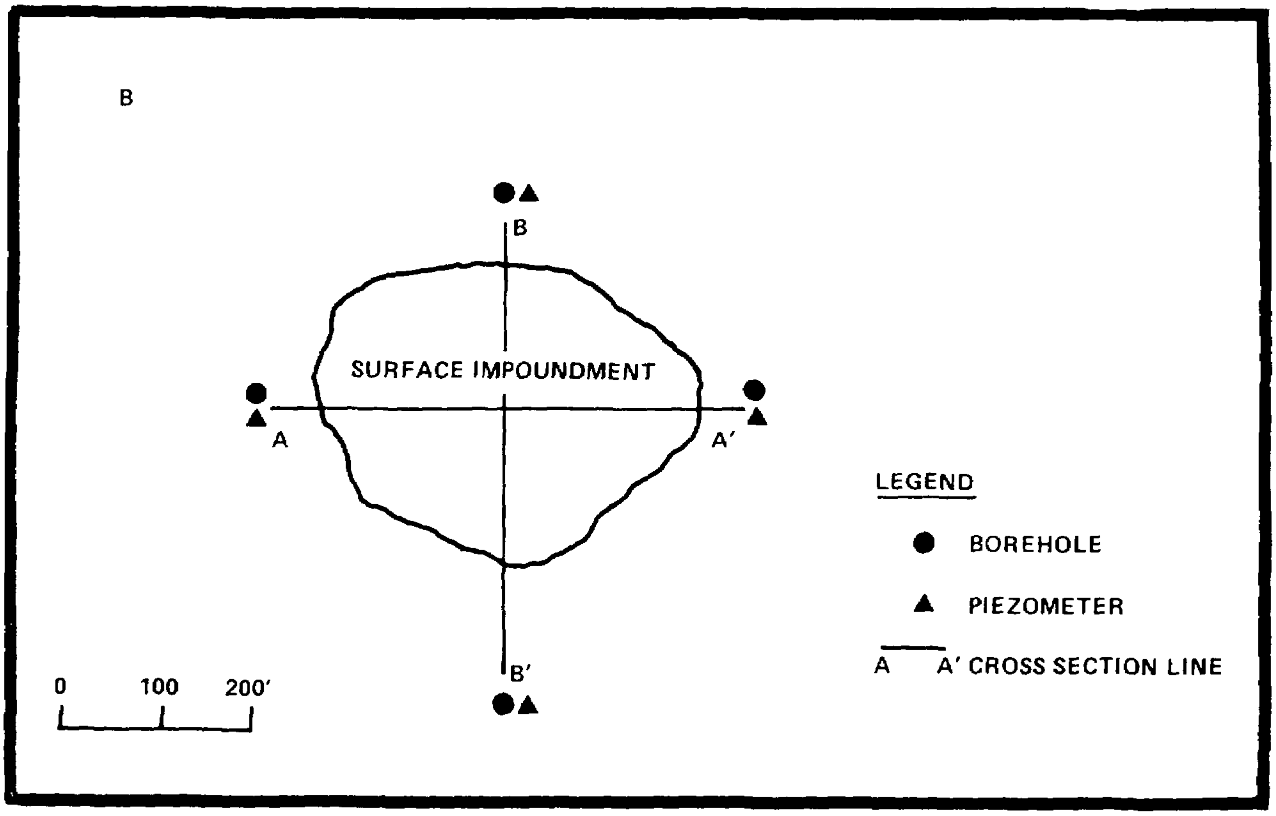


FIGURE 1-1. POSSIBLE BOREHOLE CONFIGURATION FOR A SMALL SURFACE IMPOUNDMENT

The distance between these initial boreholes should be varied based on site-specific criteria, yet should have been close enough so that cross sections would have accurately portrayed stratigraphy with minimal reliance on inference (see Table 1-2). In this way, a suitably restricted configuration of a limited number of initial boreholes, in combination with indirect investigative techniques and research data, will serve to guide efficiently the placement of additional boreholes where needed to characterize potential pathways for contaminant migration. A parallel program using piezometers should also be undertaken. Lithologic data should ultimately correlate with hydraulic parameters (e.g., clean, well sorted, unconsolidated sands should exhibit high hydraulic conductivity). If they do not, further hydraulic testing should be done.

During the completion of the borings, the owner/operator should check drill logs for:

- Correlation of stratigraphic units between soil/rock borings;
- Identification of zones of potentially high hydraulic conductivity;
- Identification of the confining formation/layer;
- Indication of unusual or unpredicted geologic features such as fault zones, fracture traces, facies changes, solution channels, buried stream deposits, cross cutting structures, pinch out zones, etc.; and
- Continuity of petrographic features such as sorting, grain size distribution, cementation, etc., in significant formations.

If the owner/operator is unable to define such structural anomalies, or zones of potentially high conductivity, or to correlate petrographic features and/or stratigraphy between any two adjacent boreholes, then additional intermediate boreholes should be drilled and ancillary investigative techniques employed to describe potential contaminant migration.

On the other hand, if the necessary characterization is largely achieved at the initial placement, fewer additional boreholes and less additional indirect investigation would be necessary to describe pathways.

Figure 1-2 illustrates how subsequent boreholes and indirect supplementary techniques can be added to the initial borehole configuration to characterize potential pathways for contaminant migration. In most cases, additional boreholes will be necessary to complete the characterization because the majority of hydrogeologic settings are complex.

It is vitally important that the owner/operator consider the thickness and potential reactivity of confining clays or other fine-grained sediments in the presence of site-specific waste types. Marl, for instance, is chemically attacked by low pH wastes because of its high carbonate content. Smectites and, to a lesser extent, illitic clays are ineffective impediments to the migration of various organic chemicals (e.g., xylene). In contaminated areas, a chemically degraded confining layer may lead to hydraulic communication unanticipated by literature reviews of stratigraphy. An example is shown in Figure 1-3. In pristine areas, the possible future chemical degradation of a confining layer should be of concern during any assessment monitoring or corrective action necessary at the facility.

All samples should have been logged in the field by a qualified professional in geology (see glossary). These samples should have been collected with a shelby tube, split barrel sampler, or rock corer, and represent the significant formations and stratigraphic contacts. Continuous cores should have been taken initially to obtain stratigraphic control. Samples could have been taken at regular intervals, depending on site-specific conditions once stratigraphic control was established. Drilling logs and field records should have been prepared detailing the following information:

- Gross petrography (e.g., soil classification or rock type) of each geologic unit, including the confining unit;
- Gross structural interpretation of each geologic unit and structural features (e.g., fractures, fault gouge, solution channels, buried streams or valleys), bioturbation zones, petrology, and discontinuities;

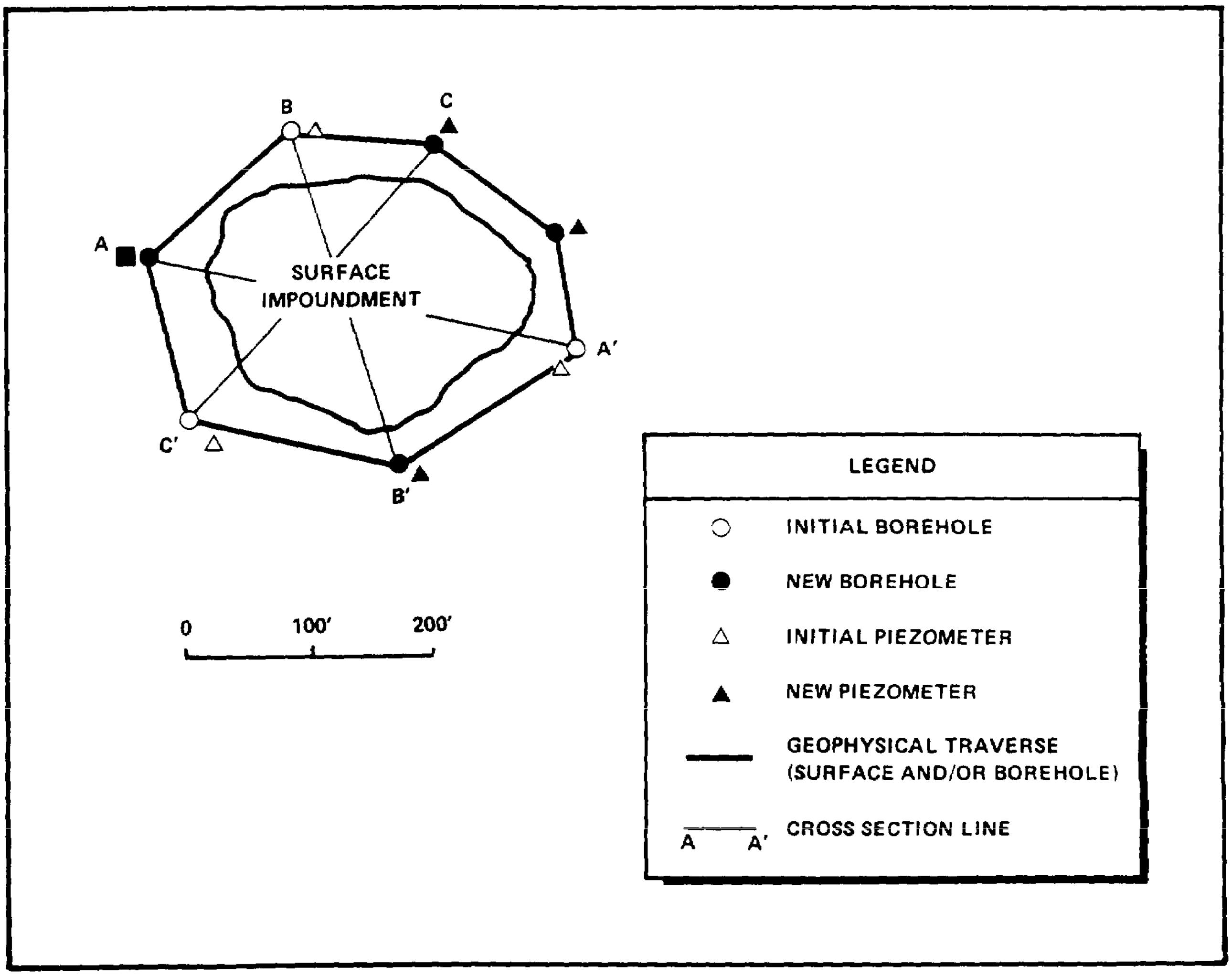
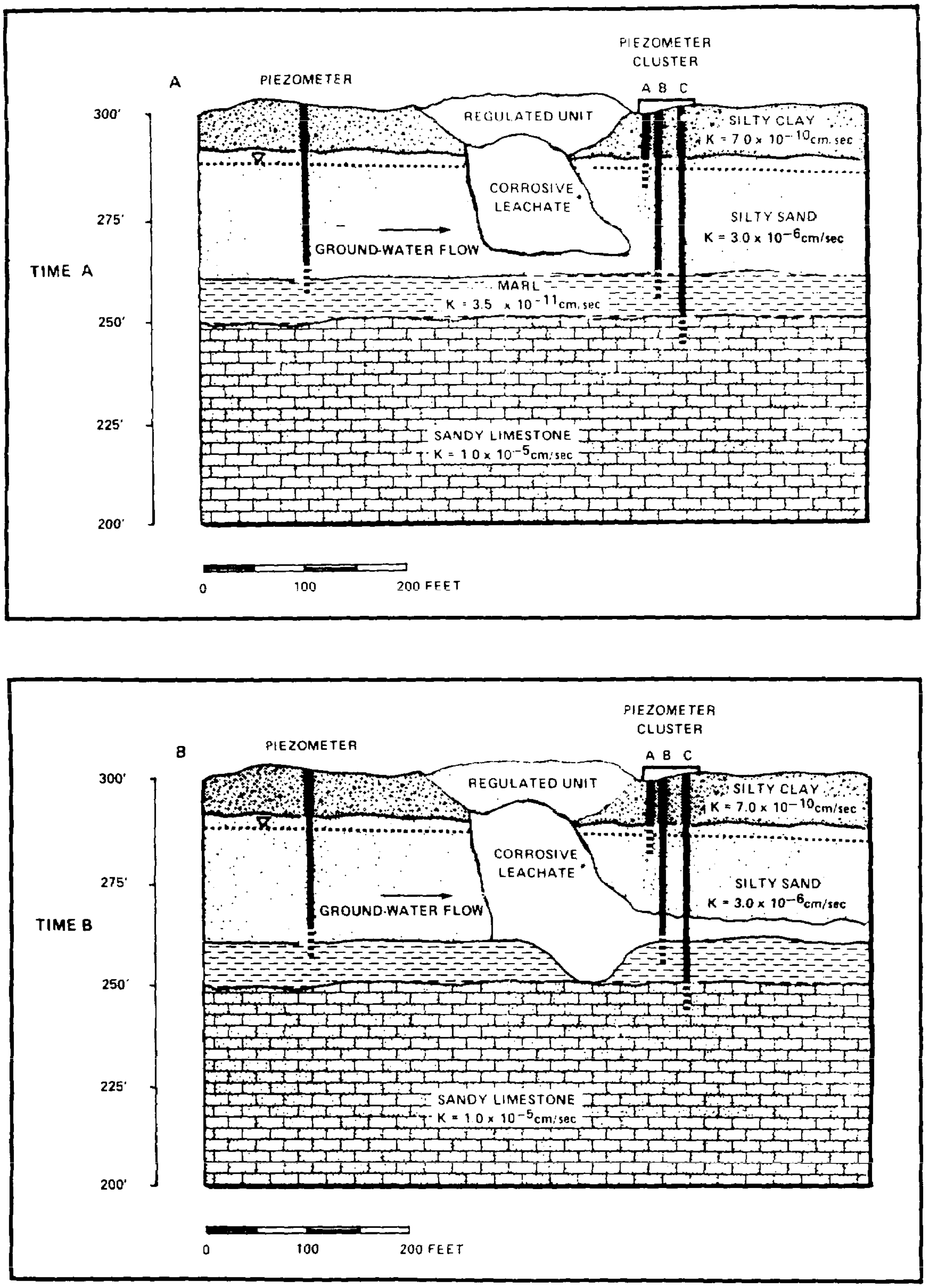


FIGURE 1-2 SUBSEQUENT ITERATION OF BOREHOLE PROGRAM AT A SMALL SURFACE IMPOUNDMENT FROM FIGURE 1-1A.



* SOME CLAYS SUCH AS MONTMORILLONITE AND ILLITE ARE SUSCEPTIBLE TO CHEMICAL ATTACK BY SOLVENT-BASED LEACHATE.

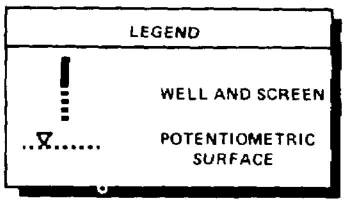


FIGURE 1-3 EXAMPLE OF A CONTAMINANT THAT MAY AFFECT THE QUALITY OF A CONFINING LAYER

- Development of soil zones and vertical extent and field description of soil type (prior to any necessary laboratory analysis);
- Depth of water-bearing unit(s) and vertical extent of each;
- Depth and reason for termination of borehole;
- Depth, location, and identification of any contamination encountered in borehole; and
- Blow counts, colors, and grain-size distributions(s).

Table 1-3 identifies the minimum required information that should have been included in a drilling log. These items are marked with asterisks.

In addition to field descriptions as described above, the owner/operator should have provided, where necessary, a laboratory analysis of each significant geologic unit and soil zone. These analyses should contain the following information:

- Mineralogy and mineralogic variation of the confining layer and confining units/layers, especially clays (e.g., microscopic analysis and other methods such as X-ray diffraction as necessary);
- Petrology and petrologic variation of the confining layer and each unit above the confining unit/layer (e.g., petrographic analysis, other laboratory methods for unconsolidated materials as deemed necessary) to determine among other things:
  - degree of crystallinity and cementation of matrix
  - degree of sorting, size fraction, and textural variation
  - existence of small-scale structures that may affect fluid flow
- Moisture content and moisture variation of each significant soil zone and geologic unit; and
- Hydraulic conductivity and variation of each significant soil zone and type and geologic unit in the unsaturated zone.

Some laboratory analysis methods available to investigate these laboratory parameters are shown in Table 1-4.

TABLE 1-3
FIELD BORING LOG INFORMATION

General

- Project name
- *Hole name/number
- *Date started and finished
- *Geologist's name
- *Driller's name
- Sheet number
- *Hole location; map and elevation
- *Rig type bit size/auger size
- *Petrologic lithologic classification scheme used (Wentworth, unified soil classification system)

Information Columns

- *Depth
- *Sample location/number
- Blow counts and advance rate
- *Percent sample recovery
- *Narrative description
- *Depth to saturation

Narrative Description

- Geologic Observations:
  - *- soil/rock type
  - *- color and stain
  - *- gross petrology
  - - friability
  - *- moisture content
  - *- degree of weathering
  - *- presence of carbonate
  - *- fractures
  - *- solution cavities
  - *- bedding
  - *- discontinuities; e.g., foliation
  - *- water-bearing zones
  - *- formational strike and dip
  - - fossils
  - *- depositional structures
  - *- organic content
  - *- odor
  - *- suspected contaminant

- Drilling Observations:
  - - loss of circulation
  - *- advance rates
  - - rig chatter
  - *- water levels
  - - amount of air used, air pressure
  - *- drilling difficulties
  - *- changes in drilling method or equipment
  - *- readings from detective equipment, if any
  - *- amount of water yield or loss during drilling at different depths
  - *- amounts and types of any liquids used
  - *- running sands
  - *- caving/hole stability

- Other Remarks:
  - - equipment failures
  - *- possible contamination
  - *- deviations from drilling plan
  - *- weather

*Indicates items that the owner/operator should record, at a minimum.

TABLE 1-4

SUGGESTED LABORATORY METHODS FOR SEDIMENT/ROCK SAMPLES

Sample Origin	Parameter	Laboratory Method	Used to Determine
Geologic formation, unconsolidated sediments, consolidated sediments, solum	Hydraulic conductivity	Falling head, static head test	Hydraulic conductivity
	Size fraction	Sieving (ASTM) Settling measurements (ASTM)	Hydraulic conductivity
	Sorting	Petrographic analysis	Hydraulic conductivity
	Specific yield	Column drawings	Porosity
	Specific retention	Centrifuge tests	Porosity
	Petrology/Pedology	Petrographic analysis	Soil type, rock type
	Mineralogy	X-ray diffraction confining clay mineralogy/chemistry	Geochemistry, potential flow paths
	Bedding	Petrographic analysis	
	Lamination	Petrographic analysis	
	Atterberg Limits	ASTM	Soil cohesiveness
Contaminated samples (e.g., soils producing higher than background organic vapor readings)	Appropriate subset of Appendix VIII parameters (§261)	SW-846	Identity of contaminants

*Owners and operators might also want to consider performing this test while they are obtaining the other types of information listed on this table.

1.2.2 Interpretation of Geology Beneath the Site

The technical reviewer should review the owner/operator's geologic characterization and verify:

- The completeness of the narrative and the accuracy of the owner/operator's interpretation, and
- That the geologic assessment addresses or provides means to resolve any information gaps which may be suggested by the geologic data.

In order to assess the completeness and accuracy of the owner/operator's interpretation, the technical reviewer should:

- Examine and evaluate the raw data;
- Compare his own interpretation, based on the raw data, with that of the owner/operator;
- Compare with other studies and information; and
- Identify any information gaps that relate to incomplete data and/or to narrative presentation.

The technical reviewer should independently conduct the following tasks to support and develop his interpretation of the site geology:

- Review drilling logs to identify major rock or soil types and establish their horizontal and vertical variability;
- Construct representative cross sections from well log data;
- Identify zones of suspected high permeability, or structures likely to in luence contaminant migration through the unsaturated and saturated zones;
- Review laboratory data, determine whether laboratory data corroborate field data and that both are sufficient to define petrology; and
- Review mineralogic identification of confining clays and the owner/operator's assessment of general geochemistry and determine corroboration between analytic and field data.

After the technical reviewer has interpreted the geologic data, these results should be compared to the results developed by the owner/operator. The technical reviewer should:

- Identify information gaps between narrative and data.
- Determine whether resolution requires collection of additional data or reassessment of existing data; and
- Identify any information gaps that will affect the owner/operator's ability to have located his/her RCRA monitoring well system.

1.2.3 Presentation of Geologic Data

In addition to the generation and interpretation of site-specific geologic data, the technical reviewer should review the owner/operator's presentation of data in geologic cross sections, topographic maps, and aerial photographs.

An adequate number of cross sections should be presented by an owner/operator to depict significant geologic or structural trends and reflect geologic/structural features in relation to local and regional ground-water flow. Figure 1-4 illustrates an example of a waste disposal unit that is traversed by an adequate number of cross-section lines from which a fence diagram may be created.

On each cross section, the owner/operator should have identified: petrography of significant formations/strata, significant structural features, stratigraphic contacts between significant formations/strata, zones of high permeability or fracture, the location of each borehole, depth of termination, depth to the zone of saturation, and depiction of any geophysical logs. If the owner/operator is unable to supply such details, the site characterization may be inadequate. Figure 1-5 illustrates an example of a geologic cross section. Vertical exaggeration in cross sections should be minimized.

Additionally, surficial features may affect ground-water hydrogeology. An owner/operator should have provided a surface topographic

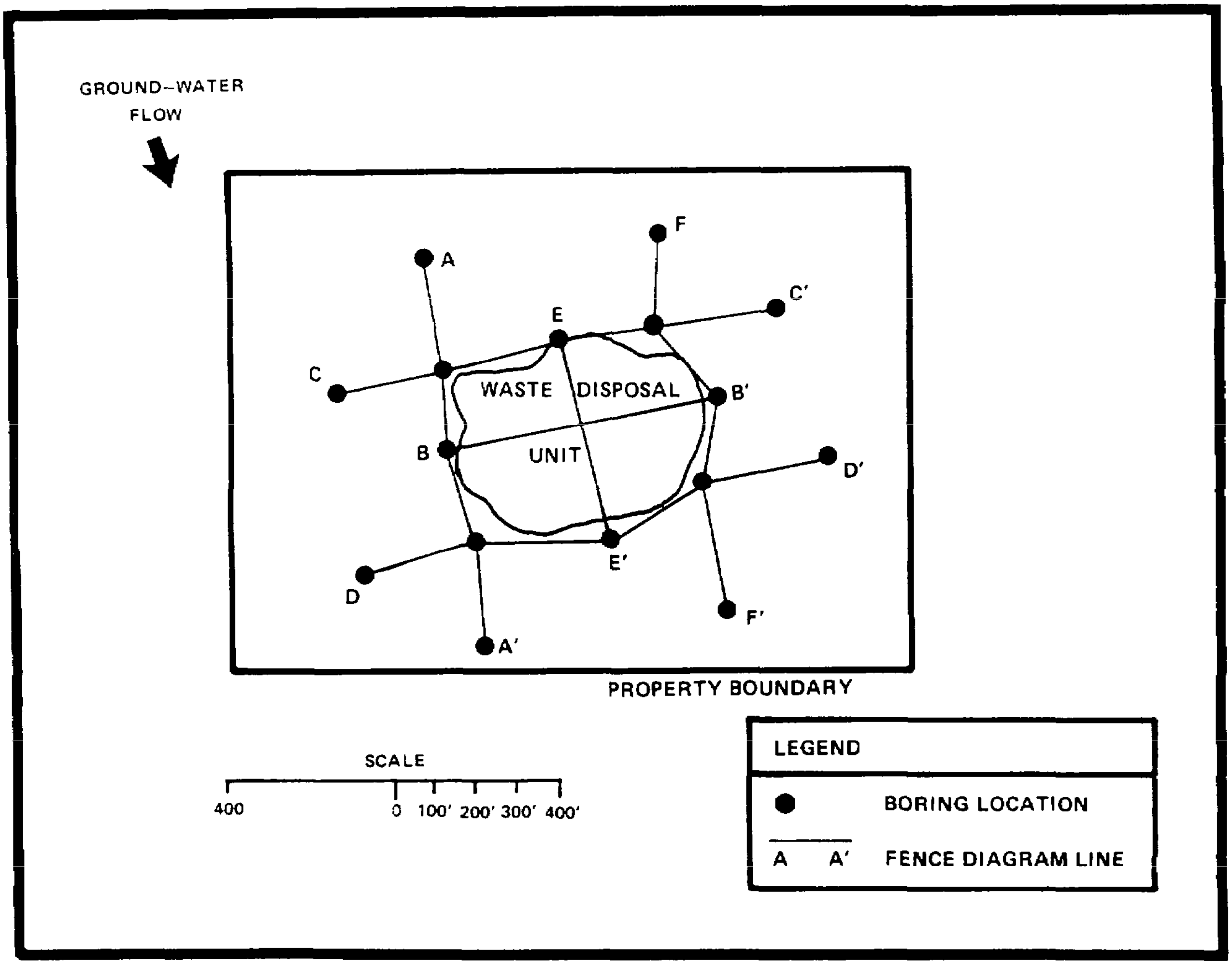


FIGURE 1-4 DATA POINTS USED TO GENERATE A GEOLOGIC FENCE DIAGRAM

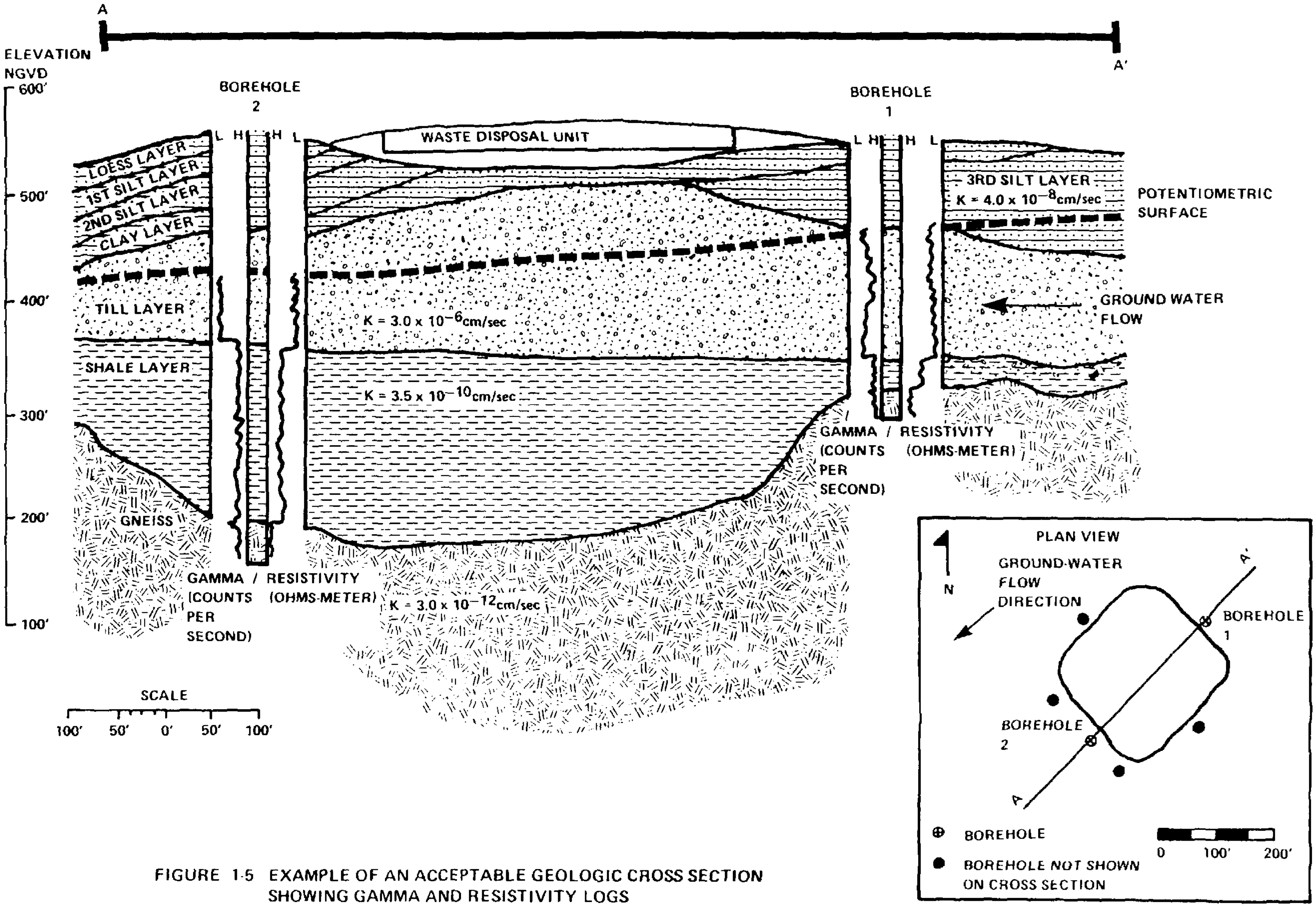


FIGURE 1-5 EXAMPLE OF AN ACCEPTABLE GEOLOGIC CROSS SECTION SHOWING GAMMA AND RESISTIVITY LOGS

map and aerial photograph of the site. The topographic map should have been constructed under the supervision of a licensed surveyor and should provide contours at a two-foot contour interval, locations and illustrations of man-made features (e.g., parking lots, factory buildings, drainage ditches, storm drains, pipelines, etc.), descriptions of nearby water bodies and/or off-site wells, site boundaries, individual RCRA units, delineation of the waste management areas, solid waste management areas, and well and boring locations. An example of a site map is depicted in Figure 1-6. An aerial photograph of the site should depict the site and adjacent off-site features. This photograph should have the site clearly delineated and labeled. In addition, adjacent surface water bodies, municipalities and residences should be labeled.

1.3 Identification of Ground-Water Flow Paths

In addition to evaluating the owner/operator's characterization of geology, technical reviewers must determine whether owner/operators have identified ground-water flow paths. The characterization must have included:

- The direction(s) of ground-water flow (including both horizontal and vertical components of flow);
- The seasonal/temporal, naturally and artificially induced (i.e., off-site production well pumping, agricultural use) variations in ground-water flow; and
- The hydraulic conductivities of the significant hydrogeologic units underlying their site.

In addition, technical reviewers must ensure that owner/operators used appropriate methods for obtaining the above information.

1.3.1 Determining Ground-Water Flow Directions

To locate wells so as to provide upgradient and downgradient well samples, owner/operators should have a thorough understanding of how ground water flows beneath their facility. Of particular importance is

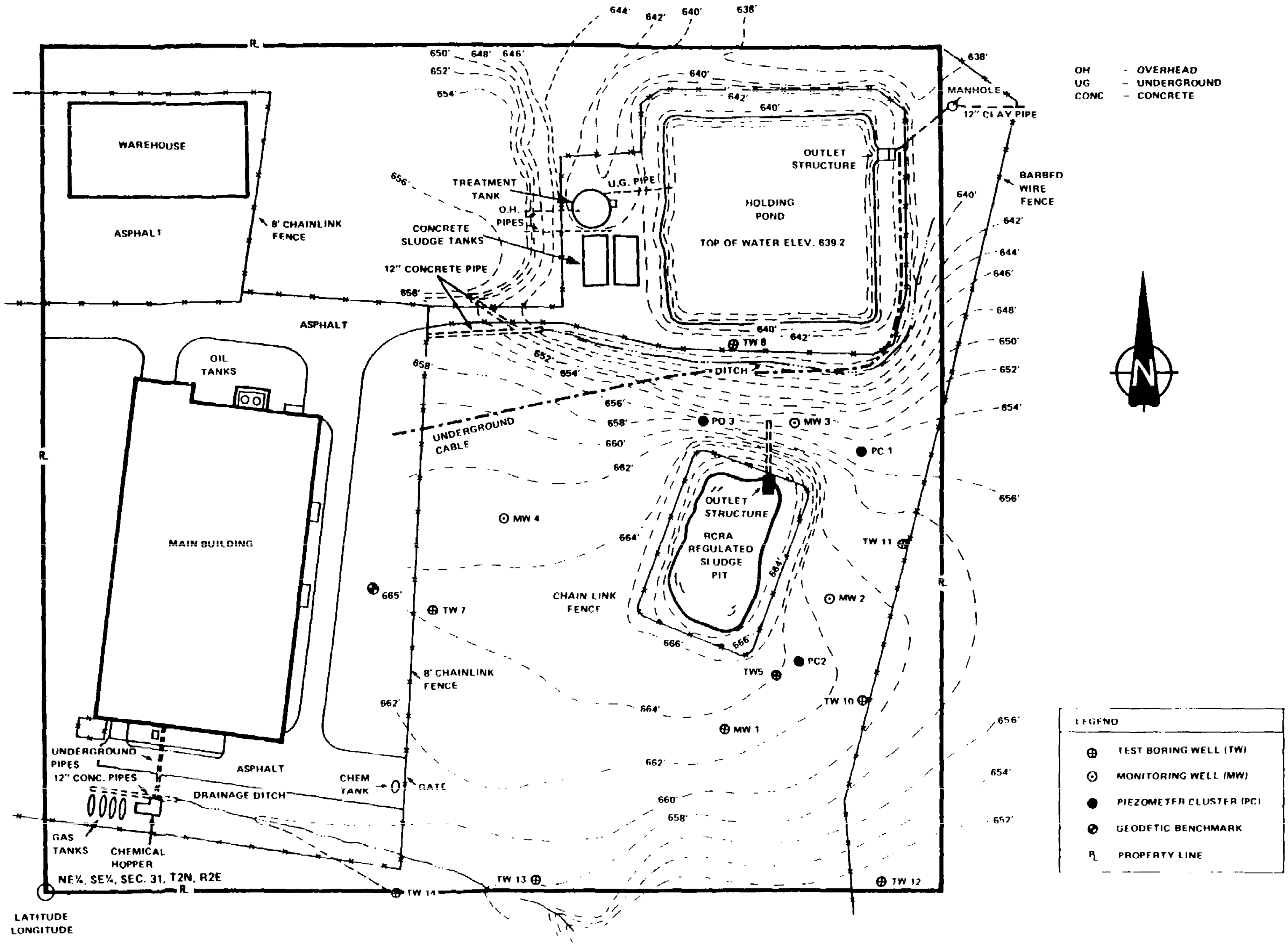


FIGURE 1 6 EXAMPLE OF A TOPOGRAPHIC MAP (2-FOOT CONTOUR INTERVAL) the direction of ground-water flow and the impact that external factors (intermittent well pumping, temporal variations in recharge patterns, etc.) may have on ground-water patterns. In order for an owner/operator to have assessed these factors, a program should have been developed and implemented for precise water level monitoring. This program should have been structured to provide precise water level measurements in a sufficient number of piezometers and at a sufficient frequency to gauge both seasonal average flow directions and to account for seasonal or temporal fluctuation of flow directions.

In addition to considering the components of flow in the horizontal direction, a program should have been undertaken by the owner/operator to accurately and directly assess the vertical components of ground-water flow. Ground-water flow information must be based at least in part on empirical data from borings and piezometers. Technical reviewers should review independently an owner/operator's methodology for obtaining information on ground-water flow and account for factors that may influence that flow at the facility. The following sections provide acceptable methods by which an owner/operator should have assessed the vertical and horizontal components of flow at the site.

1.3.1.1 Ground-water level measurements

In order for the owner/operator to have initially determined the elevation of the potentiometric surface in any monitoring well or piezometer, several criteria should have been considered by the owner/operator.

- The casing height should have been measured by a licensed surveyor to an accuracy of 0.01 feet. This may have required the placement of a topographic benchmark on the facility property.
- Generally, water level measurements from boreholes, piezometers, or monitoring wells used to construct a single potentiometric surface should have been collected within a 24-hour period. This practice is adequate if the magnitude of change is small over

that period of time. There are other situations, however, which necessitate that all measurements be taken within a short time interval:

- tidally influenced aquifers;
- aquifers affected by river stage, impoundments, and/or unlined ditches;
- aquifers stressed by intermittent pumping of production wells; and
- aquifers being actively recharged due to a precipitation event.

* The method used to measure water levels should have been adequate to attain an accuracy of 0.01 feet.
* A survey mark should be placed on the casing for use as a measuring point. Many times the lip of the riser pipe is not flat. Another measuring reference should be located on the grout apron.
* Piezometers should be re-surveyed periodically to determine the extent of subsidence or rise in ground surface.
* Water levels in piezometers should have been allowed to stabilize for a minimum of 24 hours after well construction and development, prior to measurement. In low yield situations, recovery may take longer.

If an owner/operator cannot produce accurate documentation or provide assurance that these criteria were met during the collection of water level measurements, this may indicate that the generated information may be inadequate.

In cases where immiscible contamination is found during the characterization, water level measurements should be adjusted to reflect its true elevation.

1.3.1.2 Interpretation of ground-water level measurements

After the technical reviewer has assured that the water level data are valid, he should proceed to independently interpret the information. The technical reviewer should:

- Use the owner/operator's raw data to construct a potentiometric surface map (see Figure 1-7). The data used to develop the potentiometric map should be data from piezometers/wells screened at equivalent stratigraphic horizons;

- Compare these data with that of the owner/operator and determine whether the owner/operator has accurately presented the information, and ascertain if the information is sufficient to describe ground-water flow trends; and

- Identify any information gaps.

In reviewing this information, the technical reviewer should now have an approximate idea of the general flow direction; however, in order to have properly located monitoring wells, the owner/operator should have established hydraulic gradient (flow direction) in both the horizontal and vertical directions.

1.3.1.3 Establishing vertical components of ground-water flow

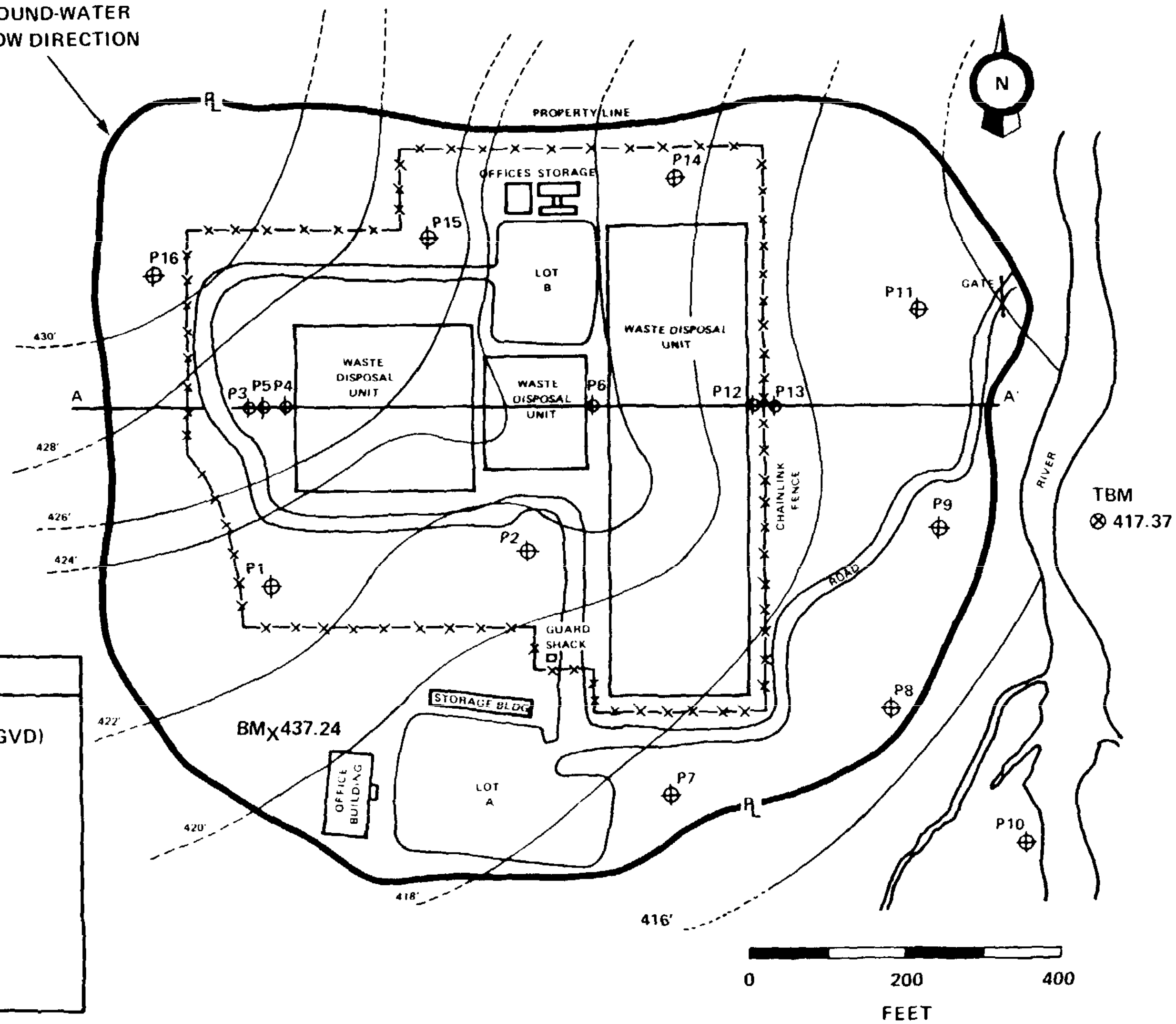
In order for the owner/operator to have determined the direction of flow, vertical components of flow must have been directly determined. This will have required the installation of piezometers in clusters. A piezometer cluster is a closely spaced group of wells screened at different depths to measure vertical variations in hydraulic head. To obtain reliable measurements, the following criteria should be considered in the placement of piezometer clusters:

- Information obtained from multiple piezometer placement in single boreholes may generate erroneous data. Placement of vertically nested piezometers in closely spaced separate boreholes is the preferred method.

- Piezometer measurements should have been collected at least within a 24-hour period, and within shorter intervals under certain conditions, if measurements are to be used in any correlative presentation of data.

- Piezometer measurements should have been determined along a minimum of two vertical profiles across the site. These profiles should be cross sections roughly parallel to the direction of ground-water flow indicated by the potentiometric surface.

PIEZOMETER	WATER - LEVEL ELEVATION	DATE RECORDED
P1	423.10	3/2/85
P2	421.76	3/2/85
P3	427.13	3/2/85
P4	426.96	3/2/85
P5	427.05	3/2/85
P6	422.36	3/2/85
P7	417.55	3/2/85
P8	416.32	3/2/85
P9	417.10	3/2/85
P10	413.26	3/2/85
P11	416.35	3/2/85
P12	419.10	3/2/85
P13	419.01	3/2/85
P14	420.63	3/2/85
P15	426.73	3/2/85
P16	431.48	3/2/85



LEGEND

420	POTENTIOMETRIC SURFACE (NGVD)
⊕ P3	PIEZOMETER LOCATION
BM x 437.24	BENCH MARK
TBM ⊗ 417.37	TEMPORARY BENCH MARK
℞	PROPERTY LINE

FIGURE 1-7 POTENTIOMETRIC SURFACE MAP

When reviewing piezometer information obtained from multiple placement of piezometers in single boreholes, the technical reviewer should closely scrutinize the construction details for the well. It is extremely difficult to adequately seal several piezometers at discrete depths within a single borehole, and special design considerations should have been considered by the owner/operator. If detailed information for the design is not available, it may indicate that adequate construction considerations have not been used. Placement of piezometers in closely spaced well clusters, where piezometers have been screened at different, discrete depth intervals, is more likely to produce accurate information. Additionally, multiple well clusters sample a greater proportion of the aquifer, and thus may provide a greater degree of accuracy for considerations of vertical potentiometric head in the aquifer as a whole.

The information obtained from the piezometer readings should have been used by the owner/operator to construct flow nets (see Figure 1-8). These flow nets should include information as to piezometer depth and length of screening. The flow net in Figure 1-8 was developed from information obtained from piezometer clusters screened at different, discrete intervals. The technical reviewer should be able to verify the accuracy of the owner/operator's presentation and calculations by either constructing a flow net independently from the owner/operator's data or spot-checking the owner/operator's presentation. It is also important to verify that the screened interval is accurately portrayed and to determine whether the piezometer is actually monitoring the water level of the desired water-bearing unit.

If there is reasonable concurrence between the information presented by the owner/operator and the technical reviewer's interpretation, the technical reviewer should next interpret the flow directions from the waste management area.

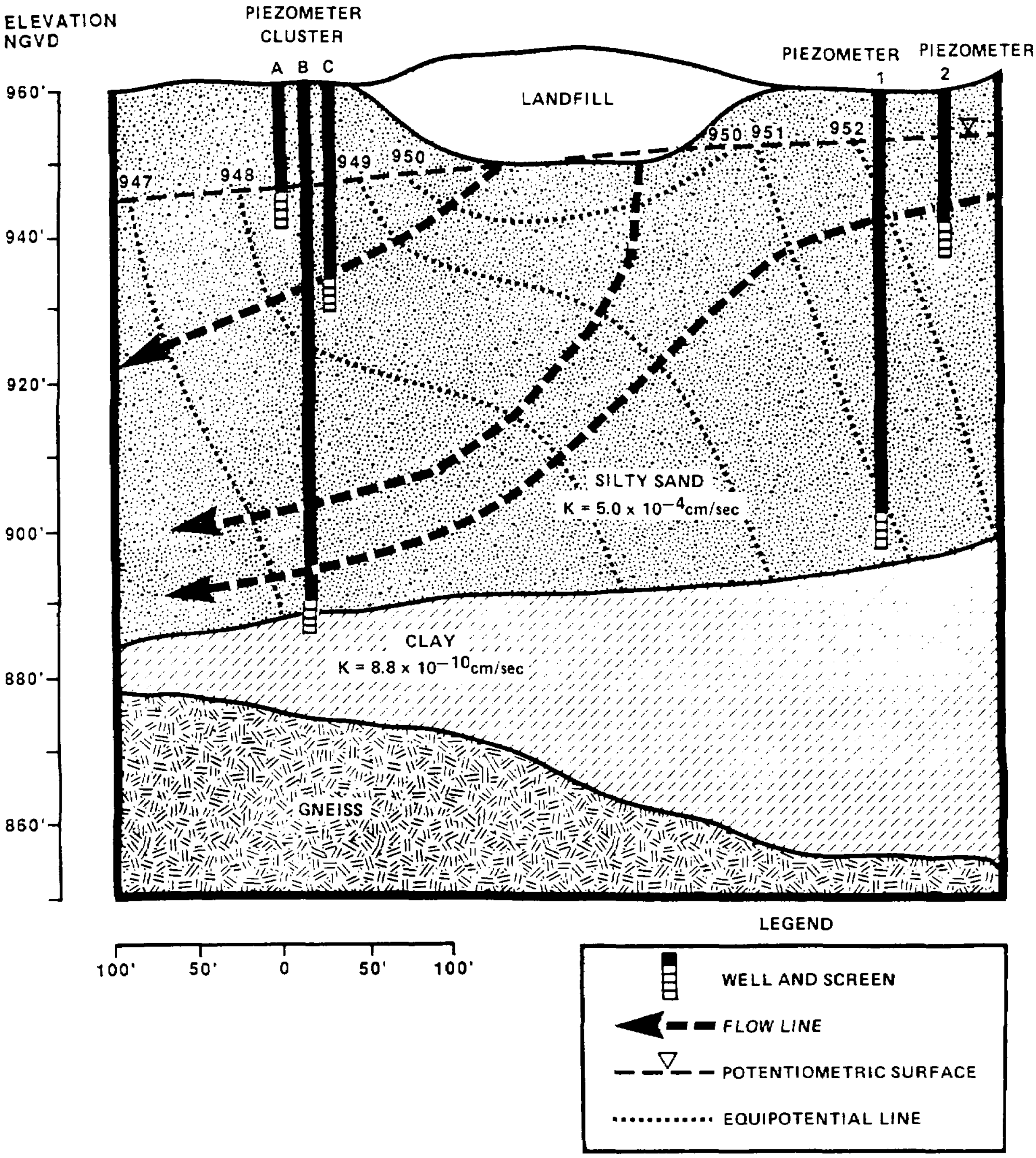


FIGURE 1-8. AN EXAMPLE OF A FLOW NET DERIVED FROM PIEZOMETER DATA

1.3.1.4 Interpretation of flow direction and flow rates

In considering flow directions established by the owner/operator, the technical reviewer should have first established:

- That the potentiometric surface measurements are valid; that is the distributions of hydraulic head and hydraulic conductivity are known, and that the total porosities as approximations of effective porosities (determination of effective porosity can be time consuming) of significant strata are known to permit estimation of flow rate; and

- That the vertical components of flow have been accurately depicted and are based on valid data.

At this point, general direction(s) and rate(s) of ground-water flow may be estimated. The technical reviewer should construct vertical intercepts with the potentiometric contours for both the potentiometric surface map and flow nets. Once the vertical and horizontal directions of flow are established (from points of higher to lower hydraulic head), it is possible to estimate where monitoring wells will most likely intercept contaminant flow in the vertical plane. To consider the placement that will most effectively intercept contaminant flow, hydraulic conductivity(ies) must be calculated.

1.3.2 Seasonal and Temporal Factors: Ground-Water Flow

It is important to note if the owner/operator has identified and assessed factors that may result in short-term or long-term variations in ground-water level and flow patterns. Such factors that may influence ground-water conditions include:

- Off-site well pumping, recharges, and discharges;
- Tidal processes or other intermittent natural variations (e.g., river stage, etc.);
- On-site well pumping;
- Off-site, on-site construction or changing land use patterns;
- Deep well injection; and
- Waste disposal practices.

Off-site or on-site well pumping may affect both the rate and direction of ground-water flow. Municipal, industrial, or agricultural ground-water use may significantly change ground-water flow patterns and levels over time. Pumpage may be seasonal or dependent upon complex water use patterns. The effects of pumpage thus may reflect continuous or discontinuous patterns. Water level measurements in piezometers must have been frequent enough to detect such water use patterns.

Natural processes such as riverine, estuarine, or marine tidal movement may result in variations of well water levels and/or ground-water quality. An owner/operator should have documented the effects of such patterns. Seasonal patterns have a significant effect on hydraulic head and ground-water flow. Short-term recharge patterns may affect ground-water flow patterns that are markedly different from ground-water flow patterns determined by seasonal averages. An owner/operator should have gauged such transitional patterns.

Additionally, an owner/operator should have implemented means for gauging long-term effects on water movement that may result from on-site or off-site construction or changes in land-use patterns. Development may affect ground-water flow by altering recharge or discharge patterns. Examples of such changes might include the paving of recharge areas or damming of waterways.

In reviewing the owner/operator's assessment of ground-water flow patterns, the technical reviewer should consider whether the owner/operator's program was sensitive to such seasonal or temporal variations. An owner/operator should have, in effect, determined not only the location of water resources, but the sources and source patterns that contribute to or affect ground-water patterns below the regulated site.

1.3.3 Determining Hydraulic Conductivities

In addition to defining vertical and horizontal gradients and sources of spatial and temporal variation, the owner/operator must identify the distribution hydraulic conductivity (K) values within each significant formation. Variations in the hydraulic conductivity within or between formations or strata can create irregularities in ground-water flow paths. Strata/formations of high hydraulic conductivity represent areas of greater ground-water flow and therefore zones of potential migration. Further, anisotropy within strata or formations affects the magnitude and direction of ground-water flow. Thus, information on hydraulic conductivities is necessary before owner/operators can make reasoned decisions regarding well placements.

Technical reviewers should review the owner/operator's hydrogeologic assessment to ensure that it contains data on the hydraulic conductivities of the significant formations underlying the site. In addition, technical reviewers should review the method the owner/operator used to derive the conductivity values. It may be beneficial to use analogous or laboratory methods to augment results of field tests; however, field methods provide the best definition of the hydraulic conductivity in most cases.

Hydraulic conductivity can be determined in the field using either single or multiple well tests. Single well tests, more commonly referred to as slug tests, are performed by suddenly adding or removing a slug (known volume) of water from a well and observing the recovery of the water surface to its original level. Similar results can be achieved by pressurizing the well casing, depressing the water level, and suddenly releasing the pressure to simulate removal of water from the well. One recommended method, which will be proposed for inclusion in SW-846 (Test Methods for Evaluating Solid Waste, U.S. EPA, July 1982), is Method 9100, which is also recommended for use in determining aquifer vulnerability.

When reviewing information obtained from single well tests, the technical reviewer should consider several criteria. First, they are run on one well and, as such, the information is limited in scope to the geologic area directly adjacent to the screen. Second, the vertical extent of screening will control the part of the geologic formation that is being tested during the test. That part of the column above or below the screened interval that has not been tested may also have to be tested for hydraulic conductivity. Third, the methods that the owner/operator used to collect the information obtained from single well tests should be adequate to measure accurately parameters such as changing static water (prior to initiation, during, and following completion of the test), the amount of water added to, or removed from, the well, and the elapsed time of recovery. This is especially important in highly permeable formations where pressure transducers and high speed recording equipment may need to be used. The owner/operator's interpretation of the single well test data should be consistent with the existing geologic information (boring log data). The well screen and filter pack adjacent to the interval under examination should have been properly developed to ensure the removal of fines or correct deleterious drilling effects. It is, therefore, important that reviewers examine the owner/operator's program of single well testing to ensure that enough tests were run to provide representative measures of hydraulic conductivity and to document lateral variations of hydraulic conductivity at various depths in the subsurface.

Multiple well tests, more commonly referred to as pumping tests, are performed by pumping water from one well and observing the resulting drawdown in nearby wells. Tests conducted with wells screened in the same water-bearing formation provide hydraulic conductivity data. Tests conducted with wells screened in different water-bearing zones furnish information concerning hydraulic communication. Multiple well tests for hydraulic conductivity are advantageous because they characterize a greater proportion of the subsurface and thus provide a greater amount of detail. Multiple well tests are subject to similar constraints to those listed above for single well tests. Some additional problems that should have been considered by the owner/operator conducting a multiple well test include: (1) storage of potentially contaminated water pumped from the well system and (2) potential effects of ground-water pumping on existing waste plumes. The technical reviewer should consider the geologic constraints that the owner/operator has used to interpret the pumping test results. Incorrect assumptions regarding geology may translate into incorrect estimations of hydraulic conductivity.

In reviewing the owner/operator's hydraulic conductivity measurements, the technical reviewer should use the following criteria to determine the accuracy or completeness of information.

- Values of hydraulic conductivity between wells in similar lithologies should not exceed one order of magnitude difference. If values exceed this difference, the owner/operator may not have provided enough information to sufficiently define a potential flow path, or there is a mistake in the logs.

- Hydraulic conductivity determinations based upon multiple well tests are preferred. Multiple well tests provide more complete information because they characterize a greater portion of the subsurface.

- Use of single well tests will require that more individual tests be conducted at different locations to sufficiently define hydraulic conductivity variation across the site.

- Hydraulic conductivity information generally provides average values for the entire area across a well screen. For more depth discrete information, well screens will have to be shorter. If the average hydraulic conductivity for a formation is required, entire formations may have to be screened, or data taken from overlapping clusters.

It is important that measurements define hydraulic conductivity both vertically and horizontally across an owner/operator's regulated site. Laboratory tests may be necessary to ascertain vertical hydraulic conductivity in saturated formations or strata. In assessing the completeness of an owner/operator's hydraulic conductivity measurements, the technical reviewer should also consider results from the boring program used to characterize the site geology. Zones of high permeability or fractures identified from drilling logs should have been considered in the determination of hydraulic conductivity. Additionally, information from boring logs can be used to refine the data generated by single well or pumping tests.

1.4 Identification of the Uppermost Aquifer

The owner/operator is required under 40 CFR §265 Subpart F to monitor the uppermost aquifer beneath the facility in order to immediately detect a release. Proper identification of the uppermost aquifer is therefore essential to the establishment of a compliant ground-water monitoring system. EPA has defined the uppermost aquifer as the geologic formation, group of formations, or part of a formation that is the aquifer nearest to the ground surface and is capable of yielding a significant amount of ground water to wells or springs (40 CFR §260.10) and may include fill material that is saturated. The identification of the confining layer or lower boundary is an essential facet of the definition of uppermost aquifer. There should be very limited interconnection, based upon pumping tests, between the uppermost aquifer and lower aquifers.* If zones of saturation capable of yielding significant amounts of water are interconnected, they all comprise the uppermost aquifer. Quality and use of ground water are not factors in the definition. Even though a saturated formation may not be presently in use, or may contain water not suitable for human consumption, it may deserve protection because contaminating it may threaten human health or the environment. Identification of formations capable of "significant yield" must be made on a case-by-case basis.

There are saturated zones, such as low permeability clay, that do not yield a significant amount of water, yet act as pathways for contamination that can migrate horizontally for some distance before reaching a zone which yields a significant amount of water. If there is reason to believe that a potential exists for contamination to escape along such pathways, the technical reviewer may invoke enforcement and permitting authorities other than §265.91 to require such zones to be monitored. These authorities include 3008(h) for interim status

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*Some hydrogeologic settings (e.g., basin and range provinces, alluvial depositional environments) do not offer a clear confining layer. In such cases, the technical reviewer should note the situation and concentrate on the placement of wells in the uppermost aquifer to immediately detect potential releases of contaminants.

corrective action, 3004(u) for corrective action for permitting, the omnibus condition authority under 3005(c) which mandates permit conditions to protect human health and the environment, and 3013 authority which permits broad investigations. Of course, if a release has been detected the plume should be characterized in such saturated zones regardless of yield.

In all cases, the obligation to assess any hydraulic communication and the proper definition of the uppermost aquifer rests with the owner/operator. The owner/operator should be able to prove that the confining unit is of sufficiently low permeability as to minimize the passage of contaminants to saturated, stratigraphically lower units.

The following examples illustrate geologic settings wherein hydraulic communication must be demonstrated before proper identification of the uppermost aquifer can be made. The examples are not intended to be exhaustive in the situations they portray; rather, they are meant to provide a sample of geologic settings that depict hydraulic communication.

Figure 1-9 illustrates a site where preliminary drill logs indicated a confining layer of unfractured, continuous clay beneath the site. (Note: the actual geologic conditions are pictured for purposes of clarity in the figure.) In order to confirm whether the clay layer is continuous or discontinuous, the owner/operator conducted a pumping test. A well at drill point No. 2 was screened at the uppermost part of the potentiometric surface. Another well at drill point No. 3 was located close by and screened below the clay layer. Measurable drawdown was observed in the upper well when the well below the confining layer was pumped. This indicated that the confining unit is not of sufficient impermeability to serve as a significant boundary to contaminant flow. In this case, the water-bearing unit below the clay layer and the formation above the clay layer are both part of the uppermost aquifer.

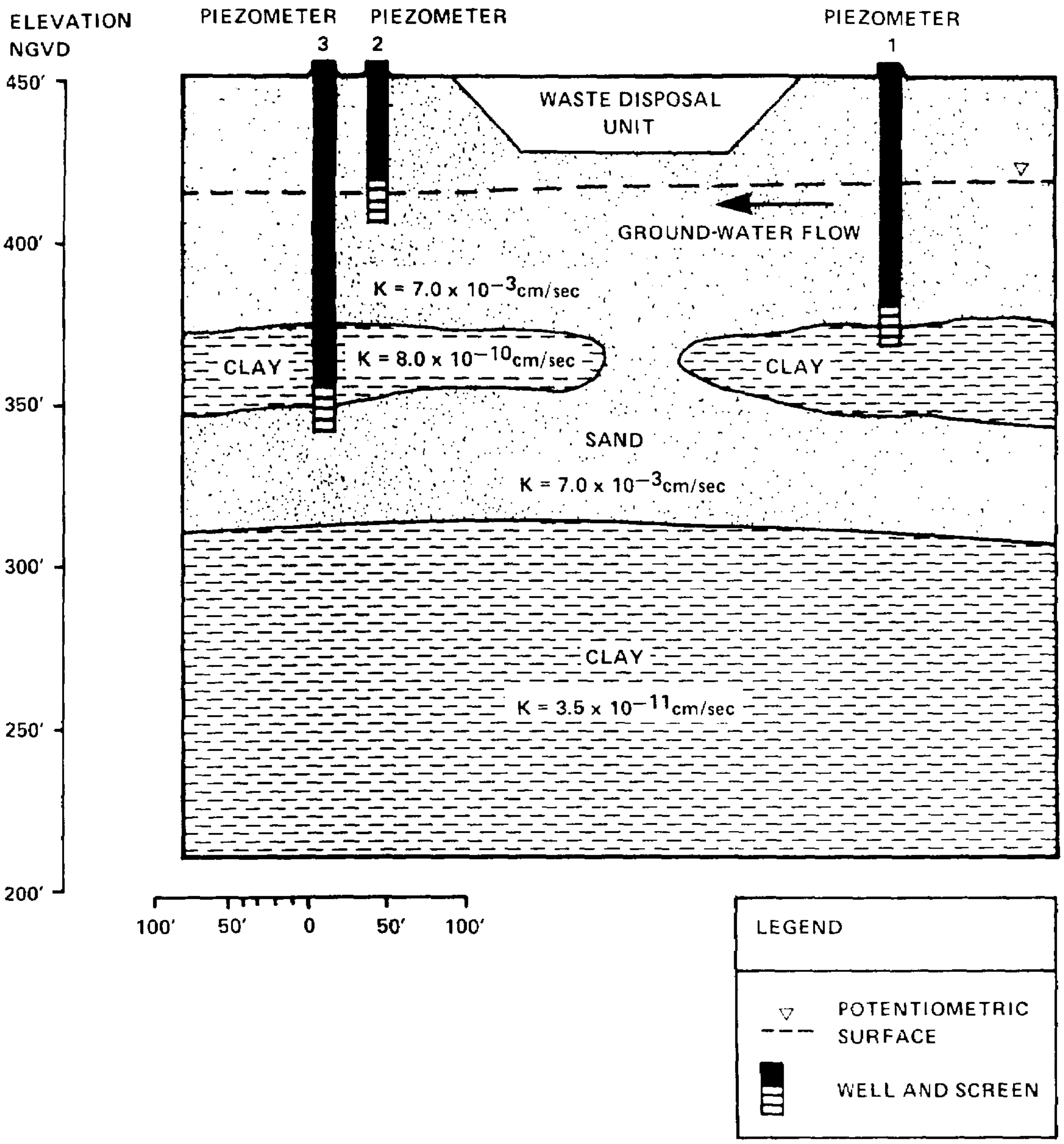

FIGURE 1-9 EXAMPLE OF HYDRAULIC COMMUNICATION BETWEEN WATER - BEARING UNITS

In Figure 1-10, the owner/operator drilled test borings through sand and limestone formations into a sandstone unit. In the initial cores, no indication of fracturing of the limestone unit was observed. The owner/operator initially assumed that the limestone unit dips at a moderate slope due to differing levels of contact. However, as illustrated by the figure, actual conditions involve faulting and post-depositional erosion of the limestone formation (additional corings and geophysical studies detected fracture zones). These fractures represent hydraulic communication between the upper unconsolidated sand layer and the sandstone formation below the limestone unit. The uppermost aquifer, therefore, includes the unconsolidated sand formation, the limestone formation, and the sandstone formation.

Figure 1-11 illustrates a situation where perched water zones lie above the potentiometric surface. The containment pathway includes the perched water zones and that part of the sand formation from the top of the potentiometric surface to the top of the granitic basement.

In Figure 1-12, initial test borings indicated that horizontal sand units are underlain by a consolidated, well-cemented, limestone unit. Initial borings did not indicate the presence of the anticline. The owner/operator incorrectly assumed that the sandstone unit was a confining layer that extended across the subsurface below the site. A dolomite unit, in contact with the unconsolidated sandy silts and directly below the waste unit, is fractured and highly permeable. Additional investigation including pump tests, borings, and/or geophysical analysis better defined the subsurface. The uppermost aquifer, in this case, includes the anticlinal formations.

In Figure 1-13, unconsolidated units are underlain by a consolidated series of variable, near-shore, shallow marine sediments. The owner/operator has installed three borings near the waste management unit to identify the uppermost aquifer. Interpretation of these borings indicates that the unconsolidated units are underlain by a well-cemented limestone

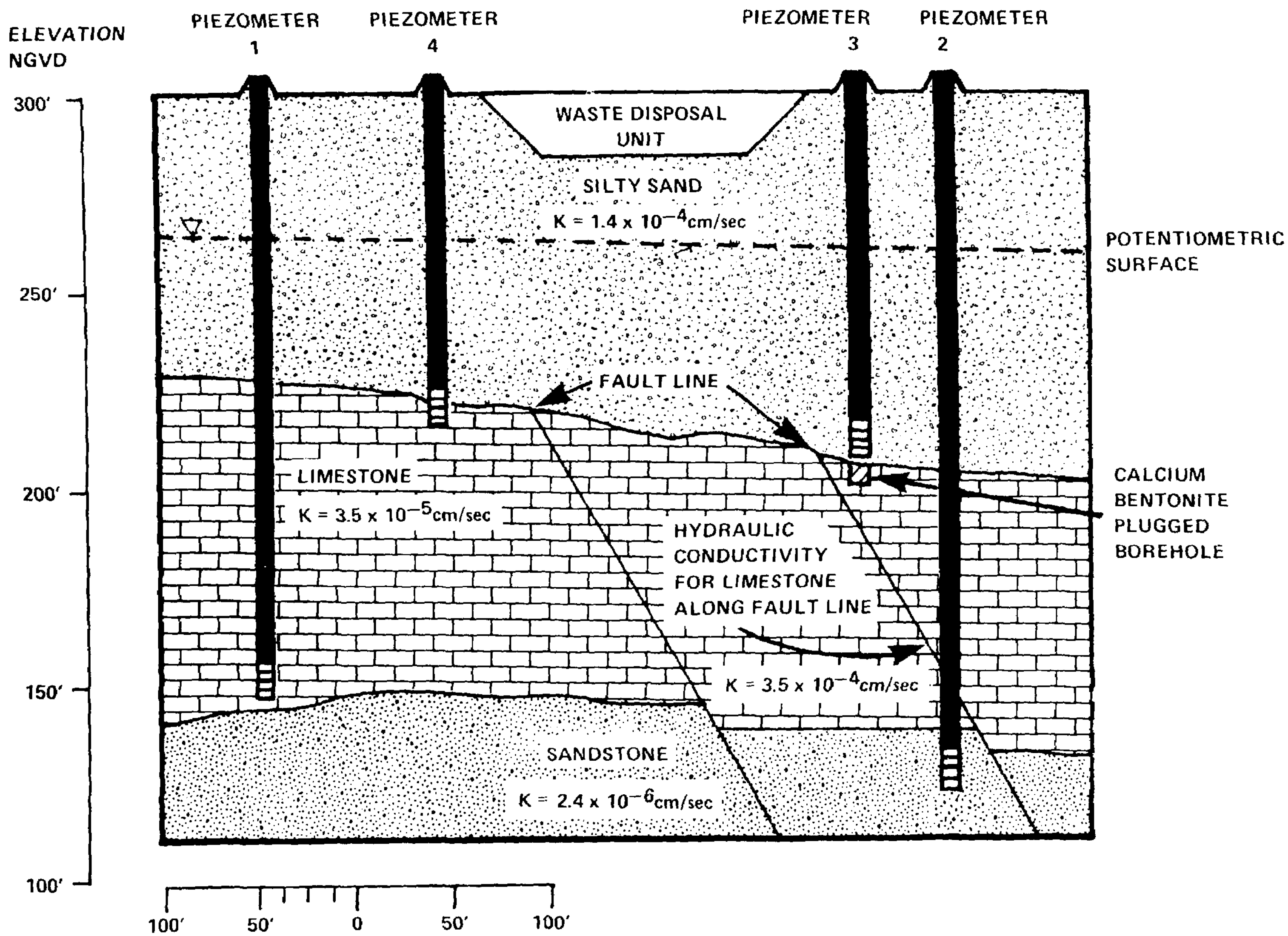

FIGURE 1-10 AN EXAMPLE OF HYDRAULIC COMMUNICATION CAUSED BY FAULTING

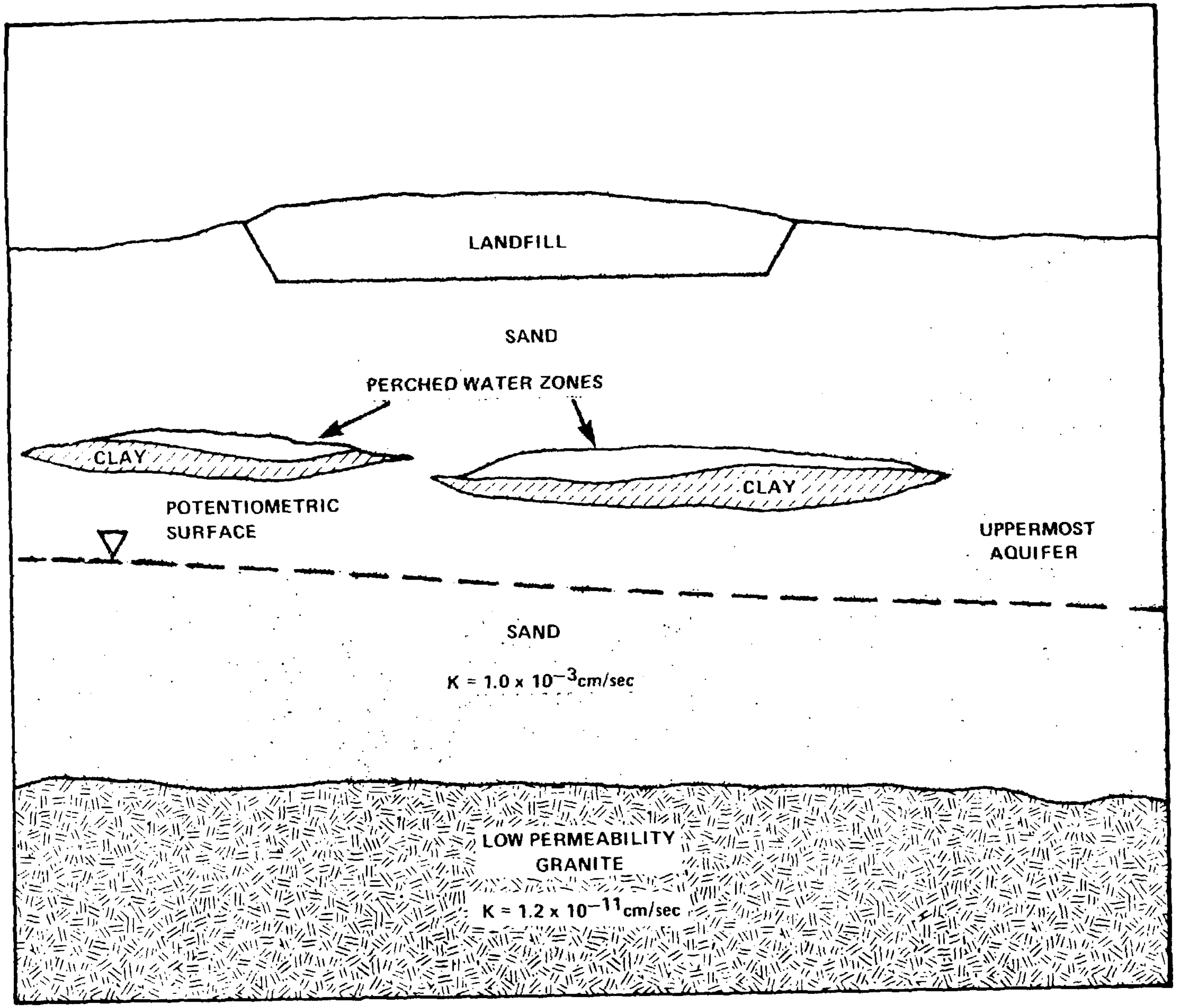

FIGURE 1-11 PERCHED WATER ZONES AS PART OF THE UPPERMOST AQUIFER

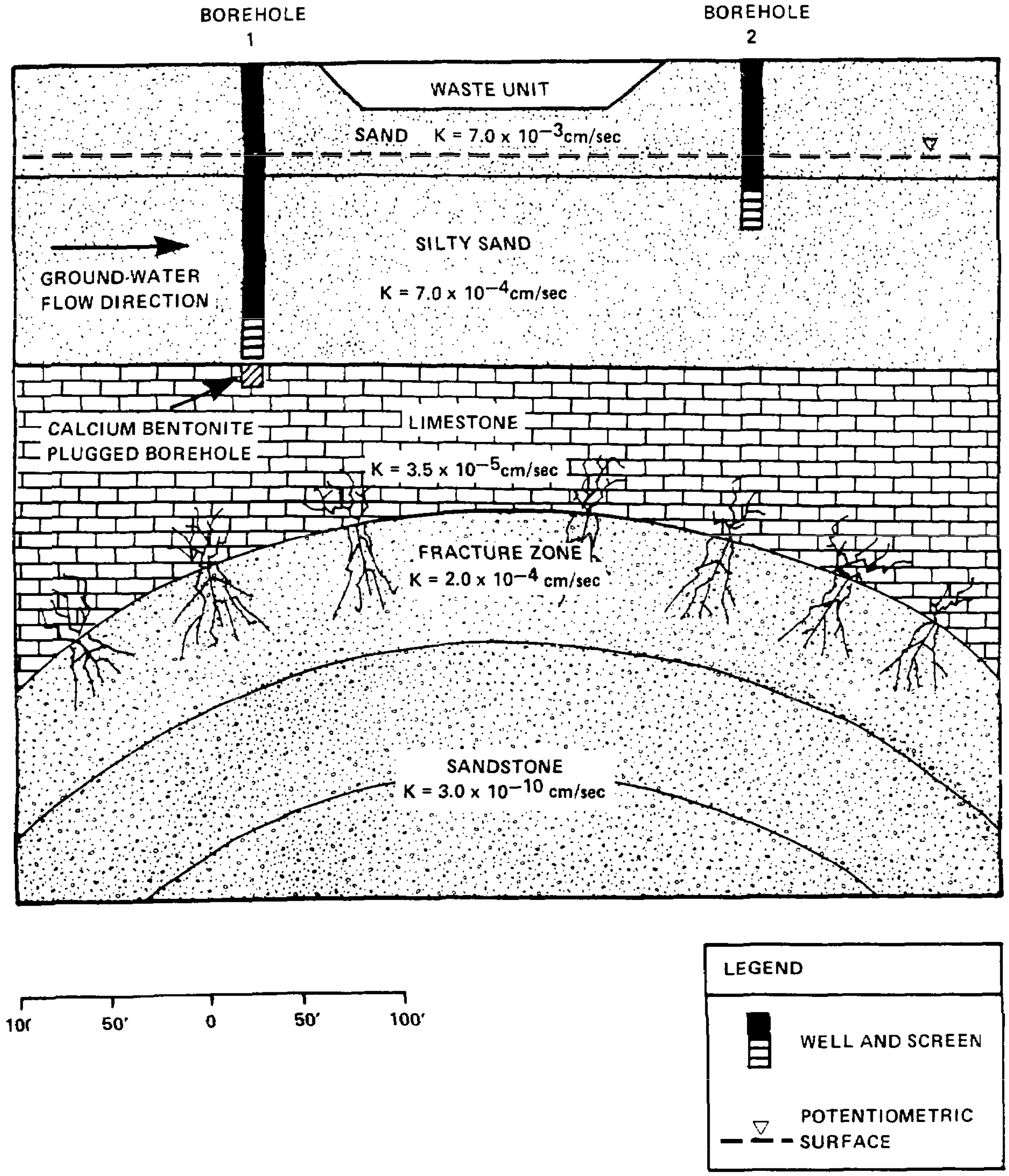

FIGURE 1-12 AN EXAMPLE OF AN UNDETECTED STRUCTURE IN THE UPPERMOST AQUIFER (VERTICAL SCALE IS EXAGGERATED).

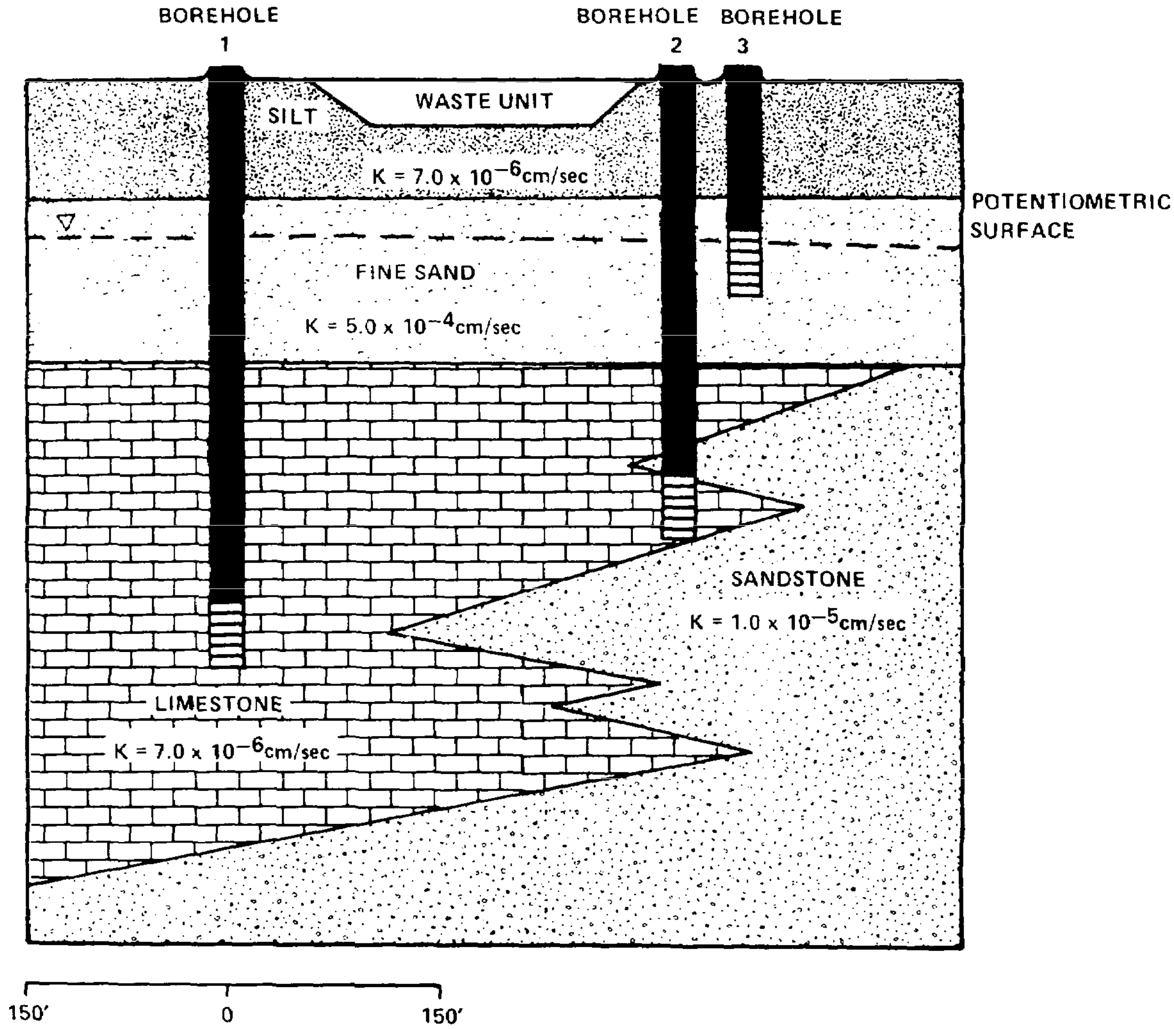

FIGURE 1-13 AN EXAMPLE OF AN UNDETECTED PORTION OF THE UPPERMOST AQUIFER DUE TO AN IMPROPERLY SCREENED BOREHOLE (VERTICAL SCALE IS EXAGGERATED)

of very low permeability. However, an undetected sandstone unit, which is laterally continuous with the limestone unit, is highly permeable and saturated and represents an undetected portion of the uppermost aquifer. Interpretation of the depositional environment of the limestone unit, coupled with a knowledge of the local or regional geology, should have been used in addition to other investigatory techniques to establish the presence of the transitional lateral structural feature and thus properly define the uppermost aquifer.

A special case that should be considered by the technical reviewer is the possibility that existing wells may provide avenues for hydraulic communication between hydrogeologic units. This is of special importance when considering a site where a contaminant plume may have migrated down-gradient to the extent that the plume approaches off-site wells. Such wells may not have been constructed in a manner sensitive to problems of cross-contamination between aquifers (see Chapter Four).

The goal of the site characterization is the identification of potential pathways for contaminant migration in the uppermost aquifer. The next step is to complete the installation of monitoring wells and piezometers in those pathways and upgradient, which will comprise the detection monitoring network.

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CHAPTER TWO

PLACEMENT OF DETECTION MONITORING WELLS

The purpose of this chapter is to examine criteria the technical reviewer should use in deciding if the owner/operator has made proper decisions regarding the number and location of detection monitoring wells. In evaluating the design of an owner/operator's detection monitoring system, the technical reviewer should examine the placement of upgradient and downgradient monitoring wells relative to hazardous waste management units, and review the placement and screening of detection monitoring wells for their interception of predicted pathways of migration. The minimum number of monitoring wells an owner/operator may install in a detection monitoring system under the regulations is four--one upgradient well and three downgradient wells. Typically, site hydrogeology is too complex or the hazardous waste unit is too large for the regulatory minimum number of wells to prove adequate in achieving the performance objectives of a detection monitoring system.

A fundamental concept that will be emphasized throughout this chapter is that the placement and screening of wells in the detection monitoring network will be based on the results of a thorough site characterization. The basic goals of the site characterization process as described in Chapter One are the description of the hydrogeological regime and the identification of the uppermost aquifer and potential pathways for contaminant migration. This information is the foundation for the entire ground-water monitoring program and crucial to the placement of detection monitoring wells in particular. It is likely that the technical reviewer may encounter situations where the owner/operator has collected little or no site hydrogeologic information or has relied exclusively on regional data to design a monitoring system. In this situation, the technical reviewer should carefully examine the decisions the owner/operator has made regarding well placement and screen depths, and it may be necessary to require the owner/operator to collect additional site information.

Upgradient monitoring wells are to provide background ground-water quality data in the uppermost aquifer. Upgradient wells must be (1) located beyond the upgradient extent of potential contamination from the hazardous waste management unit to provide samples representative of background water quality, (2) screened at the same stratigraphic horizon(s) as the downgradient wells to ensure comparability of data, and (3) of sufficient number to account for heterogeneity in background ground-water quality.

It is important to recognize that potential pathways for contaminant migration are three dimensional. Consequently, the design of a detection monitoring network that intercepts these potential pathways requires a three-dimensional approach. Downgradient monitoring wells must be located at the edge of hazardous waste management units to satisfy the regulatory requirements for immediate detection. The placement of detection monitoring wells along the downgradient perimeter of hazardous waste management units must be based upon the abundance, extent, and the physical/chemical characteristics of the potential contaminant pathways. The depths at which contaminants may be located and at which downgradient wells must be screened are functions of (1) geologic factors influencing the potential contaminant pathways of migration to the uppermost aquifer, (2) chemical characteristics of the hazardous waste controlling its likely movement and distribution in the aquifer, and (3) hydrologic factors likely to have an impact on contaminant movement (and detection). The consideration of these factors in evaluating the design of detection monitoring systems is described in Section 2.1.3.

A sufficient number of detection monitoring wells screened at the proper depths must be installed by the owner/operator to ensure that the ground-water monitoring system provides prompt detection of contaminant releases. A detection monitoring system should be judged against site-specific conditions; however, there are a number of criteria that technical reviewers can apply to ensure that detection monitoring systems satisfy the RCRA regulatory requirements. This chapter describes those criteria and provides examples on how technical reviewers can evaluate detection monitoring systems in various hydrologic situations. This chapter also examines three common geologic environments: alluvial, karst, and a glacial till. The rationale for well placement and vertical sampling intervals within each geologic environment is discussed.

2.1 Placement of Downgradient Detection Monitoring Wells

The criteria for evaluating the location of downgradient wells relative to waste management areas are described in Section 2.1.1. Section 2.1.2 contains the criteria for evaluating horizontal placement of downgradient detection wells. Section 2.1.3 details the rationale for selection of the vertical placement and sampling intervals of detection monitoring wells. Discussed in Section 2.1.4 are three geologic settings that have been encountered at hazardous waste sites and the rationale for detection well placement at each site.

2.1.1 Location of Wells Relative to Waste Management Areas

In order to immediately detect releases as required by the regulations, the owner/operator must install downgradient detection monitoring wells adjacent to hazardous waste management units. In a practical sense, this means the owner/operator must install detection monitoring wells as close as physically possible to the edge of hazardous waste management unit(s). The two drawings in Figure 2-1 (A and B) illustrate the concept of the placement of wells immediately adjacent to hazardous waste management unit(s). Note: the placement of wells relative to the units shifts as a function of the direction of ground-water flow.

Geologic environments with discrete solution channels such as Karst formations must have detection monitoring wells located in those solution channels likely to serve as conduits for contamination migration.

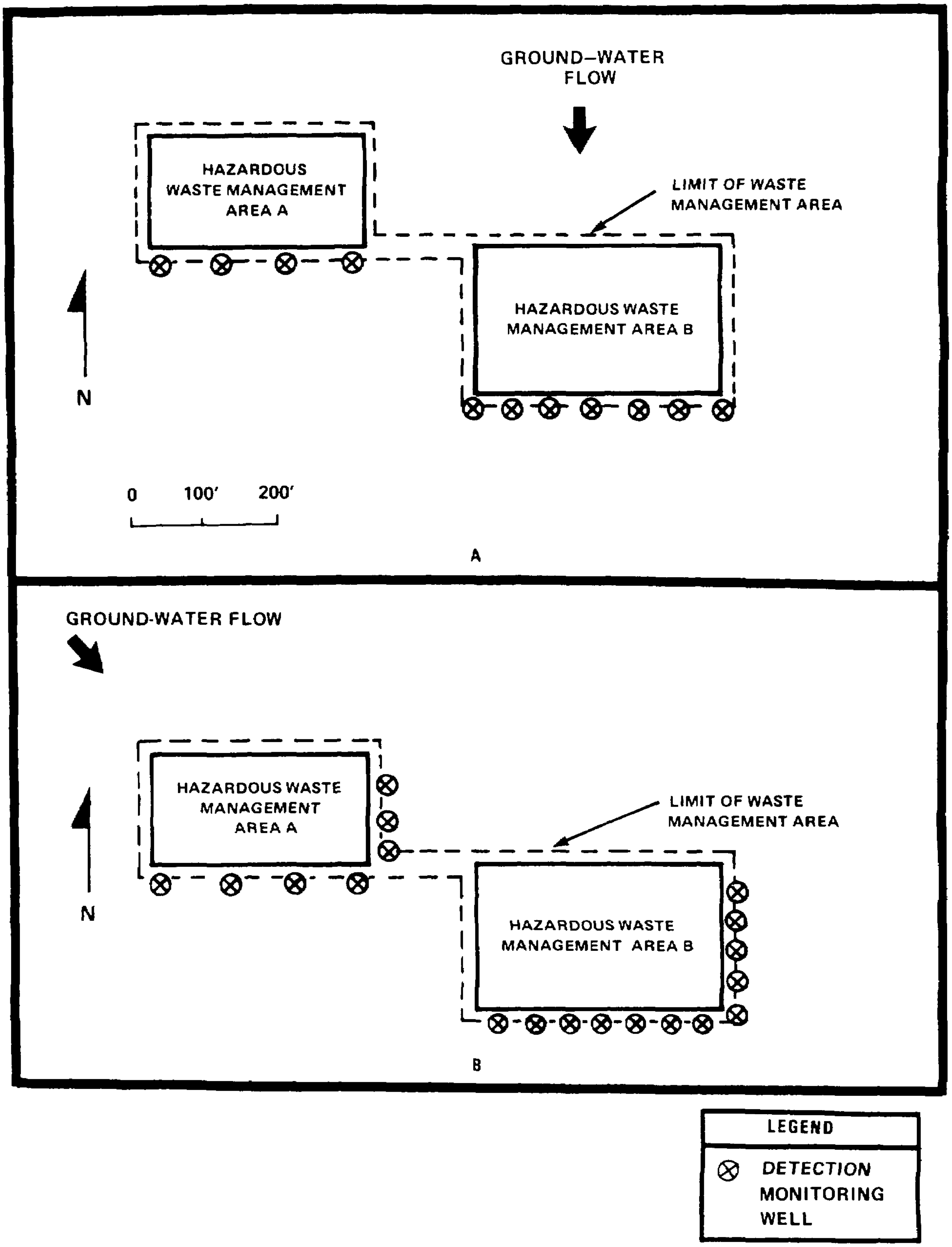


FIGURE 2-1 DOWNGRADIENT WELLS IMMEDIATELY ADJACENT TO HAZARDOUS WASTE MANAGEMENT LIMITS

At sites underlain by interbedded, unconsolidated sands, silts, and clays (e.g., alluvial facies) where the potentiometric surface is deep-seated, the lateral component of contaminant migration may carry contaminants beyond the ground-water monitoring system before they reach ground water, and therefore beyond detection. The owner/operators could institute a program of vadose zone monitoring as a supplement to the ground-water monitoring program in such cases, to provide immediate detection of any release(s) from the hazardous waste management area. Volatile organics that escape to the vadose zone, for instance, may be detected and characterized through soil gas analysis.

2.1.2 Horizontal Placement of Downgradient Monitoring Wells

The horizontal placement of detection monitoring wells along the downgradient perimeter of hazardous waste management units should be predicated on the interception of potential pathways for contaminant migration. The majority of hazardous waste sites will have identifiable pathways for potential contaminant migration. Some potential pathways for contaminant migration are: zones with relatively high intrinsic (matrix) hydraulic conductivities, fractured/faulted zones, solution channels, and zones suspected to be incompatible with the waste(s) present. Sites located in heterogeneous geologic settings can have numerous, discrete zones of potential migration. Each zone of potential migration must be identified and monitored.

Within a potential migration pathway, the horizontal distance between wells should be based upon site-specific factors such as those described in Table 2-1 should be considered by technical reviewers when evaluating the horizontal distance between detection wells. These factors cover a variety of physical and operational aspects relating to the facility, including hydrogeologic setting, dispersivity, seepage velocity, facility design, and waste characteristics.

TABLE 2-1

FACTORS INFLUENCING THE INTERVALS BETWEEN INDIVIDUAL MONITORING WELLS WITHIN A POTENTIAL MIGRATION PATHWAY

WELL INTERVALS MAY BE CLOSER IF THE SITE:	WELL INTERVALS MAY BE WIDER IF THE SITE:
• Manages or has managed liquid waste	
• Is very small	
• Has fill material near the waste management units (where preferential flow might occur)	
• Has buried pipes, utility trenches, etc., where a point-source leak might occur	
• Has complicated geology - closely spaced fractures - faults - tight folds - solution channels - discontinuous structures	• Has simple geology - no fractures - no faults - no folds - no solution channels - continuous structures
• Has heterogeneous conditions - variable hydraulic conductivity - variable lithology	• Has homogeneous conditions - uniform hydraulic conductivity - uniform lithology
• Is located in or near a recharge zone	
• Has a steep or variable hydraulic gradient	• Has a low (flat) and constant hydraulic gradient
• Is characterized by low dispersivity potential	• Is characterized by high dispersivity potential
• Has a high seepage velocity	• Has a low seepage velocity

In the less common homogeneous geologic setting where no preferred pathways are identified, a more regular well placement pattern can be utilized based on formational characteristics (e.g., dispersivity, hydraulic conductivity, and other factors listed in Table 2-1).

2.1.3 Vertical Placement and Screen Lengths

This document addresses separately the horizontal placement and the vertical sampling intervals of detection monitoring wells. These two parameters, however, should be evaluated together in the design of the ground-water detection monitoring system. Proper selection of the vertical sampling interval provides the third dimension to the detection monitoring of potential contaminant pathways to the uppermost aquifer. Site-specific hydrogeologic data obtained by the owner/operator during the site characterization are essential for the determination of the horizontal placement of detection wells, and for the selection of the vertical sampling interval(s). Proper design of a detection monitoring system enables the owner/operator to select the vertical sampling interval capable of immediately detecting a release from the hazardous waste management area. It is essential, therefore, that the owner/operator's decisions regarding vertical sampling intervals are based upon a full site characterization, which defines both the depth and thickness of the stratigraphic horizon(s) that could serve as contaminant pathways. There are several guidelines or criteria that the technical reviewer should follow in evaluating owner/operator decisions. A discussion of these guidelines follows in the examples in Section 2.1.4.

The owner/operator should have determined from the site characterization which stratigraphic horizons represent potential pathways for contaminant migration, and should screen monitoring wells at the appropriate horizon(s) to provide immediate detection of a release. It is extremely important to screen upgradient and downgradient wells in the same stratigraphic horizon(s) to obtain comparable ground-water quality data, as long as the strata are not dipping too strongly. The owner/operator should have ensured and demonstrated that the upgradient and downgradient well screens intercepted the same uppermost aquifer. The determination of the depth to a potential contaminant migration pathway may be made from soil/rock cores, supplemented by geophysical and available regional/local hydrogeological data.

Another factor to be considered in selecting the depth at which wells should be placed (and the selection of well screen lengths) is the physical/chemical characteristics of the hazardous waste or hazardous waste constituents controlling the movement and distribution of contamination in the aquifer. The technical reviewer should consider the mobility of the hazardous waste, its potential reaction products, and the potential for chemical degradation of clays. Different transport processes control contaminant movement depending on whether the contaminant dissolves in water or is immiscible. Immiscible contaminants may vary from extremely light volatiles to dense organic liquids whose migration is governed largely by density and viscosity. Lighter than water phases spread rapidly in the capillary zone just above the potentiometric surface. Alternatively, "the migration of dense organic liquids is largely uncoupled from the hydraulic gradient that drives advective transport and movement may have a dominant vertical component even in horizontally flowing aquifers" (MacKay, et al., 1985).

In addition to the normal flow of ground water (advection), the chemical processes of dispersion and sorption (retardation) greatly influence the potential migration pathways of contaminants within an aquifer. Dispersion is the spread of contaminants resulting from molecular diffusion and mechanical mixing and "may result in the arrival of detectable contaminant concentrations at a given location significantly before the arrival time that is expected solely on the basis of the average ground-water flow rate" (MacKay, et al., 1985). The mobility of different leachate constituents will vary depending upon the extent to which each constituent is adsorbed to solid surfaces (sorption processes). Some nonreactive ionic species (e.g., chloride ion) and low molecular weight organics of relatively high water solubility (e.g., trichloroethylene) can be quite mobile. Heavy metals (e.g., lead) and organics with high molecular weights and relatively low solubilities in water (e.g., chlorinated benzenes) tend to be the least mobile in natural conditions of near neutral pH and Eh.

All of these processes are important in choosing the depth of the screened interval and locating monitoring wells, because contaminants may be confined to and move within narrow zones. For instance, to monitor for heavy metals the screened interval should be just above the confining layer--for light organics, at the potentiometric surface/capillary zone interface. The local lithological variation can influence the rate, quantity, and degree of sorption of particular contaminants and is important in the proper location of monitoring wells.

Studies have shown that certain organic liquids can cause desiccation cracks in clay which can lead to significant increases in permeability. When organic chemicals and strongly acidic wastes are present, the compatibility of these wastes and chemicals with any potentially confining clay layer(s) should be confirmed.

Determination of the appropriate thickness of the vertical sampling interval(s) is a natural extension of the depth selection. The owner/operator should have made the decision on the basis of site characterization data. Sources of information that can be used in determining the thickness of potential contaminant pathways can include isopach maps of highly permeable strata, coring data, sieve analysis, and fracture traces.

The lengths of well screens used in ground-water monitoring wells can be a significant factor in the detection of releases of contaminants. The complexity of the hydrogeology at a site is an important consideration when selecting the lengths of well screens. Most hydrogeologic settings are complex (heterogeneous, anisotropic) and the permeability is variable with depth due to interbedded sediments. Highly variable formations require shorter well screens, which allow sampling of discrete portions of the formation. Longer well screens that span more than a single flow zone can result in excessive dilution of a contaminant present in one zone by uncontaminated ground water in another zone. This dilution can make contaminant detection difficult or impossible, since contaminant concentrations may be reduced to levels below the detection limits for the prescribed analytical methods.

Even in hydrologically simple (homogeneous) formations or within a potential pathway for contaminant migration, the use of shorter well screens may be required to detect contaminants concentrated at a particular depth. A contaminant may be concentrated at a particular depth because of its physical/chemical properties and/or hydrologic factors. In this situation, a longer well screen (length of well screen >> thickness of the contamination zone) can permit excessive amounts of uncontaminated formation water to dilute the contaminated ground water entering the well. This resultant dilution may prevent the detection of statistically significant changes in indicator parameters (pH changes) and, in extreme cases, the diluted concentration of contaminants may be below detection limits of the laboratory method being used.

The use of shorter well screens helps to maintain chemical resolution by reducing excessive dilution and, when placed at depths of predicted preferential flow, such screens can monitor the aquifer or portion of the aquifer of concern. The importance of determining these preferential flow paths in the ground-water monitoring process confirms the need for a complete hydrogeologic site investigation prior to the design and placement of detection wells.

Monitoring wells can be used to confirm or detect changes in ground-water flow directions (determined during the site characterization) by comparisons of potentiometric levels in neighboring wells. In heterogeneous geologic settings, however, longer well screens can intercept stratigraphic horizons with different (contrasting) ground-water flow directions. In this situation, the potentiometric surface will not provide the depth discrete head measurements required for accurate ground-water flow direction determination.

Certain hydrogeologic settings necessitate the use of longer well screens for detection monitoring. Hydrogeologic settings with widely fluctuating potentiometric surfaces are better monitored with longer screens that continuously intercept the water surface and provide monitoring for the presence of contaminants less dense than water. Formations with low hydraulic conductivities can also necessitate the use of longer well screens to allow sufficient amounts of formation water to enter the well for sampling.

Note: The vertical sampling interval is not necessarily synonymous with aquifer thickness. In other words, the owner/operator may select an interval which represents a portion of the thickness of the uppermost aquifer. When a single well cannot adequately intercept and monitor the vertical extent of a potential pathway of contaminant migration at each sampling location, the owner/operator should have installed a well cluster. A well cluster is a number of wells grouped closely together but not in the same borehole and often screened at different stratigraphic horizons. The greater the need for stratified sampling, the more wells the owner/operator should place in a cluster. The use of well clusters is illustrated in the examples in Section 2.1.4.

There are situations where the owner/operator should have multiple wells at a sampling location and others where typically one well is sufficient. They are summarized in Table 2-2. The potential for

TABLE 2-2

FACTORS AFFECTING NUMBER OF WELLS PER LOCATION (CLUSTERS)

One Well Per Sampling Location	More Than One Well Per Sampling
• No "sinkers" or "floaters" (immiscible liquid phases; see glossary for more detail)	• Presence of sinkers or floaters
• Thin flow zone (relative to screen length)	• Heterogeneous uppermost aquifer; complicated geology - multiple, interconnected aquifers - variable lithology - perched water zone - discontinuous structures
• Homogeneous uppermost aquifer; simple geology	• Discrete fracture zones

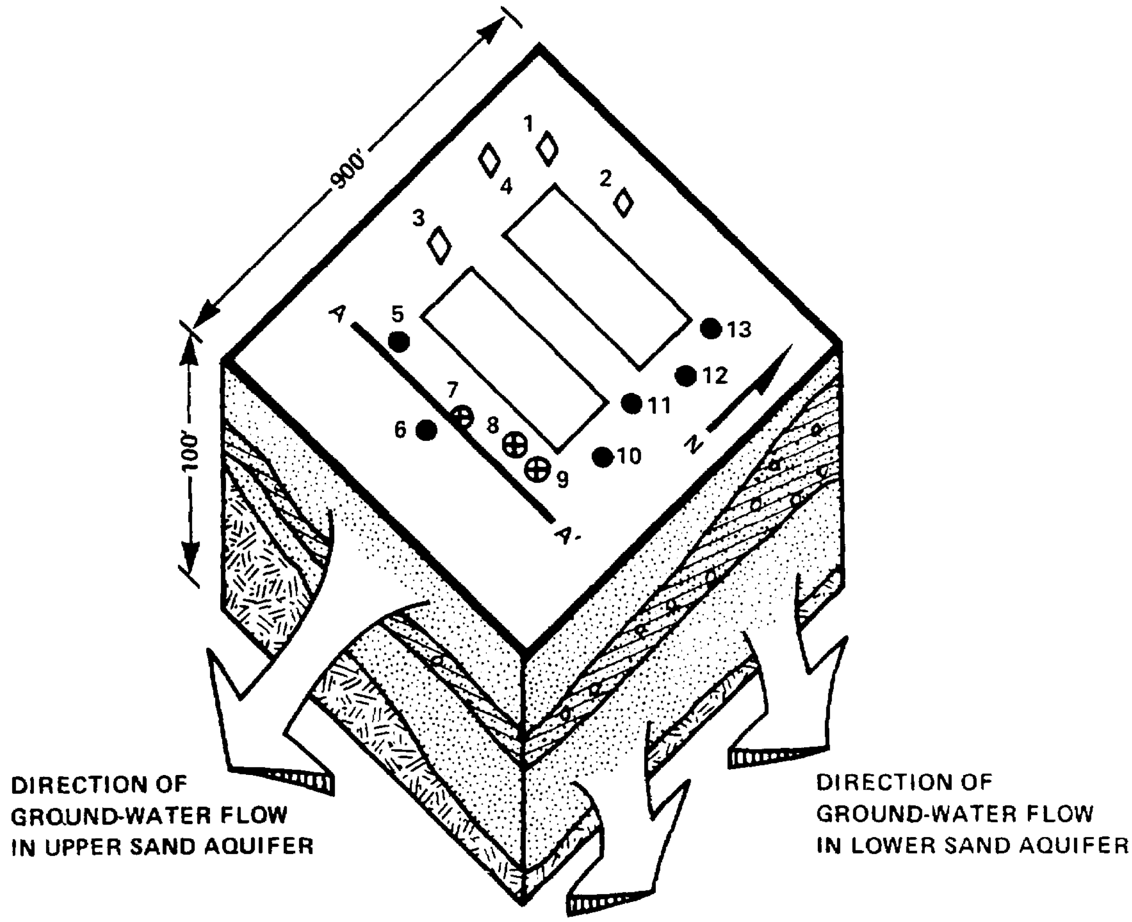
immiscibles in a thick, complex saturated zone of the uppermost aquifer should prompt the owner/operator to use well clusters. Conversely, in situations where ground water is contaminated by a single contaminant, and geologically there is a thin saturated zone within the uppermost aquifer or homogeneous hydrologic properties are prevalent in the uppermost aquifer, the need for multiple wells at each sampling location is reduced. The number of wells screened at specific depths that should be installed at each sampling location increases with site complexity. Each potential contaminant pathway must be screened to ensure prompt detection of a hazardous waste or hazardous waste constituent release.

2.1.4 Examples of Detection Well Placement in Three Common Geologic Environments

The following examples are based on actual geologic environments encountered during hydrogeologic investigations. The three geologic settings presented--a Karst, an alluvial, and a glacial till--are not intended to be inclusive of all hydrogeologic factors; however, they are illustrative of the technique used in the design of a minimum detection monitoring system. The basic steps in the development of a detection monitoring network include: (1) a review of existing information to determine the regional geologic regime and regional ground-water flow rates and direction; (2) a hydrogeologic investigation of the site to determine the depth to and the extent of the uppermost aquifer; the presence and extent of any confining layers/units; the abundance, location(s), and extent of any potential pathways for contaminant migration; and the direction and flow rates of the ground water; (3) a review of the waste analysis plan to determine the chemical/physical properties that may affect the distribution of a contaminant in the aquifer; (4) the installation of detection wells in order to intercept and completely monitor the potential pathways of contaminant migration; (5) the selection of well screen lengths to provide resolute ground-water samples; and (6) the placement/screening of upgradient monitoring wells to provide representative background samples.

Figures 2-2, 2-3, and 2-4 depict a block diagram, a cross section, and plan views of two lined waste impoundments located in a glacial till environment. This heterogeneous glacial terrain is encountered in many parts of the country, especially northern states. A review of the published regional geologic data aided the subsequent and thorough site-specific hydrogeologic investigation that made it possible to identify three lithologic units in the upper 100 feet of sediments overlying a granite with low hydraulic conductivity. These units were identified by geologic and geophysical analysis. Color, grain size, and texture were also used to characterize each unit. Two sand units are separated by an undulating glacial till varying between 10 and 50 feet thick. Pumping/slug tests were conducted to determine the hydraulic conductivities of each unit. These tests in conjunction with piezometer (not shown in Figure 2-3) readings identified hydraulic intercommunication between the two sand units. This vertical flow from the upper sand unit to the lower sand unit is predominantly a function of the thickness and continuity of the till unit. In locations where the till is thinnest, vertical flow is most prevalent. Borings show that the granite confining unit extends laterally across the entire site. Therefore, the uppermost aquifer includes the two sand units and the till.

Flow in the upper sand unit is southerly, towards a nearby river, and has a moderate hydraulic gradient of 0.01. Flow in the lower sand is representative of regional ground-water flow generally to the south-east. This lower outwash sand has a low hydraulic gradient of .004. Figure 2-4 contains two plan views showing the equipotential lines in the upper and lower sand units. These equipotential lines were drawn using information from the well/piezometric data tabulated on Figure 2-4. The block diagram in Figure 2-2 illustrates the multiple ground-water flow paths present in this glacial terrain. The southern and eastern perimeters of the waste lagoons are downgradient and therefore require monitoring. The cross section in Figure 2-3 depicts the well placement



LEGEND			
◇	UPGRADIENT MONITORING WELL		SAND
●	DOWNGRADIENT MONITORING WELL		GLACIAL TILL
⊕	MONITORING WELL CLUSTER		GRANITE

FIGURE 2-2 ILLUSTRATION OF MULTIPLE GROUND-WATER FLOW PATHS IN THE UPPERMOST AQUIFER DUE TO HYDROGEOLOGIC HETEROGENEITY

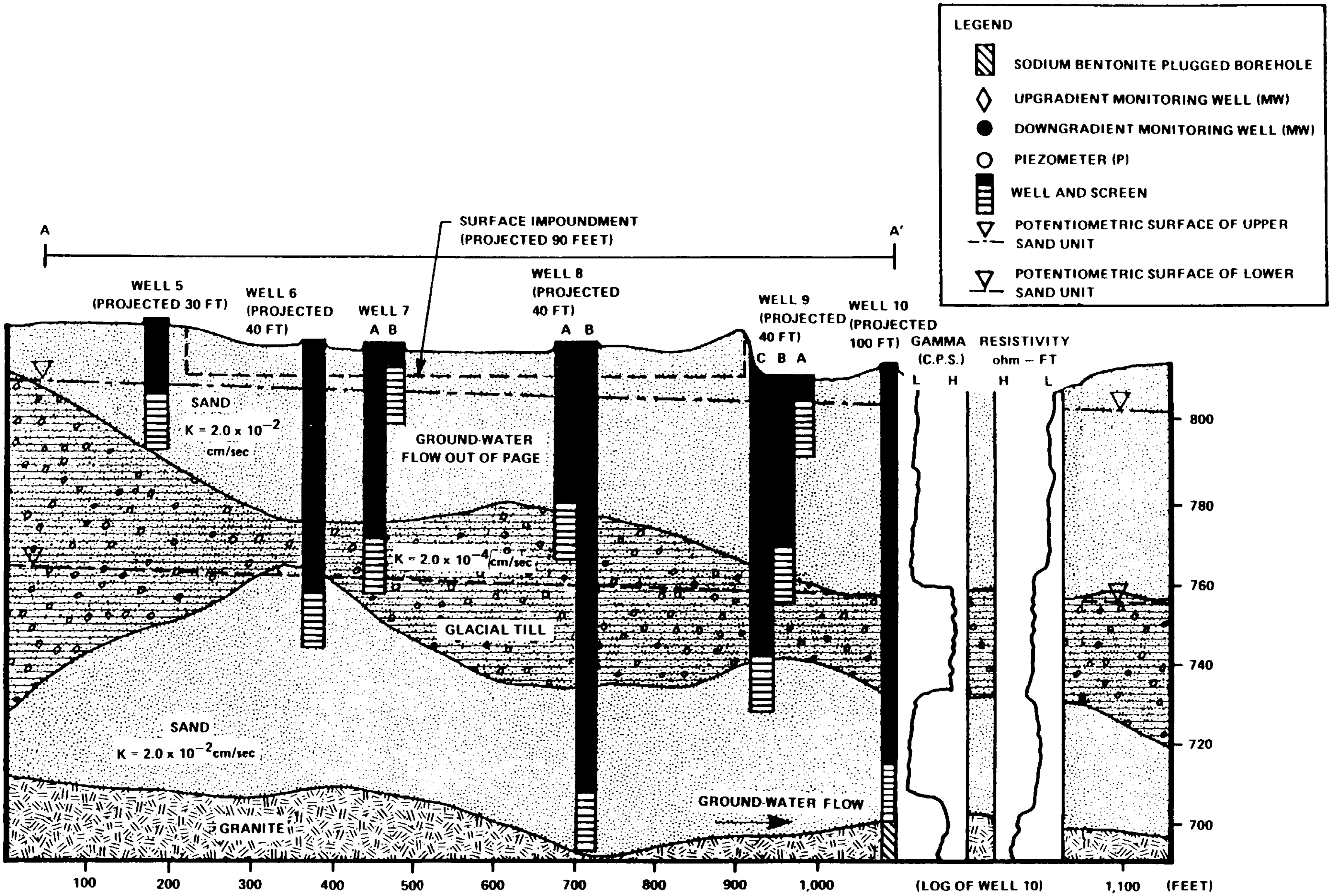
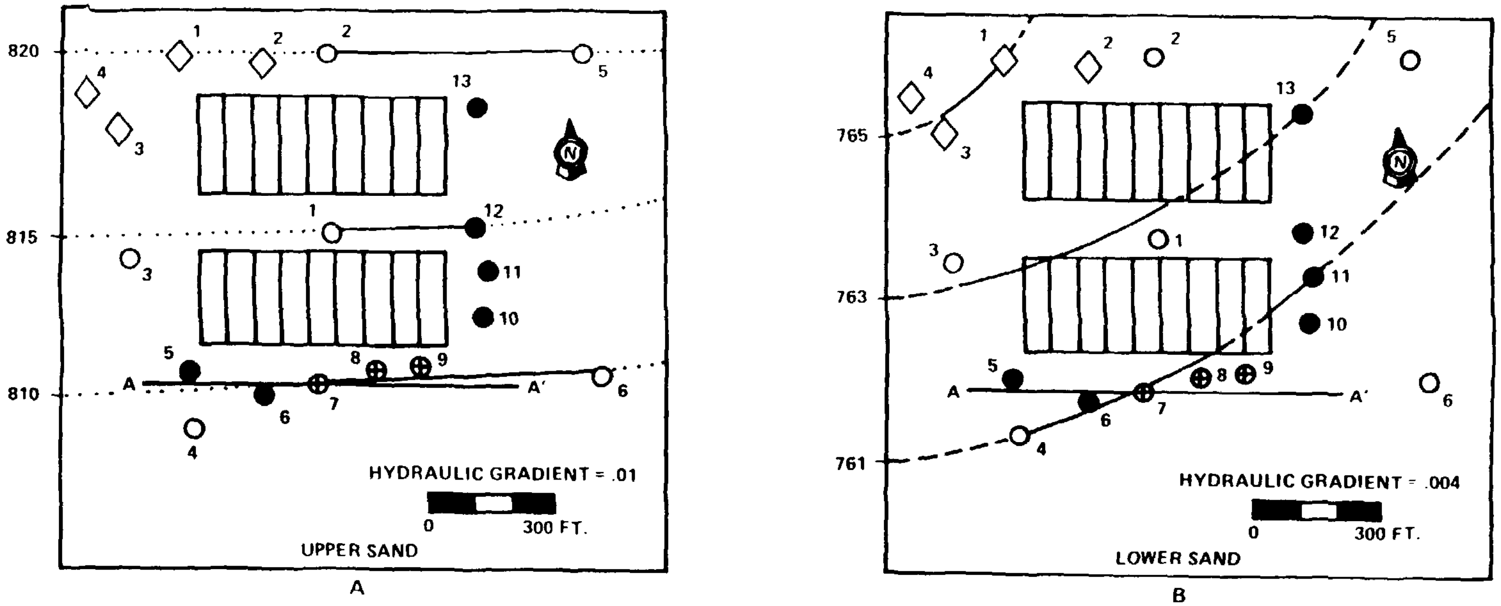


FIGURE 2-3 MONITORING WELL PLACEMENT AND SCREEN LENGTHS IN A GLACIAL TERRAIN



MONITORING WELL/PIEZOMETER TOP OF CASING ELEVATIONS
(IN FEET RELATIVE TO NATIONAL GEODETIC VERTICAL DATUM)

P1	815.35	(4/1/85)	MW 1	765.04	(4/2/85)
P2	819.81	(4/1/85)	MW 2	765.10	(4/2/85)
P3	763.19	(4/2/85)	MW 6	761.60	(4/2/85)
P4	761.48	(4/2/85)	MW 7A	811.30	(4/1/85)
P5	819.50	(4/1/85)	MW 7B	761.55	(4/1/85)
P6	811.26	(4/1/85)	MW 9A	811.45	(4/1/85)
			MW 11	761.59	(4/2/85)
			MW 12	815.67	(4/1/85)
			MW 13	763.24	(4/2/85)

FIGURE 2-4 A & B. PLAN VIEW OF FIGURE 2-3 SHOWING LINES OF EQUIPOTENTIAL IN THE UPPER (A) AND LOWER (B) SAND UNITS

and screen lengths for the detection monitoring network along the southern perimeter of the impoundment. Along the southern perimeter, the upper sand unit requires more stringent monitoring than the lower sand unit because of the higher ground-water velocity and steeper gradient in the upper zone. Any release must seep through the upper sand before it reaches the till. The hydraulic head resulting from the depth of liquid in the lagoons, and an inventory of wastes and byproducts, indicate the potential for "sinkers and floaters." The decision regarding horizontal well placement was also based upon the likely size of a leak, the distance from a leak source to the downgradient perimeter, dispersion, and seepage velocity. Well placement in the lower sand unit along the southern perimeter reflects the easterly component of ground-water flow in the lower sand, that is, wells screened in the lower sand are located toward the eastern end of the lagoons. It is important to note the care that must be taken to properly grout the boreholes (wells) penetrating the less permeable till to avoid increasing the (or cause a) hydraulic communication between the sand units.

Figure 2-5 illustrates a cross section and plan view of a landfill that may occur in an alluvial setting. A review of the regional and local geology indicated that the area was possibly underlain by interbedded sand and clay units. Split spoon samples collected during the site-specific characterization revealed a massive clay unit extending across the entire area at a depth of approximately 100 feet. Borehole samples and interpretation of geophysical logs suggested that two sand units overlie the massive clay, separated by a clay layer of variable thickness. The upper sand contains several clay lens, each averaging approximately 20 feet thick, beneath the disposal area. Pumping tests within the sand units provided hydraulic conductivity values for the sand units. Laboratory tests were used to determine hydraulic conductivity values for the clay. Further analysis of clay samples identified an illitic clay. Pumping tests across the intervening clay established hydraulic communication between the sand units with downward flow.

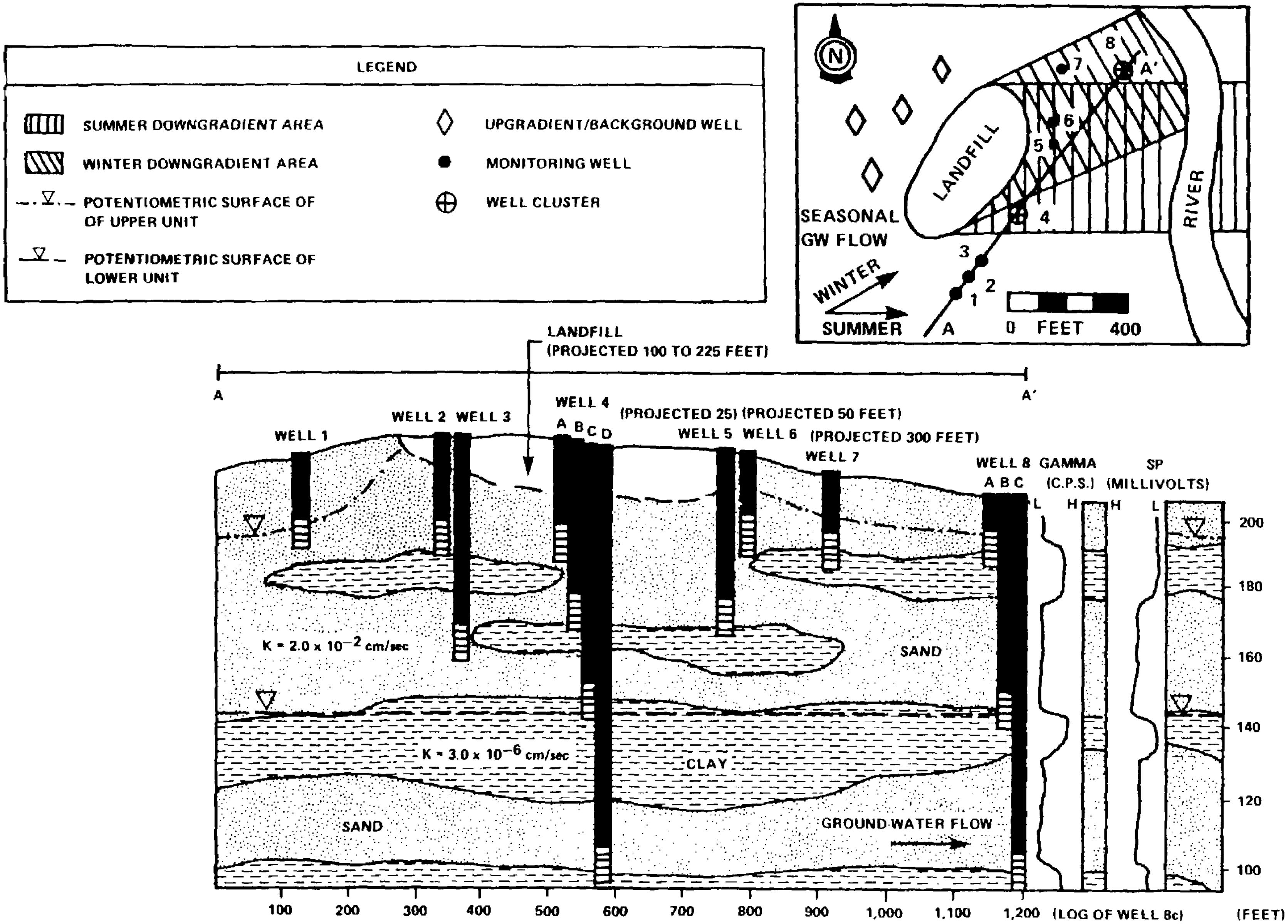


FIGURE 2-5 MONITORING WELL PLACEMENT AND SCREEN LENGTHS IN AN ALLUVIAL SETTING

It is determined through research and substantiated by piezometers that the direction of ground-water flow is predominantly east northeast (out of the page). This direction fluctuates seasonally, however, due to the influence of the river. In the summer, flow is toward the east; in the winter, it shifts to the northeast. The potentiometric surface in the upper sand varies by approximately six feet during the year. Dense phase immiscible wastes are known to be disposed of at the site.

The resultant horizontal and vertical placement of wells (and screen lengths) reflects all of the waste management practices and hydrogeologic factors at the site. The potential pathways for contaminant migration are the two sand units. A greater number of wells are established in the overlapping east-northeast flow zone, because ground-water flow there is continuous and not seasonal. Wells are also placed in the area of intermittent flow. Generally, the lengths of well screens installed at the site reflect the vertical extent of the potential contaminant pathway at the desired sampling location. However, shorter well screens (not fully penetrating the depth of the sand unit) are employed in the thick sand units where dilution effects may impair potential contaminant detection. Several wells are screened at the sand/clay interfaces where high specific gravity (dense) immiscibles may be expected to accumulate. Also, those screens that intercept the potentiometric surface in the upper sand are at least long enough to accommodate seasonal fluctuations in ground-water elevations.

Figure 2-6 illustrates a cross-sectional and plan view of a waste landfill situated in a mature Karst environment. This setting is characteristic of carbonate environments encountered in various parts of the country, but especially in the southeastern states. An assessment of the geologic conditions at the site, through the use of borings, geophysical surveys, aerial photography, tracer studies, and other geological investigatory techniques, made it possible to identify a mature Karst geologic formation characterized by well-defined sinkholes, solution

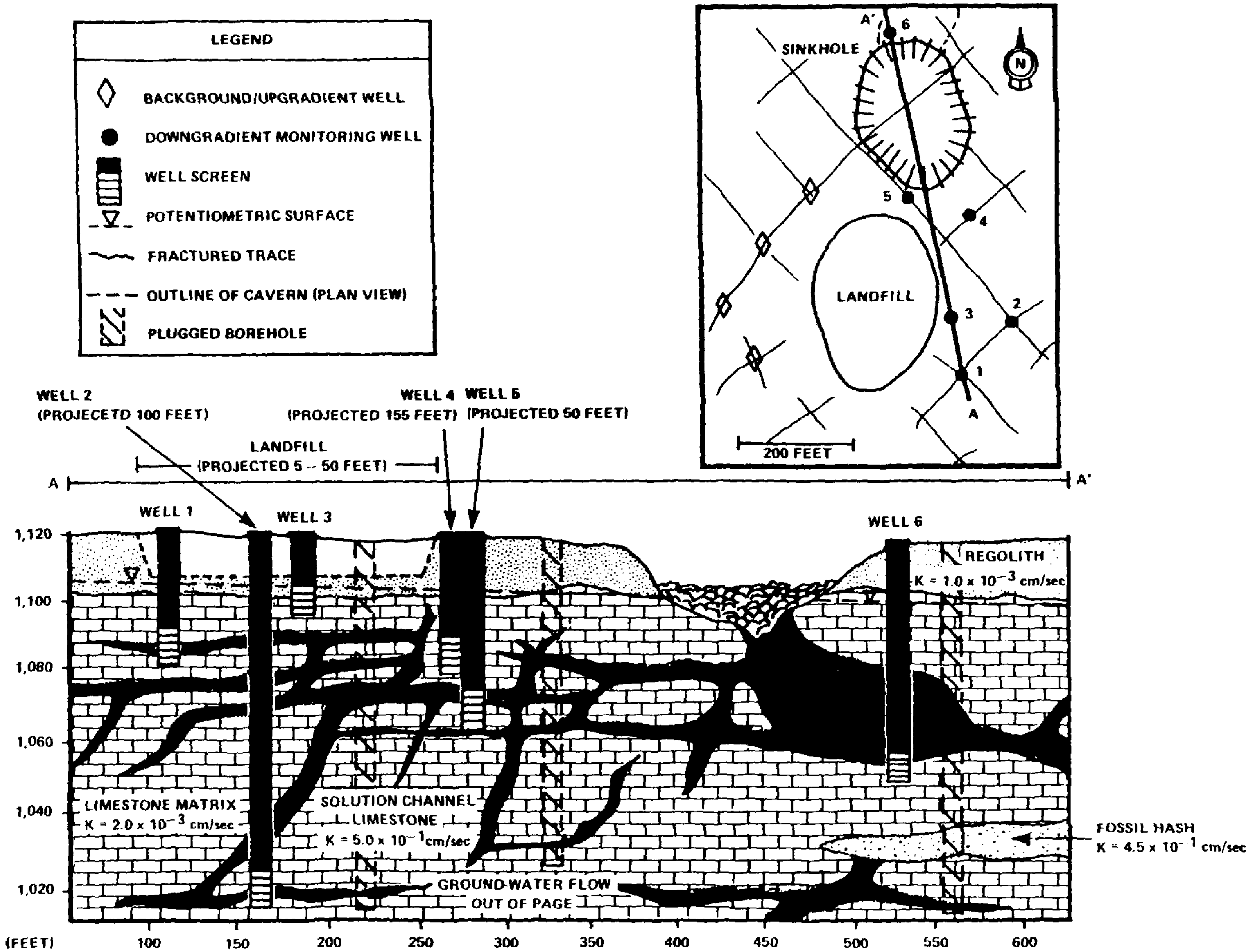


FIGURE 2-6 MONITORING WELL PLACEMENT AND SCREEN LENGTHS IN A MATURE KARST TERRAIN/FRACTURED BEDROCK SETTING

channels, and extensive vertical and horizontal fracturing in an interbedded limestone/dolomite. Using potentiometric data, ground-water flow direction was found to be to the east. Solution channels are formed by the flow of water through the fractures. The chemical reaction between the carbonate rock and the ground water in the fractures produces voids. These voids are referred to as solution channels. Through time, these solution channels are enlarged to the point where the weight of the overlaying rock (overburden) may be too great to provide support, thereby causing a "roof" collapse and the formation of a sinkhole. The location of these solution channels dictates the placement of detection monitoring wells. Note in the plan view the placement of well No. 2 is offset 50 feet from the perimeter of the landfill. The horizontal placement of well No. 2, although not immediately adjacent to the landfill, is necessary in order to monitor all potential contaminant pathways. The discrete nature of these solution channels dictates that each potential pathway be monitored.

The distance between the "floor" and "ceiling" (vertical extent) (height) of the solution channels ranges from three to six feet directly beneath the sinkhole to one foot under the landfill except for the 40-foot deep cavern. This limited vertical distance of the cavities allows for a full screened interval in the solution channels. (Note the change in orientation of solution channels due to the presence of the shell hash layer.)

2.2 Placement of Upgradient (Background) Monitoring Wells

The downgradient wells must be designed and installed to immediately detect releases of hazardous waste or hazardous waste constituents to the uppermost aquifer. The upgradient wells must be located and constructed to provide representative samples of ground water in the same portion of the aquifer monitored by the downgradient wells to permit a comparison of ground-water quality (40 CFR 265, Subpart F, 265.92(a)(1)).

There are at least three main questions that the technical reviewer should ask when reviewing the decisions the owner/operator has made regarding the placement of the background monitoring wells:

- Are the background wells far enough away from waste management areas to prevent contamination from the hazardous waste management units?
- Are enough wells installed and screened at appropriate depths to adequately account for spatial variability in background water quality?
- Are well clusters used at sampling locations to permit comparisons of background ground-water data with downgradient ground-water data obtained from the same hydrologic unit?

By regulation, the owner/operator must install as a minimum one background well. However, a facility that uses only one well for sampling background water quality may not be able to account for spatial variability. It is, in fact, a very unusual circumstance in which only one background well will fully characterize background ground-water quality. The owner/operator who makes comparisons of background and downgradient monitoring well results with data from only one background well increases the risk of a false indication of contaminant release. In most cases, the owner/operator should install multiple background monitoring wells in the uppermost aquifer to account for spatial variability in background water quality data.

The owner/operator should also install enough background monitoring wells to allow for depth-discrete comparisons of water quality. This means simply that for downgradient wells completed in a particular geologic formation, the owner/operator should install upgradient well(s) in the same portion of the aquifer, so that the data can be compared on a depth-discrete basis (Figure 2-7).

Owner/operators should avoid installing background monitoring wells that are screened over the entire thickness of the uppermost aquifer.

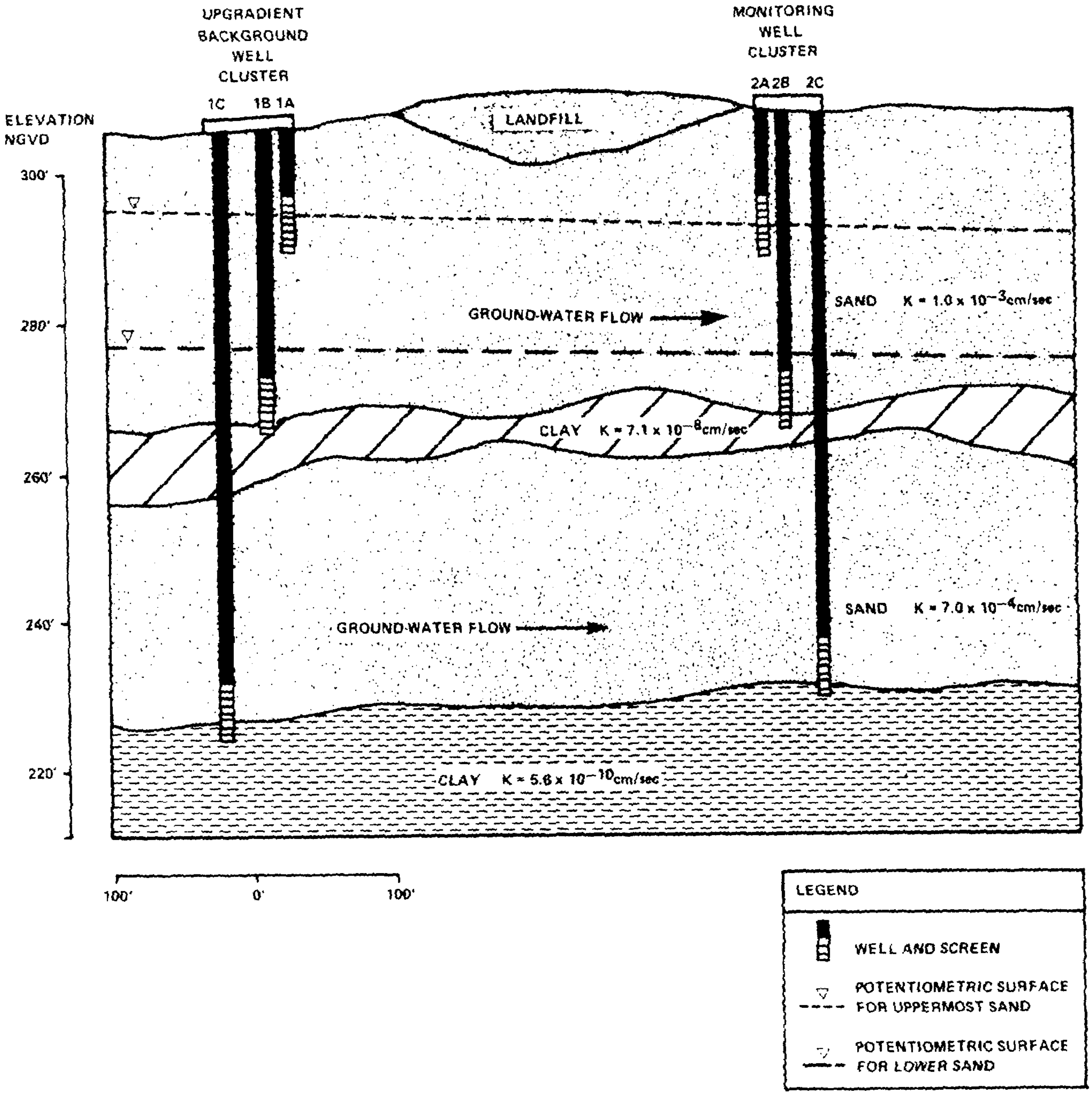


FIGURE 2-7 PLACEMENT OF BACKGROUND WELLS

Screening the entire thickness of the uppermost aquifer will not allow the owner/operator to obtain depth-discrete water quality data. Instead, the owner/operator should use shorter well screens in order to obtain depth-discrete water quality data.

In order to establish background ground-water quality, it is necessary to properly identify the ground-water flow direction and place wells hydraulically upgradient to the waste management area. Usually, this is accomplished by locating the background wells far enough from waste management units to avoid contamination by the hazardous waste management units. There are geologic and hydrologic situations for which determination of the hydraulically upgradient location is often difficult. These cases require further site-specific examination to properly position or place background wells. Examples of such cases include the following:

- Waste management areas above ground-water mounds;
- Waste management areas located above aquifers in which ground-water flow directions change seasonally;
- Waste management areas located close to a property boundary that is in the upgradient direction;
- Waste facilities containing significant amounts of immiscible contaminants with densities greater than or less than water;
- Waste management facilities located in areas where nearby surface water can influence ground-water levels (e.g., river floodplains);
- Waste management facilities located near intermittently or continuously used production wells; and
- Waste management facilities located in Karst areas or faulted areas where fault zones may modify flow.

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CHAPTER THREE

MONITORING WELL DESIGN AND CONSTRUCTION

The purpose of this chapter is to examine important aspects of RCRA monitoring well design and construction. Included in this chapter are discussions on the following topics:

- Drilling methods for installing wells (Section 3.1);
- Monitoring well construction materials (Section 3.2);
- Design of well intakes (Section 3.3);
- Development of wells (Section 3.4);
- documentation of well construction activity (Section 3.5);
- Specialized well design (Section 3.6); and
- Replacement of existing wells (Section 3.7).

In order to better understand proper ground-water monitoring procedure, a differentiation between monitoring wells and piezometer wells should be made. Monitoring wells provide for the measurement of total well depth, the collection of representative ground-water samples, the detection of light- and dense-phase organics, and, under certain circumstances, the collection of samples of light- and dense-phase organics. Piezometer wells are used to determine static water level, in addition to establishing horizontal and vertical ground-water flow directions.

3.1 Drilling Methods

A variety of well-drilling methods can be used in the installation of ground-water monitoring wells. It is important that the drilling method or methods used minimize disturbance of subsurface materials and not contaminate the subsurface and ground water (40 CFR 265.91(c)). Table 3-1 lists the drilling methods that are most commonly used to install wells. The selection of the actual drilling method is, of course,

TABLE 3-1

DRILLING METHODS FOR
VARIOUS TYPES OF GEOLOGIC SETTINGS

Geologic Environment	Drilling Methods				
	Air** Rotary	Water/Mud Rotary	Cable Tool	Hollow-Stem Continuous Auger	Solid-Stem Continuous Auger*
Glaciated or unconsolidated materials less than 150 feet deep	•	•	•	•	•
Glaciated or unconsolidated materials more than 150 feet deep	•	•	•		
Consolidated rock formations less than 500 feet deep (minimal or no fractured formations)	•	•	•		
Consolidated rock formations less than 500 feet deep (highly fractured formations)	•	•	•		
Consolidated rock formations more than 500 feet deep (minimal formations)	•	•	•		
Consolidated rock formations more than 500 feet deep (highly fractured formations)	•	•	•		

* Above potentiometric surface.

** Includes conventional and wireline core drilling.

NOTE:
Although several methods are suggested as appropriate for similar conditions, one method may be more suitable than the others.

a function of site-specific geologic conditions. Table 3-1 provides an interpretation of how geologic conditions may influence the choice of drilling method. The following sections discuss each drilling method and its applicability to the installation of RCRA monitoring wells. It is important to note that regardless of the drilling method selected, the owner/operator is responsible for the drilling equipment and for having it decontaminated. This procedure should be followed before use and between borehole locations to prevent cross contamination of wells where contamination has been detected or is suspected from the site characterization work that precedes the well installation work. In addition to selecting the proper drilling techniques, other precautions to prevent distribution of any existing contaminants throughout a borehole should be taken.

3.1.1 Hollow-Stem Continuous-Flight Auger

The hollow-stem continuous-flight auger is among the most frequently employed tools used in drilling monitoring wells in unconsolidated materials. The drill rigs used for this drilling method are usually mobile, fast, and relatively inexpensive to operate. Drilling fluids normally are not used, and disturbance to the aquifers of concern is minimal. Auger drilling is usually limited to unconsolidated materials and to depths of approximately 150 feet. In formations where the borehole will not stand open, the well is constructed inside the hollow-stem auger prior to the auger's removal from the ground. Hollow-stem augers with inside diameters of six inches or six and one-quarter inches are readily available for this purpose. Generally, the diameter of the well that can be constructed with this type of drill rig is limited to four inches or less, although firms now manufacture eight and one-quarter inch inside diameter hollow-stem augers and are experimenting with ten and one-quarter inch inside diameter hollow-stem augers. The differential between the inner diameter of the auger and the outer diameter of the well casing should ideally be at least three to five inches to permit effective placement of filter pack and annular sealant.

The use of hollow-stem auger drilling in heaving sand environments also presents some difficulties. However, with care and the use of proper drilling procedures, this difficulty can be overcome. For example, a positive pressure head within the auger stem can be developed by filling the auger with clean water. The heaving sands are thus displaced when a knock-out plug (which is part of the auger) is removed. If casing is driven, the added outer diameter of the drive shoe must be considered in the calculation of sealant and filter pack volume.

3.1.2 Solid-Stem Continuous-Flight Auger

The use of solid-stem continuous-flight auger drilling techniques for monitoring well construction is limited to fine-grained unconsolidated materials that will maintain an open borehole or in consolidated sediments. The method is similar to the hollow-stem continuous-flight augers except that the augers must be removed from the ground to allow insertion of the well casing and screen. This method is also limited to a depth of approximately 150 feet. In areas characterized by less competent sediments or soils (i.e., unstable, unable to retain the sphericity of the borehole during drilling operations), solid-stem auger drilling can be utilized to limited depths. Caving of the borehole, however, is an imposing problem. Another limitation of the solid-stem auger is its use below the potentiometric surface. Maintaining the integrity of the borehole in the saturated zone is also difficult at times, especially in poorly consolidated sediments. Solid-stem auger drilling is not used for in-place well construction, whereas hollow-stem auger drilling is. Collection of soil or formation samples is impractical, and therefore, accurate depiction of site stratigraphy is difficult. Solid-stem augers have very limited utility in the boring program for site characterization.

3.1.3 Cable Tool

Cable tool drilling is relatively slow but offers many advantages for monitoring well construction in relatively shallow consolidated formations and unconsolidated formations. The method allows for the collection of excellent formation samples and detection of even relatively fine-grained permeable zones. The installation of a steel casing as drilling progresses also provides an excellent temporary host for the construction of a monitoring well once the desired depth is reached.

Small amounts of water must be added to the hole as drilling progresses until the potentiometric surface is encountered. The owner/operator should only use water that cannot itself contaminate formation water. A minimum six-inch diameter drive pipe should be used to facilitate the placement of the well casing, screen, and gravel pack, and a minimum five-foot long seal should be made prior to beginning the removal of the drive pipe. The drive pipe should be pulled while the sealant is still fluid and capable of flowing outward to fill the annular space vacated by the drive pipe and shoe. The drive pipe also should be pulled in sections and additional sealant added to ensure that a satisfactory seal is obtained. Cable tool rigs have generally been replaced by rotary rigs for water well construction in most areas of the United States. Therefore, cable tool rigs may not be readily available in many regions.

3.1.4 Air Rotary

Rotary drilling involves the use of circulating fluids, i.e., mud, water, or air, to remove the drill cuttings and maintain an open hole as drilling progresses. The different types of rotary drilling methods are named according to the type of fluid and the direction of fluid flow. Air rotary drilling forces air down the drill pipe and back up the bore hole to remove the drill cuttings. The use of air rotary drilling techniques is best suited for use in hard-rock formations. In soft unconsolidated formations, casing is driven to keep the formations from caving.

Air rotary drilling can be used without affecting the quality of ground water from monitoring wells in hard rock formations with minimum unconsolidated overburden. The successful construction of monitoring wells using this drilling technique hinges on the bore hole remaining open after the air circulation ceases. It is an inappropriate method in areas where the upper soil horizons are contaminated and sloughing of sidewalls would likely result in contamination of the well. The air from the compressor on the rig should be filtered to ensure that oil from the compressor is not introduced into the ground-water system to be monitored. Foam or joint compounds for the drill rods should not be used with air rotary drilling because of the potential for introduction of contaminants into the hydrogeologic environment. Caution should be taken in using air rotary drilling techniques in highly polluted or hazardous environments. Contaminated solids and water that are blown out of the hole are difficult to contain and may adversely affect the drill crew and observers. When air rotary is used, shrouds, canopies, bluooey lines, or directional pipes should be used to contain and direct the drill cuttings away from the drill crew. Any contaminated materials (soil and/or water) should be collected and disposed of in an approved waste disposal facility. On the other hand, air rotary drilling techniques have actually improved safety conditions.

3.1.5 Water Rotary

Water rotary drilling involves the introduction of water into the borehole through the drill pipe and subsequent circulation of water back up the hole to remove drill cuttings. Great care must be taken to ensure that water used in the drilling process does not contain contaminants. If the driller uses water rotary drilling to install wells, drilling water should be analyzed to ensure that it is contaminant-free. Generally, except when core drilling in hard rock units, the water becomes muddy after a few circulations.

There are problems associated with the use of water rotary drilling. The recognition of water-bearing zones is hampered by the addition of water into the system. Also, in poorly consolidated sediments, the drillers may have a problem with caving of the borehole prior to installation of the screen and casing. In highly fractured terrains, it may also be hard to maintain water circulation.

3.1.6 Mud Rotary

Mud rotary drilling techniques involve the use of various types of drilling muds as the fluid that is introduced into the borehole. The mud circulates back up the hole during drilling, carrying away drill cuttings in the same manner as the air and water rotary drilling methods. Muds provide the additional benefit of stabilizing the hole.

There are several types of muds available at present, primarily bentonite, barium sulfate, organic polymers, cellulose polymers, and polyacrylamides. The owner/operator should provide any chemical data regarding potential impacts on water quality. While there are hydrogeologic conditions under which mud rotary drilling is the best option, the technical reviewer should make certain that the mud(s) utilized do not affect the chemistry of ground-water samples, samples from the borehole, or the operation of the well. The latter may adversely affect the assessment of aquifer characteristics, for example:

- Bentonite muds reduce the effective perosity of the formation around the well, thereby compromising estimates of well recovery. Bentonite may also affect local ground-water pH. Additives to modulate viscosity and density may also introduce contaminants to the system or force large, irrecoverable quantities of mud into the formation.

- Some organic polymers and compounds provide an environment for bacterial growth which, in turn, reduces the reliability of sampling results.

3.2 Monitoring Well Construction Materials

The technical reviewer must ensure that the owner/operator used well construction materials that are durable enough to resist chemical and physical degradation and do not interfere with the quality of ground-water samples. Specific well components that are of concern include well casings, well screens, filter packs, and annular seals or backfills. Figure 3-1 is a drawing of a typical ground-water monitoring well. The following sections describe various acceptable materials the owner/ operator should have used in constructing the well as depicted in Figure 3-1.

3.2.1 Well Casings and Well Screen

A variety of construction materials have been used for the casings and well screens, including virgin fluorocarbon resins (i.e., fluorinated ethylene propylene (FEP), polytetrafluoroethylene (PTFE), Teflon®), stainless steel (304, 316, or 2205), cast iron, galvanized steel, polyvinyl chloride (PVC), polyethylene, epoxy biphenol, and polypropylene. Many of these materials, however, may affect the quality of ground-water samples and may not have the long-term structural characteristics required of RCRA monitoring wells. For example, steel casing deteriorates in corrosive environments; PVC deteriorates when in contact with ketones, esters, and aromatic hydrocarbons; polyethylene deteriorates in contact with aromatic and halogenated hydrocarbons; and polypropylene deteriorates in contact with oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons. In addition, steel, PVC, polyethylene, and polypropylene may adsorb and leach constituents that may affect the quality of ground-water samples.

The selection of well casing and screen materials should have been made with due consideration to geochemistry, anticipated lifetime of the monitoring program, well depth, chemical parameters to be monitored and other site-specific factors. Fluorocarbon resins or stainless steel should be specified for use in the saturated zone when volatile organics are to be determined, or may be tested, during a 30-year period. In such cases, and where high corrosion potential exists or is anticipated, fluorocarbon resins are preferable to stainless steel. An example of a stainless steel monitoring well is provided in Figure 3-2. National Sanitation Foundation (NSF) or ASTM-approved polyvinylchloride (PVC) well casing and screens may be appropriate if only trace metals or nonvolatile

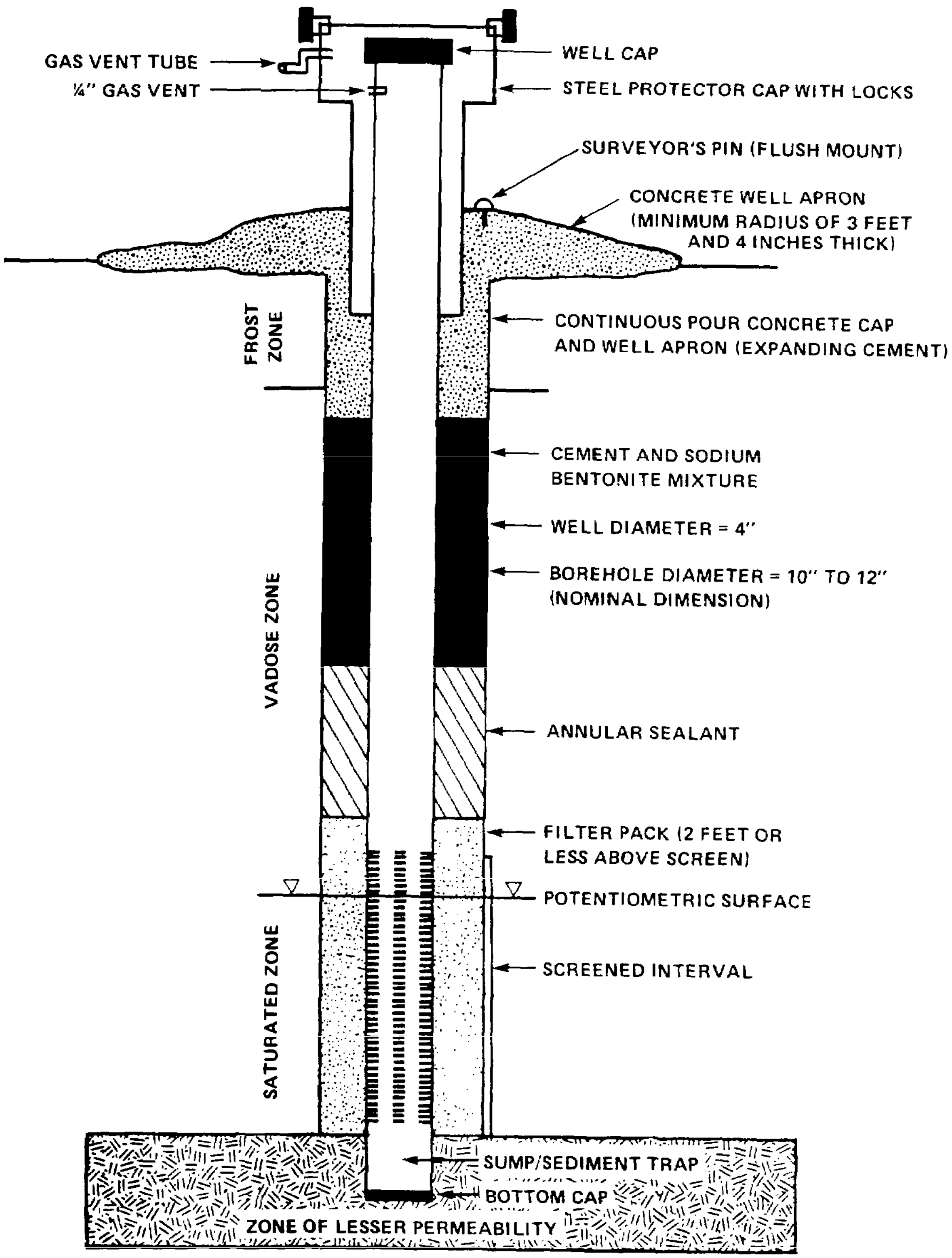

FIGURE 3-1. GENERAL MONITORING WELL – CROSS SECTION

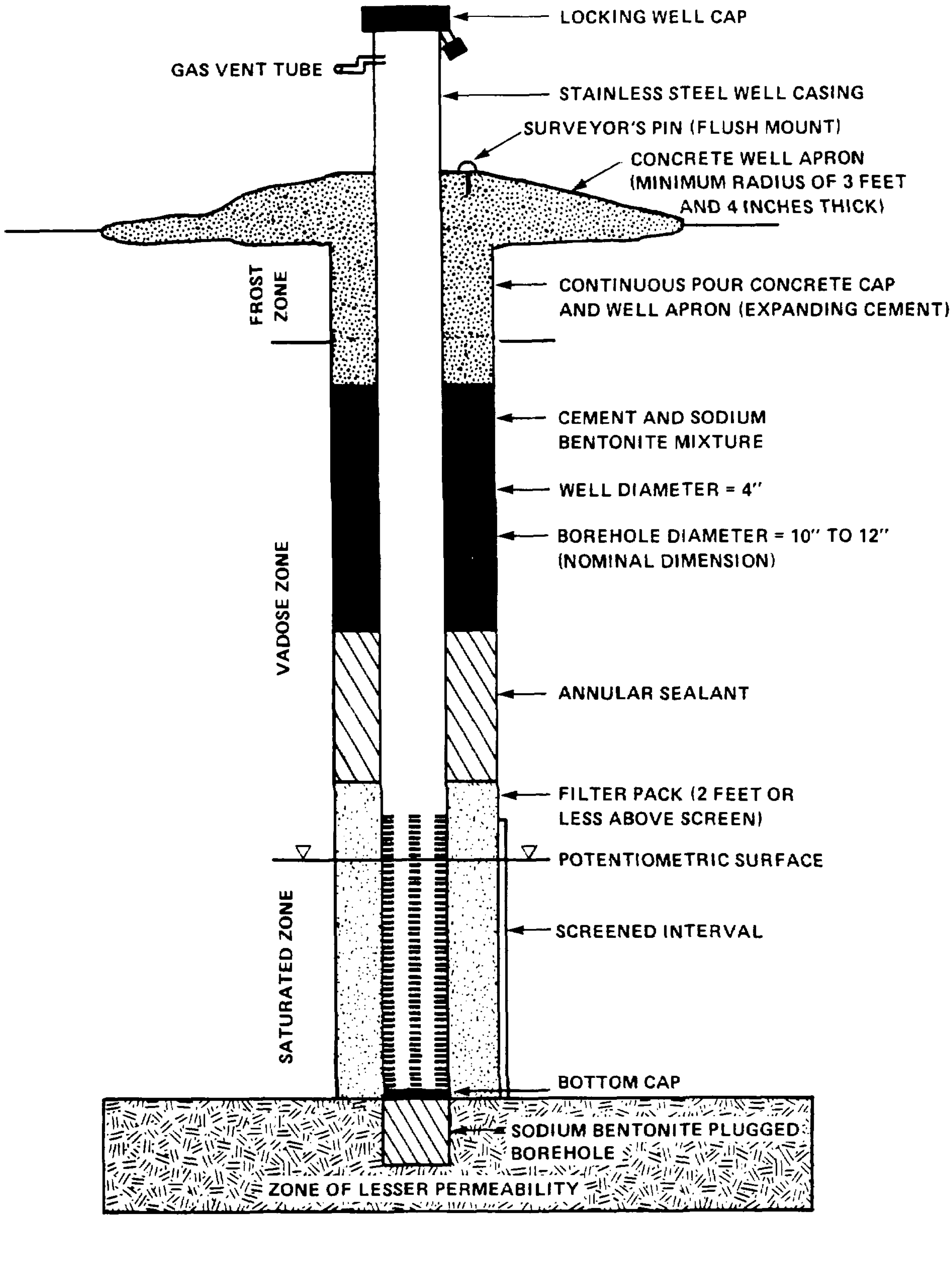

FIGURE 3-2 GENERAL STAINLESS STEEL MONITORING WELL – CROSS SECTION

organics are the contaminants anticipated. As research demonstrates the appropriateness of other materials for screens or casing in the saturated or vadose zones, they may be utilized on a site-specific basis. Stainless steel, fluorocarbon resins, or PVC are appropriate casing materials in the unsaturated zone.

Figure 3-3 illustrates the concept of a composite well. Many combinations of materials may be employed in a manner consistent with this guidance. One combination that should be avoided is the use of dissimilar metals, such as stainless steel and galvanized steel, without an electrically isolating (dielectric) bushing. If such dissimilar metals are in direct contact in the soil, a potential difference is created and leads to accelerated corrosion of the galvanized steel (in this example). More generically, in the Galvanic series the less noble metal becomes the anode to the more noble metal and is corroded at an accelerated rate. In well construction, this acceleration in corrosion at the point of connection will lead to failure of the construction materials and loss of a RCRA monitoring well. Theoretically, a potential difference is created in one type of metal penetrating heterogeneous strata, but the difference in potentials would not be as great. In conclusion, a dielectric coupling should be used for connecting dissimilar metals in either the saturated or vadose zone.

There are two reasons why owners/operators should have selected appropriate well screen and casing materials:

- Long term structural integrity, i.e., 30 or more years, is essential to the collection of unbiased ground-water samples over the active life of the facility and post-closure period.

- Owner/operators of facilities whose Part B or post-closure permit application has been called are required under 270.14(c)(4) to analyze any plume(s) for Appendix VIII constituents (see the RCRA Ground-Water Monitoring Compliance Order Guide, August 1985). The remainder of facilities must monitor for Appendix VII constituents. Well construction materials should not bias the collection and analysis of low concentrations of hazardous constituents by reacting with the ground-water samples.

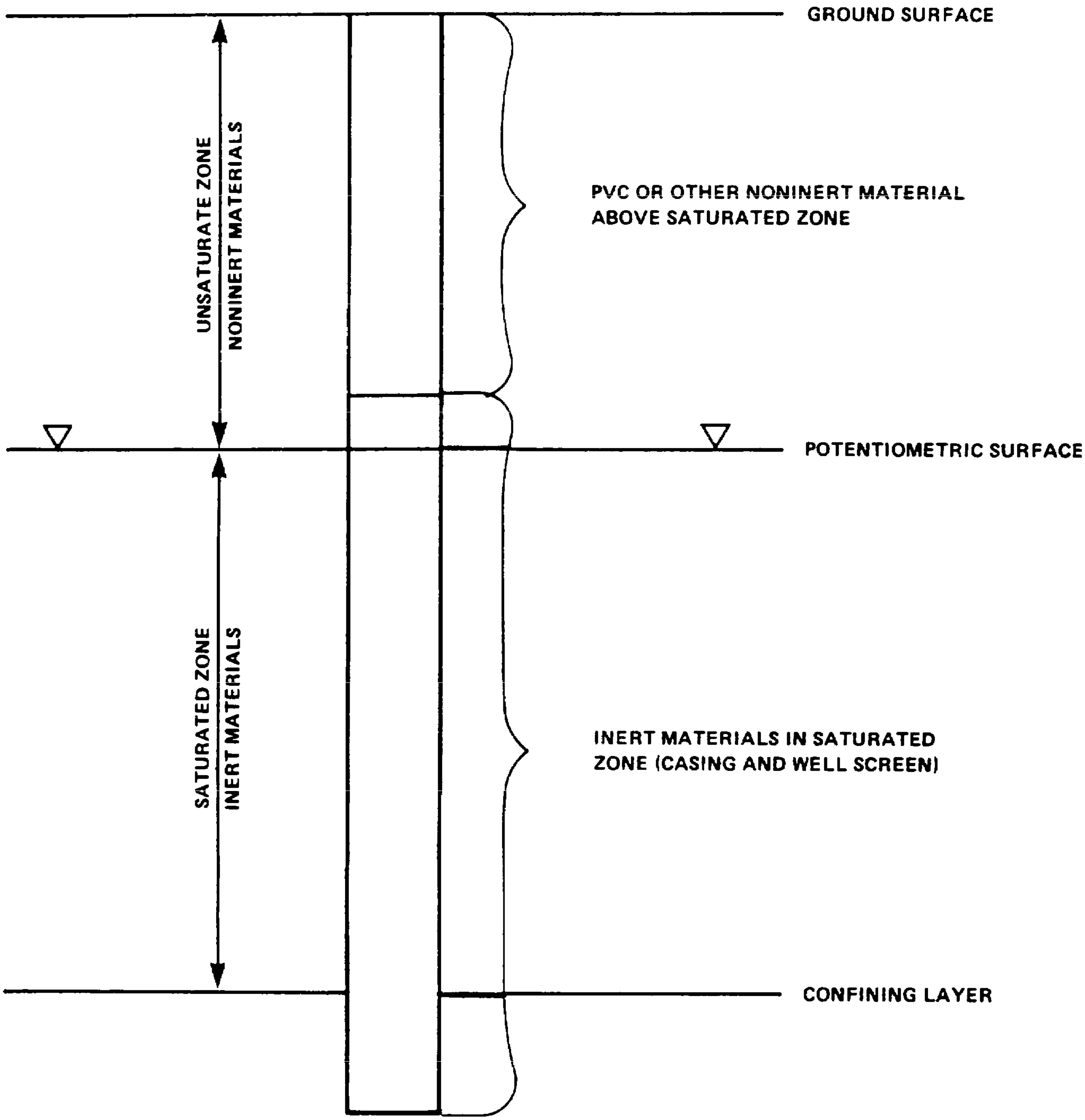

FIGURE 3-3. COMPOSITE WELL CONSTRUCTION
(INERT CONSTRUCTION MATERIALS IN SATURATED ZONE)

Plastic pipe sections must be flush threaded or have the ability to be connected by another mechanical method that does not introduce contaminants such as glue or solvents into the well. Also, monitoring wells must be structurally sound in order to withstand vigorous well development procedures. Well casings and screens should be steam cleaned prior to emplacement to ensure that all oils, greases, and waxes have been removed. Because of the softness of casings and screens made of fluorocarbon resins, these materials should be detergent-washed, not steam-cleaned, prior to installation.

The owner/operator should normally use well casing with either a two-inch or four-inch inside diameter. Larger casing diameters, however, may be necessary where dedicated purging or sampling equipment is used or where the well is screened in a deep formation.

The installation of a sump (sampling cup device) at the bottom of a monitoring well (Figure 3-1) is recommended. The sump will aid in collecting fine-grain sediments and result in prolonging the operating life of the screen. An extra benefit of using a sump is its ability to capture intermittent dense-phase contaminants for analysis. In zones composed of fine-grained material (clays and silts) where turbidity may be problematic, the decision flow chart (Figure 3-4) for turbid ground-water samples should be consulted to evaluate well construction and development.

3.2.2 Monitoring Well Filter Pack and Annular Sealant

The materials used to construct the filter pack should be chemically inert (e.g., clean quartz sand, silica, or glass beads), well rounded, and dimensionally stable (see Section 3.3 for more detail on well intake design). Fabric filters should not be used as filter pack materials. Natural gravel packs are acceptable, provided that the owner/operator conducts a sieve analysis to establish the appropriate well screen slot size and determine chemical inertness of the filter pack materials in anticipated environments.

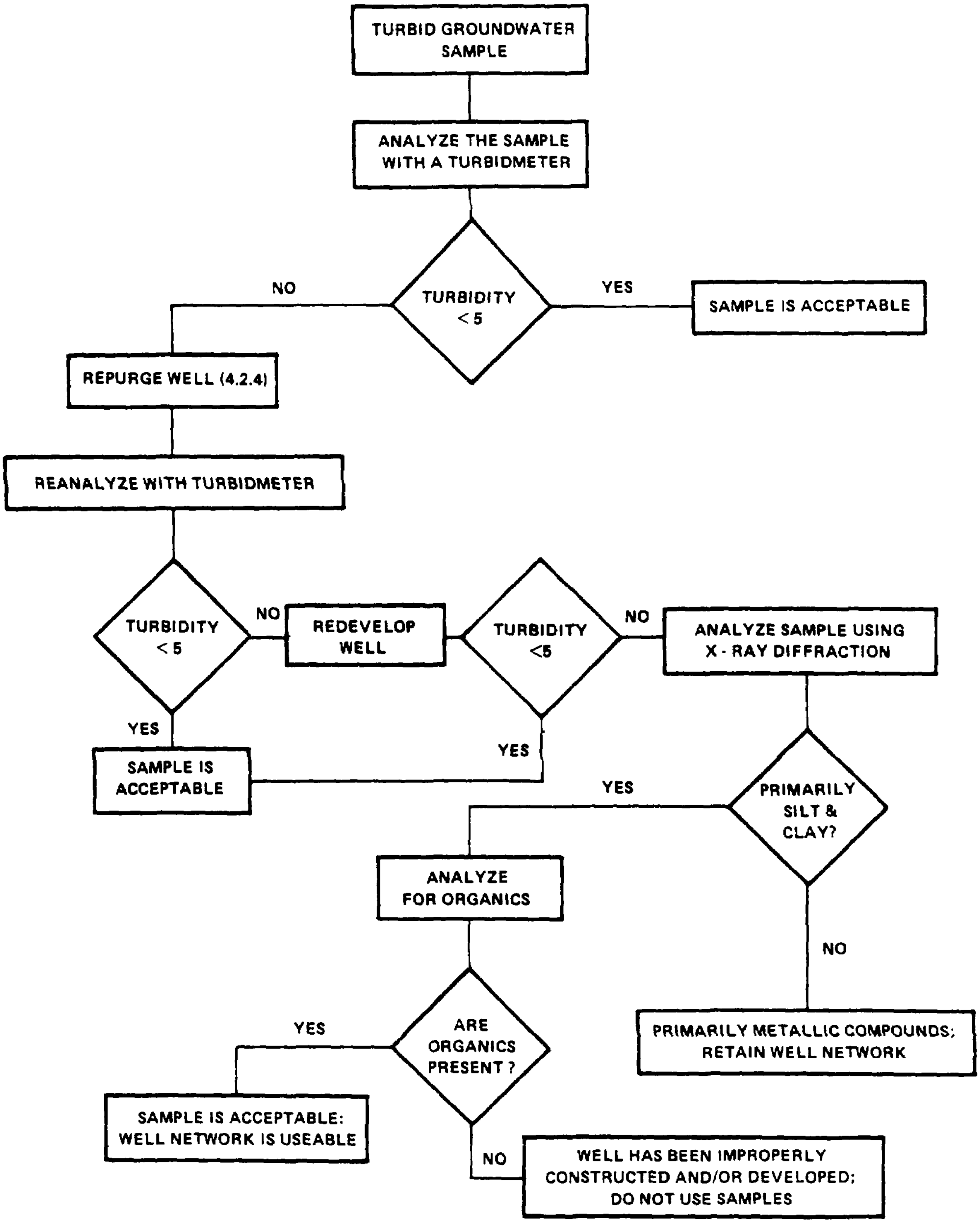

FIGURE 3-4 DECISION CHART FOR TURBID GROUND-WATER SAMPLES

The materials used to seal the annular space must prevent the migration of contaminants to the sampling zone from the surface or intermediate zones and prevent cross contamination between strata. The materials should be chemically compatible with the anticipated waste to ensure seal integrity during the life of the monitoring well and chemically inert so they do not affect the quality of the ground-water samples. The permeability of the sealants should be one to two orders of magnitude less than the surrounding formation. Figure 3-1 illustrates an appropriate distribution of annular sealants. An example of an appropriate use of annular sealant material is using a minimum of two feet of certified sodium bentonite pellets immediately over the filter pack when in a saturated zone. The pellets are most appropriate in a saturated zone because they will penetrate the column of water to create an effective seal. Coarse grit sodium bentonite is likely to hydrate and bridge before reaching the filter pack. A cement and bentonite mixture, bentonite chips, or antishrink cement mixtures should be used as the annular sealant in the unsaturated zone above the certified-bentonite pellet seal and below the frost line. Again, the appropriate clay must be selected on the basis of the environment in which it is to be used. In most cases, sodium bentonite is appropriate. The addition of bentonite to the cement admixture should generally be in the amount of 2 to 5 percent by weight of cement content. This will aid in reducing shrinkage and control time of setting. Calcium bentonite may be more appropriate in calcic sediments/soils due to reduced cation exchange potential. Clays should be pure, i.e., free of additives that may affect ground-water quality. From below the frost line, the cap should be composed of concrete blending into a four-inch thick apron extending three feet or more from the outer edge of the borehole.

The untreated sodium bentonite seal should be placed around the casing either by dropping it directly down the borehole or, if a hollow-stem auger is used, putting the bentonite between the casing and the inside of the auger stem. Both of these methods present a potential for bridging. In shallow monitoring wells, a tamping device should be used to reduce this potential. In deeper wells, it may be necessary to pour a small amount of formation water down the casing to wash the bentonite down the hole. In either case, a spacing differential of 3 to 5 inches should exist between the outer diameter of the casing and the inner diameter of the auger or the surface of the borehole to facilitate emplacement of filter pack and annular sealants. Moreover, the precise volume of filter pack and sealant required should be calculated to establish their correct subsurface distribution. The actual volume of materials used should be determined during well construction. Discrepancies between calculated volumes and volumes used require explanation.

The cement-bentonite mixture should be prepared using clean water and placed in the borehole using a tremie pipe. The tremie method ensures good sealing of the borehole from the bottom.

The remaining annular space should be sealed with expanding cement to provide for security and an adequate surface seals. Locating the interface between the cement and bentonite-cement mixture below the frost line serves to protect the well from damage due to frost heaving. The cement should be placed in the borehole using the tremie method.

Upon completion of the well, installation of a suitable threaded or flanged cap or compression seal should be placed or locked in properly to prevent either tampering with the well or the entrance of foreign material into it (Figure 3-2). A one-quarter inch vent hole pipe provides an avenue for the escape of gas. Placement of concrete or steel bumper guards around the well will prevent external damage by a vehicular collision with the exposed casing.

3.3 Well Intake Design

The owner/operator should have designed and constructed the intake of the monitoring wells to (1) allow sufficient ground-water flow to the well for sampling; (2) minimize the passage of formation materials (turbidity) into the well; and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure.

For wells completed in unconsolidated materials, the intake of a monitoring well should consist of a screen or slotted casing with openings sized to ensure that formational material is prohibited from passing through the well during development. Extraneous fine-grained material (clays and silts) that has been dislodged during drilling may be left on the screen and the water in the well. These fines should be removed from the screen and filter pack during development of the well. The owner/operator should use commercially manufactured screens or slotted casings. Field slotting of screens should not be allowed.

The annular space between the face of the formation and the screen or slotted casing should be filled to minimize passage of formation materials into the well. The driller should therefore install a filter pack in each monitoring well that is constructed on site. Furthermore, in order to ensure discrete sample horizons, the filter pack should extend no more than two feet above the well screen as illustrated in Figure 3-1.

3.4 Well Development

After the owner/operator completed constructing monitoring wells, natural hydraulic conductivity of the formation should have been restored and all foreign sediment removed to ensure turbid-free ground-water samples.

A variety of techniques are available for developing a well. To be effective, they require reversals or surges in flow to avoid bridging by particles, which is common when flow is continuous in one direction. These reversals or surges can be created by using surge blocks, bailers, or pumps. Formation water should be used for surging the well. In low-yielding water-bearing formations, an outside source of water may sometimes be introduced into the well to facilitate development. In these cases, this water should be chemically analyzed to evaluate its potential impact on in-situ water quality. The driller should not have used air to develop the wells. All developing equipment should have been decontaminated prior to use as should have the materials of construction.

The owner/operator should have developed wells to be clay- and silt-free. If, after development of the well is complete, it continues to yield turbid ground-water samples, the owner/operator should follow the procedure described in Figure 3-4. The recommended acceptance/rejection value of five nephelometric turbidity units (N.T.U.) is based on the need to minimize biochemical activity and possible interference with ground-water sample quality. The same criteria applies to turbidity measurements expressed in other units such as the formazin turbidity unit (F.T.U.) or Jackson turbidity unit (J.T.U.).

One should determine the relative hydraulic conductivity of different layers within the aquifer in which the screen is placed (the transmissivity/pumping test method is recommended). Using this information along with pH, temperature measurements and mean seasonal flow rates, one should evaluate the initial performance of the well and use these values for periodic redevelopment and maintenance assessments.

3.5 Documentation of Well Design and Construction

In the context of a compliance order, the technical reviewer should require the owner/operator to compile information on the design and construction of wells. Such information may include:

- Date/time of construction
- Drilling method and drilling fluid used
- Well location (± 0.5 ft.)
- Bore hole diameter and well casing diameter
- Well depth (± 0.1 ft.)
- Drilling and lithologic logs
- Casing materials

- Screen materials and design
- Casing and screen joint type
- Screen slot size/length
- Filter pack material/size, grain analysis (D10)
- Filter pack volume calculations
- Filter pack placement method
- Sealant materials (percent bentonite)
- Sealant volume (lbs/gallon of cement)
- Sealant placement method
- Surface seal design/construction
- Well development procedure
- Type of protective well cap
- Ground surface elevation (± 0.01 ft.)
- Surveyor's pin elevation (± 0.01 ft.) on concrete apron
- Top of monitoring well casing elevation (± 0.01 ft.)
- Top of protective steel casing elevation (± 0.01 ft.)
- Detailed drawing of well (include dimensions)

3.6 Specialized Well Designs

There are two cases where owners/operators should use special monitoring well designs:

- Where the owner/operator has chosen to use dedicated pumps to draw ground-water samples; and
- Where light and/or dense-phase immiscibles may be present.

If the owner/operator elected to use a dedicated system, it should be a fluorocarbon resin or stainless steel bailer, or a dedicated positive gas displacement bladder pump composed of the same two materials. As other sampling devices that can perform at least equivalently become available, they may be employed as well.

The introduction of this pump, however, necessitates certain changes in the well cross section depicted in Figure 3-1. Figure 3-5 represents

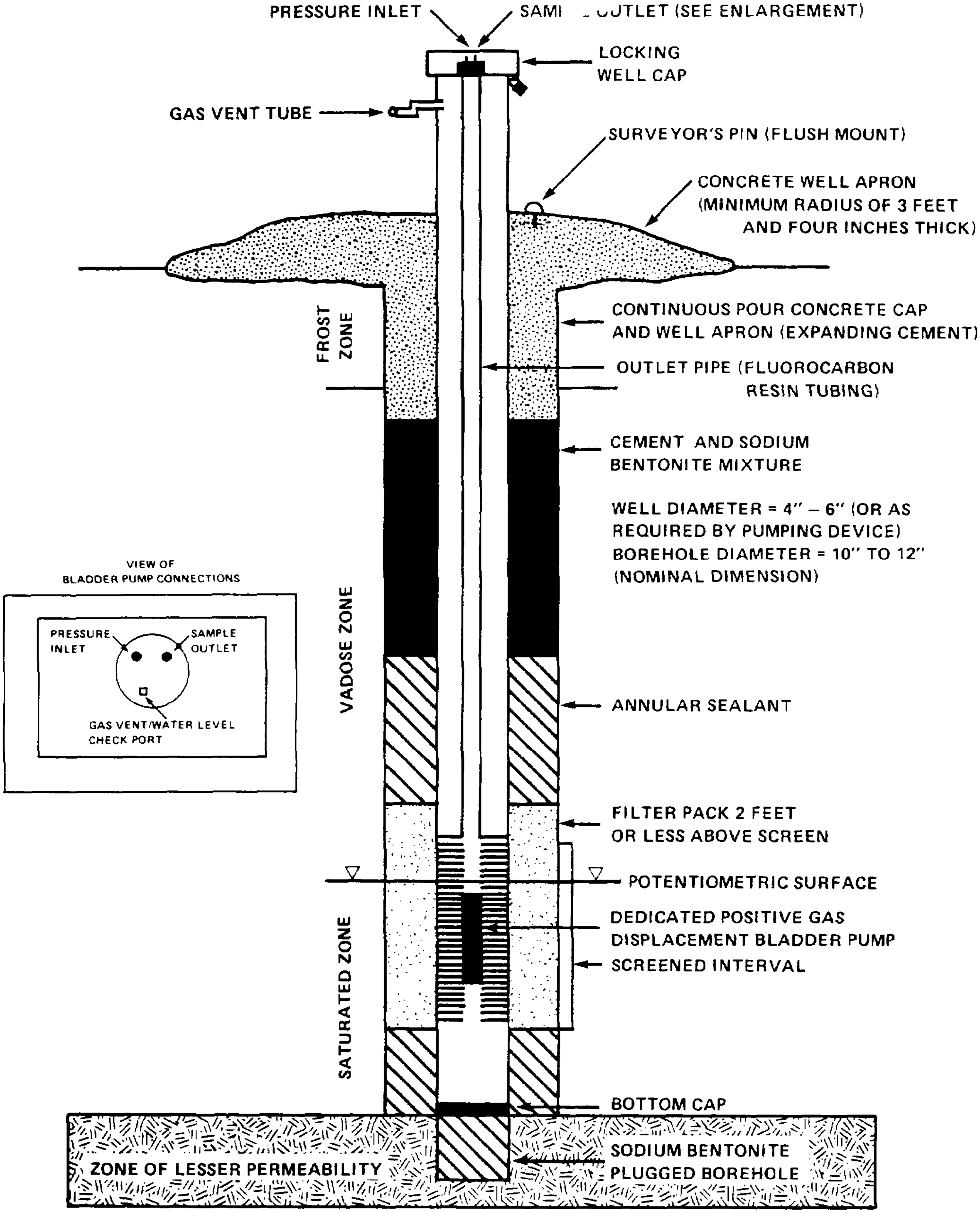

FIGURE 3-5 MONITORING WELL CROSS-SECTION – DEDICATED POSITIVE GAS DISPLACEMENT BLADDER PUMP SYSTEM.

an appropriate cross section of a well that uses a dedicated positive gas displacement bladder pump as the sampling device/well evacuation device. The principal change is the addition of a two-inch diameter pump with fluorocarbon resin outlet tubing to the well. A four-inch interior diameter outer well casing should easily accommodate this additional equipment. However, should a larger pump (e.g., three inches in diameter) be required because of greater well depth or yield, a larger outer casing may prove necessary (six-inch inside diameter). The pump should be positioned midway along the screened interval, and the top of its outlet pipe should extend into the well cap as depicted in Figure 3-5.

If light and dense-phase immiscible layers are presumed to be present, the owner/ operator must obtain discrete samples of them. The well system should have been designed to allow sampling of both light and dense phases by using a well screen that extends from above the potentiometric surface to the lower confining layer. Where well clusters are employed, one well in the cluster may be screened at horizons where floaters are expected (e.g., potentiometric surface, Figure 3-5), another at horizons where dense phases are expected (e.g., aquifer/aquiclude interface, Figure 3-6), and others within other portions of the uppermost aquifer.

A periodic check of the dedicated sampling system should be exercised to prevent damage and maximize efficiency. This inspection should include removal of samples for verification of proper function. The design of the dedicated sampling system should also allow access for regular testing of aquifer characteristics. It is also recommended that the well be periodically resurveyed using the protective casing and apron (constructed to specific dimensions, Figure 3-1) as points of reference. An option that can be exercised in constructing a monitoring well (e.g., dedicated sampler) is the use of fine sand at the top of the filter pack to reduce or minimize invasion.

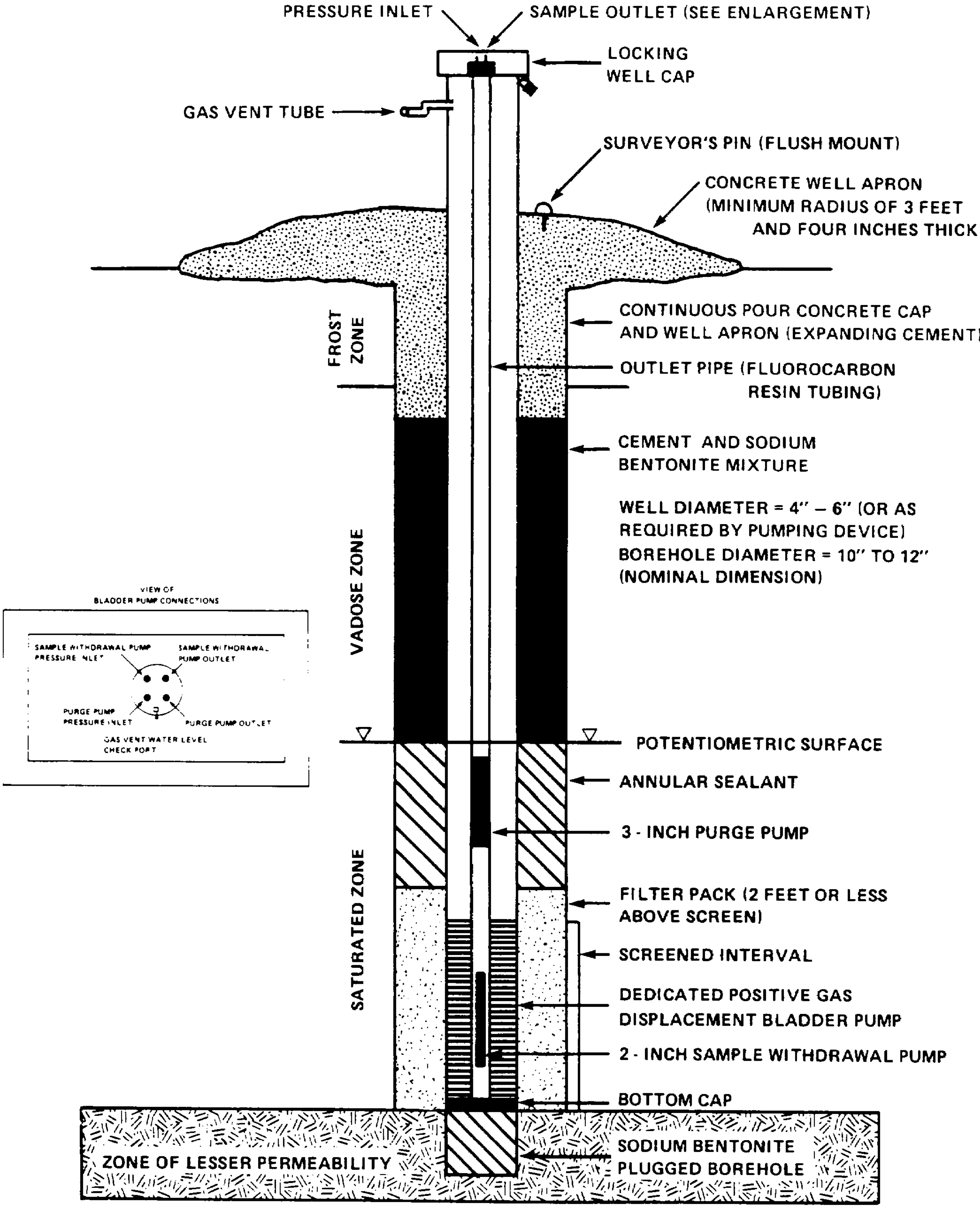

FIGURE 3-6 MONITORING WELL CROSS-SECTION – DEDICATED PURGE PUMP AND SAMPLE WITHDRAWAL PUMP. WELL SCREENED IN A HIGH YIELDING AQUIFER.

3.7 Evaluation of Existing Wells

The technical reviewer must decide whether wells--as designed and constructed--allow for the collection of representative ground-water samples. There are two situations the technical reviewer may encounter: (1) where existing wells produce consistently turbid samples, i.e., greater than 5 N.T.U. (F.T.U. or J.T.U. depending on the method used), and (2) where the owner/operator can produce little or no documentation on how the wells were designed and installed.

Wells with turbidity or lack of information on well design and construction may prompt the technical reviewer to order the owner/operator to replace monitoring wells. In other, less obvious, cases the technical reviewer must use best judgment in deciding when to order an owner/operator to replace wells. The technical reviewer must decide whether the owner/operator's wells--as built--allow the sampler to collect representative ground-water samples (40 CFR 265.91(a)). This may not be an easy judgment to make. In cases where it is not clear whether the wells can produce representative ground-water samples, the technical reviewer may consider requiring the owner/operator to conduct a field demonstration. This demonstration would involve the installation of new well(s) near existing wells. The owner/operator would sample and analyze for the same set of parameters in both wells. If parameter values are comparable, the technical reviewer should assume the owner/operator's existing wells are producing representative samples. The field demonstration for existing and new wells will be extremely difficult to evaluate in practice. Differences in construction may or may not manifest themselves during the field test. The results may lead to false conclusions in view of the normal variabilities inherent in water quality parameters or sampling which may be attributed to differences between old and new wells. Similarly, differences in well construction, development, etc., that can never be duplicated may also result in negative or positive biases due to causes other than well construction. When such situations arise, the wells should be decommissioned, sealed, and replaced. Where the only question is whether or not the well casing material is negatively affecting the chemical quality of the ground-water samples, a side-by-side comparison at selected wells should be undertaken using stainless steel or one of the fluorocarbon resins. If analysis results are comparable, then it is likely that chemical bias is not a major issue at the time of the test.

Once wells have been properly designed and constructed, an appropriate sampling and analysis plan must be developed and implemented. These procedures are discussed in Chapter Four.

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CHAPTER FOUR

SAMPLING AND ANALYSIS

Federal regulation 40 CFR Part 265, Subpart F, Section 265.92, requires the owner/operator to prepare and implement a written ground-water sampling and analysis (S&A) plan. This plan must include procedures and techniques for sample collection, sample preservation and shipment, analytical procedures, and chain-of-custody control. The plan is an important document. It allows the technical reviewer to thoroughly review how the owner/operator has structured the S&A program. Also, comparison of the written plan to field activities will allow the technical reviewer to ensure the owner/operator is, in fact, following his plan while collecting and analyzing ground-water samples. The purpose of this chapter is to describe important elements of written S&A plans and to discuss the level of detail that owner/operators should include in their plans.

EPA has observed a number of problems in the way in which owner/operators prepare their S&A plans or implement their S&A programs. Some of the more common problems are listed below.

- Owner/operators have not prepared S&A plans or do not keep plans on site.
- Plans contain very little information or do not adequately describe the S&A program that the owner/operator is employing at his facility.
- Field sampling personnel are not following the written plan or are not even aware that it exists.
- Improper well evacuation techniques are used.
- Sampling equipment is used that may alter chemical constituents in ground water.
- Sampling techniques are used that may alter chemical composition of samples, particularly in regard to stripping of volatile organic compounds in samples.

- Facility personnel are not using field blanks, chemical standards, and chemically spiked samples to identify changes in sample quality after collection.

- Field personnel do not properly clean nondedicated sampling equipment after use.

- Field personnel are placing sampling equipment (rope, bailer, tubing) on the ground where it can become contaminated prior to use.

- Field personnel do not document their field activities adequately (e.g., keep sampling logs).

- Field personnel are not following proper chain-of-custody procedures.

- Little attention is paid to data reporting errors or anomalies.

- QA/QC protocol is inadequate (field and/or laboratory).

This chapter describes important elements in S&A plans (Section 4.1), and then discusses the level of detail the owner/operator should include (Sections 4.2 through 4.6). Furthermore, this chapter describes important aspects of evaluating the field implementation of S&A plans (Sections 4.2 through 4.6). Section 4.7 describes how technical reviewers may examine ground-water data to identify problems in the way owner/operators acquire, process, and evaluate data.

4.1 Elements of Sampling and Analysis Plans

The owner/operator's S&A plan should, at a minimum, address a number of elements. Specifically, the S&A plan should include information on:

- Sample collection (Section 4.2);
- Sample preservation and handling (Section 4.3);
- Chain-of-custody control (Section 4.4);
- Analytical procedures (Section 4.5); and
- Field and laboratory quality assurance/quality control (Section 4.6).

4.2 Sample Collection

4.2.1 Measurement of Static Water Level Elevation

The sampling and analysis plan should include provisions for measurement of static water elevations in each well prior to each sampling event. Collection of water elevation on a continuing basis is important to determine if horizontal and vertical flow gradients have changed since initial site characterization. A change in hydrologic conditions may necessitate modification to the design of the owner/operator's ground-water monitoring system. The S&A plan should specify the device to be used for water level measurements, as well as the procedure for measuring water levels.

The owner/operator's field measurements should include depth to standing water and total depth of the well to the bottom of the intake screen structure. This information is required to calculate the volume of stagnant water in the well and provide a check on the integrity of the well (e.g., identify siltation problems). The measurements should be taken to 0.01 foot. Each well should have a permanent, easily identified reference point from which its water level measurement is taken. The reference points should be established by a licensed surveyor and typically located and marked at the top of the well casing with locking cap removed or on the apron, and, where applicable, the protective casing. The references points should be established in relation to an established National Geodetic Vertical Datum (NGVD). In remote areas, a temporary benchmark should be established to facilitate resurveying. The reference point should be established in relation to an established NGVD, and the survey should also note the well location coordinates and the coordinates of any temporary benchmarks. The device used to detect the water level surface must be sufficiently sensitive so that a measurement to ±0.01 foot can be obtained reliably. A steel tape will usually suffice; however, it is recommended that an electronic device (e.g., M-Scope) be used to measure depth to the surface of the ground water or light phase immiscibles. Whenever nondedicated equipment is used, procedures need to be instituted to ensure that the sample is not contaminated. Equipment should be constructed of inert materials and decontaminated prior to use at another well.

4.2.2 Detection of Immiscible Layers

The S&A plan should include provisions for detecting immiscible contaminants (i.e., "floaters" and "sinkers") where they would not be detected in an aqueous phase if the owner/operator manages wastes of this type at his facility. "Floaters" are those relatively insoluble organic liquids that are less dense than water and which spread across the potentiometric surface. "Sinkers" are those relatively insoluble organic liquids that are more dense than water and tend to migrate vertically through the sand and gravel aquifers to the underlying confining layer. The detection of these immiscible layers requires specialized equipment that must be used before the well is evacuated for conventional sampling. The S&A plan should specify the device to be used to detect light phases and dense phases, as well as the procedures to be used for detecting and sampling these contaminants.

Owner/operators should follow the procedures below for detecting the presence of light and/or dense phase immiscible organic layers. These procedures should be undertaken before the well is evacuated for conventional sampling:

1. Remove the locking and protective caps.
2. Sample the air in the well head for organic vapors using either a photoionization analyzer or an organic vapor analyzer, and record measurements.
3. Determine the static liquid level using a manometer and record the depth.
4. Lower an interface probe into the well to determine the existence of any immiscible layer(s), light and/or dense.

The air above the well head should be monitored in order to determine the potential for fire, explosion, and/or toxic effects on workers. This test also serves as a first indication of the presence of light phase immiscible organics. A manometer or acoustical sounder (for very shallow wells) will provide an accurate reading of the depth to the surface of the liquid in the well, but neither are capable of differentiating between the potentiometric surface and the surface of an immiscible layer. Nonetheless, it is very useful to determine that surface depth first to guide the lowering of the interface probe. The interface probe serves two related purposes. First, as it is lowered into the well, the probe registers when it is exposed to an organic liquid and thus identifies the presence of immiscible layers. Careful recording of the depths of the air/floater and floater/water interfaces establishes a measurement of the thickness of the light phase immiscible layer. Secondly, after passing through the light phase immiscible layer, the probe indicates the depth to the water level. The presence of floaters precludes the exclusive use of sounders to make a determination of static water level. Dense phase immiscible layers are detected by lowering the device to the bottom of the well where, again, the interface probe registers the presence of organic liquids.

The approach to collecting light phase immiscibles is dependent on the depth to the surface of the floating layer and the thickness of that layer. The immiscible phase must be collected prior to any purging activities. If the thickness of this phase is 2 feet or greater, a bottom valve bailer is the equipment of choice. The bailer should be lowered slowly until contact is made with the surface of the immiscible phase, and lowered to a depth less than that of the immiscible/water interface depth as determined by preliminary measure with the interface probe.

When the thickness of the floating layer is less than 2 feet, but the depth to the surface of the floating layer is less than 25 feet, a peristaltic pump can be used to "vacuum" a sample.

When the thickness of the floating layer is less than 2 feet and the depth to the surface of the floating layer is beyond the effective "reach" of a peristaltic pump (greater than 25 feet), a bailer must be modified to allow filling only from the top. Sampling personnel should disassemble the bottom check valve of the bailer and insert a piece of 2-inch diameter fluorocarbon resin sheet between the ball and ball seat. This will seal off the bottom valve. The ball from the top check valve should be removed to allow the sample to enter from the top. The buoyancy that occurs when the bailer is lowered into the floater can be overcome by placing a length of 1-inch stainless steel pipe (304, 316, 2205) on the retrieval line above the bailer (this pipe may have to be notched to allow sample entry if the pipe remains within the top of the bailer). The device should be lowered carefully, measuring the depth to the surface of the floating layer, until the top of the bailer is level with the top of the floating layer. The bailer should be lowered an additional one-half thickness of the floating layer and the sample collected. This technique is the most effective method of collection if the floating phase is only a few inches thick.

The best method for collecting dense phase immiscibles is to use a double check valve bailer. The key to sample collection is controlled, slow lowering (and raising) of the bailer to the bottom of the well. The dense phase must be collected prior to any purging activities.

4.2.3 Well Evacuation

The water standing in a well prior to sampling may not be representative of in-situ ground-water quality. Therefore, the owner/operator should remove the standing water in the well and filter pack so that formation water can replace the stagnant water. The owner/operator's S&A plan should include detailed, step-by-step procedures for evacuating wells. The equipment the owner/operator plans to use to evacuate wells should also be described.

The owner/operator's evacuation procedure should ensure that all stagnant water is replaced by fresh formation water upon completion of the process. The owner/operator's approach should allow drawing the water down from above the screen in the uppermost part of the water column in high yield formations to ensure that fresh water from the formation will move upward in the screen. In low-yield formations, water should be purged so that it is removed from the bottom of the screened interval.

The procedure the owner/operator should use for well evacuation depends on the hydraulic yield characteristics of the well. When evacuating low-yield wells (wells that are incapable of yielding three casing volumes), the owner/operator should evacuate wells to dryness once. As soon as the well recovers sufficiently, the first sample should be tested for pH, temperature, and specific conductance. Samples should then be collected and containerized in the order of the parameters' volatilization sensitivity. The well should be retested for pH, temperature, and specific conductance after sampling as a measure of purging efficiency and as a check on the stability of the water samples over time. Whenever full recovery exceeds two hours, the owner/operator should extract the sample as soon as sufficient volume is available for a sample for each parameter. At no time should an owner/operator pump a well to dryness if the recharge rate causes the formation water to vigorously cascade down the sides of the screen and cause an accelerated loss of volatiles. The owner/operator should anticipate this problem and purge three casing volumes from the well at a rate that does not cause recharge water to be excessively agitated. For higher yielding wells, the owner/operator should evacuate three casing volumes prior to sampling.

In order to minimize the introduction of contamination into the well positive-gas-displacement, fluorocarbon resin bladder pumps are recommended for purging wells. Fluorocarbon resin or stainless steel bailers are also recommended purging equipment. Where these devices cannot be used, peristaltic pumps, gas-lift pumps, centrifugal pumps, and venturi pumps may be used. Some of these pumps cause volatilization and produce high pressure differentials, which result in variability in the analysis of pH, specific conductance, metals, and volatile organic samples. They are, however, acceptable for purging the wells if sufficient time is allowed to let the water stabilize prior to sampling.

When purging equipment must be reused, it should be decontaminated, following the same procedures required for the sampling equipment. Clean gloves should be worn by the sampling personnel. Measures should be taken to prevent surface soils from coming in contact with the purging equipment and lines, which in turn could introduce contaminants to the well. Purged water should be collected and screened with photoionization or organic vapor analyzers, pH, temperature, and conductivity meters. If these parameters and facility background data suggest that the water is hazardous, it should be drummed and disposed of properly.

4.2.4 Sample Withdrawal

The technique used to withdraw a ground-water sample from a well should be selected based on a consideration of the parameters to be analyzed in the sample. To ensure the ground-water sample is representative of the formation, it is important to minimize physically altering or chemically contaminating the sample during the withdrawal process. In order to minimize the possibility of sample contamination, the owner/operator should:

- Use only fluorocarbon resin or stainless steel sampling devices, and

- Use dedicated samplers for each well. (If a dedicated sampler is not available for each well, the owner/operator should thoroughly clean the sampler between sampling events, and should take blanks and analyze them to ensure cross-contamination has not occurred.)

The S&A plan should specify the order in which samples are to be collected. Samples should be collected and containerized in the order of the volatilization sensitivity of the parameters. A preferred collection order for some common ground-water parameters follows:

- Volatile organics (VOA)
- Purgeable organic carbon (POC)
- Purgeable organic halogens (POX)
- Total organic halogens (TOX)
- Total organic carbon (TOC)
- Extractable organics
- Total metals
- Dissolved metals
- Phenols
- Cyanide
- Sulfate and chloride
- Turbidity
- Nitrate and ammonia
- Radionuclides

Temperature, pH, and specific conductance measurements should be made in the field before and after sample collection as a check on the stability of the water sampled over time. The S&A plan should also specify in detail the devices the owner/operator will use for sample withdrawal. The plan should state that devices are either dedicated to a specific well or are capable of being fully disassembled and cleaned between sampling events. Procedures for cleaning the sampling equipment should be included in the plan. Any special sampling procedures that the owner/operator must use to obtain samples for a particular constituent (e.g., TOX or TOC) should also be described in the plan.

Equipment and procedures that minimize sample agitation and reduce/eliminate contact with the atmosphere during sample transfer must be used. When used properly, the following are acceptable sampling devices for all parameters:

- Gas-operated, fluorocarbon resin or stainless steel squeeze pump (also referred to as a bladder pump with adjustable flow control);

- Bailer (fluorocarbon resin or stainless steel), provided it is equipped with double check valves and bottom emptying device;

- Syringe bailer (stainless steel or fluorocarbon resin); and

- Single check valve fluorocarbon resin or stainless steel bailer.

Sampling equipment should be constructed of inert material. Equipment with neoprene fittings, PVC bailers, tygon tubing, silicon rubber bladders, neoprene impellers, polyethylene, and viton is not acceptable. If the owner/operator is using bailers, an inert cable/chain (e.g., fluorocarbon resin-coated wire, single strand stainless steel wire) should be used to raise and lower the bailer.

While in the field, the technical reviewer should observe the owner/operator's sampling technique to ensure that the owner/operator satisfies the following:

- Positive gas displacement bladder pumps should be operated in a continuous manner so that they do not produce pulsating samples that are aerated in the return tube or upon discharge.

- Check valves should be designed and inspected to assure that fouling problems do not reduce delivery capabilities or result in aeration of the sample.

- Sampling equipment (e.g., especially bailers) should never be dropped into the well, because this will cause degassing of the water upon impact.

- The contents should be transferred to a sample container in a way that will minimize agitation and aeration.

- Clean sampling equipment should not be placed directly on the ground or other contaminated surfaces prior to insertion into the well.

When dedicated equipment is not used for sampling (or well evacuation), the owner/operator's sampling plan should include procedures for disassembly and cleaning of equipment before each use. If the constituents of interest are inorganic, the equipment should be cleaned with a nonphosphate detergent/soap mixture. The first rinse should be a dilute (0.1 N) hydrochloric acid or nitric acid, followed by a rinse of tap water and finally Type II reagent grade water. Dilute hydrochloric acid is generally preferred to nitric acid when cleaning stainless steel because nitric acid may oxidize stainless steel. When organics are the constituents of concern, the owner/operator should wash equipment with a nonphosphate detergent and rinse with tap water, distilled water, acetone, and pesticide-quality hexane, in that order. The sampling equipment should be thoroughly dried before use to ensure that the residual cleaning agents (e.g., HCl) are not carried over to the sample. The owner/operator should sample background wells first and then proceed to downgradient wells.

When collecting samples where volatile constituents or gases are of interest using a positive gas displacement bladder pump, pumping rates should not exceed 100 milliliters/minute. Higher rates can increase the loss of volatile constituents and can cause fluctuation in pH and pH-sensitive analytes. Once the portions of the sample reserved for the analysis of volatile components have been collected, the owner/operator may use higher pumping rate, particularly if a large sample volume must be collected. The sampling flow rate should not exceed the flow rate used while purging.

4.2.5 In-Situ or Field Analyses

Several constituents of the parameters being evaluated are physically or chemically unstable and must be tested either in the borehole using a probe (in-situ) or immediately after collection using a field test kit. Examples of unstable elements or properties include pH, redox potential, chlorine, dissolved oxygen, and temperature. Although specific conductivity (analogous to electrical resistance) of a substance is relatively stable, it is recommended that this characteristic be determined in the field. Most conductivity instruments require temperature compensation; therefore, the temperature of the samples should be measured at the time conductivity is determined. If the owner/operator uses probes (pH electrode, specific ion electrode, thermistor) to measure any of the above properties, it is important that this is done on water samples taken after well evacuation and after any samples for chemical analysis have been collected, so that the potential for probe(s) to contaminate a sample designated for laboratory analysis is minimized. Monitoring probes should not be placed in shipping containers containing ground-water samples for laboratory analysis.

The owner/operator should complete the calibration of any in-situ monitoring equipment or field-test probes and kits at the beginning of each use, according to the manufacturers' specifications and consistent with Test Methods for Evaluating Solid Waste - Physical/Chemical Methods (SW-846), 2nd Edition, 1982.

4.3 Sample Preservation and Handling

Many of the chemical constituents and physiochemical parameters that are to be measured or evaluated in ground-water monitoring programs are not chemically stable, and therefore sample preservation is required. Test Methods for Evaluating Solid Waste - Physical/Chemical Methods (SW-846) includes a discussion by analyte of the appropriate sample preservation procedures. In addition, SW-846 specifies the sample containers that the owner/operator should use for each constituent or common set of parameters. The owner/operator should identify in the S&A plan what preservation methods and sample containers will be employed. Each sampling and analysis plan should also detail all procedures and techniques for transferring the samples to either a field or off-site laboratory.

Improper sample handling may alter the analytical results of the sample. Samples should be transferred in the field from the sampling equipment directly into the container that has been specifically prepared for that analysis or set of compatible parameters. It is not an acceptable practice for samples to be composited in a common container in the field and then split in the laboratory, or poured first into a wide mouth container and then transferred into smaller containers. The S&A plan should specify how the samples for volatiles will be transferred from the sample collection device to the sample container in order to minimize loss through agitation/volatilization.

4.3.1 Sample Containers

The owner/operator's S&A plan should identify the type of sample containers to be used to collect samples, as well as the procedures the owner/operator will use to ensure that sample containers are free of contaminants prior to use.

When metals are the analytes of interest, fluorocarbon resin or polyethylene containers with polypropylene caps should be used. When organics are the analytes of interest, glass bottles with fluorocarbon resin-lined caps should be used. The plan should refer to the specific analytical method (in SW-846) that designates an acceptable container.

Containers should be cleaned based on the analyte of interest. When samples are to be analyzed for metals, the sample containers as well as the laboratory glassware should be thoroughly washed with nonphosphate detergent and tap water, and rinsed with (1:1) nitric acid, tap water, (1:1) hydrochloric acid, tap water, and finally Type II water, in that order.

Similarly, an EPA-approved procedure is available for cleaning containers used to store samples for organics analysis. The sampling container should be emptied of any residual materials, followed by washing with a nonphosphate detergent in hot water. It should then be rinsed with tap water, distilled water, acetone, and finally with pesticide-quality hexane. Dirty or contaminated glassware does not form a very thin sheet of water on its surface and may require treatment with chromic acid and/or baking in a muffle furnace at 400°C for 15 to 30 minutes to ensure that the glass is clean. Chromic acid may be useful to remove organic deposits from glassware; however, the analyst should be cautioned that the glassware must be thoroughly rinsed with water to remove the last traces of chromium. The use of chromic acid can cause a contamination problem and must be avoided if chromium is an analyte of interest.

Glassware should be sealed and stored in a clean environment immediately after drying or cooling to prevent any accumulation of dust or other contaminants. It should be stored capped with aluminum foil and inverted.

The cleanliness of a batch of precleaned bottles should be verified in the laboratory. The residue analysis should be available prior to sampling in the field.

4.3.2 Sample Preservation

The owner/operator's S&A plan should identify sample preservation methods that the owner/operator plans to use. Methods of sample preservation are relatively limited and are generally intended to (1) retard biological action, (2) retard hydrolysis, and (3) reduce sorption effects. Preservation methods are generally limited to pH, control, chemical addition, refrigeration, and protection from light. The owner/operator should refer to the specific preservation method in SW-846 that will be used for the constituent in the sample. A summary list of appropriate sample container types and sample preservation measures is presented in Table 4-1.

4.3.3 Special Handling Considerations

Samples requiring analysis for organics should not be filtered. Samples should not be transferred from one container to another, because

TABLE 4-1

SAMPLING AND PRESERVATION PROCEDURES FOR DETECTION MONITORING[a]

Parameter	Recommended Container[b]	Preservative	Maximum Holding Time	Minimum Volume Required for Analysis
		<u>Indicators of Ground-Water Contamination</u>[c]		
pH	T, P, G	Field determined	None	25 ml
Specific conductance	T, P, G	Field determined	None	100 ml
TOC	G, amber, T-lined cap[e]	Cool 4°C,[d] HCl to pH <2	28 days	4 x 15 ml
TOX	G, amber, T-lined septa or caps	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 Manganese Sodium	T, P	Field acidified to pH <2 with HNO_3	6 months	200 ml
Phenols	G	4°C/H_2SO_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 Barium Cadmium Chromium Lead Mercury Selenium Silver	T, P Dark Bottle	<u>Total Metals</u> Field acidified to pH <2 with HNO_3 <u>Dissolved Metals</u> 1. Field filtration (0.45 micron) 2. Acidify to pH <2 with HNO_3	6 months 6 months	1,000 ml 1,000 ml
Fluoride	T, P	Cool, 4°C	28 days	300 ml
Nitrate/Nitrite	T, P, G	4°C/H_2SO_4 to pH <2	14 days	1,000 ml

(continued)

TABLE 4-1 (Continued)

SAMPLING AND PRESERVATION PROCEDURES FOR DETECTION MONITORING

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	Cool, 4°C	7 days	2,000 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
	Other Ground-Water Characteristics of Interest			
Cyanide	P, G	Cool, 4°C, NaOH to pH >12. 0.6 g ascorbic acid[f]	14 days[g]	500 ml
Oil and Grease	G only	Cool, 4°C H_2SO_4 to pH <2	28 days	100 ml
Semivolatile, nonvolatile organics	T, G	Cool, 4°C	14 days	60 ml
Volatiles	G, T-lined	Cool, 4°C	14 days	60 ml

[a]References: 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).

[b]Container Types:
P = Plastic (polyethylene)
G = Glass
T = Fluorocarbon resins (PTFE, Teflon®, FEP, PFA, etc.)
PP = Polypropylene

(Continued)

TABLE 4-1 (Continued)

SAMPLING AND PRESERVATION PROCEDURES FOR DETECTION MONITORING

[c]Based 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.

[d]Shipping containers (cooling chest with ice or ice pack) should be certified as to the 4°C temperature at time of sample placement into these containers. Preservation of samples requires that the temperature of collected samples be adjusted to the 4°C immediately after collection. Shipping coolers must be at 4°C and maintained at 4°C upon placement of sample and during shipment. Maximum-minimum thermometers are to be placed into the shipping chest to record temperature history. Chain-of-custody forms will have Shipping/Receiving and In-transit (max/min) temperature boxes for recording data and verification.

[e]Do not allow any head space in the container.

[f]Use ascorbic acid only in the presence of oxidizing agents.

[g]Maximum holding time is 24 hours when sulfide is present. Optionally, all samples may be tested with lead acetate paper before the pH adjustment in order to determine if sulfide is present. If sulfide is present, it can be removed by addition of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then NaOH is added to pH 12.

losses of organic material onto the walls of the container or aeration may occur. Total organic halogens (TOX) and total organic carbon (TOC) samples should be handled and analyzed as materials containing volatile organics. No headspace should exist in the sample containers to minimize the possibility of volatilization of organics. Field logs and laboratory analysis reports should note the headspace in the sample container(s) at the time of receipt by the laboratory, as well as at the time the sample was first transferred to the sample container at the wellhead.

Metallic ions that migrate through the unsaturated (vadose) and saturated zones and arrive at a ground-water monitoring well may be present in the well. Particles (e.g., silt, clay), which may be present in the well even after well evacuation procedures, may absorb or adsorb various ionic species to effectively lower the dissolved metal content in the well water. Ground-water samples on which metals analysis will be conducted should be split into two portions. One portion should be filtered through a 0.45-micron membrane filter, transferred to a bottle, preserved with nitric acid to a pH less than 2 (Table 4-1), and analyzed for dissolved metals. The remaining portion should be transferred to a bottle, preserved with nitric acid, and analyzed for total metals. Any difference in concentration between the total and dissolved fractions may be attributed to the original metallic ion content of the particles and any sorption of ions to the particles.

4.4 Chain-of-Custody

The owner/operator must describe a chain-of-custody program in the S&A plan. An adequate chain-of-custody program will allow for the tracing of possession and handling of individual samples from the time of field collection through laboratory analysis. An owner/operator's chain-of-custody program should include:

- Sample labels, which prevent misidentification of samples;
- Sample seals to preserve the integrity of the sample from the time it is collected until it is opened in the laboratory;

- Field logbook to record information about each sample collection during the ground-water monitoring program;

- Chain-of-custody record to establish the documentation necessary to trace sample possession from the time of collection to analysis;

- Sample analysis request sheets, which serve as official communication to the laboratory of the particular analysis(es) required for each sample and provide further evidence that the chain of custody is complete; and

- Laboratory logbook and analysis notebooks, which are maintained at the laboratory and record all pertinent information about the sample.

4.4.1 Sample Labels

To prevent misidentification of samples, the owner/operator should affix legible labels to each sample container. The labels should be sufficiently durable to remain legible even when wet and should contain the following types of information:

- Sample identification number
- Name of collector
- Date and time of collection
- Place of collection
- Parameter(s) requested (if space permits)
- Internal temperature of shipping container at time sample was placed
- Internal temperature of shipping container upon opening at laboratory
- Maximum and minimum temperature range that occurred during shipment

4.4.2 Sample Seal

In cases where samples may leave the owner/operator's immediate control, such as shipment to a laboratory by a common carrier (e.g., air freight), a seal should be provided on the shipping container or individual sample bottles to ensure that the samples have not been disturbed during transportation.

4.4.3 Field Logbook

An owner/operator or the individual designated to perform ground-water monitoring operations should keep an up-to-date field logbook that documents the following:

- Identification of well
- Well depth
- Static water level depth and measurement technique
- Presence of immiscible layers and detection method
- Well yield - high or low
- Purge volume and pumping rate
- Time well purged
- Collection method for immiscible layers and sample identification numbers
- Well evacuation procedure/equipment
- Sample withdrawal procedure/equipment
- Date and time of collection
- Well sampling sequence
- Types of sample containers used and sample identification numbers
- Preservative(s) used
- Parameters requested for analysis
- Field analysis data and method(s)
- Sample distribution and transporter
- Field observations on sampling event
- Name of collector
- Climatic conditions including air temperature
- Internal temperature of field and shipping (refrigerated) containers

4.4.4 Chain-of-Custody Record

To establish the documentation necessary to trace sample possession from time of collection, a chain-of-custody record should be filled out and should accompany every sample. The record should contain the following types of information:

- Sample number
- Signature of collector
- Date and time of collection
- Sample type (e.g., ground water, immiscible layer)
- Identification of well
- Number of containers
- Parameters requested for analysis
- Signature of person(s) involved in the chain of possession
- Inclusive dates of possession

- Internal temperature of shipping (refrigerated) container (chest) when samples were sealed into the shipping container
- Maximum temperature recorded during shipment
- Minimum temperature recorded during shipment
- Internal temperature of shipping (refrigerated) container upon opening in the laboratory

4.4.5 Sample Analysis Request Sheet

This document should accompany the sample(s) on delivery to the laboratory and clearly identify which sample containers have been designated (e.g., use of preservatives) for each requested parameter. The record should include the following types of information:

- Name of person receiving the sample
- Laboratory sample number (if different from field number)
- Date of sample receipt
- Analyses to be performed
- Internal temperature of shipping (refrigerated) container upon opening in the laboratory

4.4.6 Laboratory Logbook

Once the sample has been received in the laboratory, the sample custodian and/or laboratory personnel should clearly document the processing steps that are applied to the sample. All sample preparation techniques (e.g., extraction) and instrumental methods must be identified in the logbook. Experimental conditions, such as the use of specific reagents (e.g., solvents, acids), temperatures, reaction times, and instrument settings, should be noted. The results of the analysis of all quality control samples should be identified specific to each batch of ground-water samples analyzed. The laboratory logbook should include the time, date, and name of the person who performed each processing step.

4.5 Analytical Procedures

The S&A plan should describe in detail the analytical procedures that will be used to determine the concentrations of constituents or parameters of interest. These procedures should include suitable analytical methods as well as proper quality assurance and quality control protocols. The required precision, accuracy, detection limits, and percent recovery (if applicable) specifications should be clearly identified in the plan.

The S&A plan should identify one method that will be used for each specific parameter or constituent. The plan should specify a method in SW-846 or an EPA-approved method, and clearly indicate if there are going to be any deviations from the stated method and the reasons for these deviations.

Records of ground-water analyses should include the methods used, extraction date, and date of actual analysis. Data from samples that are not analyzed within recommended holding times should be considered suspect. Any deviation from an EPA-approved method (SW-846) should be adequately tested to ensure that the quality of the results meets the performance specifications (e.g., detection limit, sensitivity, precision, accuracy) of the reference method.

4.6 Field and Laboratory Quality Assurance/Quality Control

One of the fundamental responsibilities of the owner/operator is the establishment of continuing programs to ensure the reliability and validity of field and analytical laboratory data gathered as part of the overall ground-water monitoring program.

The owner/operator's S&A plan must explicitly describe the QA/QC program that will be used in the field and laboratory. Many owner/operators use commercial laboratories to conduct analyses of ground-water samples. In these cases, it is the owner/operator's responsibility to ensure that the laboratory of choice is exercising a proper QA/QC program. The QA/QC program described in the owner/operator's S&A plan must be used by the laboratory analyzing samples for the owner/operator.

4.6.1 Field QA/QC Program

The owner/operator's S&A plan should provide for the routine collection and analysis of two types of QC blanks: trip blanks and equipment blanks. Each time a group of bottles is prepared for use in the field, one bottle of each type (e.g., glass, fluorocarbon resin, polyethylene) should be selected from the batch and filled with deionized water. The bottles filled with the blank should be transported to the sampling location and returned to the laboratory in a manner identical to the handling procedure used for the samples. These trip blanks should be subjected to the same analysis as the ground water. Any contaminants found in the trip blanks could be attributed to (1) interaction between the sample and the container, (2) contaminated rinse water, or (3) a handling procedure that alters the sample analysis results. The concentration levels of any contaminants found in the trip blank should not be used to correct the ground-water data. The contaminant levels should be noted, and if the levels are within an order of magnitude when compared to the field sample results, the owner/operator should resample the ground water.

Various types of field blanks should be used to verify that the sample collection and handling process has not affected the quality of the samples. The owner/operator should prepare each of the following field blanks and analyze them for all of the required monitoring parameters:

Trip Blank - Fill one of each type of sample bottle with Type II reagent grade water, transport to the site, handle like a sample, and return to the laboratory for analysis. One trip blank per sampling event is recommended.

Equipment Blank - To ensure that the nondedicated sampling device has been effectively cleaned (in the laboratory or field), fill the device with Type II reagent grade water or pump Type II reagent grade water through the device, transfer to sample bottle(s), and return to the laboratory for analysis. A minimum of one equipment blank for each day that ground-water monitoring wells are sampled is recommended.

The results of the analysis of the blanks should not be used to correct the ground-water data. If contaminants are found in the blanks, the source of the contamination should be identified and corrective action, including resampling, should be initiated.

All field equipment that the owner/operator will use should be calibrated prior to field use and recalibrated in the field before measuring each sample. The owner/operator's S&A plan should describe a program for ensuring proper calibration of field equipment. Other QA/QC practices such as sampling equipment decontamination procedures and chain-of-custody procedures should also be described in the owner/operator's S&A plan.

4.6.2 Laboratory QA/QC Program

The owner/operator's S&A plan should provide for the use of standards, laboratory blanks, duplicates, and spiked samples for calibration and identification of potential matrix interferences. The owner/operator should use adequate statistical procedures (e.g., QC charts) to monitor and document performance and implement an effective program to resolve testing problems (e.g., instrument maintenance, operator training). Data from QC samples (e.g., blanks, spiked samples) should be used as a measure of performance or as an indicator of potential sources of cross-contamination, but should not be used to alter or correct analytical data. These data should be submitted to the Agency with the ground-water monitoring sample results.

4.7 Evaluation of the Quality of Ground-Water Data

A ground-water sampling and analysis program produces a variety of hydrogeological, geophysical, and ground-water chemical constituent (GWCC) data. This section pertains primarily to the evaluation of GWCC data because these data are specifically required by the regulations, are evaluated in the statistical tests, provide the fundamental evidence used to determine whether the facility is contaminating the ground water, and are used to determine the extent of plume migration during assessment monitoring. Also, details regarding how to obtain and identify quality hydrogeological and geophysical data have been discussed earlier. The GWCC data may be initially presented by the laboratory (by electronic transmittal or) on reporting sheets; these data then must be compiled and analyzed by the owner/operator prior to submission to the state or EPA in order to evaluate the degree of ground-water contamination.

It is essential for owner/operators to make sure that, during chemical analysis, laboratory reporting, computer automation, and report preparation, data are generated and processed to avoid mistakes, and that data are complete and fully documented. Data must be reported correctly to have accurate analyses and valid results. If data errors do occur, statistical analyses cannot discover, correct, or ameliorate these errors.

The following discussion considers aspects of data quality that may indicate to the technical reviewer that the data acquisition, processing, and evaluation were executed poorly or incorrectly.

The specific areas that are addressed include:

- Reporting of low and zero concentration values;
- Missing data values;
- Outliers; and
- Units of measure.

4.7.1 Reporting of Low and Zero Concentration Values

A critical concern is the interpretation, reporting, and analysis of GWCCs that are measured at less than (LT) a limit of detection. LT limit of detection values presently result from a variety of laboratory conventions and protocols. Technical reviewers, during the review of data submissions, may confront a variety of codes indicating that GWCC concentrations are below a value which the laboratory designates as the detection limit.

Values that are LT a limit of detection can result when:

- GWCCs are present at low concentrations;
- An insensitive analytical technique has been used; and
- The chemical matrix of the ground water interferes with the analytical technique.

The following guidelines should help the technical reviewer identify problems associated with the reporting of LT detection limit values, analyze the data sets that contain LT detection limit values, and prescribe remedies for future owner/operator submissions.

GWCC should be given close attention if the LT detection limit values appear to increase over time. Increasing detection limits may be used to conceal an increasing concentration trend. Similarly, if background data are reported without a LT designation at low concentrations and comparison downgradient data are presented at higher concentrations with a LT designation, then it is possible that LT detection limit values are being used to conceal larger downgradient concentrations. It is unacceptable to report only qualitative information for values that were measured below a limit of detection. The technical reviewer must ensure that numerical values accompany the LT designation, so that data are available for analysis. LT detection limit values that are high or that vary should be reduced in future work by laboratory procedures that remove or control interfering constituents.

The owner/operator must explain and follow a specific laboratory protocol for determining and reporting low concentration values. Technical reviewers should not allow the use of highly variable reporting formats. An appropriate protocol for determining and reporting GWCC data at low concentrations is described in Appendix B of 40 CFR §136, titled "Definition and Procedure for the Determination of the Method Detection Limit - Revision 1.11." Other methods are offered by the American Chemical Society and the International Union of Pure and Applied Chemistry.

LT values should not be deleted from the analysis. Instead, when data sets consist of a mixture of values that are LT a limit of detection and actual concentration measurements, LT values may be analyzed at half their reported value. This technique is simple to use and has been presented for use in the following references:

Gilbert, R.O. and Kinnison, R.R. 1981. Statistical Methods for Estimating the Mean and Variance from Radionuclide Data Sets Containing Negative, Unreported, or Less than Values. Health Physics 40:377-390.

Nehls, G.J. and Akland G.G. 1973. Procedures for Handling Aerometric Data. Journal of the Air Pollution Control Association 23:180-184.

LT values may also be analyzed using Cohen's Method. This method is also simple to use and has been described by:

Cohen C. 1961. Tables for Maximum Likelihood Estimates from Singly Truncated and Singly Censored Samples. Technometrics 3:535-541.

Finally, a variety of other techniques, which are slightly more complicated, are described in the following references:

Gilliom, R.J. and Helsel, D.R. 1986. Estimation of Distributional Parameters for Censored Trace Level Water Quality Data. 1. Estimation Techniques. Water Resources Research 22:135-146.

Helsel, D.R. and Gilliom, R.J. 1986. Estimation of Distributional Parameters for Censored Trace Level Water Quality Data. 2. Verification and Applications. Water Resources Research 22:147-155.

In some cases, the technical reviewer will be confronted with a situation where all the values for a chemical constituent in the background well system are LT a limit of detection. In this case, no data are available to estimate the background variance, and the background mean will be biased higher than its actual value, which is some value LT the limit of detection. In this case, the technical reviewer should ensure that laboratory protocols and data which are used to establish the detection limit values are provided. In addition, it is recommended that, especially in this case, the laboratory should ensure that any values, which are reported above a limit of detection, are quantifiable. The American Chemical Society's LOQ or the upper confidence limit of EPA's MDL may be used to establish a threshold criteria.

4.7.2 Missing Data Values

Owner/operators incur a substantial risk of missing an extreme environmental event and measurement of particularly large or small values if they fail to collect all of the data required for a monitoring program. This may result in an incomplete measure of environmental variability and an increased likelihood of falsely detecting contamination. Also, if assessment monitoring data are missing, there is a danger that the full extent of contamination may not be characterized. Owner/operators must take extreme care to ensure that concentration measurements result from all samples taken. Nevertheless, the technical reviewer is likely to confront situations where complete detection monitoring data have not been collected. The technical reviewer should have the owner/operator perform the t-test despite incomplete data collection, provided that the following criteria have been met:

- If there are data from one upgradient well and one downgradient well, statistical comparisons should still be made. If data exist for three quarters at a well, statistical comparisons should be made after applying the rule described in the next bullet.
- If only one quarter of data is missing, values should be assigned for the missing quarter by averaging the values obtained during the other three quarters.
- If there are missing replicate measurements from a sampling event, then average the replicate(s) that are available for that sampling event.

These guidelines have been described previously in the November 1983 EPA memorandum on statistical analyses of indicator parameter data. The intent of this methodology is to encourage use of the t-test, despite prior noncompliance with the data collection requirements in the regulations, so that a determination can be made as to whether assessment monitoring should begin. Regardless of whether there are sufficient data for performing the t-test, the technical reviewer should consider taking enforcement action to compel additional sampling on an accelerated schedule. The technical reviewer must minimize delays in the evaluation of a facility's ground water because of prior incomplete data collection.

4.7.3 Outliers

A GWCC value that is much different from most other values in a data set for the same GWCC can be referred to as an "outlier." The reasons for outliers can be:

- A catastrophic unnatural occurrence such as a spill;
- Inconsistent sampling or analytical chemistry methodology;
- Errors in the transcription of data values or decimal points; and
- True but extreme GWCC concentration measurements.

The technical reviewer should attempt to have owner/operators correct outlying values if the cause of the problem can be documented and corrected by the owner/operator without delay. The data should be corrected if outliers are caused by incorrect transcription and the correct values can be obtained and documented from valid owner/operator records. Also, if a catastrophic event or a problem in methodology occurred that can be documented, then data values should be from calculations with clear reference to this deletion at all relevant stages. Documentation and validation of the cause of outliers must accompany any attempt to correct or delete data values, because true but extreme values must not be altered. The technical reviewer should not accept the mere presence of an extreme value in data or the effect of an extreme value on the statistical analysis as a valid reason for the continuation of detection monitoring.

Ground-water contaminant concentrations when influenced by a hazardous waste management facility do not necessarily vary gradually. Instead, it is not uncommon for contamination (e.g., halogenated organic) to be reflected in a series of data collected over time with the following trend. Measurements remain below a limit of detection and then, in a single or several sampling event(s), concentrations rise to measurable levels and soon return to concentrations which are LT a limit of detection in subsequent sampling periods. In general, technical reviewers should not accept the contention that contaminant concentrations measured in wells immediately downgradient or in the vicinity of hazardous waste management areas increase only gradually. Rapidly increasing and decreasing concentrations can occur in ground waters subjected to contamination; the high concentrations in these cases would be true extreme values but not outliers.

4.7.4 Units of Measure

Associated with each GWCC value is a unit of measure that must be reported accurately. Mistakes in the reporting of the units of measure can result in gross errors in the apparent concentrations of GWCCs. For example, a lead value of 30.2 might have a unit of measure of parts per billion (ppb). Alternatively, the same lead value of 30.2 might have been incorrectly reported with a unit of measure in parts per million (ppm). The reported value would transform to a concentration with the units of measure in ppb as 30,200 ppb of lead or three orders of magnitude larger than it was measured.

The following guidelines should help the technical reviewers ensure that units of measure associated with data values are reported consistently and unambiguously:

- The units of measure should accompany each chemical parameter name. Laboratory data sheets that include a statement "values are reported in ppm unless otherwise noted" should generally be discouraged but at least reviewed in detail by the technical reviewer. It is common to find errors in reporting the units of measure on this type of data reporting sheet especially when these reporting sheets have been prepared manually.

- The units of measure for a given chemical parameter must be consistent throughout the report.

- Finally, reporting forms for detection monitoring, as specified in the EPA November 1983 memorandum, and the data presentation methods described in Chapter Five should help to reduce problems associated with the reporting of units of measure.

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CHAPTER FIVE

STATISTICAL ANALYSIS OF DETECTION MONITORING DATA

Owner/operators of hazardous waste facilities must implement a ground-water monitoring program capable of determining if a facility has had an effect on the quality of the ground water. This determination is based on the results of a statistical test. This chapter discusses the data that should be collected to perform the statistical test while facilities are operating under interim status detection monitoring, and what actions should be taken based on the results of the statistical test. A general description of a recommended statistical procedure is described below. A more specific description, which includes the computational details and an example, appears in Appendix B.

5.1 Methods for Presenting Detection Monitoring Data

Data reporting sheets such as those presented in the November 30, 1983, EPA memorandum titled "Guidance on Implementation of Subpart F Requirements for Statistically Significant Increases in Indicator Parameter Values" should be used when owner/operators present data as required by §265.94(a). The technical reviewer should make sure that owner/operators are aware of and use standardized data reporting forms.

The technical reviewer should have in the file all of the ground-water data that have been collected to date from the facility. An explicit presentation of the statistical test methodology should also be in the file for the facility.

5.2 Introductory Topics: Available t-Tests, Definition of Terms, Components of Variability, Validity of the t-Test Assumptions, False Positives Versus False Negatives, and the Transition to Permitting

Several introductory topics pertaining to the statistical analysis of detection monitoring data are discussed in this section. First, the statistical tests that the owner/operator can use to analyze detection monitoring data are examined. Then, definitions of the terms background, upgradient, and downgradient are presented. The measurement of environmental variability and its relationship to the number of upgradient wells, analytical replicates, and the statistical test that should be used is reviewed. In the next section, the t-test assumptions, including the importance of independent and normally distributed data, are discussed and methods for correcting nonconformance with the assumptions are offered. Also, included is a discussion emphasizing the importance of controlling and evaluating the false positive and false negative rates associated with the statistical procedures. The final section describes broad categories of alternative statistical procedures that may be explored for future application during the permit.

5.2.1 Available t-Tests

The interim status regulations specify that a Student's t-test be used to determine whether there has been a statistically significant increase in any ground-water contamination indicator parameter (IP) in any well. The §265 regulations do not, however, require a specific Student's t-test. The owner/operator has the latitude within the regulations to choose a t-test that will accommodate the data collected. One reason that interim status facilities frequently adopt the Cochran's Approximation to the Behrens-Fisher (CABF) t-test is that the Part 264 permit regulations require the use of the CABF t-test, unless an equivalent statistical test is accepted by the Regional Administrator. Other more appropriate t-tests are available for owner/operators to use in the analysis of their interim status detection monitoring data.

One alternative t-test, which has been recommended for use, is referred to as the averaged replicate (AR) t-test. The AR t-test is a preferred test for owner/operators to apply to their interim status detection monitoring data because it helps to reduce statistically-caused false positives. Although special situations demanding alternative t-test procedures may arise, this document generally recommends the use of the AR t-test for maintaining compliance with the statistical analysis requirements of 40 CFR §265, Subpart F.

Other t-tests are available for use while facilities are operating under interim status detection monitoring. T-tests designed to control the false positive rate despite the installation of additional wells, measurement of additional chemical parameters, and an increased sampling frequency may be appropriate (Miller, 1981). An owner/operator choosing to employ a t-test methodology that controls the false positive rate or overall significance level must evaluate the procedure's impact on the false negative rate, that is, the failure to identify contamination when it has occurred. The false negative problem should be the primary concern of the technical reviewer. An alternative t-test may be appropriate during the administration of enforcement cases when, as described below, accelerated data collection requirements are imposed. In these cases, background data from the upgradient wells and downgradient data may be collected simultaneously, and a t-test that accommodates the data structure resulting from this sort of sampling program may apply. The owner/operator may perform the t-test of choice, but the results must be presented and action taken based on the results of only one type of t-test. The technical review team should acquire the professional expertise needed to evaluate thoroughly the statistical methodology.

Regardless of the specific procedure, the t-test methodology should be explicit and include:

- A clear, understandable explanation of the methodology;
- Presentation of explicit example calculations;
- The inclusion and documentation of all the original data used in the statistical analysis procedure;
- Literature reference citations documenting alternative t-test procedures; and

- A detailed explanation of how data were manipulated and evaluated prior to the statistical analysis, including goodness-of-fit testing, transformations, less than detection limit value manipulations, and power evaluations.

Also, it should be noted that although owner/operators have latitude with respect to the statistical test used, there is much less choice with regard to the data collection requirements. Finally, no matter which t-test is used, the comparisons that must be made cannot change. Thus for example, regardless of the t-test used, the owner/operator must collect a background data set and compare these data to the data from each well individually each time they are sampled.

5.2.2 Definition of Terms

Three terms used frequently in discussions regarding the interim status detection monitoring statistical analysis are: background, upgradient, and downgradient. The terms upgradient and downgradient describe well locations (e.g., with respect to the ground-water hydraulics) and performance (e.g., downgradient wells must be able to immediately detect contamination). The terms upgradient and downgradient also describe the data collected from those wells. References to background data, unlike those to upgradient or downgradient data, which are well specific, concern all data collected from all upgradient wells during the period when background levels are being established. Modification of the background data may be required during the life of the facility; guidance related to the modification of background data is presented in Section 5.4.1.

5.2.3 Components of Variability

The inclusion and exclusion of various components of variability in background ground-water data have a substantial impact on the performance of the statistical test. When a background sampling program includes data from only one upgradient well, there is no component of spatial variability in the background data. Moreover, when the four measurements from each sample are included in the analysis, the background data set is influenced heavily by analytical variability. The result of no spatial contribution to variability and a large contribution by analytical variability is a background data distribution that typically has little variability. This results in a statistical evaluation procedure that readily identifies small differences, because the background distribution of concentration values, which has little variability, tends to be distinct and not "overlap" with the downgradient distribution of concentration values.

To alleviate this situation, the background data set should include a component of spatial variability and not be heavily influenced by the typically small component of analytical variability. Two recommendations are provided to help with this problem.

- First, the owner/operator should install additional upgradient wells to ensure measurement of spatial variation in the ground water in the upgradient area.
- Second, the AR t-test, when applied to the data from well systems with multiple upgradient wells, can be used by owner/operators to remove the excessive influence of the analytical replicate variability.

5.2.4 Validity of the t-Test Assumptions

Frequently, technical reviewers are confronted with the argument from owner/operators that the t-test is not an appropriate methodology for use, because the collected data are not independent and normally distributed. Technical reviewers may find that the following discussion is useful for supporting the need to evaluate the distributional properties of the background data.

First, the contention that the background data are not normally distributed should be supported by a goodness-of-fit analysis. A contention of non-normality without the supporting analysis is not valid.

Second, goodness-of-fit tests generally require a data set with a substantial number of values in order to have enough statistical power to discriminate among distributional types. The background data sets from interim status facilities are rarely large enough for reasonable performance of a goodness-of-fit test. A graphical approach evaluating the cumulative probabilities of the data in comparison with a standard normal may be useful.

Third, the presence of LT detection limits does not in itself imply that the data values do not follow a normal distribution. The censoring of the data values (which is essentially what happens when chemical concentrations are reported LT a limit of detection) below a level and the shape of the distribution above the level are not necessarily related. In short, a data set with LT detection limit values may or may not have normal distribution properties above the detection limit.

Fourth, in the case where firm evidence indicating that values do not follow a normal distribution, owner/operators can use mean and variance estimates from other distributions such as the lognormal. The validity of any procedure must be documented and validated as a technically sound approach (see Appendix B for details).

Finally, other non-t-test statistical procedures (e.g., nonparametric), which are less dependent on distributional assumptions, do not satisfy the requirements for interim status detection monitoring. The "Transition to Permitting" section of this chapter describes when alternative non-t-test procedures may be useful.

5.2.5 False Positives Versus False Negatives

Technical reviewers are frequently called upon to respond to contentions from owner/operators that the statistically significant increase, suggested by the statistical tests, has not actually occurred. This has been referred to as a false positive. There are several points that should be considered when a technical reviewer confronts a false positive claim. First, false positives are not necessarily the result of the statistical procedure. Many other factors influence the false positive rate. These include, for example, poor well construction, improperly located wells, too few background wells, improper sampling techniques, and imprecise or inaccurate laboratory analysis. Owner/operators should not contend that the statistical test resulted in a false positive unless it can be shown that all the other aspects of the ground-water monitoring program have been implemented properly. Second, the resampling program is intended to reduce the false positive rate caused by laboratory error only. The owner/operator should not make false positive claims until the immediate resampling is performed. Third, owner/operators have the latitude within the interim status regulations to use a t-test methodology designed to control the false positive rate for the entire facility. Fourth, false positives are only statistical issues. If engineering information, including construction methods, age of the unit, waste composition, or geohydraulic properties, indicates that contamination is occurring, then a false positive claim is probably unwarranted. Fifth, a false positive claim must be supported by data substantiating the false positive claim (see Chapter 6 for more details). Finally, and most important, the technical reviewer must not consider a false positive claim or the results of the statistical procedure unless the owner/operator has evaluated the false negative rate associated with the statistical procedure in the context of facility-specific data. False negatives, that is, a failure to indicate statistically significant contamination when a release has occurred, are of more concern than false positive rates. The false negative rate is rarely evaluated by owner/operators, and is frequently higher than the false positive rate for even larger, substantial amounts of contamination.

5.2.6 The Transition to Permitting

The 40 CFR §265 Subpart F interim status regulations only allow the use of a t-test for evaluating data. However, the 40 CFR §264 Subpart F permit regulations provide greater latitude in designing a statistical evaluation methodology by allowing the use of an alternative statistical procedure. Although facilities must continue to perform t-test methods to maintain compliance with interim status, it is also wise for owner/operators to begin to explore, test, and compare methods that may be useful under the permit requirements.

A large array of methods and associated data manipulation procedures are available. These approaches may include: linear model, tolerance interval, nonparametric, control chart, or stochastic process methods.

5.3 Statistical Analysis of the Background Data

As described above, owner/operators should have measured the background concentrations of ground-water parameters in upgradient wells within one year of the effective date of the interim status Subpart F regulations. The initial background concentrations of the Appendix III parameters in §265.92(b)(1), the ground-water quality parameters in §265.92(b)(2), and the ground-water contamination (or indicator) parameters in §265.92(b)(3) should have been established by monitoring upgradient wells quarterly for a year. Four replicate measurements should have been established from each well during each sampling episode for the indicator parameters.

The background mean and variance should have been determined using all of the data obtained for the §265.92(b)(3) parameters during the first year of sampling from the wells that were upgradient of the facility. These summary statistics, which describe the background concentrations, form the basis against which all subsequent upgradient and downgradient concentration measurements will be compared. The methods used to estimate the background mean ($\bar{X}_b$) and variance (s_b^2) for AR t-test are described in Appendix B.

It is important to recognize that, in many instances, owner/operators did not obtain background data during the prescribed period of time in properly located and constructed wells, or did not sample and perform chemical analyses using appropriate methodologies. In these cases, the data used to establish the background statistics may have to be obtained under a program accommodating the site-specific circumstances. Recommendations related to modifying the background data to correct a false positive problem are described below. In the case of incomplete prior data collection, the technical reviewer should determine, using the criteria in the missing data section of Chapter Four, when comparisons can be conducted, using the existing data. Although some data sets may be limited, it may still be possible to perform the statistical comparisons of background versus downgradient data which are described below. If contamination is suggested by the results of a t-test and the resampling, then the first determination under assessment monitoring may be compelled, as discussed in Chapter Six.

5.4 Statistical Analysis of Detection Monitoring Data After the First Year

Detection monitoring data collected after the first year should be used in a comparison with the background data to determine if there is a suggestion that contamination may have occurred. A t-test is used to make this determination. If the mean concentration of any IP in any downgradient well is larger by a statistically significant amount than the background concentration, then contamination may have occurred. (NOTE: In the case of pH, the t-test is conducted such that an increase or decrease may be detected. Thus, in the case of pH, all future references to significant statistical increases imply that a significant statistical change is being evaluated.)

All of the upgradient and downgradient wells must be sampled after the first year. The ground-water quality parameters in §265.92(b)(2) must be measured at least annually, but are not analyzed statistically. The IPs in §265.92(b)(3) must be measured at least semiannually using at least four replicate measurements from each sample from each well in the detection monitoring network.

5.4.1 Comparison of Background Data with Upgradient Data Collected on Subsequent Sampling Events

There is a suggestion that IP concentrations in the upgradient ground water may be increasing when the t-tests for an upgradient well, compared with the background data as required by §265.93(c)(1), show a significant increase in the concentration of an IP. There are several reasons why the statistical test may indicate that the upgradient concentrations have increased. These include:

- Ground-water flow direction was determined incorrectly and hazardous waste constituents are migrating into the upgradient wells.
- Ground-water flow direction was determined correctly, but hazardous waste constituents are moving in a direction that is opposite the ground-water flow.
- Upgradient wells were located in a mound caused by the facility.
- An inconsistent methodology (e.g., well construction material, sampling and analysis techniques) was used, resulting in concentration differences that are unrelated to any change in the concentration of IPs in the ground water.
- The t-test indicated a difference between the background data and upgradient data when actually there was no difference.

The cause of the increase in upgradient concentrations will be important to the technical reviewer if the owner/operator successfully establishes during the first determination under assessment that no contaminants have entered the ground water. Prior to reinstating the detection monitoring program, the owner/operator may request that, because of the increase in background concentrations identified through the background versus upgradient comparisons, the historical data are unrepresentative of background conditions and should be modified.

The following recommendations are presented to help the technical reviewer decide whether and how the background data set can be corrected.

- The technical reviewer should require that the owner/operator undertake the following actions prior to modification of the background data. First, it must be explained exactly why the background data set should be modified. These demonstrations must be based upon data and considerations that are documented thoroughly. The owner/operator must also indicate specifically how the background data set will be modified. Finally, it should be shown that change in the background data will not delay the ground-water sampling and analysis program.

- One of the recommended methodologies involves both the use of more than one year of background data and a set of only the most recently acquired background data (i.e., a moving average). These procedures for modifying the background data may be appropriate; however, the decision should be based on site-specific hydrogeological and engineering circumstances. The method used to modify the background data should never become a routine part of the statistical analysis methodology (e.g., use of a "moving window").

- Many data sets will be unusable because of unacceptable analytical chemistry, hydrogeological considerations, or the physical construction of the well system, as for example, when wells have been located in an area affected by the facility. Modification of the background data set may require installation and sampling of a new well system. In this case, it may be necessary to collect background data from upgradient wells on an accelerated schedule concomitantly with downgradient data.

- The technical reviewer may find it useful and suggest the routine analysis of specific chemical parameters in addition to the interim status indicator parameters. This may help the owner/operator prepare for the ground-water monitoring and analysis program to be implemented when the facility obtains a §264 permit. These parameter-specific data would also be available for discussions regarding any future false positive contentions.

5.4.2 Comparison of Background Data with Downgradient Data

The facility may be affecting the ground water when the t-test for a downgradient well shows a statistically significant increase relative to the background data. The owner/operator must immediately resample and collect multiple ground-water samples from those downgradient wells where a significant increase in concentration was detected, as required by §265.93(c)(2). The additional ground-water samples are to be split into duplicates and analyzed. The resampling data are then evaluated using the same t-test methodology. The results of this t-test are then used to determine whether the originally detected significant increase was a result of a laboratory mistake or a consequence of ground-water contamination. If the initial results are due to laboratory error and no significant increase has occurred, the detection program may continue.

If the additional analyses performed under §265.93(c)(2) confirm the significant increase, the owner/operator's facility is in interim status assessment monitoring and must, without exception, begin immediately to fulfill the requirements of the first determination of assessment monitoring. While contamination is not verified during detection monitoring, such monitoring is used to learn whether contamination may be occurring. The first determination of assessment monitoring should be the phase of analysis in which the suggestion of contamination revealed by the statistical analysis is documented more fully. Ground-water contamination cannot be evaluated satisfactorily with a continuation of detection monitoring.

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CHAPTER SIX

ASSESSMENT MONITORING

Once contaminant leakage has been detected via detection monitoring efforts, the owner/operator must undertake a more aggressive ground-water program called assessment monitoring. Specifically, the owner/operator must determine the vertical and horizontal concentration profiles of all the hazardous waste constituents in the plume(s) escaping from waste management areas. In addition, the owner/operator must establish the rate and extent of contaminant migration. This information will be used later by the permit writer (in addition to other information collected through the permit application process) to evaluate the need for corrective action at the facility. Alternatively, this information may form the basis for issuing an enforcement order compelling corrective action prior to issuance of a permit.

The Agency has observed a number of problems in the way owner/operators have conducted their assessment monitoring programs. These include:

- Many owner/operators lack satisfactory knowledge of site hydrogeologic conditions. As a result they cannot make informed decisions on how to carry out their assessment programs. The owner/operator should have conducted a thorough site hydrogeologic investigation prior to the installation of the detection monitoring system.

- Some owner/operators fail to implement their assessment programs quickly enough or they implement programs that will take too long to provide information on the extent and migration of a plume.

- Some owner/operators do not support geophysical investigation with a sufficient monitoring well network. Geophysical methods are useful for indicating contamination and for interpolation of contaminant concentrations between wells; however, well sampling is required to provide conclusive data.

- Many owner/operators greatly underestimate the level of effort the regulatory agency expects of them in characterizing plume migration. In most cases, assessment monitoring is an intensive effort that will require the owner/operator to install numerous monitoring wells. When full plume characterization is not achieved with the initial round of well installation, additional wells will be required. The owner/operator must track and characterize both the horizontal and vertical components of the plume (i.e., a three-dimensional characterization).

This chapter describes the technical approaches and techniques the Agency feels are minimally necessary for characterizing a plume of contamination as required in Part 265 assessment monitoring.

6.1 Relationship of Assessment Monitoring to Ground-Water Responsibilities Under the Permit Application Regulations (Part 270)

Interim status assessment monitoring is just one in a series of activities that facilities must undertake to prepare adequate permit applications. The Part 270 permit application regulations require interim status facilities to describe in their permit application any plume of contamination (in terms of Appendix VIII sampling) and, based on the levels of contamination found, to develop engineering plans for the appropriate Part 264 ground-water program: detection monitoring, compliance monitoring, or corrective action. Once a facility's permit is called, either operating or post-closure, the owner/operator's ground-water obligations expand from assessment monitoring alone to also include the monitoring and plan development responsibilities imposed by Part 270.

The requirements relevant to facilities subject only to Part 265 assessment monitoring differ from those subject to Part 265 AND Part 270 (by virtue of a permit call-in) in two important ways.

First, the Part 265 assessment program requires monitoring for hazardous waste constituents (primarily Appendix VII), whereas Part 270 [§270.14(c)(4)] requires Appendix VIII monitoring (Note: Appendix VII is a subset of Appendix VIII--see Section 3.3 of the Compliance Order Guidance for a further elaboration of this point). Therefore, assessment plans of facilities subject to permitting should be based on the broader Appendix VIII monitoring requirements embodied in Part 270 (see Section 6.7).

Second, Part 265 assessment monitoring applies only to facilities that detected contamination through a significant increase (or pH decrease) in Part 265 indicator parameters (i.e., those that were formally triggered under the regulations). The requirement to look for and describe any plume of contamination in terms of Appendix VIII constituents (as a condition of the permit application process) applies to facilities that detected contamination through Part 265 detection monitoring, as well as to any facility whose Part 265 detection monitoring system is inadequate to detect a plume, should it occur.

As noted in Chapter 1 of the Compliance Order Guidance (August 1985), facilities with inadequate Part 265 monitoring systems are required to conduct the Appendix VIII sampling and assessment activities required by Part 270 (and necessary to make reasoned decisions about what Part 264 ground-water program to incorporate in the permit) simply because they have avoided compliance with Part 265 detection monitoring in the past. Furthermore, such facilities should not be allowed to start the Part 265 detection sequence over again, thus postponing the time when the facility will be compelled to sample for actual constituents in ground water even if they did not formally "trigger" into Part 265 assessment. The RCRA Ground-Water Monitoring Compliance Order Guidance explains in greater detail the legal and technical bases for advancing facilities with inadequate Part 265 detection systems into the type of assessment activities described in this chapter. While the language of the chapter speaks in terms of Part 265 assessment activities, the techniques discussed herein are equally applicable to facilities conducting plume characterization activities as part of the permit application process.

6.2 Contents of a Part 265 Assessment Monitoring Plan

Owner/operators conducting plume characterization activities as part of Part 265 assessment monitoring are required to have a written assessment monitoring plan. The plan serves as the blueprint for the activities undertaken to characterize the rate and extent of contaminant migration. Plans must contain sufficient detail to determine the nature and extent of the plume. When evaluating facilities in assessment monitoring, technical reviewers should focus both on (1) scrutinizing the adequacy of the written assessment plan, and (2) reviewing the owner/operator's implementation of the plan in the field.

There are a number of elements that owner/operators should include in their assessment monitoring plans. The remaining sections of this chapter are organized around the following elements of an adequate assessment plan:

- Section 6.3 - narrative discussion of the hydrogeologic conditions at the owner/operator's site; identification of potential contaminant pathways;
- Section 6.4 - description of the owner/operator's detection monitoring system;
- Section 6.5 - description of the approach the owner/operator will use to make the first determination (false positives rationale);
- Section 6.6 - description of the investigatory approach the owner/operator will use to fully characterize rate and extent of contaminant migration; identification and discussion of investigatory phases;
- Section 6.7 - discussion of number, location, and depth of wells the owner/operator will initially install, as well as strategy for installing more wells in subsequent investigatory phases;
- Section 6.8 - information on well design and construction;
- Section 6.9 - a description of the sampling and analytical program the owner/operator will use to obtain and analyze ground-water monitoring data;
- Section 6.10 - description of data collection and analysis procedures the owner/operator plans to employ;

- Section 6.11 - a discussion of the procedures the owner/operator will use to determine the rate of constituent migration in ground water; and

- Section 6.12 - a schedule for the implementation of each phase of the assessment program.

6.3 Description of Hydrogeologic Conditions

An owner/operator cannot conduct an adequate assessment monitoring program without a thorough understanding of site hydrogeologic conditions. Such an understanding, garnered through site characterization activities (refer to Chapter One), allows the owner/operator to identify likely contaminant pathways. Identification of these pathways allows the owner/operator to focus efforts on tracking and characterizing plume movement. It is important to note that the initial site characterization carried out by the owner/operator should provide enough hydrogeologic information to allow the owner/operator not only to design a detection monitoring system, but also to plan and carry out an assessment monitoring program.

The owner/operator's assessment plan should describe in detailed narrative form what hydrogeologic conditions exist at the owner/operator's site. The plan should describe the potential pathways of constituent migration at the site, including depth to water in aquifer, aquifer connections to surface water and/or deeper aquifers, flow rate and direction, and any structures such as fractures and faults which could affect migration. The owner/operator's plan should also describe how hydrogeologic conditions have influenced the type of assessment effort that will be used to characterize plume migration. This portion of the owner/operator's assessment plan should recapitulate the hydrogeologic investigatory program the owner/operator undertook prior to installing a detection monitoring system (see Chapter One). It should describe the investigatory approach used by the owner/operator to characterize subsurface geology and hydrology, the nature and extent of field investigatory activities, and the results of the investigation, as well as provide an explicit discussion on how those results have guided decisions the owner/operator has made concerning the planning and implementation of the assessment monitoring program. As part of the plan, the owner/operator should append various supporting documentation such as those described in Table 1-1.

6.4 Description of Detection Monitoring System

The owner/operator's assessment plan should describe the existing detection monitoring system in place at the owner/operator's facility. The primary concern is whether the existing well system is capable of detecting contaminant leakage that may be escaping from the facility. If the owner/operator's detection monitoring system is deficient, either in design or operation, plumes may exist unnoticed. This portion of the owner/operator's assessment plan should describe the physical layout of the owner/operator's detection monitoring well system (e.g., horizontal and vertical orientation of individual wells) and identify assumptions used by the owner/operator in designing the detection monitoring system (particularly how hydrogeologic condition affected the decision making process).

6.5 Description of Approach for Making First Determination - False Positives

Chapter Five described requirements that owner/operators must meet in terms of statistical analysis of detection monitoring data. Once the owner/operator resamples and the statistical test again suggests that an indicator parameter has increased in a downgradient well(s), the owner/operator must implement an assessment monitoring program. Figure 6-1 illustrates the sequence of events that occurs immediately before and after the shift to assessment monitoring. Of particular interest are those situations where the owner/operator believes that contamination may have been falsely indicated and thus describes in the

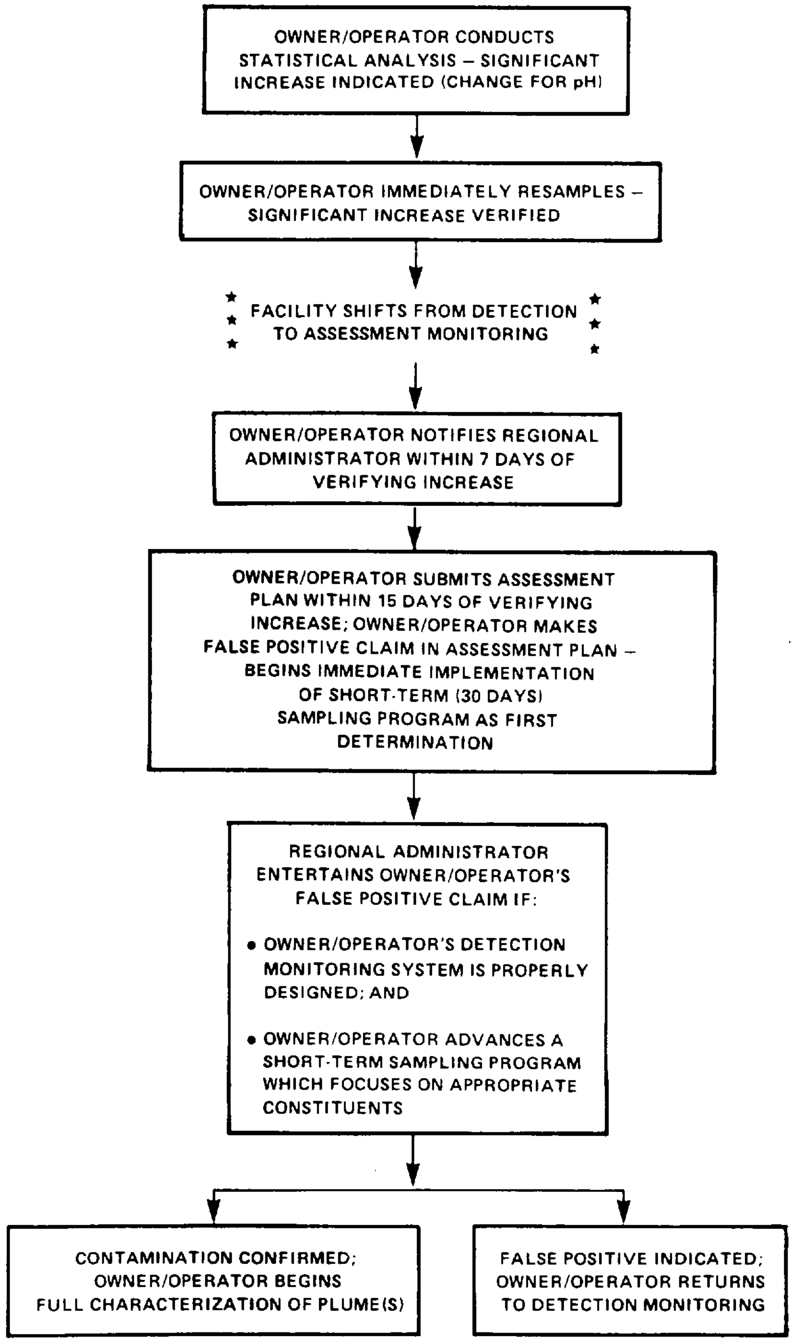

FIGURE 6-1 PROCEDURE FOR EVALUATING FALSE POSITIVE CLAIMS BY OWNER/OPERATORS

assessment plan a short-term program to substantiate or disprove this false positive claim (i.e., false positive investigation is focus of first determination - §265.93(d)(5)). There are a number of facilities for which the first determination is no longer relevant, e.g., facilities under 3008(h) enforcement action. See the RCRA Ground-Water Monitoring Compliance Order Guide for details.

When an owner/operator's detection monitoring system is properly designed, the first determination under assessment monitoring may focus on substantiating a false positive claim. If an owner/operator's detection monitoring system is inadequate, it is difficult to evaluate whether leakage has occurred. Substantiation of a false positive claim would be a lengthy process, potentially involving hydrogeologic work, the installation of a new detection well network, and evaluation of various additional sampling data. In those cases, officials should reject a false positive analysis as the focus of the first determination when the existing system is inadequate, and instead require the owner/operator to (1) correct deficiencies in the detection monitoring system; and (2) initiate a program that will consider specific constituents of concern in the existing wells, and in the new wells as they are installed.

If, however, an owner/operator's detection monitoring system is adequately designed, the owner/operator may propose, as the first determination, a short-term sampling program--generally no longer than 30 days--and an analysis of other related data that will permit investigation of whether the statistical change noted in Part 265 indicator parameters truly represents migration of leachate into the uppermost aquifer. Such short-term sampling programs, however, do not allow for the evaluation of seasonal variation. Data gathered over the short term, therefore, should be analyzed to control for the season in which the data were collected, in order to establish comparability with previous data. For units subject only to the Part 265 standards, the short-term sampling program must, at a minimum, confirm that no hazardous waste constituents (Appendix VII) have migrated into the uppermost aquifer. For units subject to the Part 270 requirements (because they are seeking an operating permit or the Agency has called in their post-closure permit), the owner/operator should include constituents selected from Appendix VIII in the sampling program.

After conducting the short-term sampling program (constituting the first determination), the owner/operator must submit to the Regional Administrator a written report describing the ground-water quality. If the sampling program confirms that leakage has not occurred, the owner/operator may continue the detection monitoring program or enter into a consent agreement with the Agency to follow a revised detection protocol designed to avoid future false triggers. If, however, the short-term sampling confirms that leakage has occurred, the owner/operator must immediately begin implementation of an assessment program.

6.6 Description of Approach for Conducting Assessment

A variety of investigatory techniques are available for use during a ground-water quality assessment. They can be broadly categorized as either direct or indirect methods of investigation.

All assessment programs should be designed around the direct method of actual collection of a sample with subsequent chemical analysis to determine actual water quality (i.e., installation of monitoring wells). Other methods of investigation may be used when appropriate to choose the locations for well installation. For certain aspects of an assessment, such as defining plume location, the use of both direct and indirect methods may be the most efficient approach.

The methods planned for use in an assessment should be clearly specified and evaluated to ensure that the performance standard established for assessments can be met. Evaluating the use of direct and indirect methods is discussed separately below.

6.6.1 Use of Direct Methods

Ground-water monitoring wells, either existing or newly installed, are necessary to provide sampling data to establish the concentration of hazardous constituents released from the hazardous waste management area, and the rate and extent of their migration. The owner/operator should construct assessment monitoring wells and conduct sampling and analysis in a manner that provides reliable data. Chapters Three and Four, respectively, present guidance in these areas.

At facilities where it is known or suspected that volatile organics have been released to the uppermost aquifer, organic vapor analysis of soil gas from shallow holes may provide an initial indication of the areal extent of the plume (Figure 6-2). To this end, the owner/operator may use an organic vapor analyzer (OVA) to measure the volatile organic constituents in shallow hand-augered holes. Alternatively, the owner/operator may extract a sample of soil gas from a shallow hole and have it analyzed in the field, using a portable gas chromatograph. These techniques are limited to situations where volatile organics are present. Further, the presence of intervening, saturated, low permeability sediments strongly interferes with the ability to extract a gas sample. Although it is not necessarily a limitation, optimal gas chromatography results are obtained when the analyte is matched with the highest resolution technique (e.g., electron capture/halogenated species). The owner/operator should attempt to evaluate the effectiveness of this approach by initial OVA sampling in the vicinity of wells known to be contaminated.

Descriptions of the direct methods and their limitations that will be employed during assessment monitoring should be included in the

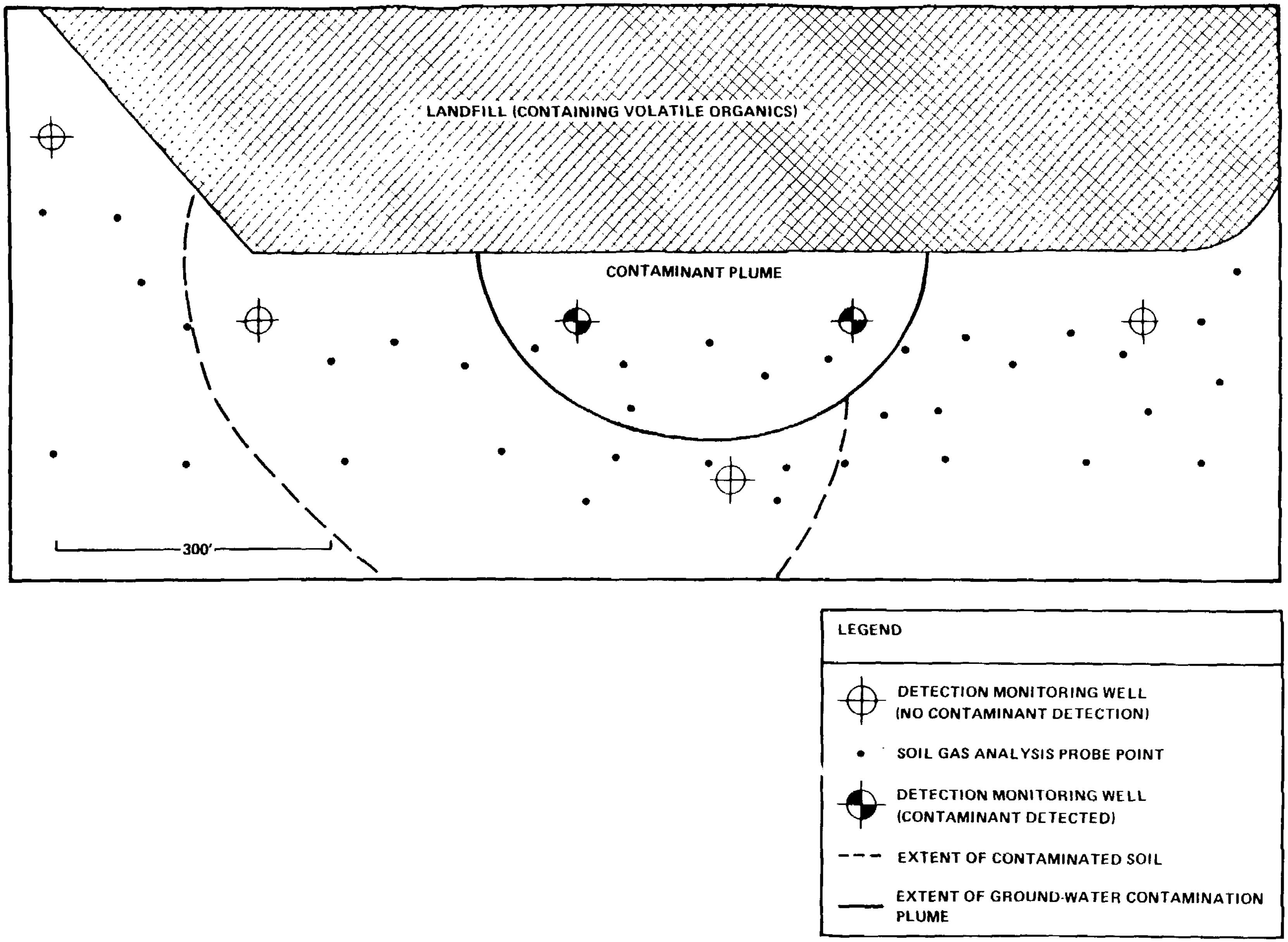

FIGURE 6-2 EXAMPLE OF USING SOIL GAS ANALYSIS TO DEFINE PROBABLE LOCATION OF GROUND-WATER PLUME CONTAINING VOLATILE ORGANICS

assessment plan. These descriptions should be sufficiently detailed to allow the method to be evaluated and to ensure that the method will be properly executed.

Other direct methods that may be used to define the extent of a plume include sampling of seeps and springs. Seeps and springs occur where the local potentiometric surface intersects the land surface and results in ground-water discharge into a stream, rivulet, or other surface water body. Seeps and springs might be observed near marshes, at road cuts, or near streams. Discharges from seeps and springs reflect the height of the potentiometric surface and are likely to be most abundant during a wet season.

6.6.2 Use of Indirect Methods

A variety of methods are currently available for identifying and, to a limited extent, characterizing contamination in the uppermost aquifer. There are several geophysical techniques of potential use to an owner/operator, including electrical resistivity, electromagnetic conductivity, ground penetrating radar, and borehole geophysics. Remote sensing and aerial photography are additional indirect methods an owner/operator may find useful. These techniques, with the exception of aerial photographic methods, operate by measuring selected physical parameters in the subsurface such as electrical conductivity, resistivity, and temperature.

The value of indirect methods is not the provision of detailed, constituent-specific data for which they presently are clearly limited, but rather for delineating the general areal extent of the plume. This is extremely important to the owner/operator for two reasons:

1. Knowing the general outline of the plume before additional wells are constructed reduces the need for speculative wells. The assessment monitoring program, therefore, becomes more efficient, since well placement is guided by analytical data.

2. As the plume migrates and its margins change, the owner/operator may track its movement to help locate new wells.

There are drawbacks to the exclusive use of geophysical techniques in assessment monitoring relating to the high level of detail necessary to characterize the chemical composition of a ground-water plume. For these methods to be successful, contaminant(s) of interest must induce a change in the subsurface parameter measured. This change, in turn, must be distinguishable from ambient conditions. For example, the electrical properties of organic hazardous constituents are generally attenuated or masked by subsurface material properties. Unless these constituents are present in high concentrations, they generally will not register during resistivity or conductivity surveys. Moreover, nonuniform subsurface conditions may obscure low levels of certain contaminants in ground water. Another drawback to the exclusive use of geophysical methods at present is their inability to measure specific concentrations of individual constituents or provide good vertical resolution of constituent concentration. In addition, man-made structures such as powerline towers, buried pipelines, roads, and parking lots may interfere with the performance and reliability of many geophysical methods. The owner/operator should, therefore, only use indirect methods to guide the installation of an assessment monitoring system and to provide an ongoing check of the extent of contaminant migration.

6.6.3 Mathematical Modeling of Contaminant Movement

Mathematical and/or computer modeling may provide information useful to the owner/operator during assessment monitoring and in the design of corrective actions. The information may prove useful in refining conceptualizations of the ground-water regime, defining likely contaminant pathways, and designing hydrologic corrective actions (e.g., pumping and treating, etc.).

Since a model is a mathematical representation of a complex physical system, simplified assumptions must be made about the physical system, so that it may fit into the more simplistic mathematical framework of the model. Such assumptions are especially appropriate, since the model assumes a detailed knowledge of the relevant input parameters (e.g., permeability, porosity, etc.) everywhere in the area being modeled. This is a limitation that must be considered since it would be impossible to obtain all of the input parameters without disturbing and altering the physical system.

Since a model uses assumptions as to both the physical processes involved and the spatial and temporal variations in field data, the results produced by the model at best provide a qualitative assessment of the extent, nature, and migration of a contaminant plume. Because of the assumptions made, a large degree of uncertainty is inherent in most modeling simulations. Therefore, modeling results should not be unduly relied upon in guiding the placement of assessment monitoring wells or in designing corrective actions.

Where a model is to be used, site-specific measurements should be collected and verified. The nature of the parameters required by a model varies from model to model and is a function of the physical processes being simulated (i.e., ground-water flow and/or contaminant transport), as well as the complexity of the model. In simulating ground-water flow, the hydrogeologic parameters that are usually required include: hydraulic conductivity (vertical and horizontal); hydraulic gradient; specific yield (unconfined aquifer) or specific storage (confined aquifer); water levels in both wells and nearby surface water bodies; and estimates of infiltration or recharge. In simulating contaminant transport, the physical and chemical parameters that are usually required include: ground-water velocity; dispersivity of the aquifer; adsorptive characteristics of the aquifer (retardation); degradation characteristics of the contaminants; and the amount of each contaminant entering the aquifer (source).

Dispersivity values of the aquifer should be based on site-specific field test (i.e., tracer test) data or on field dispersivity values obtained from the literature. Caution should be used where laboratory dispersivity values are proposed, since such values are often orders of magnitude lower than field values. Retardation is often expressed as a functional relationship (isotherm) between mass of contaminants in the ground water and mass of contaminants adhering to the soil/rock. These isotherms are based on soil bulk density, effective porosity, and cation exchange capacity. Retardation may also be determined from the octanol-water partition coefficient and fractional portion of organic matter in representative volumes of soil. Degradation of contaminants depends upon the type of constituents and the probability for chemical and biological decay. Dispersion, retardation, and degradation tend to decrease plume concentration and attenuate its travel time. Where these parameters are not well characterized, use of lower values will produce greater conservatism in the results.

Contaminants leaking/leaching from a waste facility may react with the pre-existing ground-water chemistry, resulting in an increase (or decrease) in mobility. Background ground-water quality (e.g., indicator parameters plus Cl^-, Fe, Mn, Na^+, SO_4, Ca^+, Mg^+, NO_3^-, $PO_4^=$, silicate, ammonium, alkalinity, or acidity) is important to determine the reactivity and solubility of hazardous constituents in ground water, and therefore is useful in predicting constituent mobility under actual site conditions. The physical and chemical characteristics of the site-specific leachate (e.g., density, solubility, vapor pressure, viscosity, and octanol-water partition coefficient) and hazardous waste constituents should also be known as they affect constituent movement. To fully assess the effect on contaminant mobility, a water chemistry model may be employed as a component of the overall modeling study. Since this would add a large degree of complexity to the modeling study, conservative assumptions (i.e., maximum mobility of constituents) may be appropriate where time and/or resources are limited.

Mathematical models are comprised of analytical equations by which the hydraulic head or concentration of a contaminant may be calculated for a specified location at a specified time. These models are categorized into two main categories: those which are simple enough that governing equations can be solved by analytic techniques ("analytical models"); and those which are more complex and can only be solved by computer ("numerical models"). The analytical solutions to the first category are often so sufficiently complex that they too can be solved by computer. The numerical models are usually better suited to simulate the complex conditions that describe the actual environment. Both types of models, collectively referred to in this document as computer models, require the recognition of inherent assumptions, the application of appropriate boundary conditions, and the selection of a coherent set of input parameters.

Model input parameters that can be determined directly should be measured with consideration given to selecting representative samples. Since the parameters cannot be measured continuously over the entire region but only at discrete locations, care should be taken when extrapolating over regions where there are no data. These considerations are especially important where the parameters vary significantly in space or time. The sensitivity of the model output both to the measured and assumed input parameters should be determined and incorporated into any discussion of model results. In addition, the ability of the model to be adequately calibrated (i.e., the ability of the model to reproduce current conditions (water levels, contaminant concentrations, etc.)) and to reproduce past conditions should be carefully evaluated in assessing reliability of model predictions. Model calibration with observed physical conditions is critical to any successful ground-water modeling exercise.

A plethora of ground-water computer models exists, many of which would be suitable for a given situation. Since EPA is a public agency and models used by or for EPA may become part of a judicial action, EPA approval of model use should be restricted to those models that are publicly available (i.e., those models that are available to the public for no charge or for a small fee). The subset of ground-water models that are publicly available is quite large and should be sufficient for most ground-water applications. Publicly available models include those models developed by or for government agencies (e.g., EPA, USGS, DOE, NRC, etc.) and national laboratories (e.g., Sandia, Oak Ridge, Lawrence Berkeley, etc.), as well as models made publicly available by private contractors. Any publicly available model chosen should, however, be widely used, well documented, have its theory published in peer-reviewed journals, or have some other characteristics reasonably assuring its credibility. For situations where publicly available computer models are not appropriate, proprietary models (i.e., models not reasonably accessible for use or scrutiny by the public) should only be used where the models have been well documented and have undergone substantial peer review. Where these minimal requirements have not been met, the model should not be considered reliable. A partial list of publicly available computer models includes:

- Modular 3-Dimensional Finite Difference Groundwater Flow Model (USGS), to evaluate complex hydrologic conditions;
- Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water (USGS), to predict contaminant transport;
- Illinois State Water Survey Random Walk Solute Transport Model (ISGS), to predict contaminant transport;
- AT123D (Oak Ridge or EPA), to calculate concentrations isopleths for transient contaminant flow through a simplistic aquifer flow field in up to three dimensions;
- FEMWATER/FEMWASTE (Oak Ridge), to predict contaminant transport in both the saturated and unsaturated zones;
- SWIFT (NRC or Sandia), to predict contaminant transport and complex hydrologic flow conditions in up to three dimensions; and
- SWIP (EPA), similar to SWIFT.

If an owner/operator plans to use a model to guide an assessment monitoring program, the owner/operator must be able and willing to describe how the model works, as well as to explain all assumptions used in calibrating and applying the model to the site in question. In addition, the model and all related documentation should be made available to EPA and its contractors for review and scrutiny.

6.7 Description of Sampling Number, Location, and Depth

The regulations require that the assessment plan specify the number, location, and depth of wells to be installed as part of the assessment. As the discussion on assessment methodology provided in Section 6.4 has indicated, the owner/operator may use other sampling techniques (e.g., indirect methods and coring) in addition to the installation of permanent monitoring wells to augment the data generated by wells. The owner/operator's assessment plans should, however, specify the number, location, and depth of wells that will be installed to characterize rate and extent of migration, and constituent concentrations, and present explanations for the decisions.

It may not always be possible for the owner/operator to identify at the outset of an assessment the exact number, location, and depth of all sampling that will be required to meet the goals of an assessment. Many times the investigations undertaken to characterize contamination during an assessment will proceed in phases in which data gained in one round of sampling will guide the next phase of the investigation. For example, surface geophysical techniques can be effectively used in tandem with the installation of monitoring wells as a first phase in the assessment program to obtain a rough outline of the contaminant plume. Based on these findings, a sampling program may subsequently be undertaken to more clearly define the three-dimensional limits of the contaminant plume. In the third phase, a sampling program to determine the concentrations of hazardous waste constituents in the interior of the plume may be undertaken. In this case, a detailed description of the approach that will be used to investigate the site should be included in the assessment plan. This description should clearly identify the number, location, and depth of any sampling planned for the initial phase of the investigation. The outline should also clearly identify what basis will be used to select subsequent sampling locations, including the geologic strata that are likely to be sampled and the anticipated frequency of sampling. At a minimum, several well clusters should be installed concurrently to define the extent of contamination and concentration of contaminants (see Section 6.7.2) and to profile the vertical extent of migration (see Section 6.7.3).

6.7.1 Collection of Additional Site Information

The hydrogeologic site characterization requirements for the detection monitoring program include:

- The subsurface geology below the owner/operator's hazardous waste facility;
- The vertical and horizontal components of flow in the uppermost saturated zone below the owner/operator's site;
- The hydraulic conductivity of the uppermost aquifer; and
- The vertical extent of the uppermost aquifer down to the first confining layer.

If this characterization does not include all the hydrogeologic information necessary to characterize the rate of contaminant movement, the owner/operator should obtain this information for the assessment phase. Examples of the additional information that may be needed to determine the rate of contaminant movement include: mineralogy of the materials in the migration pathway; ion exchange capacity of the material; organic carbon content of the materials; background water quality of the pathway (e.g., major cations and anions); the temperature of ground water in the migration pathway; and the transmissivity and effective porosity of the material in the pathway. This information will help define the transport mechanisms which are most important at the site. All information collected during the investigation of the plume (i.e., boring logs, core analysis, etc.) should be recorded and the hydrogeologic descriptions of the site updated when appropriate.

Prior to adding new wells, a good estimation of plume geometry can be determined from a review of current and past site characterizations. For example, piezometer readings surrounding a contaminated detection well can be taken to ascertain the current hydraulic gradient. When these values are compared to the potentiometric surface map developed during the site investigation, the general direction of plume migration can be approximated. Any seasonal or regional fluctuations should be considered during this comparison. A review of the subsurface geology may also identify preferential pathways of contaminant migration.

To limit drilling speculative wells, geophysical and modeling methods can also be employed to yield a rough outline of the plume. This expedites the assessment monitoring program. Monitoring wells can then be strategically placed to precisely define the plume geometry.

6.7.2 Sampling Density

The program of sampling undertaken during the assessment should clearly identify the full extent of hazardous waste constituent migration and establish the concentration of individual constituents throughout the plume. In the initial phase of the assessment program, the owner/operator's well installation/sampling should concentrate on defining those areas that have been contaminated by the facility. A series of well clusters should be installed in and around the plume to define the extent of contamination and concentration of contaminants in the horizontal plane. This network of monitoring wells, the number of which may vary from site-to-site, must thoroughly define the horizontal boundaries of the plume, and will identify and quantify contaminants. Well placement should be performed expediently, but in accordance with a carefully thought out and documented assessment monitoring plan. To obtain accurate plume definition at a particular moment in time it is necessary to install well clusters concurrently. Surface geophysical techniques should also be used, where appropriate, to help facilitate plume definition. An assessment monitoring program that does not thoroughly characterize the plume may result in higher assessment monitoring costs, higher corrective action costs, and unnecessary delay.

The density of wells or amount of sampling undertaken to completely identify the furthest extent of migration should be determined by the variability in subsurface geology. Formations, such as unconsolidated deposits with numerous interbedded lenses of varying permeability or consolidated rock with numerous fractures, will require a more intensive level of sampling and carefully placed wells to ensure that all contamination is detected.

Assessment monitoring wells should be constructed of inert materials to minimize chemical interaction between well casing material and contaminant constituents. Also, the length of the well screen should be relatively small, since the wells will be used to assess constituent concentrations at discrete locations in the plume.

Sampling is also required to characterize the interior of any plume detected at the site. This is important because the migration of many constituents will be influenced by natural attenuation/transformation processes. Sampling at the periphery of the plume may not identify all the constituents from the facility that are reaching ground water, and the concentration of waste constituents detected at the periphery of the plume may be significantly less than in the plume's interior. Patterns of concentration of individual constituents can be established throughout the plume by sampling along several lines that perpendicularly transect it. The number of transects and spacing between sampling points should be based on the size of the plume and variability in geology observed at the site. When sampling in fractured rock, for example, monitoring wells should be located such that the well screens intersect fracture zones along likely contaminant pathways. Sampling locations should also be selected so as to identify those areas of maximum contamination within the plume. In addition to the expected contaminants, the plume may contain constituent degradation/transformation products, as well as reaction products.

6.7.3 Sampling Depths

The owner/operator should specify in the assessment plan the depth at which samples will be taken at each of the planned sampling locations. These sampling depths should be sufficient to profile the vertical distribution of hazardous waste constituents at the site. Vertical sampling should identify the full extent of vertical constituent migration. Vertical concentration gradients, including maximum concentration of each hazardous waste constituent in the subsurface, should similarly be identified. The amount of vertical sampling required at a specific site will depend on the thickness of the plume and the vertical variability observed in the geology of the site. All potential migration pathways should be sampled. The sampling program should clearly define the vertical extent of migration by identifying those areas on the periphery of the plume that have not been contaminated.

In order to establish vertical concentration gradients of hazardous waste constituents in the plume, the owner/operator must obtain a continuous sample of the plume, which means well clusters should be employed. The owner/operator, however, cannot know the vertical extent of the plume; therefore, the first well in the cluster should be screened at the horizon where contamination was discovered, bearing in mind that screen length should be relatively small. Additional wells in the cluster should be screened, where appropriate, above and below the initial sampling depth, until the margins of the plume are established. Basically, several wells should be placed at the fringes of the plume to define its vertical margins, and several wells should be placed within the plume to identify contaminant constituents and concentrations. Care must be taken in placing contiguously screened wells close together, since the drawdown from one may influence the next, and thus change the horizon from which the samples are drawn. Figure 6-3 shows an example of assessment monitoring well cluster placement in the same setting as depicted in Figure 2-5. These figures illustrate the relationship between detection and assessment monitoring wells and clusters.

The specifications of sampling depths included in assessment plans should clearly identify the interval over which each sample will be taken. It is important that these sampling intervals be sufficiently discrete to permit vertical profiling of constituent concentrations in ground water at each sampling location. Sampling will only provide measurements of the average contaminant concentration over the interval from which that sample is taken. Samples taken from wells screened over a large interval will be subject to dilution effects from uncontaminated ground water lying outside the plume limits. Screened intervals should be kept relatively small, especially where small vertical concentration gradients are expected.

As part of the progressive assessment monitoring program, the owner/operator can use geophysical techniques to help verify the adequacy of the placement of the assessment monitoring network. Adjustments to the assessment monitoring program may be needed to reflect plume migration and changes in direction.

6.8 Description of Monitoring Well Design and Construction

The monitoring well design and construction requirements for assessment monitoring well networks are equivalent to the requirements presented in Chapter Three for detection wells.

6.9 Description of Sampling and Analysis Procedures

The owner/operator's sampling and analysis plan should be updated to reflect the different analytical requirements of assessment monitoring.

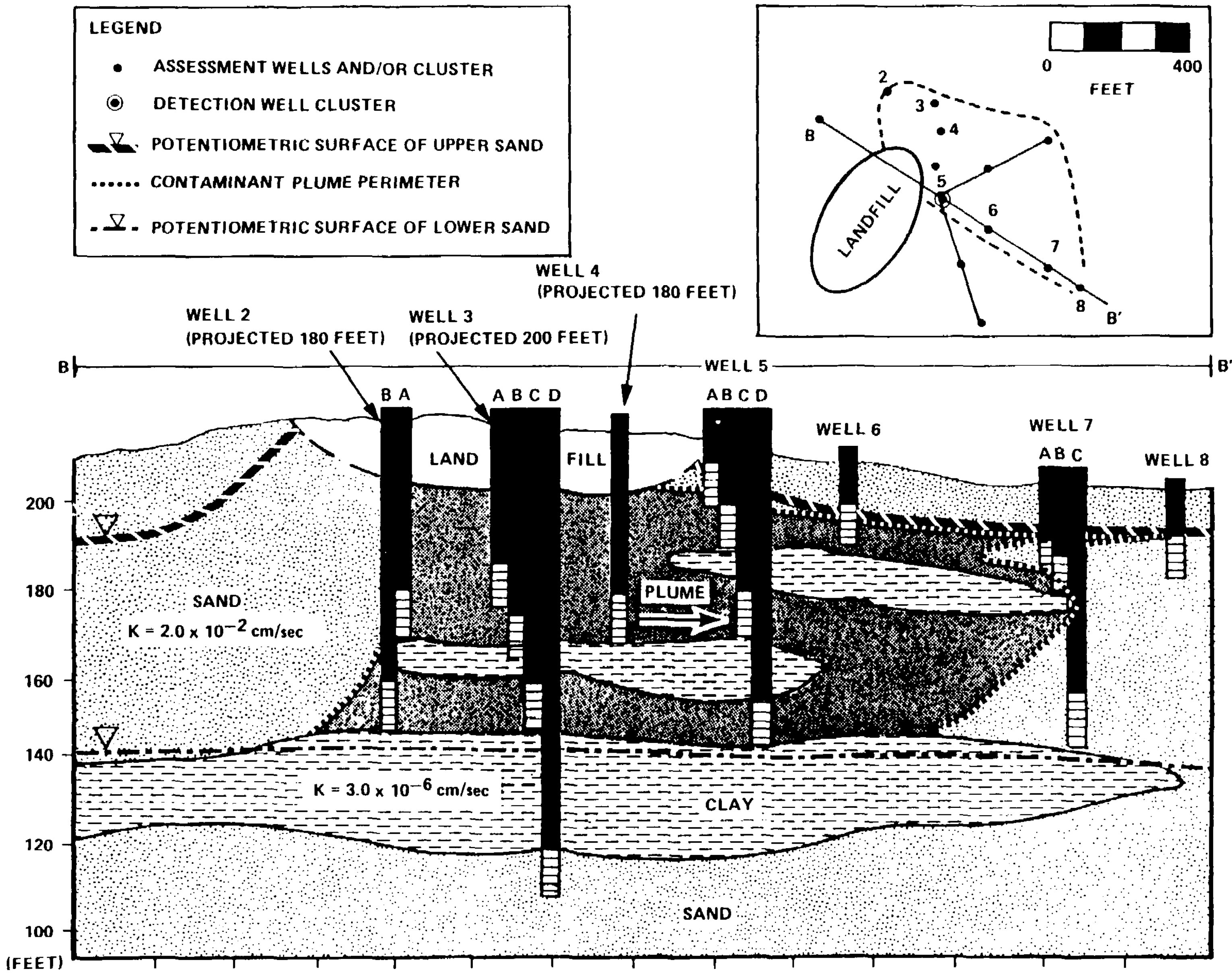

FIGURE 6-3 EXAMPLE OF ASSESSMENT MONITORING WELL PLACEMENT

Otherwise, the sampling and analysis plan used by the owner/operator in the detection monitoring program (see Chapter Four) should suffice for assessment monitoring.

The assessment monitoring plan should identify the parameters to be monitored by the owner/operator, and describe why these parameters are suitable for determining the presence and concentration of contaminants migrating from the facility in the ground water. At a minimum, the owner/operator's assessment monitoring plan should include monitoring for all hazardous waste constituents that are in the facility's waste. Hazardous waste constituents, as defined in §260.10, include all constituents listed in Appendix VII of Part 261, all constituents included in Table 1 of §261.24, and any constituent listed in Section 261.33.

An important consideration in assessment monitoring is the potential for degradation/transformation of hazardous waste constituents; that is, the chemical and/or physical change of a ground-water contaminant resulting in a different intermediate or final product. The physical and chemical properties of all hazardous waste constituents in the facility's waste are an important consideration in evaluating an assessment monitoring system. Assessment monitoring should aim at detecting all contaminants, both initial as well as intermediate or final degraded/transformed products. An example of the degradation/transformation process is the breakdown of trichloroethylene (TCE) and its various isomers into vinyl chloride, a highly toxic substance having different chemical/physical characteristics than TCE. Since vinyl chloride is more water soluble and less affected by sorption than TCE, the detection of vinyl chloride in ground water should lead the owner/operator to suspect the presence of TCE.

Facilities seeking an operating permit also have additional plume characterization responsibilities pursuant to Part 270. Section 270.14(c)(4) requires permit applicants to expand their monitoring from hazardous waste constituents (primarily Appendix VII) to the full complement of Appendix VIII constituents (Note: Appendix VII is a subset of Appendix VIII). Therefore, when a unit is subject to the Part 270 requirements (either because it seeks an operating permit or because the Agency has called in its post-closure permit), the Agency recommends that an owner/operator's assessment plan include parameters that will satisfy the requirements of both Part 265 and Part 270.

Figure 6-4 illustrates in greater detail the sampling protocol recommended by the Agency for units that are subject to both Part 265 and Part 270. First, the owner/operator should perform an Appendix VIII scan of samples from triggering detection monitoring wells. This scan will provide the owner/operator with a list of hazardous constituents in the wells that may be migrating into the uppermost aquifer. The owner/operator should then select a limited number of identified constituents for inclusion in a sampling program to establish geometric dimensions and the rate of migration of the contaminant plume(s). Once the geometric dimensions of the contaminant plume(s) have been established, the owner/opertor should sample for the full subset of identified Appendix VIII constituents to determine vertical and horizontal concentration gradients.

6.10 Procedures for Evaluating Assessment Monitoring Data

The assessment plan must stipulate and document procedures for the evaluation of assessment monitoring data. These procedures vary in a site-specific manner, but must all result in determinations of the rate of migration, extent, and composition of hazardous constituents of the plume. Where the release is obvious and/or chemically simple, it may be possible to characterize it readily from a descriptive presentation of concentrations found in monitoring wells and geophysical measurements. Where contamination is less obvious or the release is chemically complex, however, the owner/operator should employ a statistical inference approach. Owner/operators should plan initially to take a descriptive

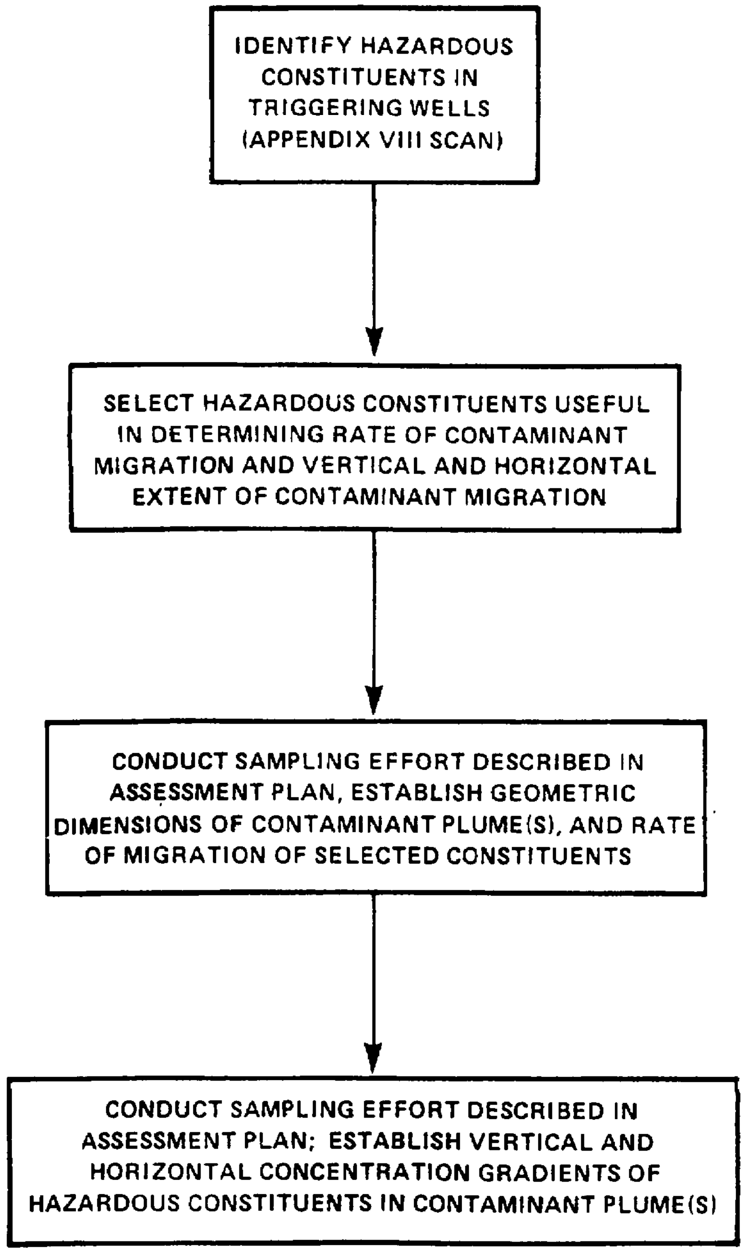

FIGURE 6-4 SELECTION OF PLUME CHARACTERIZATION PARAMETERS FOR UNITS SUBJECT TO PART 265 AND PART 270

approach to data analysis in order to broadly delineate the extent of contamination. Statistical comparisons of assessment monitoring data among wells and/or over time may be necessary, should the descriptive approach provide no clear determination of the rate of migration, extent, and hazardous constituent composition of the release.

The objective of assessment monitoring is to estimate the rate and extent of migration and the concentration of constituents in the plume. Data are therefore collected from a set of assessment monitoring wells that will allow characterization of the dimensions and concentrations of ground-water contaminant constituents (GWCCs) in the plume. In addition, compared to detection monitoring, the number of chemical species analyzed in assessment increases. Because the amount of data collected in assessment is more voluminous than detection monitoring, it is extremely important for the technical reviewer to make sure that the owner/operators specify in their assessment plans the evaluation procedures for the data required by §265.93(d)(3)(iii). The methods used to analyze assessment monitoring data must emphasize organization, data reduction, simplification, and summary.

Technical reviewers may find it useful and necessary to leave GWCC data automated to verify the analyses submitted by owner/operators, to compare recent submissions with historical data submissions, to manipulate and evaluate the information for their specific purposes, or to support permitting activities. EPA's data base system for environmental data is called STORET and is a recommended mechanism for organizing ground-water data acquired from hazardous waste management facilities. Several positive features of STORET are:

- STORET has recently been modified to include data fields that handle well-specific hydrogeological/technical information (e.g., well screen length, general lithology of the screened zone) in conjunction with the GWCC data.
- Most State and EPA regional offices have access to STORET.

- STORET is well supported with capacity for efficient storage, retrieval, and graphical analysis.

Represented below are specific evaluation and reporting procedures that should be followed by the owner/operator when recording and evaluating assessment monitoring data. These procedures are used to structure, analyze, simplify, and present the ground-water monitoring data to help the technical reviewer evaluate the extent and concentration of ground-water contaminants. The four evaluation or reporting procedures that should be described in the assessment plan used to record data in the on-site archives required by §265.94(b) are:

- Listing of Data;
- Summary Statistics Tables;
- Data Simplification; and
- Plotting of Data.

6.10.1 Listing of the Data

A list of all the detection monitoring and the assessment monitoring data (as well as any data from related State or other EPA programs) that have been collected should be available to technical reviewers when they review on-site records. First, data as originally reported and verified by the analytical laboratory for those measures requiring laboratory evaluation, or as recorded in the field for those measures collected at the time of sampling, should be available to the technical reviewer. These reporting forms should include information indicating that quality control samples (e.g., field and filter blanks) were obtained in the field. Also, the laboratory reporting should indicate that the laboratory has performed and reported standard quality control procedures (e.g., recovery analyses, analytical replicates etc.). Finally, the laboratory reporting should include the data that were used to determine the method detection limit or limit of detection (see Chapter 4). Explicit reporting of these quality control data is essential for documenting the precision and accuracy of owner/operator data submissions.

The listing of GWCC concentration data should follow a format similar to Table 6-1. The variables to be included in the listing are codes that identify the GWCC, well, date, unit of measure, whether the value was LT a limit of detection, and the concentration of the GWCC. Also, the listing may include the results of and codes identifying the quality control analyses performed. GWCC concentrations measured as LT a specific method detection limit or limit of detection should be indicated and, if possible, the GWCC concentration that was measured should be reported with the LT designation. Otherwise, the value that accompanies the LT designation should be the accepted detection limit for the method used. Documentation that describes the meaning of the codes used in the listing is required to eliminate ambiguity (e.g., Pb = lead, ppm = parts per million). The listing of GWCC data should include all measurements from all wells since sampling began, including measurements obtained during detection monitoring.

The listing should be organized to allow quick reference to specific data values. One categorization would be to first group by GWCC, then well code, and finally the date, as shown in Table 6-1. For example, all lead measurements are together, followed by all trichloroethylene measurements, etc. The values for each GWCC from one well should be grouped and ordered by date, followed by the data from the next well and so on for all wells in the ground-water monitoring system. Alternate sortings of the data listing may also be useful to the technical reviewer.

The data listing is not intended to function alone as an analytic tool, but the technical reviewer can use the data listing to assist in the review of the GWCC data. First, the ordered list of data will allow the technical reviewer quick reference to every GWCC concentration measurement if, for example, a spurious result was found in a supporting data analysis or report. Also, by requiring a consistent and orderly data listing, the technical reviewer can encourage the owner/operator to

TABLE 6-1
AN EXAMPLE OF HOW ASSESSMENT MONITORING DATA SHOULD BE LISTED

GWCC	WELL	REPLICATE	ALIQUOT	DATE	LT DETECTION	CONCENTRATION	UNITS
LEAD (UG/L)	7A	1	A	12JAN85		29.82	PPB
LEAD (UG/L)	7A	1	A	17FEB85		28.43	PPB
LEAD (UG/L)	7A	1	B	17FEB85		28.29	PPB
LEAD (UG/L)	7A	2	A	17FEB85		28.17	PPB
LEAD (UG/L)	7A	2	B	17FEB85		28.30	PPB
LEAD (UG/L)	9A	1	A	26APR84	<	10.00	PPB
LEAD (UG/L)	9A	1	B	26APR84	<	10.00	PPB
LEAD (UG/L)	9A	2	A	26APR84		20.60	PPB
LEAD (UG/L)	9A	1	A	05MAY84		21.20	PPB
LEAD (UG/L)	9A	2	A	05MAY84		21.80	PPB
LEAD (UG/L)	9B	1	A	26APR84		67.20	PPB
LEAD (UG/L)	9B	1	B	26APR84		67.80	PPB
LEAD (UG/L)	9B	2	A	26APR84		64.10	PPB
LEAD (UG/L)	9B	1	A	05MAY84		38.90	PPB
LEAD (UG/L)	9B	2	A	05MAY84		39.60	PPB
LEAD (UG/L)	9B	1	A	15JUN84		57.22	PPB
LEAD (UG/L)	9B	1	A	15JUL84		20.12	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	26APR84	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	05MAY84	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	15JUN84	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	15JUL84		11.10	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	15AUG84	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	15SEP84		10.10	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	16OCT84		10.70	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	18NOV84		10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	20DEC84	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	12JAN85	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	1A	1	A	17FEB85	<	10.00	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	26APR84		17.00	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	B	26APR84		17.30	PPB
TRICHLOROETHYLENE (UG/L)	10A	2	A	26APR84		17.60	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	05MAY84		21.00	PPB
TRICHLOROETHYLENE (UG/L)	10A	2	A	05MAY84		21.40	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	15JUN84		21.20	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	15AUG84		22.90	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	15SEP84		19.40	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	16OCT84		19.60	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	18NOV84		30.10	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	20DEC84		31.60	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	12JAN85		33.60	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	A	17FEB85		27.80	PPB
TRICHLOROETHYLENE (UG/L)	10A	1	B	17FEB85		27.80	PPB
TRICHLOROETHYLENE (UG/L)	10A	2	A	17FEB85		26.40	PPB
TRICHLOROETHYLENE (UG/L)	10A	2	B	17FEB85		26.50	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	26APR84		65.10	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	B	26APR84		65.80	PPB
TRICHLOROETHYLENE (UG/L)	10B	2	A	26APR84		65.40	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	05MAY84		84.00	PPB
TRICHLOROETHYLENE (UG/L)	10B	2	A	05MAY84		83.70	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	15JUN84		69.00	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	15JUL84		68.40	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	15AUG84		93.40	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	15SEP84		98.90	PPB
TRICHLOROETHYLENE (UG/L)	10B	1	A	16OCT84		88.50	PPB

correct many of the data quality problems, that occur frequently on "raw" laboratory reporting sheets. Finally, data can be placed more easily onto a state or regional computer if the data are organized and reported consistently in a listing, rather than on laboratory reporting sheets having only the sample number identification instead of well codes, dates of sampling, etc. (see the above discussion).

6.10.2 Summary Statistics Tables

The ground-water monitoring data should be summarized and presented in tabular formats. Eight summary statistics should be calculated and used in each of four summary tables. The eight summary statistics are:

- Number of LT detection limit values
- Total number of values
- Mean
- Median
- Standard deviation
- Coefficient of variation
- Minimum value
- Maximum value

The methodology used to estimate these summary statistics can be found in many statistical textbooks.

The four tables of summary statistics should include summaries by:

- GWCC summary (e.g., Table 6-2)
- GWCC summary by well (e.g., Table 6-3)
- GWCC summary by well and date (e.g., Table 6-4)
- Quality control data

The tables should be formatted so that there are from one to three columns on the left side of each table, which provide data identifying, where applicable, the GWCC, well, and date. Eight columns, one for each summary statistic, should be to the right of the identifying columns.

TABLE 6-2

AN EXAMPLE OF HOW DATA SHOULD BE SUMMARIZED BY GWCC

GWCC	SAMPLE SIZE	NUMBER OF LT DETECTION LIMIT VALUES	MEAN	MEDIAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MINIMUM	MAXIMUM
CHROMIUM (UG/L)	129	14	50.83	32.10	59.43	117	5.00	345.21
METHYLENE CHLORIDE (UG/L)	137	37	21.45	14.30	23.17	108	5.00	112.70
LEAD (UG/L)	129	15	50.31	20.43	168.22	334	1.00	1879.23
TRICHLOROETHYLENE (UG/L)	139	32	31.21	20.40	27.68	88.7	5.00	98.90

TABLE 6-3
AN EXAMPLE OF HOW DATA SHOULD BE SUMMARIZED BY GWCC/WELL COMBINATION

GWCC	WELL	SAMPLE SIZE	NUMBER OF LT DETECTION LIMIT VALUES	MEAN	MEDIAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MINIMUM	MAXIMUM
CHROMIUM (UG/L)	1A	9	3	8.74	10.20	2.83	32.3	5.00	11.24
CHROMIUM (UG/L)	10A	16	0	63.57	49.00	38.99	61.3	30.90	140.00
CHROMIUM (UG/L)	10B	17	0	89.15	48.92	93.16	105	10.10	324.00
CHROMIUM (UG/L)	11A	2	0	13.51	13.51	1.70	12.6	12.31	14.72
CHROMIUM (UG/L)	12A	11	0	135.74	109.32	100.49	74.0	16.23	345.21
CHROMIUM (UG/L)	13A	11	0	27.36	28.09	3.83	14.0	20.86	32.53
CHROMIUM (UG/L)	14A	10	0	45.22	48.06	7.08	15.7	32.63	57.03
CHROMIUM (UG/L)	15A	9	0	27.76	29.69	5.13	18.5	18.62	32.01
CHROMIUM (UG/L)	16A	9	0	54.82	79.47	36.21	66.1	11.89	87.31
CHROMIUM (UG/L)	17A	3	1	10.51	12.31	4.87	46.3	5.00	14.23
CHROMIUM (UG/L)	3A	9	7	6.29	5.00	2.58	41.1	5.00	11.51
CHROMIUM (UG/L)	7A	11	0	59.64	58.71	12.48	20.9	46.91	85.01
CHROMIUM (UG/L)	9A	5	0	21.12	15.00	9.41	44.5	13.80	32.10
CHROMIUM (UG/L)	9B	7	3	11.40	11.10	7.05	61.9	5.00	21.60
METHYLENE CHLORIDE (UG/L)	1A	11	7	7.40	5.00	3.76	50.9	5.00	16.40
METHYLENE CHLORIDE (UG/L)	10A	16	0	13.66	12.95	2.26	16.6	11.00	16.90
METHYLENE CHLORIDE (UG/L)	10B	17	0	22.91	21.50	4.20	18.3	19.70	34.20
METHYLENE CHLORIDE (UG/L)	11A	2	2	5.00	5.00	0.00	0.0	5.00	5.00
METHYLENE CHLORIDE (UG/L)	12A	11	0	39.28	23.60	30.97	78.8	14.30	98.40
METHYLENE CHLORIDE (UG/L)	13A	11	0	20.73	18.90	7.36	35.5	11.00	28.60
METHYLENE CHLORIDE (UG/L)	14A	10	0	86.21	76.95	18.25	21.2	70.10	112.70
METHYLENE CHLORIDE (UG/L)	15A	9	1	11.27	11.90	2.44	21.7	5.00	12.90
METHYLENE CHLORIDE (UG/L)	16A	9	0	30.40	28.70	7.75	25.5	16.70	40.10
METHYLENE CHLORIDE (UG/L)	17A	3	3	5.00	5.00	0.00	0.0	5.00	5.00
METHYLENE CHLORIDE (UG/L)	2A	2	2	5.00	5.00	0.00	0.0	5.00	5.00
METHYLENE CHLORIDE (UG/L)	3A	11	10	5.60	5.00	1.99	35.5	5.00	11.60

TABLE 6-4

AN EXAMPLE OF HOW DATA SHOULD BE SUMMARIZED BY GWCC/WELL/DATE COMBINATION

GWCC	WELL	DATE	TOTAL NUMBER OF VALUES	NUMBER OF LT DETECTION LIMIT VALUES	MEAN	MEDIAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MINIMUM	MAXIMUM
CHROMIUM (UG/L)	3A	17FEB85	1	1	5.00	5.00	.	.	5.00	5.00
CHROMIUM (UG/L)	7A	15JUL84	1	0	85.01	85.01	.	.	85.01	85.01
CHROMIUM (UG/L)	7A	15AUG84	1	0	73.52	73.52	.	.	73.52	73.52
CHROMIUM (UG/L)	7A	15SEP84	1	0	67.50	67.50	.	.	67.50	67.50
CHROMIUM (UG/L)	7A	16OCT84	1	0	64.38	64.38	.	.	64.38	64.38
CHROMIUM (UG/L)	7A	16NOV84	1	0	60.01	60.01	.	.	60.01	60.01
CHROMIUM (UG/L)	7A	20DEC84	1	0	58.71	58.71	.	.	58.71	58.71
CHROMIUM (UG/L)	7A	12JAN85	1	0	58.70	58.70	.	.	58.70	58.70
CHROMIUM (UG/L)	7A	17FEB85	4	0	47.05	46.95	0.22	0.5	46.91	47.38
CHROMIUM (UG/L)	9A	26APR84	3	0	14.27	14.00	0.64	4.5	13.80	15.00
CHROMIUM (UG/L)	9A	05MAY84	2	0	31.40	31.40	0.99	3.2	30.70	32.10
CHROMIUM (UG/L)	9B	26APR84	3	1	9.47	11.10	3.91	41.4	5.00	12.30
CHROMIUM (UG/L)	9B	05MAY84	2	0	20.70	20.70	1.27	6.1	19.80	21.60
CHROMIUM (UG/L)	9B	15JUN84	1	1	5.00	5.00	.	.	5.00	5.00
CHROMIUM (UG/L)	9B	15JUL84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	26APR84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	05MAY84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	15JUN84	1	0	10.00	10.00	.	.	10.00	10.00
METHYLENE CHLORIDE (UG/L)	1A	15JUL84	1	0	10.00	10.00	.	.	10.00	10.00
METHYLENE CHLORIDE (UG/L)	1A	15AUG84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	15SEP84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	16OCT84	1	0	16.40	16.40	.	.	16.40	16.40
METHYLENE CHLORIDE (UG/L)	1A	18NOV84	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	20DEC84	1	0	10.00	10.00	.	.	10.00	10.00
METHYLENE CHLORIDE (UG/L)	1A	12JAN85	1	1	5.00	5.00	.	.	5.00	5.00
METHYLENE CHLORIDE (UG/L)	1A	17FEB85	1	1	5.00	5.00	.	.	5.00	5.00

There will be one row for each category that is being summarized. A summary statistics table by GWCC, for example, will have a number of rows equal to the number of GWCC that have been sampled. The GWCC-well table will have a number of rows equaling the number of GWCCs measured times the number of wells in the monitoring system (provided that each GWCC was measured at least once in each well). The GWCC-well-date table will be the largest table, and each row should be prefixed with a GWCC, well, and date code. The statistics in the GWCC-well-date table should summarize all replicate sampling that was performed for each GWCC, from each well, during each sampling.

The sample sizes, ranges, minimum, and maximum values will provide a rapid means for checking whether errors appear in the data. It will also facilitate rapid evaluation of GWCC concentrations over the entire ground-water monitoring system. In addition, the summary statistics will allow evaluation of spatial change in GWCC concentrations, which includes identifying the rate and extent of migration of the GWCC plume.

The quality control data should be provided whenever assessment monitoring data are submitted by an owner/operator. The quality control data can be submitted in the format in which they are received from the laboratory, provided that all data are clearly documented. The quality control samples taken in the field (e.g., field and sampling equipment blanks) may not be identified when the samples are supplied to the laboratory, but should be identified in assessment monitoring data submissions. Owner/operators should ensure that the laboratories provide the quality control data that support and validate the data resulting from the analysis of their field samples.

6.10.3 Data Simplification

Ranking procedures, which are described in this section, may be useful for simplifying and interpreting spatial trends in GWCC concentrations by allowing rapid determination of which wells have the overall highest and lowest GWCC concentrations. Table 6-5 presents an example of a data set analyzed by a ranking procedure.

The ranking can be performed using the mean, median, maximum, or minimum concentration values in the summary statistics table describing the values from each GWCC-well combination. For example, the mean concentration from each well is ranked from lowest to highest for each GWCC. The well with the lowest mean concentration of a GWCC will receive a value of 1; the well with the next highest concentration of the same GWCC will receive a value of 2, and so on. If two or more wells have the identical mean concentration, then the ranks for these wells will be averaged and applied to all wells with the same mean concentration. This procedure should be repeated for each GWCC that was detected at least once at every well in the monitoring system. The pH values may be ranked from highest to lowest rather than from lowest to highest, depending on whether the ground-water contamination is likely to result in an increase or decrease in pH. It is also useful to calculate an overall average rank for each well by averaging the ranks across all GWCCs associated with the well. These ranks should be presented in a table using GWCCs as column headings, and well codes as row headings. It may be helpful to group GWCCs with similar chemistry (e.g., volatile organics, metals, salts, etc.) and order the rows based on the wells with spacial proximity (e.g., upgradient, downgradient in plume, downgradient out of plume, shallow screen depth). This will facilitate identification of specific groups of wells where high concentrations of GWCC were detected.

6.10.4 Graphic Displays of Data

Ground-water data should be plotted to allow evaluation of temporal changes in GWCC concentrations over time. Each plot should consist of a X or horizontal axis, which represents time with year and month identified at intervals. The Y or vertical axis should represent the concentrations of GWCCs. The plots may be constructed using the mean values from the GWCC-well-date summary statistics table, and one plot

TABLE 6-5

AN EXAMPLE OF HOW RANKS OF THE MEAN CONCENTRATIONS FOR EACH GWCC/WELL COMBINATION CAN BE USED TO SIMPLIFY AND PRESENT CONCENTRATION DATA COLLECTED FOR A VARIETY OF GWCCs IN A NUMBER OF MONITORING WELLS

WELL	RANK OF MEAN CHROMIUM CONCENTRATION	RANK OF MEAN LEAD CONCENTRATION	RANK OF MEAN TCE CONCENTRATION	RANK OF MEAN MC CONCENTRATION	AVERAGE WELL RANK ACROSS GWCC
17A	3	3	1	3	2.50
2A	3	3	.	.	3.00
4A	3	3	.	.	3.00
11A	5	3	4	3	3.75
3A	1	6	2	6	3.75
9A	6	3	5	3	4.25
1A	2	8	3	7	5.00
9B	4	7	12	8	7.75
15A	8	9	6	11	8.50
13A	7	12	10	9	9.50
10A	12	10	11	10	10.75
14A	9	16	7	12	11.00
7A	11	11	9	15	11.50
12A	14	15	8	14	12.75
16A	10	14	14	13	12.75
10B	13	13	13	16	13.75

could be presented for each GWCC/well combination as in Figure 6-5. Alternatively, it may be more insightful to plot the data from several wells or GWCCs on one graph, as in Figure 6-6, provided the lines do not overlap excessively.

It may also be useful to plot data on facility maps, so that trends in GWCCs both vertically and horizontally can be evaluated. The summary statistics from the GWCC-well table can be used to provide data for plotting. A map of the facility, which identifies well locations, should be used to depict horizontal trends in concentrations. Geological cross sections and/or a facility map may be useful for plotting vertical trends in GWCC concentrations. The mean concentrations can be placed near each well location, similar to the construction of potentiometric maps described earlier. It may also be helpful to plot isopleth contours of concentration on the maps.

6.11 Rate of Migration

An assessment plan should specify the procedures the owner/operator will use to determine the rate of constituent migration in ground water. A rapid approach will generally be required for determining the rate of migration during interim status assessments. Migration rates can be determined by monitoring the concentration of GWCCs over a period of time in monitoring wells aligned in the direction of flow. If these wells are located both at the edge and the interior of the plume, subsequent analysis of the monitoring data can then provide an estimate of the rate of migration, both of the contaminant front as a whole and of individual constituents within the plume. This approach does not necessarily provide a reliable determination of the migration rates that will occur as the contaminant plume continues to move away from the facility in light of potential changes in geohydrologic conditions. More importantly, this approach requires the collection of a time series of data of sufficient duration and frequency to gauge the movement of contaminants. Such a

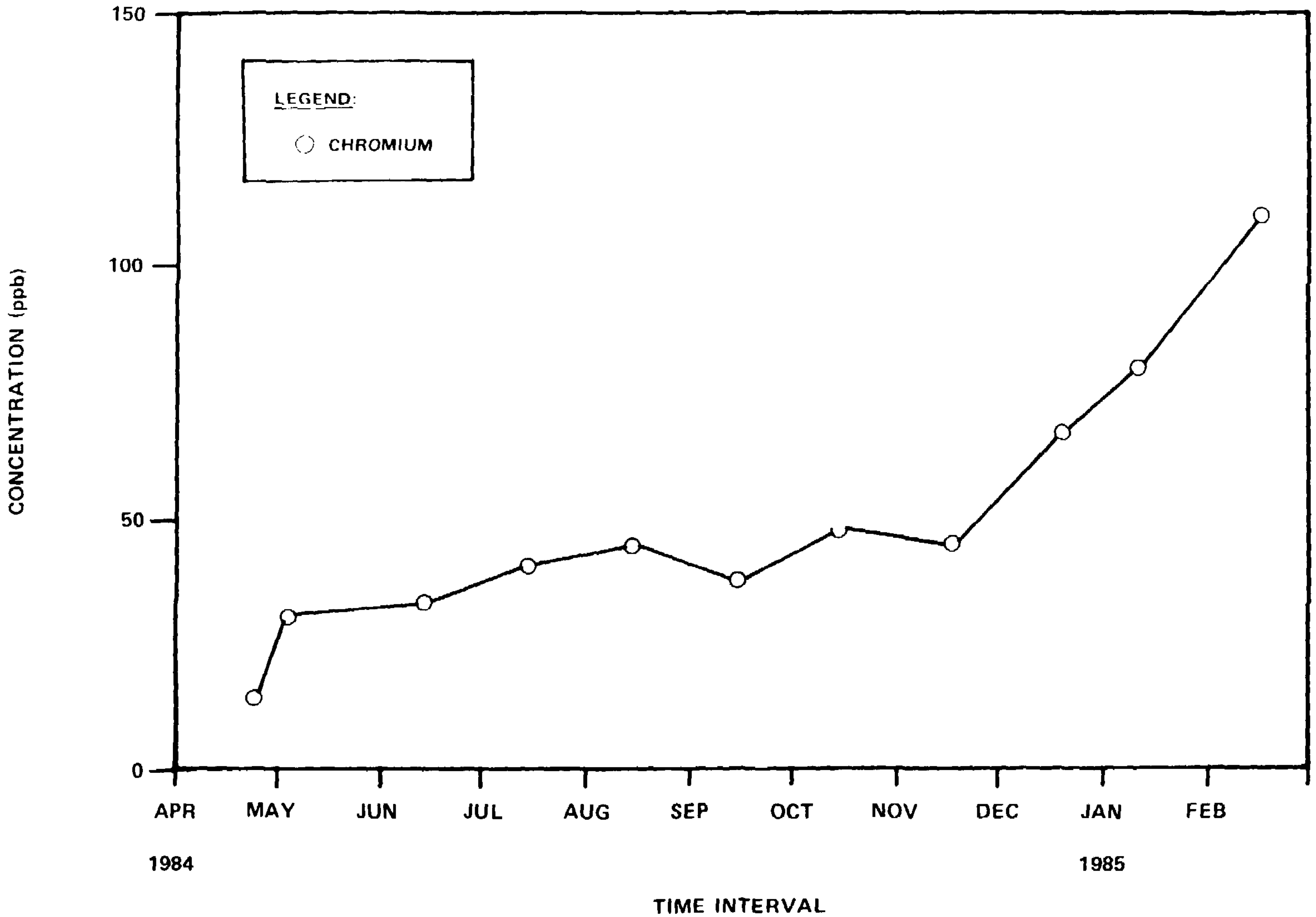

FIGURE 6-5. PLOT OF CHROMIUM CONCENTRATIONS OVER TIME (WELL 9A)

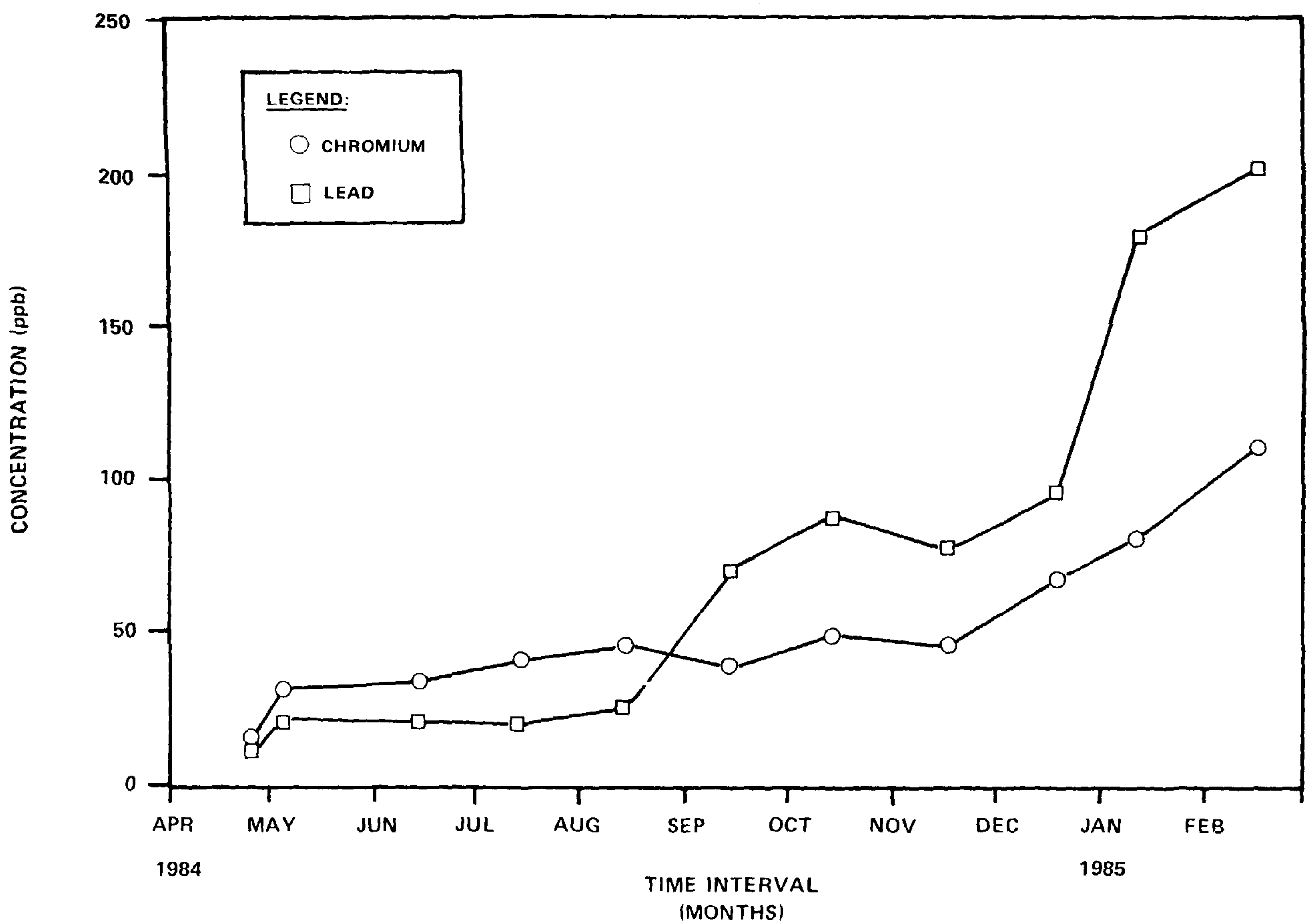

FIGURE 6-6. CHROMIUM AND LEAD CONCENTRATIONS OVER TIME (WELL 9A)

delay is normally inappropriate during initial assessment of ground-water contamination, since a relatively quick determination of at least an estimate of migration rates is required to deduce the impact of ground-water contamination and to formulate an appropriate reaction. Estimates of migration rates can be based on aquifer properties obtained during the site investigation and knowledge of the physico-chemical properties of contaminants known to be present. By recognizing the various factors that can affect transport processes of the GWCCs, the owner/operator can obtain approximate potential rates of migration during an initial assessment phase. Continued monitoring of the plume to verify rates of migration during assessment monitoring should serve as a basis for identifying additional monitoring well locations.

Initial approximations of contaminant migration rates based on ground-water flow rates are not reliable without verification because of potential differential transport rates among various classes of chemical constituents. Differential transport rates are caused by several factors including:

- Dispersion due to diffusion and mechanical mixing;
- Retardation due to adsorption and electrostatic interactions; and
- Transformation due to physical, chemical, and/or biological processes.

Dispersion results in the overall dilution of the contaminant and blurring at plume boundaries. Dispersion can result in a contaminant's arriving at a particular location before the arrival time computed solely on average rates of ground-water flow. Alternatively, retardation processes can delay the arrival of contaminants beyond that calculated by the average rates of ground-water flow. Local geology will also affect constituent migration rates. Relating rates of constituent migration to rates of ground-water flow is appropriate for a quick approximation during the initial assessment phase, but this should be followed by a more comprehensive study of migration rates.

Simple slug tests are not the preferred method for determining the aquifer characteristics. The slug test is limited to the immediate vicinity where it is performed, and its results often cannot be projected across an entire site.

At those facilities where sufficient immiscible contaminants have leaked to form and migrate as a separate immiscible phase (see Figure 6-7), additional analysis will be necessary to evaluate the migration of these contaminants away from the facility. Chapter Five contains a discussion of the ground-water monitoring techniques that can be used to sample multi-phased contamination. The formation of separate phases of immiscible contaminants in the subsurface is largely controlled by the rate of infiltration of the immiscible contaminant and the solubility of that contaminant in ground water. Immiscible contaminants generally have some limited solubility in water. Thus, some amount of immiscible contaminant leaking from the facility will enter into solution in ground water and migrate away from the facility as dissolved constituents. If the amount of immiscible fluid reaching ground water exceeds the solubility constant, however, the ground water in the upper portion of the water table aquifer will become saturated, and the contaminant will form a separate immiscible phase.

At this point, the behavior and migration of the contaminants present in the immiscible phase will be strongly influenced by their density relative to ground water. If the immiscibles are less dense than ground water, the immiscibles will tend to coalesce on the surface of the potentiometric surface and form and migrate as a separate immiscible layer floating on the ground water. If the density of the immiscible contaminants is similar to that of ground water, the immiscible will tend to mix and flow as a separate phase with the ground water, creating a condition of multiphase flow.

If the density of the immiscibles is greater than ground water, the *immiscibles* will tend to sink in the aquifer (see Figure 6-7). As the immiscibles sink and reach unaffected ground water in a deeper portion of the aquifer, more of the immiscible contaminant will tend to enter into solution in ground water and begin to migrate as dissolved constituents. If enough of the dense immiscible contaminants are present, however, some portion of these contaminants will continue to sink as a separate immiscible phase, until a formation of reduced permeability is reached. At this point, these contaminants will tend to coalesce and migrate as a layer of dense immiscibles resting on the geologic barrier.

In each of these cases, the contaminants present in the separate immiscible phase may migrate away from the facility at rates different from that of ground water. In many cases, they will migrate at rates slower than or equivalent to ground water, but in some instances migration rates can be greater. In addition, migration of the immiscibles may not be in the direction of ground-water flow. However, it is important to reemphasize that some amount of these contaminants will invariably dissolve in ground water and migrate away from the facility as dissolved constituents.

Light immiscible contaminants will migrate downgradient to form a floating layer above the saturated zone (see Figure 6-7). The direction of ground-water flow will dictate the movement of this light immiscible layer. Important factors involved in its migration rate include the intrinsic permeability of the medium and the density and viscosity of the contaminants. With time, an ellipsoidal plume develops, overlying the saturated zone as depicted in Figure 6-7. While it is possible to analyze the behavior of the light immiscible layer using analytical or numerical models, the most practical approach for determining the rate and direction of migration of such a light immiscible layer during an assessment may be to observe its behavior over time with appropriately located monitoring wells.

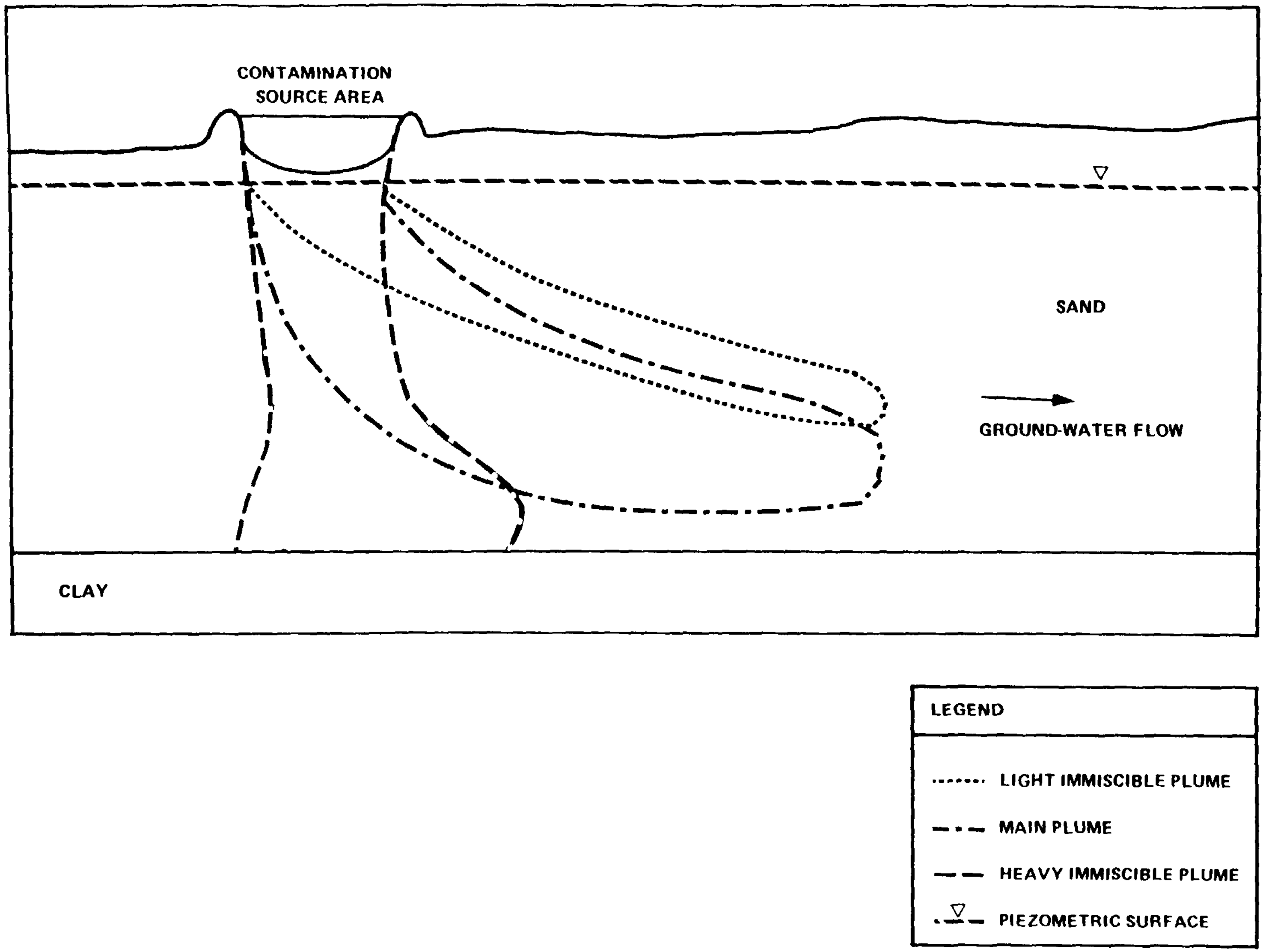

FIGURE 6-7 GENERAL SCHEMATIC OF MULTIPHASE CONTAMINATION IN SAND

The migration of a layer of dense immiscibles settled on a confining layer may be strongly influenced by gravity. Depending on the slope of the confining layer in the gradients used to calculate flow rates. A program of continued monitoring of the dense immiscible layer should always be included in the assessment plan to verify direction and rate of movement.

6.12 Reviewing Schedule of Implementation

The assessment plan should specify a schedule of implementation. Each assessment program will have to include the amount of work involved in the assessment and other local factors such as weather and availability of equipment and personnel. The schedule should include a sufficient number of milestones, so that the Agency can judge whether sufficient progress is being made toward the completion of the assessment. Any continued monitoring undertaken during the maintenance phase of assessment should be scheduled at least on a quarterly basis.

Activities planned to initially determine whether contamination has actually occurred should not unnecessarily delay the implementation of a comprehensive assessment. When an extensive program to collect additional data to remedy inadequacies in currently available data is to be undertaken, these activities should require only a short period for completion. Additional analysis of water quality data should require no more than 15 days to 30 days. Sampling to determine actual concentrations of hazardous waste constituents should require only time enough for sample collection and analysis, followed by a brief period for subsequent analysis of the data.

A thorough discussion of monitoring well placement, and monitoring well design and construction, can be found in Chapters Two and Three, respectively. A discussion of the ground-water monitoring techniques necessary to effectively characterize a multiphase containment migration is also given in Chapter Four of this document.

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GLOSSARY

AR t-Test - Averaged replicate t-test.

Adsorb - Adherence of atoms, ions, or molecules to the surface of another substance.

Aliphatic Hydrocarbons - Class of organic compounds characterized by straight or branched chain arrangement of the constituent carbon atoms.

Analyte - A specific compound or element of interest undergoing analysis.

Annular Sealant - Material used to seal the space between the borehole and the casing of the well. Annular sealants prevent surface contaminants from entering the well.

Annular Space - The open space formed between the borehole and the well casing.

Anticline - A fold, usually from 100 meters to 300 kilometers in width, that is convex upward with the oldest strata at the center.

Appendix VII Monitoring Requirements - A compilation of constituents arranged by EPA hazardous waste numbers which caused the Administrator to list the waste as an EP Toxic Waste (E) or Toxic Waste (T) in 40 CFR §261.31 and §261.32.

Appendix VIII Constituents - A list of 297 toxic constituents (Part 261) which, if present in a waste, may make the waste hazardous. The waste containing these constituents poses a substantial hazard to human health or the environment when improperly treated, stored, transported or disposed.

Aquiclude - A geologic formation which may contain ground water but is incapable of transmitting significant quantities of ground water under normal hydraulic gradients.

Aquifer Adsorptive Characteristics - Ability of an aquifer to retain atoms, ions, or molecules.

Aquifer Degradation Characteristics - Aquifer contamination can be characterized by parameters such as pH, total organic halogens, total organic carbon, temperature, and specific conductance.

Aromatic Hydrocarbons - Class of unsaturated cyclic organic compounds containing one or more ring structures. The name aromatic is derived by the distinctive and often fragrant odors of these compounds.

Assessment Monitoring - A program of monitoring ground water under interim status requirements. After a release of contaminants to ground water has been determined, the rate of migration, extent of contamination, and hazardous constituent concentration gradients of the contamination must be identified.

Assessment Plan - The written detailed plan drawn up by the owner/operator which describes and explains the procedures the owner/operator intends to take to perform assessment monitoring.

Attenuation - To reduce, weaken, dilute, or lessen in severity, value, or amount such as the attenuation of contaminants as they migrate from a particular source.

Background Concentrations - A schedule of sampling and analysis that is completed during the first year of monitoring. All wells in the monitoring system must be sampled on a quarterly basis to determine drinking water characteristics, ground-water quality, and contamination indicator parameters. For each upgradient well, at least four replicate measurements must be made for the contamination indicator parameters.

Background Mean - The arithmetic average of a set of data, used as a control value in subsequent statistical tests.

Background Variance - The variance is the measure of how far an observation value departs from the mean. Background refers to the observations used for control in subsequent statistical tests.

Basement - The oldest rocks recognized in a given area, a complex of metamorphic and igneous rocks that underlies all the sedimentary formations.

Bentonite - A sedimentary rock largely comprised of clay minerals that has a great ability to absorb water and swell in volume.

Bluooey Line - Air supply line during drilling operations.

Borehole - A circular hole drilled or bored into the earth, usually for exploratory or economic purposes, such as a water well or oil well.

Borehole Geophysics (Geophysical Borehole Logging) - A general term that encompasses all techniques in which a sensing device is lowered into a borehole for the purpose of characterizing the associated geologic formations and their fluids. The results can be interpreted to determine lithology, geometry resistivity, bulk density, porosity, permeability, and moisture content and to define the source, movement, and physical/chemical characteristics of ground water.

CABF t-Test - Cochran's Approximation to the Behrens-Fisher t-Test.

Carbonate Environments - Refers to sedimentary rock environments composed of calcium or magnesium carbonate.

Casing - The pipe between the intake (screen) section and the surface, serving as a housing for pumping equipment and conduit for the pumped water.

Chain of Custody - Method for documenting the history and possession of a sample from the time of its collection through its analysis and data reporting to its final disposition.

Chemical Standards - Materials made from ultra-pure compounds used to calibrate laboratory analytical equipment.

Chemical Spike (Spike) - A sample that contains a measured amount of a known analyte, used for determining matrix interferences.

Cluster - (see Well Cluster).

Coefficient of Variation - The standard deviation divided by the mean of a set of data. (Note: the coefficient of variation can be expressed as a percentage by multiplying the number obtained by 100).

Color - A diagnostic property of a rock, mineral, or sediment.

Components of Variability - The characteristics that vary from one statistical population to another, such as well locations, and analytical lab errors.

Concentration Profiles - Graphic representations of the horizontal and vertical locations of contaminant concentration levels on maps and cross-sections.

Confined Aquifer - An aquifer under greater than atmospheric pressure bounded above and below by impermeable layers with distinctly lower permeabilities (aquitards) than the aquifer itself.

Confining Layer - A geologic stratum exhibiting low permeability and having little or no intrinsic permeability.

Core - A continuous columnar sample of the lithologic units extracted from a borehole. Such a sample preserves stratigraphic contacts and structural features.

Corrosive Environments - Subsurface zones containing ground water or soil corrosive to monitoring well construction materials.

Dedicated (Sampling Equipment) - Sampling equipment (e.g., bladder pump, bailer) which is reserved for use in only one monitoring well.

Deposition Environment - A geographically restricted complex where a sediment accumulates, described in geomorphic terms and characterized by physical, chemical, and biological conditions (e.g., flood plain, lake, beach).

Dielectric - Substance having a very low electrical conductivity.

Direct Methods for Hydrogeological Investigations - Methods (e.g, borehole logging, pump tests) which involve the drilling, collection, observation, and analysis of geologic materials, water samples, and drawdown/recovery data.

Dispersivity - Ability of a contaminant to disperse within the ground water by molecular diffusion and mechanical mixing.

Disposal Facility - A facility as defined in 40 CFR 260.10 where hazardous waste is intentionally placed into or on land or water, and at which waste will remain after closure of the facility.

Dolomite - A carbonate sedimentary rock composed predominantly of $CaMg(CO_3)_2$.

Downgradient - In the direction of decreasing static head.

Downgradient Well - A well which has been installed hydraulically downgradient of the site, and is capable of detecting the migration of contaminants from a regulated unit. Regulations require the installation of three or more downgradient wells depending upon the site- specific hydrogeological conditions and potential zones of contaminant migration.

Drawdown - The lowering of the water level in a well as a result of withdrawal.

Drilling Mud - Fluids which are used during the drilling of a borehole or well to wash soil cuttings away from the drill bit and adjust the specific gravity of the liquid in the borehole so that the sides of the hole do not cave in prior to installation of a casing.

Drive Pipe - Casing consisting of the drive shoe and riser. This casing follows the auger bit as it advances.

Drive Shoe - Steel coupling or band at the bottom edge of the casing reinforced to withstand drive pressures during cable tool and drill-through casing driver methods.

Dunnett's Modification - Dunnett's version of the t-Test. Uses Dunnett's calculated t-statistics rather than the Student's t-statistics.

Electrical Resistivity (ER) - A surficial geophysical method whereby known current is applied to spaced electrodes in the ground and the resulting electrical resistance is used to detect changes in earth materials between and below the electrodes. ER is particularly useful for facilities receiving electrically conductive wastes (e.g., inorganic) at sites characterized by settings having minimal quantities of high resistance materials.

Electromagnetic Conductivity (EM) - A surficial geophysical method whereby induced currents are produced and measured in conductive formations from electromagnetic waves generated at the surface. EM is used to define shallow ground water zones characterized by high dissolved solids content.

Equipment Blank - Chemically pure solvent (typically reagent grade water) that is passed through an item of field sampling equipment and returned to the laboratory for analysis, to determine the effectiveness of equipment decontamination procedures.

Equipotential - Equal pressure. Equipotential lines are lines drawn between points of equal pressure.

Esters - Class of organic compounds derived by the reaction of an organic acid with an alcohol.

False Negative - Contamination has occurred but the results of the t-Test fail to indicate contamination.

False Positive - No contamination has occurred, but the results of the t-test indicate contamination.

Field Blank - A laboratory-prepared sample of Type II-Reagent grade water or pure solvent which is transported to the sampling site for use in QA/QC evaluation of field sampling procedures. See equipment blank and trip blank.

Filter Pack - Sand or glass beads that are placed in the annulus of the wall between the borehole wall and the well screen to prevent formation material from entering through the well screen. Glass beads are smooth, uniform, clean, well rounded, and siliceous. The filter pack typically extends 2 feet above the screen.

Floaters - Light phase organic liquids in ground water capable of forming an immiscible layer which can float on the water table.

Flow Net - A set of intersecting equipotential lines and flow lines representing a two-dimensional steady flow through porous media.

Fluvio-Glacial Depositional Environment - A complex melange of glacially borne and riverine sediments deposited at the head of a melting glacier. The sediments range in grain size from clays to boulders, and in places are typically unsorted.

Fracture Zone - A thickness of strata that has undergone mechanical failure due to stress (e.g., cracks, joints, and faults).

Geophysical Borehole Logging - See Borehole Geophysics.

Glacial Till - Unsorted and unstratified sediment originating directly from glacial ice (i.e., not reworked by glacial meltwater).

Goodness of Fit - A statistical test to determine the likelihood that sample data have been generated from a population that conforms to a specified type of probability distribution.

Grain Size - The general dimensions of the particles in a sediment or rock, or of the grains of a particular mineral that make up a sediment or rock. It is common for these dimensions to be referred to with broad terms, such as fine, medium, and coarse. A widely used grain size classification is the Udder-Wentworth grade scale.

Ground Penetrating Radar (GPR) - A geophysical method used to identify surface formations which will reflect electromagnetic radiation. GPR is useful for defining the boundaries of buried trenches and other subsurface installations on the basis of time-domain reflectrometry.

Ground-Water Detection Monitoring Program - A monitoring well system capable of yielding ground-water samples for analysis. Upgradient wells must be installed to obtain representative background ground-water quality in the uppermost aquifer and be unaffected by the facility. Downgradient wells must be placed immediately adjacent to the hazardous waste management area(s) to detect hazardous waste or hazardous waste constituents migrating from the facility.

Halogenated Hydrocarbons - An organic compound containing one or more halogens (e.g., fluorine, chlorine, bromine, and iodine).

Hazardous Waste - A solid waste which exhibits any of the hazardous characteristics defined in 40 CFR §261.2 and has not been specifically excluded as a hazardous waste. Categorical list of hazardous waste are provided in 40 CFR §261.3.

Hazardous Waste Constituent - A constituent which causes a waste to be classified hazardous based upon the criteria cited in 40 CFR §§261.2 and 261.3.

Hazardous Waste Management - The collection, source separation, storage, transportation, processing, treatment, recovery, and disposal of hazardous waste.

Hazardous Waste Management Area - The area within a facility's property boundary which encompasses one or more hazardous waste management unit or cell.

Headspace - The empty volume in a sample container between the water level and the cap.

Heaving Sand - Unconsolidated sand that cannot maintain the integrity of the borehole wall.

High Corrosion Potential - Material with a high propensity for electrochemical degradation.

High-Yield Well - A relative term referring to a well capable of quick recovery after it has been purged of at least three casing volumes (i.e., samples can be collected immediately after purging).

Hydraulic Conductivity - A coefficient of proportionality which describes the rate at which a fluid can move through a permeable medium. It is a function of the media and of the fluid flowing through it.

Hydraulic Connection - The hydraulic relationship between two different lithologic layers.

Hydraulic Head - Water-level elevation in a well or piezometer. The elevation typically referenced to mean sea level to which water rises as a result of hydrostatic pressure.

Illite (Illitic) - A general name for a group of three layer, mica-like clay minerals. These clay minerals are intermediate in composition and structure (between muscovite and montmorillonite).

Indicator Parameters - pH, specific conductance, total organic carbon (TOC), total organic halogens (TOX).

Indirect Methods for Hydrogeological Investigations - Methods which include the measurement or remote sensing of various physical and/or chemical properties of the earth (e.g., electromagnetic conductivity, electrical resistivity, specific conductance, geophysical logging, aerial photography).

Interim Status Detection Monitoring - Ground-water monitoring conducted under 40 CFR 265, Subpart F.

Intrinsic Permeability - The characteristic of a porous medium to transmit liquid under a hydraulic gradient, it is independent of the liquid itself.

Ion Exchange Capacity - Measured ability of a formation to adsorb charged atoms or molecules.

Karst Topography (Karst) - A topographic area which has been created by the dissolution of a carbonate rock terrain. This type of topography is characterized by sinkholes, caverns, and lack of surface streams.

Ketones - Class of organic compounds where the carbonyl group is bonded to two alkyl groups.

Landfill - A disposal facility or part of a facility where hazardous waste is placed in or on the land, and which is not a land treatment facility, a surface impoundment, or an injection well.

Leach - To wash or drain by percolation.

Leachate - A solution produced by the movement or percolation of liquid through soil or solid waste and the subsequent dissolution of certain constituents in the water.

Leachate Management System - A method of collecting leachate and directing it to a treatment or disposal area.

Less Than Detection Limits - A phrase which indicates that a chemical constituent was either not identified or not quantified at the lowest level of sensitivity of the analytical method being employed by the laboratory. Therefore, the chemical constituent either is not present in the sample, or it is present in such a small concentration that it cannot be measured by the analytical procedure.

Limestone - Sedimentary rock primarily made up of calcium carbonate.

Liner - A continuous layer of natural or man-made materials lining the bottom and/or sides of a surface impoundment, landfill, or landfill cell that restricts the downward or lateral escape of hazardous waste, hazardous waste constituents, or leachate.

Lithology - The systematic description of rocks, in terms of mineral composition and texture.

Low-Yield Well - A relative term referring to a well that cannot recover in sufficient time after well evacuation to permit the immediate collection of water samples.

Mature Karst - Karst environment where the physical features (e.g., sinkholes, caves) are well defined (see Karst).

Maximum Value - In a set of data, the measurement having the highest numerical value.

Mean - The sum of all measurements collected over a statistically significant period of time (e.g., one year) divided by the number of measurements.

Median - The middle point in a set of measurements ranked by numerical value. If there are an even number of measurements, the medium is the mean of the two central measurements.

Mineralogy - The study of minerals, including their formation, occurrence, properties, composition, and classification.

Minimum Value - In a set of data, the measurement having the lowest numerical value.

Mounding - A phenomenon usually created by the recharge of ground water from a manmade structure into a permeable geologic material. Associated ground-water flow will be away from the manmade structure in all directions.

Mud - See Drilling Mud.

Non-Dedicated Sampling Equipment - Equipment used to sample more than a single sampling point.

Normal Distribution - The character of data that follows the Gaussian distribution (bell) curve.

Number of LT Detection Limit Values - The number of times a chemical parameter was not detected by a given analytical procedure over a statistically significant period of time (e.g., one year).

Octanol-Water Partition Coefficient - A coefficient representing the ratio of solubility of a compound in octanol to its solubility in water. As the octanol-water partition coefficient increases, water solubility decreases.

Organic Polymers - Drilling fluid additives comprised of long-chained, heavy organic molecules. Drilling fluid additives are used to increase drilling rates and drilling fluid yields, thereby decreasing operational costs.

Organic Vapor Analyzer - A field monitoring device used to determine the concentrations of organic compounds in air using flame ionization or photoionization detection systems.

Outwash Sand - Stratified sediment (usually sand and gravel) removed from a glacier by meltwater streams and deposited beyond the active margin of a glacier.

Oxidizing Acids - An acid (e.g., HNO_3) which tends to lose electrons in a reaction.

PVC - Abbreviation for polyvinyl chloride.

Permeability - The capacity of a porous rock, sediment, or soil to transmit a fluid.

Petrographic Analysis - Systematic description and classification of rocks.

Photoionization Analyzer - See Organic Vapor Analyzer.

Phreatic Zone - See Saturated Zone.

Piezometers - Generally a small diameter, non-pumping well used to measure the elevation of the water table or potentiometric surface.

Plume Characterization - Provides information on concentration profiles and rates of migration.

Polyethylene - A plastic composed of synthetic crystalline polymer of ethylene ($H_2C{:}CH_2$). Polymer may be low density (branched) or high density (linear).

Polypropylene - A plastic composed of synthetic crystalline polymer of propylene $(C_3H_5)_n$.

Potentiometric Data - Ground-water surface elevation values obtained at wells and piezometers. The data is primarily used to construct potentiometric maps indicating the ground-water flow direction and elevation.

Potentiometric Surface (Piezometric Surface) - The surface that represents the level to which water from a given aquifer will rise by hydrostatic pressure. When the water-bearing zone is the uppermost unconfined aquifer, the potentiometric surface is identical to the water table.

Pump Test - A test made by pumping a well for a period of time and observing the change in hydraulic head in adjacent wells. A pump test may be used to determine degree of hydraulic interconnection between different water-bearing units, as well as the recharge rate of a well.

Purged Water - Wastewater from wells undergoing evacuation or being used for aquifer testing.

Qualified Professional in Geology - A professional, by degree, experience, or certification, specializing in the study of the earth material science.

Rate of Migration - The time a contaminant takes to travel from one stationary point to another. Generally expressed in units of time/ distance.

Regional Administrator - The Regional Administrator of the appropriate Regional Office of the Environmental Protection Agency, or the authorized representative.

Regulated Unit - Hazardous waste management unit. The number of regulated units will define the extent of the hazardous waste management area.

Retardation - Preferential retention of contaminant movement in the subsurface zone. Retention may be a result of adsorbtion processes or solubility differences.

Sampling and Analysis Plan - A detailed document describing the procedures used to collect, handle, and analyze ground-water samples for detection or assessment monitoring parameters. The plan should detail all quality control measures which will be implemented to ensure that sample collection, analysis, and data presentation activities meet the prescribed requirements.

Saturated Zone (Phreatic Zone) - A subsurface zone below which all rock pore space is filled with water.

Seismic Prospecting - Any of the various geophysical methods for characterizing subsurface properties based on the analysis of elastic waves artificially generated at the surface (e.g., seismic reflection, seismic refraction).

Shelby Tube or Split Spoon Sampler - Devices used in conjunction with a drilling rig to obtain an undisturbed core sample of the strata.

Significant Digits - The number of digits reported as the result of a calculation or measurement (exclusive of following zeroes).

Sinkers - Dense phase organic liquids which coalesce in an immiscible layer at the bottom of the saturated zone.

Slug Test - A single well test to determine the in-situ hydraulic conductivity of an aquifer by the instantaneous addition or removal of a known quantity (slug) of water into or from a well, and the subsequent measurement of the resulting well recovery time.

Smectite - A commonly used name for the montmorillonite group of clay minerals. These clay minerals have swelling properties and a high cation exchange capacity.

Solution Channel - A tubular or planar channel formed by solution in carbonate-rock (Karst) terrains.

Standard Deviation - The positive square root of the variance. The variance is the average of the squares of the differences between the actual measurements and the mean.

Stratigraphy - The science (study) of original succession and age of rock strata, also dealing with their form, distribution, lithologic composition, fossil content, and geophysical and geochemical properties. Stratigraphy also encompasses unconsolidated materials (i.e., soils).

Structural Anomaly - A geologic feature, especially in the subsurface, distinguished by geophysical, geological, or geochemical means, which is different from the general surroundings.

Surface Impoundment - A facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of liquid wastes or wastes containing free liquids, and which is not an injection well. Examples of surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons.

T-Test - The t-test is a statistical method used to determine the significance of difference or change between sets of initial background and subsequent parameter values.

TOC - Total organic carbon.

TOX - Total organic halogens.

Teflon® - Trade name for polyperfluorethylene.

Texture - The interrelationship between the size, shape, and arrangement of minerals or particles in a rock.

Total Number of Values - The number of measurements (including less than detection values) made for a chemical parameter over a statistically significant period of time (e.g., one year).

Transformation - Process of establishing correspondence between elements in one set of data to elements in another set of data, such that each element in the first set corresponds to a unique element in the second set.

Tremie Method - Method whereby bentonite/cement slurries are pumped uniformly within the annular space of a well.

Trip Blank - A field blank that is transported to the sampling site, handled the same as other samples, then returned to the laboratory for analysis in determining QA/QC of sample handling procedures.

Type II Water - Water prepared by using a still (deionized supply water may be necessary) designed to produce a distillate having a conductivity of less than 1.0 umho/cm at 25°C and a maximum total matter content of 0.1 mg/l.

Undulating - A periodic rise and fall of a surface; having a wavy outline or appearance.

Unsaturated Zone - A subsurface zone above the water table in which the interstices of a porous medium are only partially filled with water. Also referred to as Vadose Zone.

Upgradient - In the direction of increasing static head.

Upgradient Well - One or more wells which are placed hydraulically upgradient of the site and are capable of yielding ground-water samples that are representative of regional conditions and are not affected by the regulated facility.

Uppermost Aquifer - The geologic formation, group of formations, or part of a formation that contains the uppermost potentiometric surface capable of yielding a significant amount of ground water to wells or springs and may include fill material that is saturated. There should be very limited interconnection, based upon pumping tests, between the uppermost aquifer and lower aquifers. Consequently, the uppermost aquifer includes all interconnected water-bearing zones capable of significant yield that overlie the confining layer.

Vadose Zone - See Unsaturated Zone.

Volatile Constituents - Solid or liquid compounds which are relatively unstable at standard temperature and pressure and undergo spontaneous phase change to a gaseous state.

Volatile Organics - Liquid or solid organic compounds with a tendency to pass into the vapor state.

Wastewater Treatment System - A collection of treatment processes designed and built to reduce the amount of suspended solids, bacteria, oxygen-demanding materials, and chemical constituents in wastewater.

Water Table - The water level surface below the ground at which the vadose zone ends and the phreatic zone begins. It is the level to which a well screened in the unconfined aquifer would fill with water.

Well - A shaft or pit dug or bored into the earth, generally of a cylindrical form, and often walled with tubing or pipe to prevent the earth from caving in.

Well Cluster - A well cluster consists of two or more wells completed (screened) to different depths in a single borehole or a series of boreholes in close proximity to each other. From these wells, water samples that are representative of the different horizons within one or more aquifers can be collected.

Well Evacuation - Process of removing stagnant water from a well prior to sampling.

X-Ray Diffraction - An analytical technique used for mineralogical characterization. A sample is exposed to a filtered and monochromatic beam of X-rays and the reflected energy is measured and used to identify soil colloid types, degree of interleafing, or interstratification, and variations in interplatelet spacings.

Zone of Potential Contaminant Migration - Any subsurface formation or layer which is permeable and would preferentially channel the flow of contaminants away from a regulated facility.

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APPENDIX A

EVALUATION WORKSHEETS

APPENDIX A.1

CHARACTERIZATION OF SITE HYDROGEOLOGY WORKSHEET

The following worksheets have been designed to assist the enforcement official in evaluating the program the owner/operator used in characterizing hydrogeologic conditions at his site. This series of worksheets has been compiled to parallel the information presented in Chapter 1 of the TEGD.

I. Review of Site Hydrogeologic Investigatory Techniques

A. Was the site investigation and/or data collection performed by a qualified professional in geology? (Y/N)____

B. Did the owner/operator survey the following existing regional data:

1. U.S.G.S. Maps? (Y/N)____
2. Water supply well logs? (Y/N)____
3. Other (specify) ______________________________
____

C. Did the owner/operator use the following direct techniques in the hydrogeologic assessment:

1. Soil borings/rock corings? (Y/N)____
2. Materials tests (e.g., grain size analyses, standard penetration tests, etc.)? (Y/N)____
3. Piezometer installation for water level measurements at different depths? (Y/N)____
4. Slug tests? (Y/N)____
5. Pump tests? (Y/N)____
6. Geochemical analyses of soil samples? (Y/N)____
7. Other (specify) ______________________________
____

). Did the owner/operator use the following indirect techniques to supplement direct techniques data:

1. Geophysical well logs? (Y/N)____
2. Tracer studies? (Y/N)____
3. Resistivity and/or electromagnetic conductance? (Y/N)____
4. Seismic survey? (Y/N)____
5. Hydraulic conductivity measurements of cores? (Y/N)____

6. Aerial photography? (Y/N) ____
7. Ground penetrating radar? (Y/N) ____
8. Other (specify) ______________________________
____

E. Did the owner/operator document and present the raw data from the site hydrogeologic assessment? (Y/N) ____

F. Did the owner/operator document methods (criteria) used to correlate and analyze the information? (Y/N) ____

G. Did the owner/operator prepare the following:

1. Narrative description of geology? (Y/N) ____
2. Geologic cross sections? (Y/N) ____
3. Geologic and soil maps? (Y/N) ____
4. Boring/coring logs? (Y/N) ____
5. Structure contour maps of aquifer and aquitard? (Y/N) ____
6. Narrative description of ground-water flows? (Y/N) ____
7. Water table/potentiometric map? (Y/N) ____
8. Hydrologic cross sections? (Y/N) ____

H. Did the owner/operator obtain a regional map of the area and delineate the facility? (Y/N) ____

I. If yes, does this map illustrate:

1. Surficial geology features? (Y/N) ____
2. Streams, rivers, lakes, or wetlands near the facility? (Y/N) ____
3. Discharging or recharging wells near the facility? (Y/N) ____

J. Did the owner/operator obtain a regional hydrogeologic map? (Y/N) ____

K. If yes, does this hydrogeologic map indicate:

1. Major areas of recharge/discharge? (Y/N) ____
2. Regional ground-water flow direction? (Y/N) ____
3. Potentiometric contours which are consistent with observed water level elevations? (Y/N) ____

L. Did the owner/operator prepare a facility site map? (Y/N) ____

M. If yes, does the site map show:

1. Regulated units of the facility (e.g., landfill areas, impoundments)? (Y/N) ____
2. Any seeps, springs, streams, ponds, or wetlands? (Y/N) ____

3. Location of monitoring wells, soil borings, or test pits? (Y/N) ____
4. How many regulated units does the facility have? ______
   If more than one regulated unit then,
   - Does the waste management area encompass all regulated units? (Y/N) ____
     Or
   - Is a waste management area delineated for each regulated unit? (Y/N) ____

II. Characterization of Subsurface Geology of Site

A. Soil boring/test pit program:

1. Were the soil borings/test pits performed under the supervision of a qualified professional? (Y/N) ____
2. Were the borings placed close enough to accurately portray stratigraphy with minimal reliance on inference? (Y/N) ____
3. If not, did the owner/operator provide documentation for selecting the spacing for borings? (Y/N) ____
4. Were the borings drilled to the depth of the first confining unit below the uppermost zone of saturation? (Y/N) ____
5. Indicate the method(s) of drilling:
   - Auger (hollow or solid stem) ______
   - Mud rotary ______
   - Air rotary ______
   - Reverse rotary ______
   - Cable tool ______
   - Jetting ______
   - Other (specify) ____________________________
6. Were continuous sample corings taken? (Y/N) ____
7. How were the samples obtained (check method[s])
   - Split spoon ______
   - Shelby tube, or similar ______
   - Rock coring ______
   - Ditch sampling ______
   - Other (explain) ______

   ____

   ____
8. Were the continuous sample corings logged by a qualified professional in geology? (Y/N) ____
9. Does the field boring log include the following information:
   - Hole name/number? (Y/N) ____
   - Date stared and finished? (Y/N) ____
   - Geologist's name? (Y/N) ____

- Driller's name? (Y/N)____
- Hole location (i.e., map and elevation)? (Y/N)____
- Drill rig type and bit/auger size? (Y/N)____
- Gross petrography (e.g., rock type) of each geologic unit? (Y/N)____
- Gross mineralogy of each geologic unit? (Y/N)____
- Gross structural interpretation of each (Y/N)____ geologic unit and structural features (e.g., fractures, gouge material, solution channels, buried streams or valleys, identification of depositional material)? (Y/N)____
- Development of soil zones and vertical extent and description of soil type? (Y/N)____
- Depth of water-bearing unit(s) and vertical extent of each? (Y/N)____
- Depth and reason for termination of borehole? (Y/N)____
- Depth and location of any contaminant encountered in borehole? (Y/N)____
- Sample location/number? (Y/N)____
- Percent sample recovery? (Y/N)____
- Narrative descriptions of:
  - -- Geologic observations? (Y/N)____
  - -- Drilling observations? (Y/N)____

10. Were the following analytical tests performed on the core samples:
    - Mineralogy (e.g., microscopic tests and x-ray diffraction)? (Y/N)____
    - Petrographic analysis:
      - degree of crystallinity and cementation of matrix? (Y/N)____
      - degree of sorting, size fraction (i.e, sieving), textural variations? (Y/N)____
      - rock type(s)? (Y/N)____
      - soil type? (Y/N)____
      - approximate bulk geochemistry? (Y/N)____
      - existence of microstructures that may effect or indicate fluid flow? (Y/N)____
    - Falling head tests? (Y/N)____
    - Static head tests? (Y/N)____
    - Settling measurements? (Y/N)____
    - Centrifuge tests? (Y/N)____
    - Column drawings? (Y/N)____

B. Verification of subsurface geological data

1. Has the owner/operator used indirect geophysical methods to supplement geological conditions between borehole locations? (Y/N)____

2. Does the number of borings and analytical data indicate that the confining layer displays a low enough permeability to impede the migration of contaminants to any stratigraphically lower water-bearing units? (Y/N)____
3. Is the confining layer laterally continuous across the entire site? (Y/N)____
4. Did the owner/operator consider the chemical compatibility of the site-specific waste types and the geologic materials of the confining layer? (Y/N)____
5. Did the geologic assessment address or provide means for resolution of any information gaps of geologic data? (Y/N)____
6. Does the laboratory data corroborate the field data for petrography? (Y/N)____
7. Does the laboratory data corroborate the field data for mineralogy and subsurface geochemistry? (Y/N)____

C. Presentation of geologic data

1. Did the owner/operator present an adequate number of geologic cross sections of the site? (Y/N)____
2. Do each of these cross sections:
   - identify the types and characteristics of the geologic materials present? (Y/N)____
   - define the contact zones between different geologic materials? (Y/N)____
   - note the zones of high permeability or fracture? (Y/N)____
   - give detailed borehole information including:
     -- location of borehole? (Y/N)____
     -- depth of termination? (Y/N)____
     -- location of screen (if applicable)? (Y/N)____
     -- depth of zone of saturation? (Y/N)____
     -- depiction of any geophysical logs? (Y/N)____
3. Did the owner/operator provide a topographic map which was constructed by a licensed surveyor? (Y/N)____
4. Does the topographic map provide:
   - contours at a maximum interval of two-feet? (Y/N)____
   - locations and illustrations of man-made features (e.g., parking lots, factory buildings, drainage ditches, storm drains, pipelines, etc.)? (Y/N)____
   - descriptions of nearby water bodies? (Y/N)____
   - descriptions of off-site wells? (Y/N)____
   - site boundaries? (Y/N)____
   - individual RCRA units? (Y/N)____
   - delineation of the waste management area(s)? (Y/N)____
   - solid waste management areas? (Y/N)____
   - well and boring locations? (Y/N)____

5. Did the owner/operator provide an aerial photograph depicting the site and adjacent off-site features? (Y/N)____
6. Does the photograph clearly show surface water bodies, adjacent municipalities, and residences and are these clearly labelled? (Y/N)____

III. Identification of Ground-Water Flow Paths

A. Ground-water flow direction

1. Was the well casing height measured by a licensed surveyor to the nearest 0.01 feet? (Y/N)____
2. Were the well water level measurements taken within a 24 hour period? (Y/N)____
3. Were the well water level measurements taken to the nearest 0.01 feet? (Y/N)____
4. Were the well water levels allowed to stabilize after construction and development for a minimum of 24 hours prior to measurements? (Y/N)____
5. Was the water level information obtained from (check appropriate one):
   - multiple piezometers placement in single boreholes? ________
   - vertically nested piezometers in closely spaced separate boreholes? ________
6. Did the owner/operator provide construction details for the piezometers? (Y/N)____
7. How were the static water levels measured (check method(s).
   - Electric water sounder ______
   - Wetted tape ______
   - Air line ______
   - Other (explain) ______

   ____
8. Was the well water level measured in wells drilled to an equivalent depth below the saturated zone, or screened at an equivalent depth below the saturated zone? (Y/N)____
9. Has the owner/operator provided a site water table (potentiometric) contour map? If yes, (Y/N)____
   - Do the potentiometric contours appear logical based on topography and presented data? (Consult water level data) (Y/N)____
   - Are ground-water flowlines indicated? (Y/N)____
   - Are static water levels shown? (Y/N)____
   - Can hydraulic gradients be estimated? (Y/N)____

10. Did the owner/operator develop two, or more, hydrologic cross sections of the vertical flow component across the site? (Y/N)____
11. Do the owner/operator's flow nets include:
    - piezometer locations? (Y/N)____
    - depth of screening? (Y/N)____
    - width of screening? (Y/N)____

B. Seasonal and temporal fluctuations in ground-water level

1. Do fluctuations in static water levels occur? (Y/N)____
    - If yes, are the fluctuations caused by any of the following:
        -- Off-site well pumping (Y/N)____
        -- Tidal processes or other intermittent natural variations (e.g., river stage, etc.) (Y/N)____
        -- On-site well pumping (Y/N)____
        -- Off-site, on-site construction or changing land use patterns (Y/N)____
        -- Deep well injection (Y/N)____
        -- Waste disposal practices (Y/N)____
        -- Seasonal variations (Y/N)____
        -- Other (specify) ____________________
2. Has the owner/operator documented the source and patterns that contribute to or affect the ground-water flow patterns below the waste management area? (Y/N)____
3. Do the water level fluctuations alter the general ground-water gradients and flow directions? (Y/N)____
4. Based on water level data, do any head differentials occur that may indicate a vertical flow component in the saturated zone? (Y/N)____
5. Did the owner/operator implement means for gauging long term effects on water movement that may result from on-site or off-site construction or changes in land-use patterns? (Y/N)____

C. Hydraulic conductivity

1. How were hydraulic conductivities of the subsurface materials determined?
    - Single-well tests (slug tests)? (Y/N)____
    - Multiple-well tests (pump tests)? (Y/N)____
2. If single-well tests were conducted, was it done by:
    - Adding or removing a known volume of water? (Y/N)____
      or
    - Pressurizing well casing (Y/N)____

3. If single well tests were conducted in a highly permeable formation, were pressure transducers and high-speed recording equipment used to record the rapidly changing water levels? (Y/N) ____
4. Since single well tests only measure hydraulic conductivity in a limited area, were enough tests run to ensure a representative measure of conductivity in each hydrogeologic unit? (Y/N) ____
5. Is the owner/operator's slug or pump test data consistent with existing geologic information (e.g., boring logs)? (Y/N) ____
6. Were other hydraulic conductivity properties determined? (Y/N) ____
7. If yes, provide any of the following data, if available:
   - Transmissivity ______
   - Storage coefficient ______
   - Leakage ______
   - Permeability ______
   - Porosity ______
   - Specific capacity ______
   - Other (specify) ______________________________

D. Identification of the uppermost aquifer

1. Has the extent of the uppermost aquifer in the facility area been defined? If yes, (Y/N) ____
   - Are soil boring/test pit logs included? (Y/N) ____
   - Are geologic cross-sections included? (Y/N) ____
2. Is there evidence of confining (competent, unfractured, continuous, and low permeability) layers beneath the site? (Y/N) ____
   - If yes, was continuity demonstrated through the evidence of lack of drawdown in the upper well when separate, closely-spaced wells (one screened at the uppermost part of the water table, and the other screened on the lower side of the confining layer) are pumped simultaneously? (Y/N) ____
3. Was hydraulic conductivity of the confining unit determined by direct field measurements to be of sufficient low permeability to prevent passage of contaminants to saturated, stratigraphically lower units? (Y/N) ____
4. Does potential for other hydraulic interconnection exist (e.g., lateral incontinuity between geologic units, facies changes, fracture zones, cross cutting structures, or chemical corrosion/alteration of geologic units by leachate)? (Y/N) ____

IV. Conclusions

A. Subsurface geology

1. Has sufficient data been collected to adequately define petrography and petrographic variation? (Y/N)____
2. Has the subsurface geochemistry been adequately defined? (Y/N)____
3. Was the boring/coring program adequate to define subsurface geologic variation? (Y/N)____
4. Was the owner/operator's narrative description complete and accurate in its interpretation of the data? (Y/N)____
5. Does the geologic assessment address or provide means to resolve any information gaps? (Y/N)____

B. Ground-water flow paths

1. Did the owner/operator adequately establish the horizontal and vertical components of ground-water flow? (Y/N)____
2. Were appropriate methods used to establish ground-water flow paths? (Y/N)____
3. Did the owner/operator provide accurate documentation? (Y/N)____
4. Are the potentiometric surface measurements valid? (Y/N)____
5. Did the owner/operator adequately consider the seasonal and temporal effects on the ground-water? (Y/N)____
6. Were sufficient hydraulic conductivity tests performed to document lateral and vertical variation in hydraulic conductivity in the entire hydrogeologic subsurface below the site? (Y/N)____

C. Uppermost aquifer

1. Did the owner/operator adequately define the uppermost aquifer? (Y/N)____

APPENDIX A.2

PLACEMENT OF DETECTION MONITORING WELLS WORKSHEET

The following worksheets are designed to assist the enforcement officer's evaluation of an owner/operator's approach for selecting the number, location, and depth of all detection phase monitoring wells. This series of worksheets has been compiled to closely track the information presented in Chapter 2 of the TEGD. The guide for the evaluation of an owner/operator's placement of monitoring wells is highly dependent upon a thorough characterization of the site hydrogeology as described in Chapter 1 of the TEGD and Appendix A.1 worksheets.

I. Placement of Downgradient Detection Monitoring Wells

A. Are the ground-water monitoring wells or clusters located immediately adjacent to the waste management area? (Y/N) ____

B. Does the owner/operator provide a rationale for the location of each monitoring well or cluster? (Y/N) ____

C. Does the owner/operator provide an explanation for the density of the ground-water monitoring wells? (Y/N) ____

D. Has the owner/operator identified the screen length(s) of each monitoring well or cluster? (Y/N) ____

E. What length screens has the owner/operator employed in the ground-water monitoring wells on site?

____

____

____

____

F. Does the owner/operator provide an explanation for the screen lengths of each monitoring well or cluster? (Y/N) ____

G. Do the actual locations of monitoring wells or clusters correspond to those identified by the owner/operator? (Y/N) ____

II. Placement of Upgradient Monitoring Wells

A. Has the owner/operator documented the location of each upgradient monitoring well or cluster? (Y/N) ____

B. Does the owner/operator provide an explanation for the location(s) of the upgradient monitoring wells? (Y/N) ____

C. What length screens has the owner/operator employed in the background monitoring well(s)?

____
____
____
____

D. Does the owner/operator provide an explanation for the screen length(s) chosen? (Y/N)____

E. Are the upgraident monitoring wells installed in the same portion of the uppermost aquifer as the downgradient monitoring wells? (Y/N)____

F. Does the actual location of each background monitoring well or cluster correspond to that identified by the owner/operator? (Y/N)____

III. Conclusions

A. Downgradient Wells

Do the location, number, and screen lengths of the ground-water monitoring wells or clusters in the detection monitoring system allow for the immediate detection of a release of hazardous waste or constituents from the hazardous waste management area? (Y/N)____

B. Upgradient Wells

Do the location and screen lengths of the upgradient (background) ground-water monitoring wells ensure the capability of collecting ground-water samples representatiave of upgradient (background) ground-water quality including any ambient heterogeneous chemical characteristics? (Y/N)____

APPENDIX A.3

MONITORING WELL DESIGN AND CONSTRUCTION WORKSHEET

The following worksheets have been designed to assist the enforcement officer in evaluating the techniques used by an owner/operator for designing and constructing monitoring wells. This series of worksheets has been compiled to parallel the information presented in Chapter 3 of the TEGD.

I. Monitoring Well Design

A. Complete the attached well construction summary sheet for the monitoring well unless similar documentation is already available from the owner/operator. Include the locations where the well intercepts changes in geological formation.

II. Drilling Methods

A. What drilling method was used for the well?

- Hollow-stem auger ______
- Solid-stem auger ______
- Cable tool ______
- Air rotary ______
- Water rotary ______
- Mud rotary ______
- Reverse rotary ______
- Jetting ______
- Air drill with casing hammer ______
- Other (specify) ____________________

B. Were any drilling fluids (including water) or additives used during drilling? (Y/N) ____

If yes, specify

Type of drilling fluid ____________________

Source of water used ____________________

Foam ____________________

Polymers ____________________

Other ____________________

C. Was the drilling fluid, or additive, analyzed? (Y/N) ____

D. Was the drilling equipment steam-cleaned prior to drilling the well? (Y/N) ____

PROJECT ______________________

SITE ______________________

COORDINATES ______________________

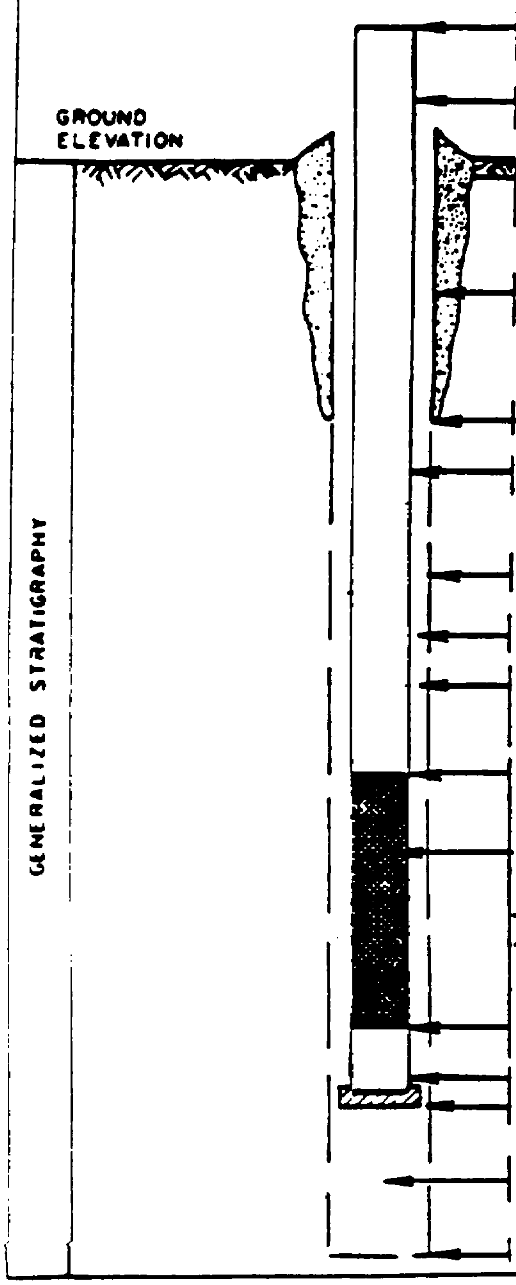
DATE COMPLETED ______________________

SUPERVISED BY ______________________

WELL NO. ________

AQUIFIER ________

____



Elevation of reference point ________

Height of reference point above ground surface ________

Depth of surface seal ________

Type of surface seal: ________

____

I.D. of surface casing ________

Type of surface casing: ________

____

Depth of surface casing ________

I.D. of riser pipe ________

Type of riser pipe: ________

____

Diameter of borehole ________

Type of filler: ________

Elevation / depth of top of seal ________

Type of seal: ________

Type of gravel pack ________

Elev./depth of top of gravel pack ________

Elevation / depth of top of screen ________

Description of screen ________

____

____

I.D. of screen section ________

Elevation / depth of bottom of screen ________

Elev./depth of bottom of gravel pack ________

Elev./depth of bottom of plugged blank section ________

Type of filler below plugged section ________

Elevation of bottom of borehol ________

Well Construction Summary.

E. Was compressed air used during drilling? (Y/N) ____
   1. If yes, was the air treated to remove oil (e.g., filtered)? (Y/N) ____

F. Did the owner/operator document procedure for establishing the potentiometric surface? (Y/N) ____
   1. If yes, how was the location established?

____
____
____
____
____

G. Formation samples
   1. Were continuous formation sample cores collected initially during drilling? (Y/N) ____
   2. How were the samples obtained?
      - Split spoon ______
      - Shelby tube ______
      - Core drill ______
      - Other (specify) ______________________________
   3. Indicate the intervals at which formation samples were collected ______________________________

      ____
   4. Identify if any physical and/or chemical tests were performed on the formation samples (specify) ______________

      ____
      ____

III. Monitoring Well Construction Materials

List of Potential Construction Materials for the Saturated Zone

1. Stainless steel (316, 304, 2205)
2. Fluorocarbon resins (specify) ______________________________
3. Other (specify) ______________________________

Teflon

A. Identify construction materials (by number) and diameters (ID/OD)

	Material	Diameter (ID/OD)
1. Primary Casing	______	______
2. Secondary or outside casing (double construction)	______	______
3. Screen	______	______

B. How are the sections of casing and screen connected?
- Pipe sections threaded ______
- Couplings (friction) with adhesive or solvent ______
- Couplings (friction) with retainer screws ______
- Other (specify) ______

C. Were the materials steam-cleaned prior to installation? (Y/N)____
Other cleaning methods (specify) ______

IV. <u>Well Intake Design and Well Development</u>

A. Was a well intake screen installed? (Y/N)____
1. What is the length of the screen for the well?

______

2. Is the screen manufactured? (Y/N)____

B. Was a filter pack installed? (Y/N)____
1. Wase the material used to construct the filter pack chemically inert? Specify the material ______

______ (Y/N)____

2. Has a turbidity measurement of the well water ever been made? (Y/N)____

C. Well development
1. What technique was used for well development?
- Surge block ______
- Bailer ______
- Air surging ______
- Water pumping ______
- Other (specify) ______

V. <u>Annular Space Seals</u>

A. Is the annular space in the saturated zone directly above the filter pack filled with?
- Sodium bentonite (specify type and grit)

______

- Cement (specify neat or concrete) ______
- Other (specify) ______

1. Was the seal installed by?
- Dropping material down the hole and tamping ______
- Dropping material down the inside of hollow-stem auger ______
- Tremie pipe method ______
- Other (specify) ______

B. Was a different seal used in the unsaturated zone? (Y/N)____
If yes,
1. Was this seal made with?
   - Sodium bentonite (specify type and grit) ____________
     ____
   - Cement (specify neat or concrete) ____________
   - Other (specify) ____________
2. Was this seal installed by?
   - Dropping material down the hole and tamping ________
   - Dropping material down the inside of hollow-stem auger ________
   - Tremie pipe method ________
   - Other (specify) ____________

C. Is the upper portion of the borehole sealed with a concrete cap to prevent infiltration from the surface? (Y/N)____

D. Is the well fitted with an above-ground protective device? (Y/N)____

E. Has the protective cover been installed with locks to prevent tampering? (Y/N)____

VI. Field Tests/Field Demonstration

A. Do field measurements of the following agree with reported data:
1. Casing diameter? (Y/N)____
2. Well depth? (Y/N)____
3. Water level elevation? (Y/N)____

B. If the existing well is being field demonstrated, complete Questions 1 through 7.
1. Is the location of the demonstration well hydraulically equivalent to the existing well? (Y/N)____
2. Was the demonstration well installed using EPA-approved methods and materials? (Y/N)____
3. How were the wells evacuated (e.g., bailer or bladder pump)?
   existing well: ____________
   demonstration well: ____________
4. Were the wells sampled concurrently? (Y/N)____
5. Were the wells each sampled using the appropriate EPA methodology? (Y/N)____

6. What parameters were the ground water samples analyzed for?

____
____
____
____
____

7. Are the values for these parameters equivalent for each well (i.e., within the acceptable standard deviations)? (Y/N)____

VII. Conclusions

A. Do the design and construction of the owner/operator's ground-water monitoring wells permit depth discrete ground-water samples to be taken? (Y/N)____

B. Are the samples representative of ground-water quality? (Y/N)____

C. Are the ground-water monitoring wells structurally stable? (Y/N)____

D. Does the ground-water monitoring well's design and construction permit an accurate assessment of aquifer characteristics? (Y/N)____

APPENDIX A.4

SAMPLING AND ANALYSIS WORKSHEET

The following worksheets have been designed to assist the enforcement officer in evaluating the techniques an owner/operator uses to collect and analyze ground-water samples. This series of worksheets has been compiled based on the information provided in Chapter 4 of the TEGD.

I. Review of Sample Collection Procedures

A. Measurement of well depths elevation:

1. Are measurements of both depth to standing water and depth to the bottom of the well made? (Y/N) ____
2. Are measurements taken to the nearest centimeter or 0.01 foot? (Y/N) ____
3. What device is used?

____

4. Is there a reference point(s) established by a licensed surveyor? (Y/N) ____

B. Detection of immiscible layers:
1. Are procedures used which will detect light phase immiscible layers? (Y/N) ____
2. Are procedures used which will detect dense phase immiscible layers? (Y/N) ____

C. Sampling of immiscible layers:
1. Are the immiscible layers sampled separately prior to well evacuation? (Y/N) ____
2. Do the procedures used minimize mixing with water soluble phase? (Y/N) ____

D. Well evacuation:
1. Are low yielding wells evacuated to dryness? (Y/N) ____
2. Are high yielding wells evacuated so that at least three casing volumes are removed? (Y/N) ____
3. What device is used to evacuate the wells?

____

4. If any problems are encountered (e.g., equipment malfunction) are they noted in a field logbook? (Y/N) ____

E. Sample withdrawal:
1. For low-yielding wells, are first samples tested for pH, temperature, and specific conductance after the well recovers? (Y/N) ____

2. Are samples collected and containerized in order of the parameters volatilization sensitivity? (Y/N) ____
3. For higher-yielding wells, are samples retested for pH, temperature, and specific conductance to determine purging efficiency? (Y/N) ____
4. Are samples withdrawn with either fluorocarbon resins or stainless steel (304, 316, 2205) sampling devices? (Y/N) ____
5. Are sampling devices either bottom valve bailers or positive gas displacement bladder pumps? (Y/N) ____
6. If bailers are used, is fluorocarbon resin-coated wire, single strand stainless steel wire, or monofilament used to raise and lower the bailer? (Y/N) ____
7. If bladder pumps are used, are they operated in a continuous manner to prevent aeration of the sample? (Y/N) ____
8. If bailers are used, are they lowered slowly to prevent degassing of the water? (Y/N) ____
9. If bailers are used, are the contents transferred to the sample container in a way that will minimize agitation and aeration? (Y/N) ____
10. Is care taken to avoid placing clean sampling equipment on the ground or other contaminated surfaces prior to insertion into the well? (Y/N) ____
11. If dedicated sampling equipment is not used, is equipment disassembled and thoroughly cleaned between samples? (Y/N) ____
12. If samples are for inorganic analysis, does the cleaning procedure include the following sequential steps:
    a. Nonphosphate detergent wash? (Y/N) ____
    b. Dilute acid rinse (HNO_3 or HCl)? (Y/N) ____
    c. Tap water rinse? (Y/N) ____
    d. Type II reagent grade water? (Y/N) ____
13. If samples are for organic analysis, does the cleaning procedure include the following sequential steps:
    a. Nonphosphate detergent wash? (Y/N) ____
    b. Tap water rinse? (Y/N) ____
    c. Distilled/deionized water rinse? (Y/N) ____
    d. Acetone rinse? (Y/N) ____
    e. Pesticide-grade hexane rinse? (Y/N) ____
14. Is sampling equipment thoroughly dry before use? (Y/N) ____
15. Are equipment blanks taken to ensure that sample cross-contamination has not occurred? (Y/N) ____
16. If volatile samples are taken with a positive gas displacement bladder pump, are pumping rates below 100 ml/min? (Y/N) ____

F. In-situ or field analyses:
1. Are the following labile (chemically unstable) parameters determined in the field:
   a. pH? (Y/N) ____
   b. Temperature? (Y/N) ____
   c. Specific conductivity? (Y/N) ____
   d. Redox potential? (Y/N) ____
   e. Chlorine? (Y/N) ____
   f. Dissolved oxygen? (Y/N) ____
   g. Turbidity? (Y/N) ____
   h. Other (specify) ________________________________
2. For in-situ determinations, are they made after well evacuation and sample removal? (Y/N) ____
3. If sample is withdrawn from the well, is parameter measured from a split portion? (Y/N) ____
4. Is monitoring equipment calibrated according to manufacturers' specifications and consistent with SW-846? (Y/N) ____
5. Is the date, procedure, and maintenance for equipment calibration documented in the field logbook? (Y/N) ____

II. Review of Sample Preservation and Handling Procedures

A. Sample containers:
1. Are samples transferred from the sampling device directly to their compatible containers? (Y/N) ____
2. Are sample containers for metals (inorganics) analyses polyethylene with polypropylene caps? (Y/N) ____
3. Are sample containers for organics analysis glass bottles with fluorocarbon resin-lined caps? (Y/N) ____
4. If glass bottles are used for metals samples are the caps fluorocarbon resin-lined? (Y/N) ____
5. Are the sample containers for metal analyses cleaned using these sequential steps?
   a. Nonphosphate detergent wash? (Y/N) ____
   b. 1:1 nitric acid rinse? (Y/N) ____
   c. Tap water rinse? (Y/N) ____
   d. 1:1 hydrochloric acid rinse? (Y/N) ____
   e. Tap water rinse? (Y/N) ____
   f. Type II reagent grade water rinse? (Y/N) ____
6. Are the sample containers for organic analyses cleaned using these sequential steps?
   a. Nonphosphate detergent/hot water wash? (Y/N) ____
   b. Tap water rinse? (Y/N) ____
   c. Distilled/deionized water rinse? (Y/N) ____
   d. Acetone rinse? (Y/N) ____
   e. Pesticide-grade hexane rinse? (Y/N) ____

7. Are trip blanks used for each sample container type to verify cleanliness? (Y/N)____

B. Sample preservation procedures:

1. Are samples for the following analyses cooled to 4°C:
   a. TOC? (Y/N)____
   b. TOX? (Y/N)____
   c. Chloride? (Y/N)____
   d. Phenols? (Y/N)____
   e. Sulfate? (Y/N)____
   f. Nitrate? (Y/N)____
   g. Pesticides/Herbicides? (Y/N)____
   h. Coliform bacteria? (Y/N)____
   i. Cyanide? (Y/N)____
   j. Oil and grease? (Y/N)____
   k. Volatile, semi-volatile, and nonvolatile organics? (Y/N)____
2. Are samples for the following analyses field acidified to pH <2 with HNO_3:
   a. Iron? (Y/N)____
   b. Manganese? (Y/N)____
   c. Sodium? (Y/N)____
   d. Total metals? (Y/N)____
   e. Dissolved metals? (Y/N)____
   f. Radium? (Y/N)____
   g. Gross alpha? (Y/N)____
   h. Gross beta? (Y/N)____
3. Are samples for the following analyses field acidified to pH <2 with H_2SO_4:
   a. Phenols? (Y/N)____
   b. Oil and grease? (Y/N)____
4. Is the sample for TOC analyses field acidified to pH <2 with H_2SO_4 or HCl? (Y/N)____
5. Is the sample for TOX analysis preserved with 1 ml of 1.1 M sodium sulfite? (Y/N)____
6. Is the sample for cyanide analysis preserved with NaOH to pH >12? (Y/N)____
7. Are pesticides pH adjusted to between 6 and 8 with NaOH or H_2SO_4? (Y/N)____

C. Special handling considerations:

1. Are organic samples handled without filtering? (Y/N)____
2. Are samples for volatile organics transferred to the appropriate vials to eliminate headspace over the sample? (Y/N)____
3. Are samples for metal analysis split into two portions? (Y/N)____
4. Is the sample for dissolved metals filtered through a 0.45 micron filter? (Y/N)____

5. Is the second portion not filtered and analyzed for total metals? (Y/N)____
6. Is one equipment blank prepared each day of ground-water sampling? (Y/N)____

III. Review of Analytical Procedures

A. Laboratory analysis procedures:

1. Are all samples analyzed using an EPA-approved method (SW-846)? (Y/N)____
2. Are appropriate QA/QC measures used in laboratory analysis (e.g., blanks, spikes, standards)? (Y/N)____
3. Are detection limits and percent recovery (if applicable) provided for each parameter? (Y/N)____
4. If a new analytical method or laboratory is used, are split samples run for comparison purposes? (Y/N)____
5. Are samples analyzed within specified holding times? (Y/N)____

B. Laboratory logbook:

1. Is a laboratory logbook maintained? (Y/N)____
2. Are experimental conditions (e.g., temperature, humidity, etc.) noted? (Y/N)____
3. If a sample for volatile analysis is received with headspace, is this noted? (Y/N)____
4. Are the results for all QC samples identified? (Y/N)____
5. Is the time, date, and name of person noted for each processing step? (Y/N)____

IV. Review of Chain-of-Custody Procedures

A. Sample labels:

1. Are sample labels used? (Y/N)____
2. Do they provide the following information:
   a. Sample identification number? (Y/N)____
   b. Name of collector? (Y/N)____
   c. Date and time of collection? (Y/N)____
   d. Place of collection? (Y/N)____
   e. Parameter(s) requested: (Y/N)____
3. Do they remain legible even if wet? (Y/N)____

B. Sample seals:

1. Are sample seals placed on those containers to ensure the samples are not altered? (Y/N)____

C. Field logbook:
   1. Is a field logbook maintained? (Y/N)____
   2. Does it document the following:
      a. Purpose of sampling (e.g., detection or assessment)? (Y/N)____
      b. Identification of well? (Y/N)____
      c. Total depth of each well? (Y/N)____
      d. Static water level depth and measurement technique? (Y/N)____
      e. Presence of immiscible layers and detection method? (Y/N)____
      f. Collection method for immiscible layers and sample identification numbers? (Y/N)____
      g. Well yield - high or low? (Y/N)____
      h. Purge volume and pumping rate? (Y/N)____
      i. Time well purged? (Y/N)____
      j. Well evacuation procedures? (Y/N)____
      k. Sample withdrawal procedure? (Y/N)____
      l. Date and time of collection? (Y/N)____
      m. Well sampling sequence? (Y/N)____
      n. Types of sample containers and sample identification numbers? (Y/N)____
      o. Preservative(s) used? (Y/N)____
      p. Parameters requested? (Y/N)____
      q. Field analysis data and method(s)? (Y/N)____
      r. Sample distribution and transporter? (Y/N)____
      s. Field observations? (Y/N)____
         - Unusual well recharge rates? (Y/N)____
         - Equipment malfunction(s)? (Y/N)____
         - Possible sample contamination? (Y/N)____
         - Sampling rate? (Y/N)____
      t. Field team members? (Y/N)____
      U. Climatic conditions and air temperature? (Y/N)____

D. Chain-of-custody record:
   1. Is a chain-of-custody record included with each sample? (Y/N)____
   2. Does it document the following:
      a. Sample number? (Y/N)____
      b. Signature of collector? (Y/N)____
      c. Date and time of collection? (Y/N)____
      d. Sample type? (Y/N)____
      e. Identification of well? (Y/N)____
      f. Number of containers? (Y/N)____
      g. Parameters requested? (Y/N)____
      h. Signatures of persons involved in the chain-of-possession? (Y/N)____
      i. Inclusive dates of possession? (Y/N)____

E. Sample analysis request sheet:
   1. Does a sample analysis request sheet accompany each sample? (Y/N) ____
   2. Does the request sheet document the following:
      a. Name of person receiving the sample? (Y/N) ____
      b. Date of sample receipt? (Y/N) ____
      c. Laboratory sample number (if different than field number)? (Y/N) ____
      d. Analyses to be performed? (Y/N) ____

F. Laboratory logbook:
   1. Is a laboratory logbook maintained? (Y/N) ____
   2. If so, does it document the following:
      a. Sample preparation techniques (e.g., extraction)? (Y/N) ____
      b. Instrumental methods? (Y/N) ____
      c. Experimental conditions? (Y/N) ____

V. Review of Quality Assurance/Quality Control

A. Is the validity and reliability of the laboratory and field generated data ensured by a QA/QC program? (Y/N) ____

B. Does the QA/QC program include:
   1. Documentation of any deviations from approved procedures? (Y/N) ____
   2. Collection and analysis of trip blanks and equipment blanks? (Y/N) ____
   3. Documentation of analytical results for:
      a. Laboratory blanks? (Y/N) ____
      b. Standards? (Y/N) ____
      c. Duplicates? (Y/N) ____
      d. Spiked samples? (Y/N) ____

C. Are approved statistical methods used? (Y/N) ____

D. Are QC samples used to correct data? (Y/N) ____

E. Are all data critically examined to ensure it has been properly calculated and reported? (Y/N) ____

VI. Review of Indicators of Data Quality

A. Reporting of low and zero concentration values:
   1. Do specific concentration values accompanying measurements reported as less than a limit of detection? (Y/N) ____
   2. Is the magnitude of detection limits consistent throughout the data set for each parameter? (Y/N) ____

3. Have techniques described in Appendix B of 40 CFR §136 been used to determine the detection limits? (Y/N)____
4. Has the method for using less than detection limit data in presentations and statistical analysis been documented? (Y/N)____

B. Significant digits:
1. Are constituent concentrations reported with a consistent number of significant digits? (Y/N)____
2. Are all indicator parameters reported with at least three significant digits? (Y/N)____

C. Missing data values:
1. Is the monitoring data set complete? (Y/N)____
2. Are t-test comparisons between upgradient and downgradient wells attempted despite missing data provided that:
   a. At least one upgradient and one downgradient well were sampled? (Y/N)____
   b. In the case of a missing quarterly sampling set, values are assigned by averaging corresponding values for the other three quarters? (Y/N)____
   c. In the case of missing replicate values from a sampling event, values are assigned by averaging the replicate(s) which are available for that sampling event? (Y/N)____

D. Outliers:
1. Have extreme values (outliers) of constituent concentrations deleted or otherwise modified because of:
   a. Incorrect transcription? (Y/N)____
   b. Methodological problems or an unnatural catastrophic event? (Y/N)____
   c. Are these above occurrences fully documented? (Y/N)____
2. Are true but extreme values unaltered and incorporated in the analysis? (Y/N)____

E. Units of measure:
1. Are all units of measure reported accurately? (Y/N)____
2. Are the units of measure for a given chemical parameter used consistently throughout the report? (Y/N)____

3. Do the reporting formats clearly indicate consistent units of measure throughout so that no ambiguity exists (i.e., do the units accompany each parameter instead of a statement, "all values are ppm unless otherwise stated")? (Y/N) ____

VII. Conclusions

A. Does the sampling and analysis plan permit the owner/operator to detect and, where applicable, assess the nature and extent of a release of hazardous constituents to ground water from the monitored hazardous waste management facility? (Y/N) ____

APPENDIX A.5

PRESENTING DETECTION MONITORING DATA WORKSHEET

The following worksheets have been designed to assist the enforcement official in evaluating the method an owner/operator uses in presenting and statistically analyzing detection monitoring data. This series of worksheets has been compiled to parallel the information provided in Chapter 5 of the TEGD.

I. Presenting Detection Monitoring Data

A. Is the owner/operator using the data reporting sheets as described in the TEGD (Chapter 5)? (Y/N) ____

B. Have all the detection monitoring data collected by the facility been obtained and reviewed? (Y/N) ____

II. T-test and Number of Wells

A. Which t-test is in use:
   1. Cochran's Approximation to the Behrens-Fisher (CABF t-test)? ____
   2. Averaged replicate t-test (AR t-test)? ____
   3. Other, describe: ________________________________

B. Does the facility have more than one upgradient monitoring well? (Y/N) ____

III. First Year's Data

A. Have upgradient wells been monitored to establish background concentrations of the following data on a quarterly basis for one year:
   1. Appendix III parameters (§265.92(b)(1))? (Y/N) ____
   2. Ground-water quality parameters (§265.92(b)(2))? (Y/N) ____
   3. Ground-water contamination indicator parameters (§265.92(b)(3))? (Y/N) ____

B. Were four replicate measurements obtained from each upgradient well during the first year of quarterly detection monitoring for indicator parameters [§265.92(b)(3)]? (Y/N) ____

C. Have the background mean and variance been determined for the §265.92(b)(3) parameters using all the data obtained from the upgradient wells during the first year of sampling? (Y/N) ____

D. Are background statistics determined from missing data using the criteria discussed in Chapter Four? (Y/N) ____

IV. Subsequent Year's Data

A. Is monitoring data collected after the first year being compared with background data to determine possible groundwater contamination? (Y/N) ____

B. Is the identified approved t-test being used properly to determine possible ground-water contamination? (Y/N) ____

C. Are the ground-water quality parameters in §265.92(b)(2) being measured at least annually? (Y/N) ____

D. Are the indicator parameters in §265.92(b)(3) being measured in at least four replicate samples from each well in the detection monitoring network at least semi-annually? (Y/N) ____

E. Are the indicator parameters collected on a semi-annual basis being used to estimate the mean and variance? (Y/N) ____

F. Is the elevation of the water table at each monitoring well determined each time a sample is collected? (Y/N) ____

V. Conclusions

A. Is the owner/operator adequately reporting and statistically analyzing the facility's monitoring well data? (Y/N) ____

B. If the t-test indicated a significant increase in IP's for downgradient wells, were they resampled and reanalyzed? (Y/N) ____

C. If the resampling still indicated a significant increase, was assessment monitoring begun? (Y/N) ____

APPENDIX A.6

ASSESSMENT MONITORING

The following worksheets have been designed to assist the enforcement officer in evaluating an owner/operator's assessment phase ground-water monitoring program. This series of worksheets has been compiled to parallel the information presented in Chapter 6 of the TEGD.

I. Review of Hydrogeologic Descriptions

A. Has the site's hydrogeologic setting been well characterized (refer to Appendix A.1 of TEGD)? (Y/N)____
   1. Has the regional and local hydrogeologic setting been thoroughly described? (Y/N)____
   2. Is there sufficient direct field information? (Y/N)____
   3. Is the information accurate and reliable? (Y/N)____
   4. Was the evaluation performed by a hydrogeologist? (Y/N)____
   5. Did indirect investigatory methods correlate with direct methods? (Y/N)____
   6. Have all possible migration pathways been identified? (Y/N)____
   7. Will the description of the hydrogeologic setting aid in characterizing the rate and extent of the plume migration? (Y/N)____

II. Review of Detection Monitoring System Description

A. Is the detection monitoring system capable of detecting all contaminant leakage that may be escaping from the facility (refer to Appendix A.2 of TEGD)? (Y/N)____
   1. Are the well designs and construction parameters fully documented? (Y/N)____
   2. Have the downgradient wells been strategically located so as to intercept migrating contaminants? (Y/N)____
   3. Are upgradient wells positioned so that they are not effected by the facility? (Y/N)____
   4. What are the screened intervals? (Y/N)____
   5. Are the well construction materials (e.g., casing, screen, seals, packing) comprised of material that will not affect the ground-water quality? (Y/N)____

III. Review of Description of Approach for Making First Determination

A. Did the detection monitoring system consistently yield statistically equivalent concentrations for all indicator parameters? (Y/N)____

B. If no:
1. Were the results based on the Student's t-test at the 0.01 level of significance? (Single-tailed t-test for testing significant increases and two-tailed t-test for testing significant differences in pH values.) (Y/N)____
2. Were the calculations performed correctly? (Y/N)____
3. If the results are deemed as a false positive, did the owner/operator fully document the reasoning? (Y/N)____
4. Is there any reasonable cause to believe that faulty data are responsible for the false positive claim? (Y/N)____
5. Can or will deficiencies in well design, sample collection, sample preservation, or analysis be corrected? (Y/N)____
6. If the owner/operator intends to collect additional data to remedy any inadequacies, will this collection result in an acceptable delay in assessing the extent of contamination at the site? (Y/N)____
7. Will positive results of these determinations initiate a drilling program for assessment monitoring? (Y/N)____

IV. Review of Approach for Conducting Assessment

A. Have the assessment monitoring objectives been clearly defined in the assessment plan? (Y/N)____
1. Does the plan include analysis and/or re-evaluation to determine if significant contamination has occurred in any of the detection monitoring wells? (Y/N)____
2. Does the plan provide for a comprehensive program of investigation to fully characterize the rate and extent of contaminant migration from the facility? (Y/N)____
3. Does the plan call for determining the concentrations of hazardous wastes and hazardous waste constituents in the ground water? (Y/N)____
4. Does the plan employ a quarterly monitoring program? (Y/N)____

B. Does the assessment plan identify the investigatory methods that will be used in the assessment phase? (Y/N)____
1. Is the role of each method in the evaluation fully described? (Y/N)____

2. Does the plan provide sufficient descriptions of the direct methods to be used? (Y/N)____
3. Does the plan provide sufficient descriptions of the indirect methods to be used? (Y/N)____
4. Will the method contribute to the further characterization of the contaminant movement? (Y/N)____

C. Are the investigatory techniques utilized in the assessment program based on direct methods? (Y/N)____
1. Does the assessment approach incorporate indirect methods to further support direct methods? (Y/N)____
2. Will the planned methods called for in the assessment approach ultimately meet performance standards for assessment monitoring? (Y/N)____
3. Are the procedures well defined? (Y/N)____
4. Does the approach provide for monitoring wells similar in design and construction as the detection monitoring wells? (Y/N)____
5. Does the approach employ taking samples during drilling or collecting core samples for further analysis? (Y/N)____

D. Are the indirect methods to be used based on reliable and accepted geophysical techniques? (Y/N)____
1. Are they capable of detecting subsurface changes resulting from contaminant migration at the site? (Y/N)____
2. Is the measurement at an appropriate level of sensitivity to detect ground-water quality changes at the site? (Y/N)____
3. Is the method appropriate considering the nature of the subsurface materials? (Y/N)____
4. Does the approach consider the limitations of these methods? (Y/N)____
5. Will the extent of contamination and constituent concentration be based on direct methods and sound engineering judgment? (Using indirect methods to further substantiate the findings) (Y/N)____

E. Does the assessment approach incorporate any mathematical modeling to predict contaminant movement? (Y/N)____
1. Will site specific measurements be utilized to accurately portray the subsurface? (Y/N)____
2. Will the derived data be reliable? (Y/N)____
3. Will the model be adequately calibrated with observed physical conditions? (Y/N)____
4. Have the assumptions been identified? (Y/N)____
5. Have the physical and chemical properties of the site-specific wastes and hazardous waste constituents been identified? (Y/N)____

V. Review of Assessment Monitoring Wells

A. Does the assessment plan specify:

1. The number, location, and depth of wells? (Y/N)____
2. The rationale for their placement and identify the basis that will be used to select subsequent sampling locations and depths in later assessment phases? (Y/N)____

B. Does the assessment period consist of a phased investigation so that data gained in initial rounds may help guide subsequent rounds? (Y/N)____

1. Do initial rounds incorporate geophysical techniques to approximate the limits of the contaminant plume? (Y/N)____
2. Has information from the triggering well (well showing elevated contaminant concentrations) been incorporated in the initial design and specifications? (Y/N)____
3. Is the sampling program designed adequately to portray a three dimensional plume configuration? (Y/N)____
4. Are evaluation procedures in place that will provide further guidance for subsequent monitoring? (Y/N)____

C. Does sufficient hydrogeologic data exist in the direction of the contaminant plume? (Y/N)____

1. Does the subsurface setting provide any information on possible transport mechanisms and attenuation processes? (Y/N)____
2. Are provisions made to secure additional data as needed? (Y/N)____
3. Are hydrogeologic descriptions updated as additional data become available? (Y/N)____

D. Sampling density:

1. Is the number of monitoring well clusters sufficient to define the horizontal boundaries of the plume? (Y/N)____
2. Are the well clusters placed both perpendicular and parallel to plume migration from the triggering well? (Y/N)____
3. Are the well clusters placed both inside and outside the contaminant plume to identify its horizontal boundaries? (Y/N)____
4. Are sampling locations situated so as to identify areas of maximum contaminant concentration within the plume? (Y/N)____
5. Does the sampling density correlate with the size of the plume and the geologic variability? (Y/N)____

E. Sampling depths:
   1. Are the intervals over which the samples are collected clearly identified? (Y/N)____
   2. Are the well screens within each cluster positioned to sample the full extent of the predicted vertical distribution of hazardous waste constituents? (Y/N)____
   3. Are the well screens depth discrete to the extent possible to minimize dilution effects? (Y/N)____
   4. Are there sufficient wells in each cluster to verbally define plume margins? (Y/N)____
   5. Are there wells within each cluster that are screened within the plume? (Y/N)____
   6. Are the wells placed alternating lower and higher screened wells to reduce the effect of drawdown on the sampling horizons? (Y/N)____
   7. Are there high fluctuations in ground-water levels, or is the subsurface characterized by fractured consolidated formations that may otherwise require longer screen lengths? (Y/N)____
   8. Are the wells screened to identify vertical concentration gradients and maximum concentrations of the contaminants? (Y/N)____

VI. Review of Monitoring Well Design and Construction

A. Are the well design and construction specification requirements equivalent to the detection requirements detailed in Chapter 3? (Y/N)____

B. Are well design and construction details provided for:
   1. Drilling methods? (Y/N)____
   2. Well construction materials? (Y/N)____
   3. Well diameter? (Y/N)____
   4. Well intake structures and procedures for well development? (Y/N)____
   5. Placement of annular seals? (Y/N)____

C. Are all these details approved and recommended considering the characteristics of the site? (Y/N)____

VII. Review of Sampling and Analysis Procedures

A. Does the list of monitoring parameters include all hazardous waste constituents from the facility? (Y/N)____

1. Does the water quality parameter list include other important indicators not classified as hazardous waste constituents? (Y/N) ___
2. Does the owner/operator provide documentation for the listed wastes which are not included? (Y/N) ___

B. Have the procedures been detailed for sample collection? (Y/N) ___
1. Do the procedures include evacuation of the borehole prior to sample collection? (Y/N) ___
2. Are special procedures delineated for collection of separate phase immiscible contaminants? (Y/N) ___
3. Has the equipment been identified? (Y/N) ___
4. Do the procedures include decontamination of equipment? (Y/N) ___
5. Have pumping rates, duration, and position in the well from which water will be evacuated been specified? (Y/N) ___

C. Do the procedures include provisions for sample preservation and shipment? (Y/N) ___

D. Do the procedures specify:
1. Type of sample containers? (Y/N) ___
2. Filtering procedures? (Y/N) ___
3. Preservation techniques? (Y/N) ___
4. Storage and time elements involved? (Y/N) ___
5. Proper documentation? (Y/N) ___

E. Do these procedures correspond to recommended procedures (SW-846 or EPA-approved procedures) for sampling and preservation? (Y/N) ___

F. Do the sampling and analysis procedures identify analytical procedures for each of the identified monitoring parameters? (Y/N) ___

G. Do the analytical procedures include:
1. Detailed description and reference of approved analytical methods? (Y/N) ___
2. QA/QC procedures? (Y/N) ___
3. Location of laboratory performing analysis? (Y/N) ___
4. Proper documentation? (Y/N) ___

H. Does the sampling and analysis plan establish procedures for chain of custody control? (Y/N) ___

I. Do these procedures include:
1. Sample labels? (Y/N) ___
2. Sample seals? (Y/N) ___
3. Field logbook? (Y/N) ___
4. Chain of custody record? (Y/N) ___
5. Sample analysis request sheet? (Y/N) ___
6. Laboratory logbook? (Y/N) ___

J. Do the procedures specify how assessment monitoring data will be evaluated to determine if contamination has actually occurred? (Y/N)____
   1. Will the evaluation delineate the full extent of contaminant migration? (Y/N)____
   2. Will significant changes in containment concentration or movement be identified? (Y/N)____
   3. Are the evaluation procedures suitable and objective? (Y/N)____

K. Does the assessment plan clearly describe the procedures that will be used for evaluating monitoring data during the assessment? (Y/N)____

L. Does the plan provide for evaluation of its methodologies to ensure each method is properly executed during the assessment period? (Y/N)____

M. Is a list of all detection monitoring and assessment monitoring (if applicable) data available from the owner/operator? (Y/N)____
   1. Do these lists include:
      - Field quality control samples (e.g., sample container and equipment blanks)? (Y/N)____
      - Laboratory quality control samples (e.g., replicates, spiked samples, etc.)? (Y/N)____
      - Method detection limits? (Y/N)____
   2. Are the lists prepared using a format which presents:
      - Codes that identify GWCCs? (Y/N)____
      - Well number? (Y/N)____
      - Date? (Y/N)____
      - Units of measure? (Y/N)____
      - Less than (LT) detection limit values? (Y/N)____
      - Concentrations of GWCCs? (Y/N)____

N. Has the owner/operator prepared summary statistics tables of the GWCC data? (Y/N)____
   1. Do the summary statistics tables include:
      - Number of LT detection limit values? (Y/N)____
      - Total number of values? (Y/N)____
      - Mean? (Y/N)____
      - Median? (Y/N)____
      - Standard deviation? (Y/N)____
      - Coefficient of variation? (Y/N)____
      - Minimum value? (Y/N)____
      - Maximum value? (Y/N)____
   2. Are there summary statistics tables that present:
      - GWCC? (Y/N)____
      - GWCC by well number? (Y/N)____
      - GWCC by well number and date? (Y/N)____
      - Quality control data? (Y/N)____

O. Has the owner/operator simplified the statistical data? (Y/N)____
   1. Was the data simplified using a ranking procedure for each GWCC-well combination? (Y/N)____
   2. Has the ranking procedure been applied to each GWCC which was detected at least once at every well in the monitoring system? (Y/N)____

P. Did the owner/operator display the data graphically? (Y/N)____
   1. Were the data plotted graphically to evaluate temporal changes? (Y/N)____
   2. Were the data plotted on facility maps to evaluate spacial trends? (Y/N)____

VIII. Review of Migration Rates

A. Did the owner/operator's assessment plan specify the procedures to be used to determine the rate of constituent migration in the ground-water? (Y/N)____

B. Do the procedures incorporate a periodic re-evaluation of sampling data to continually monitor the rate and extent of contaminant migration? (Y/N)____
   1. Do the procedures clearly establish ground-water flow rates and direction downgradient from the detection wells? (Y/N)____
   2. Are the methods employed suitable for these determinations? (Y/N)____
   3. Are the limitations of these methods known and documented? (Y/N)____
   4. Do the evaluations incorporate chemical and physical characteristics of the contaminants and the media? (Y/N)____
   5. Are adsorptive and degradative processes considered in determining any retardation of contaminant movement? (Y/N)____
   6. Have the assumptions been identified and documented? (Y/N)____

C. Does the assessment plan evaluate the presence of immiscible phase layers? (Y/N)____
   1. Do the procedures specify detection and collection of light and dense phase immiscibles prior to well evacuation? (Y/N)____
   2. Has the owner/operator used the slope of the water table and the velocity of ground-water flow to estimate light phase immiscible migration? (Y/N)____
   3. Has the owner/operator defined the configuration of the confining layer to predict dense phase immiscible migration? (Y/N)____

IX. Reviewing Schedule of Implementation

A. Has the owner/operator specified a schedule of implementation in the assessment plan? (Y/N)____

B. Does the schedule for implementing assessment monitoring data include a timetable for a comprehensive site evaluation for contamination? (Y/N)____

C. Does the timetable include:
1. A number of milestones used to judge if sufficient progress is being made toward the completion of the assessment during implementation? (Y/N)____
2. The determination if contamination has occurred? (Y/N)____
3. Completing an initial comprehensive assessment of contamination at the site? (Y/N)____
4. Implementing a program for continued monitoring after fully characterizing contamination at the site? (Y/N)____

D. Does this represent an acceptable time frame? (Y/N)____

X. Conclusions

A. Has the owner/operator adequately characterized site hydrogeology to determine contaminant migration? (Y/N)____

B. Is the detection monitoring system adequately designed and constructed to immediately detect any contaminant release? (Y/N)____

C. Are the procedures used to make a first determination of contamination adequate? (Y/N)____

D. Is the assessment plan adequate to detect, characterize, and track contaminant migration? (Y/N)____

E. Will the assessment monitoring wells, given site hydrogeologic conditions, define the extent and concentration of contamination in the horizontal and vertical planes? (Y/N)____

F. Are the assessment monitoring wells adequately designed and constructed? (Y/N)____

G. Are the sampling and analysis procedures adequate to provide true measures of contamination? (Y/N)____

H. Do the procedures used for evaluation of assessment monitoring data result in determinations of the rate of migration, extent of migration, and hazardous constituent composition of the contaminant plume? (Y/N)____

I. Are the data collected at sufficient duration and frequency to adequately determine the rate of migration? (Y/N) ____

J. Is the schedule of implementation adequate? (Y/N) ____

K. Is the owner/operator's assessment monitoring plan adequate? (Y/N) ____
   1. If the owner/operator had to implement his assessment monitoring plan, was it implemented satisfactorily? (Y/N) ____

APPENDIX B

A STATISTICAL PROCEDURE FOR ANALYZING INTERIM STATUS DETECTION MONITORING DATA: METHODOLOGY AND APPLICATION

APPENDIX B

A STATISTICAL PROCEDURE FOR ANALYZING INTERIM STATUS DETECTION MONITORING DATA: METHODOLOGY AND APPLICATION

1.0 INTRODUCTION

This appendix describes a statistical methodology for evaluating ground-water data collected under Subpart F of 40 CFR §265. The methodology is presented in the context of an example data set from an idealized RCRA facility subject to the interim status ground-water monitoring requirements. The data structures were designed to illustrate several characteristics of RCRA interim status ground-water concentration data. The data presented in this appendix are more extensive over time and space than the data available from most RCRA facilities. It is used here to illustrate the importance of an extensive and rigorous data collection program and because it is easier to simplify a detailed example than to design details based on a simple example.

Enforcement officials should understand that a proper statistical analysis and evaluation protocol involves more than a simple calculation procedure and that decisions must be made during the course of conducting preliminary data analyses, exploration, and summary. To help with the preparatory analyses, Appendix B offers a series of preliminary procedures which provide guidance on data characterization and summary, evaluation of the background data distribution, and methods for confronting a variety of data structure features including values less than (LT) a limit of detection, seasonal fluctuations in concentration, and violation of the assumptions required for the t-test.

2.0 DATA DESCRIPTION, PREPARATION, AND SUMMARY

2.1 Data Description

The data analyzed in this example include measurements of total organic carbon (TOC) in parts per million (ppm) and total halogenated organics (TOX) in parts per billion (ppb) from four upgradient wells and six downgradient wells. Background ground-water quality was characterized by sampling the four upgradient wells bimonthly for a year. The downgradient and upgradient wells were sampled quarterly after the first year. This example includes data from the background characterization period and one quarterly sampling episode that was conducted after the background characterization. Four replicate measurements were obtained for every chemical parameter each time a well was visited for sampling. Table 1 is a listing of the TOX and TOC data used to characterize the background ground-water quality, and Table 2 is a listing of the data obtained during a subsequent quarterly sampling.

2.2 Data Preparation

2.2.1 Averaging the Replicate Measurements

Prior to further evaluation, the data should be prepared for analysis by taking the average of the replicate measurements from each well. The averaging of the replicate measurements is the first step required for the averaged replicate t-test.

The methodology for averaging the replicates depends on how many of the four replicate measurements are LT detection limit values. If all of the values measured are LT a limit of detection, then the replicate average value assigned to the well for that sampling period is LT the limit of detection. However, if none of the replicate concentration measurements from a well are LT a limit of detection, then the simple averaging method described in Table 3 can be applied. The most difficult situation is when the replicate measurements consist of a mixture of values that are greater than or equal to a limit of detection and values that are LT a limit of detection. In this instance, Cohen's Method, which is referenced in Chapter Four, may be appropriate. Cohen's Method assumes that the data are selected from a normally distributed population and only requires calculation of the mean and variance of the values

TABLE 1
A LISTING OF THE TOTAL ORGANIC CARBON (TOC) AND TOTAL HALOGENATED ORGANIC (TOX) BACKGROUND DATA FROM FOUR UPGRADIENT WELLS SAMPLED BIMONTHLY FOR A YEAR

Month	Well	Replicate	TOC (ppm)	TOX (ppb)
1	1	A	60.3	<10.0
		B	60.9	<10.0
		C	61.2	<10.0
		D	60.7	<10.0
	2	A	58.3	15.2
		B	58.2	13.4
		C	58.0	18.0
		D	58.4	<10.0
	3	A	61.4	22.0
		B	61.5	16.2
		C	61.4	16.3
		D	61.0	15.9
	4	A	64.2	13.0
		B	64.0	13.9
		C	63.2	13.7
		D	63.3	13.8
3	1	A	63.2	11.0
		B	63.2	12.2
		C	63.4	<10.0
		D	64.0	<10.0
	2	A	59.9	12.4
		B	60.1	13.3
		C	59.7	16.6
		D	59.7	11.9
	3	A	61.4	18.4
		B	61.8	17.0
		C	61.3	19.2
		D	62.0	19.9
	4	A	65.7	13.8
		B	66.1	13.9
		C	65.8	13.0
		D	65.9	13.2

(Continued)

TABLE 1 (Continued)
A LISTING OF THE TOTAL ORGANIC CARBON (TOC) AND TOTAL HALOGENATED ORGANIC (TOX) BACKGROUND DATA FROM FOUR UPGRADIENT WELLS SAMPLED BIMONTHLY FOR A YEAR

Month	Well	Replicate	TOC (ppm)	TOX (ppb)
5	1	A	70.2	11.8
		B	71.8	12.0
		C	69.9	<10.0
		D	69.8	<10.0
	2	A	62.0	14.3
		B	62.7	20.0
		C	62.0	13.6
		D	62.2	14.2
	3	A	63.8	21.2
		B	62.0	20.8
		C	63.2	21.8
		D	63.4	20.8
	4	A	65.5	<10.0
		B	65.5	<10.0
		C	65.4	14.0
		D	65.0	14.1
7	1	A	69.2	<10.0
		B	68.4	<10.0
		C	68.8	<10.0
		D	69.0	12.0
	2	A	59.7	16.0
		B	59.2	17.0
		C	59.1	17.0
		D	60.0	21.0
	3	A	61.2	18.9
		B	61.1	17.7
		C	61.5	18.2
		D	61.7	17.0
	4	A	64.0	<10.0
		B	64.1	<10.0
		C	64.3	13.7
		D	64.6	13.3

(Continued)

TABLE 1 (Continued)
A LISTING OF THE TOTAL ORGANIC CARBON (TOC) AND TOTAL HALOGENATED ORGANIC (TOX) BACKGROUND DATA FROM FOUR UPGRADIENT WELLS SAMPLED BIMONTHLY FOR A YEAR

Month	Well	Replicate	TOC (ppm)	TOX (ppb)
9	1	A	66.7	12.2
		B	65.9	<10.0
		C	66.2	12.0
		D	66.2	12.7
	2	A	57.7	15.7
		B	57.9	14.9
		C	57.8	15.2
		D	57.7	13.7
	3	A	61.0	19.9
		B	60.5	15.4
		C	60.2	14.8
		D	60.5	16.3
	4	A	63.3	<10.0
		B	63.7	12.3
		C	63.4	13.8
		D	63.5	12.4
11	1	A	62.9	<10.0
		B	62.8	<10.0
		C	62.4	13.3
		D	62.0	13.8
	2	A	58.2	14.7
		B	58.3	14.6
		C	58.1	14.3
		D	58.3	14.6
	3	A	60.7	21.7
		B	60.0	21.4
		C	60.4	21.5
		D	60.4	21.5
	4	A	61.6	13.8
		B	61.6	12.0
		C	61.9	12.3
		D	62.0	12.2

TABLE 2
AN EXAMPLE OF TOX AND TOC DATA COLLECTED DURING A SEMIANNUAL MONITORING EPISODE AFTER THE FIRST YEAR OF BACKGROUND MONITORING

Well	Location	Replicate	TOC (ppm)	TOX (ppb)
1	Upgradient	A	71.7	11.4
		B	72.3	15.3
		C	70.9	11.2
		D	72.4	12.8
2	Upgradient	A	62.9	24.7
		B	64.7	23.8
		C	63.0	21.4
		D	63.2	27.8
3	Upgradient	A	62.9	19.4
		B	64.2	18.6
		C	63.5	19.2
		D	63.4	19.0
4	Upgradient	A	64.8	<10.0
		B	64.3	<10.0
		C	64.8	<10.0
		D	64.8	11.2
5	Downgradient	A	69.3	18.2
		B	68.4	18.3
		C	67.9	18.1
		D	68.5	18.1
6	Downgradient	A	76.4	12.4
		B	75.9	12.7
		C	75.8	12.3
		D	75.8	12.1
7	Downgradient	A	70.1	17.3
		B	70.1	12.4
		C	70.2	19.8
		D	64.2	15.4
8	Downgradient	A	89.4	29.4
		B	88.6	29.2
		C	88.7	29.2
		D	88.4	24.5

(Continued)

TABLE 2 (Continued)
AN EXAMPLE OF TOX AND TOC DATA COLLECTED DURING A SEMIANNUAL MONITORING EPISODE AFTER THE FIRST YEAR OF BACKGROUND MONITORING

Well	Location	Replicate	TOC (ppm)	TOX (ppb)
9	Downgradient	A	59.7	16.2
		B	60.1	16.4
		C	60.1	16.2
		D	58.3	16.1
10	Downgradient	A	62.1	23.4
		B	62.3	27.2
		C	62.0	18.1
		D	62.2	22.7

TABLE 3
METHODS FOR CALCULATING SUMMARY STATISTICS
DESCRIBING THE REPLICATE MEASUREMENTS

The background and monitoring well averages resulting from the methodology described below become the data values that are used in the averaged replicate t-test.

BACKGROUND WELLS

Average of the Replicates

$$\bar{X}_{b,ij} = \sum_{k=1}^{p_b} X_{b,ijk}/p_b$$

Where: $X_{b,ijk}$ = Concentration measurement from the ith background well, the jth sampling period, and the kth replicate measurement. Where i = 1 to n_b, j = 1 to o_b, and k = 1 to p_b

Variance Among the Replicates

$$s^2_{b,ij} = \sum_{k=1}^{p_b} (X_{b,ijk} - \bar{X}_{b,ij})^2/(p_b-1)$$

Coefficient of Variation Among the Replicates

$$CV_{b,ij} = (s_{b,ij}/\bar{X}_{b,ij}) \cdot 100$$

MONITORING WELLS

Average of the Replicates

$$\bar{X}_{m,i} = \sum_{k=1}^{p_m} X_{m,ik}/p_m$$

Where: $X_{m,ik}$ = A quarterly concentration measurement from the ith monitoring well and the kth replicate measurement. Where i = 1 to n_m and k = 1 to p_m.

(Continued)

TABLE 3 (Continued)
Methods for Calculating Summary Statistics
Describing the Replicate Measurements.

Variance Among the Replicates

$$s^2_{m,i} = \sum_{k=1}^{p_m} (X_{m,ik} - \bar{X}_{m,i})^2/(p_m-1)$$

Coefficient of Variation Among the Replicates

$$CV_{m,i} = (s_{m,i}/\bar{X}_{m,i}) \cdot 100$$

greater than or equal to the detection limit and the proportion of values LT the detection limit. Cohen's methodology in the context of the averaged replicate t-test as applied to RCRA interim status facilities is described in Table 4, and the parameter estimates required to complete the calculations are included in Table 5.

Examples of averaging the replicate measurements under the three scenarios described above are presented in Table 6. These methods apply regardless of how many replicate measurements are available. If no replicate measurements were taken, there is no need for preparatory averaging, and the single measured value from the well is used in the analysis.

2.2.2 Additional Summary Statistics Describing the Replicate Measurements

It is also advisable to evaluate the variance and standard deviation among the replicate measurements. Although this component of variability is not considered in the averaged replicate test, it does provide an indication of the consistency of the replicate measurements and therefore a notion of how the owner/operator's sampling and laboratory protocols (depending on when and how the samples are split and collected) are performing. Another, more interpretable, measure of variability is the coefficient of variation. The coefficient expresses the standard deviation in terms of a percent of the mean. Large coefficients of variation are generally unacceptable and suggest poor laboratory quality control. Table 3 describes the methodology for calculating the variance and coefficient of variation among the replicate measurements. Tables 7 and 8 display the summary statistics which describe the replicate measurements taken during the background characterization period for TOC and TOX, respectively. Table 9 includes the summary statistics describing the replicate measurements taken during the first monitoring period.

TABLE 4
A METHODOLOGY FOR CALCULATING THE MEAN AND VARIANCE OF THE REPLICATE MEASUREMENTS WHEN SOME OF THE REPLICATE MEASUREMENTS ARE LESS THAN A LIMIT OF DETECTION

The mean and variance of the values greater than or equal to the limit of detection must be calculated using the methodology described in Table 3. An example application of this methodology is presented in Table 6 as Case 3.

BACKGROUND

Estimate $T_{b,ij}$ as follows:

$$T_{b,ij} = s^{2'}_{b,ij}/(\bar{X}'_{b,ij} - DL_{b,ij})^2$$

Where: $\bar{X}'_{b,ij}$ = Mean of the measurements above or equal to the limit of detection from the ith background well sampled on the jth sampling period. This mean is computed as follows:

$$\bar{X}'_{b,ij} = \sum_{k=1}^{p'_b} X'_{b,ijk}/p'_b$$

Where: $X'_{b,ijk}$ = Measurements above or equal to the limit of detection

p'_b = Number of measurements above or equal to the limit of detection

$s^{2'}_{b,ij}$ = Variance of the measurements above the limit of detection from the ith background well sampled on the jth sampling period. This variance is computed as follows:

$$s^{2'}_{b,ij} = \sum_{k=1}^{p'_b} (X'_{b,ijk} - \bar{X}'_{b,ij})^2/(p'_b - 1)$$

$DL_{b,ij}$ = Detection limit for measurements from the ith background well sampled on the jth sampling period.

(Continued)

TABLE 4 (Continued)
A METHODOLOGY FOR CALCULATING THE MEAN AND VARIANCE OF THE REPLICATE MEASUREMENTS WHEN SOME OF THE REPLICATE MEASUREMENTS ARE LESS THAN A LIMIT OF DETECTION

Obtain values for $h_{b,ij}$ and $\lambda_{b,ij}$ as follows:

$h_{b,ij}$ = Proportion of the replicate measurements below the limit of detection at well i on sampling period j.

$\lambda_{b,ij}$ = A parameter estimate obtained from entering Table 5 with $T_{b,ij}$ and $h_{b,ij}$.

Replicate mean and variance estimates considering the LT detection limit values:

$$\bar{X}_{b,ij} = \bar{X}'_{b,ij} - \lambda_{b,ij}(\bar{X}'_{b,ij} - DL_{b,ij})$$

$$s^2_{b,ij} = s^{2'}_{b,ij} + \lambda_{b,ij}(\bar{X}'_{b,ij} - DL_{b,ij})^2$$

MONITORING WELL

Estimate $T_{m,i}$ as follows:

$$T_{m,i} = s^{2'}_{m,i}/(\bar{X}'_{m,i} - DL_{m,i})^2$$

Where: $\bar{X}'_{m,i}$ = Mean of the measurements above or equal to the limit of detection from the ith monitoring well. This mean is computed as follows:

$$\bar{X}'_{m,i} = \sum_{k=1}^{p'_m} X'_{m,ik}/p'_m$$

Where: $X'_{m,ik}$ = Measurements above or equal to the limit of detection

p'_m = Number of measurements above or equal to the limit of detection

(Continued)

TABLE 4 (Continued)
A METHODOLOGY FOR CALCULATING THE MEAN AND VARIANCE OF THE REPLICATE MEASUREMENTS WHEN SOME OF THE REPLICATE MEASUREMENTS ARE LESS THAN A LIMIT OF DETECTION

$s^{2}_{m,i}$ = Variance of the measurements above the limit of detection from the ith monitoring well. This variance is computed as follows:

$$s^{2'}_{m,i} = \sum_{k=1}^{p'_m} (X'_{m,ik} - \bar{X}'_{m,i})^2/(p'_m - 1)$$

$DL_{m,i}$ = Detection limit for measurements from the ith monitoring well.

Obtain values for $h_{m,i}$ and $\lambda_{m,i}$ as follows:

$h_{m,i}$ = Proportion of the replicate measurements below the the limit of detection at well i.

$\lambda_{m,i}$ = A parameter estimate obtained from Table 5 using $T_{m,i}$ and $h_{m,i}$.

Replicate mean and variance estimates, considering the LT detection limit values:

$$\bar{X}_{m,i} = \bar{X}'_{m,i} - \lambda_{m,i}(\bar{X}'_{m,i} - DL_{m,i})$$

$$s^2_{m,i} = s^{2'}_{m,i} + \lambda_{m,i}(\bar{X}'_{m,i} - DL_{m,i})^2$$

TABLE 5
VALUES OF λ FOR ESTIMATING THE MEAN AND VARIANCE
OF A NORMAL DISTRIBUTION WHEN LESS THAN DETECTION
LIMIT VALUES ARE PRESENT

T	h					
	.01	.10	.20	.25	.30	.40
.00	.010100	.11020	.24268	.31862	.4021	.5961
.05	.010551	.11431	.25033	.32793	.4130	.6101
.10	.010950	.11804	.25741	.33662	.4233	.6234
.15	.011310	.12148	.26405	.34480	.4330	.6361
.20	.011642	.12469	.27031	.35255	.4422	.6483
.25	.011952	.12772	.27626	.35993	.4510	.6600
.30	.012243	.13059	.28193	.36700	.4595	.6713
.35	.012520	.13333	.28737	.37379	.4676	.6921
.40	.012784	.13595	.29260	.28033	.4755	.6927
.45	.013036	.13847	.29765	.38665	.4831	.7029
.50	.013279	.14090	.30253	.39276	.4904	.7129
.55	.013513	.14325	.30725	.39870	.4978	.7225
.60	.013739	.14552	.31184	.40447	.5045	.7320
.65	.013958	.14773	.31630	.41008	.5114	.7412
.70	.014171	.14987	.32065	.41555	.5180	.7502
.75	.014378	.15196	.32489	.42090	.5245	.7590
.80	.014579	.15400	.32903	.42612	.5308	.7676
.85	.014775	.15599	.33307	.43122	.5370	.7761
.90	.014967	.15793	.33703	.43622	.5430	.7844
.95	.015154	.15983	.34091	.44112	.5490	.7925
1.00	.015338	.16170	.34471	.44592	.5548	.8005

(Continued)

TABLE 5 (Continued)
VALUES OF λ FOR ESTIMATING THE MEAN AND VARIANCE
OF A NORMAL DISTRIBUTION WHEN LESS THAN DETECTION
LIMIT VALUES ARE PRESENT

T	h				
	.50	.60	.70	.80	.90
.00	.8368	1.145	1.561	2.176	3.283
.05	.8540	1.166	1.585	2.203	3.314
.10	.8703	1.185	1.608	2.229	3.345
.15	.8860	1.204	1.630	2.255	3.376
.20	.9012	1.222	1.651	2.280	3.405
.25	.9158	1.240	1.672	2.305	3.435
.30	.9300	1.257	1.693	2.329	3.464
.35	.9437	1.274	1.713	2.353	3.492
.40	.9570	1.290	1.732	2.376	3.520
.45	.9700	1.306	1.751	2.399	3.547
.50	.9826	1.321	1.770	2.421	3.575
.55	.9950	1.337	1.788	2.443	3.601
.60	1.007	1.351	1.806	2.475	3.628
.65	1.019	1.366	1.825	2.486	3.654
.70	1.030	1.380	1.841	2.507	3.679
.75	1.042	1.394	1.858	2.528	3.705
.80	1.053	1.408	1.875	2.548	3.730
.85	1.064	1.422	1.892	2.568	3.754
.90	1.074	1.435	1.908	2.588	3.779
1.00	1.095	1.461	1.940	2.626	3.827

From: A Clifford Cohen (1961), Technometrics 3:538

TABLE 6

EXAMPLE CALCULATIONS WHICH ILLUSTRATE HOW TO ESTIMATE THE REPLICATE AVERAGE WHEN: (1) ALL THE VALUES ARE LESS THAN A LIMIT OF DETECTION, (2) ALL VALUES ARE GREATER THAN A LIMIT OF DETECTION, AND (3) THE VALUES CONSIST OF A MIXTURE OF VALUES ABOVE, EQUAL, AND BELOW A LIMIT OF DETECTION

CASE 1: All values are less than a limit of detection

January, Well No. 1

Replicate	TOX (ppb)
A	<10.0
B	<10.0
C	<10.0
D	<10.0

The replicate average is <10.0

CASE 2: All values are greater than the limit of detection

March, Well No. 4

Replicate	TOX (ppm)
A	65.7
B	66.1
C	65.8
D	65.9

$$\bar{X}_{b,ij} = \sum_{k=1}^{p_b} \bar{X}_{b,ijk}/p_b$$

$$= (65.7 + 66.1 + 65.8 + 65.9)/4$$

$$= 65.88$$

CASE 3: The values consist of a mixture of values above, equal anc below a limit of detection

January, Well No. 2

Replicate	TOX (ppb)
A	15.2
B	13.4
C	18.0
D	<10.0

(Continued)

TABLE 6 (Continued)
EXAMPLE CALCULATIONS WHICH ILLUSTRATE HOW TO ESTIMATE THE REPLICATE AVERAGE WHEN: (1) ALL THE VALUES ARE LESS THAN A LIMIT OF DETECTION, (2) ALL VALUES ARE GREATER THAN A LIMIT OF DETECTION, AND (3) THE VALUES CONSIST OF A MIXTURE OF VALUES ABOVE AND BELOW A LIMIT OF DETECTION

Mean of the values greater than or equal to a limit of detection

$$\bar{X}'_{b,ij} = \sum_{k=1}^{p'_b} X'_{b,ijk}/p'_b$$

$$= (15.2 + 13.4 + 18.0)/3$$

$$= 15.53$$

Variance of the values greater than or equal to a limit of detection

$$s^{2'}_{b,ij} = \sum_{k=1}^{p'_b} (X'_{b,ijk} - \bar{X}'_{b,ij})^2/(p'_b-1)$$

$$= ((15.2 - 15.53)^2 + \cdots +$$

$$(18.0 - 15.53)^2/(3-1)$$

$$= 5.373$$

Proportion of values LT the limit of detection

$$h_{b,ij} = 1/4 = 0.25$$

Detection limit

$$DL_{b,ij} = 10$$

Estimate of $T_{b,ij}$

$$T_{b,ij} = s^{2'}_{b,ij}/(\bar{X}'_{b,ij} - DL_{b,ij})^2$$

$$= 5.373/(15.53 - 10)^2$$

$$= 0.178$$

(Continued)

TABLE 6 (Continued)

EXAMPLE CALCULATIONS WHICH ILLUSTRATE HOW TO ESTIMATE THE REPLICATE AVERAGE WHEN: (1) ALL THE VALUES ARE LESS THAN A LIMIT OF DETECTION, (2) ALL VALUES ARE GREATER THAN A LIMIT OF DETECTION, AND (3) THE VALUES CONSIST OF A MIXTURE OF VALUES ABOVE AND BELOW A LIMIT OF DETECTION

The value of $\lambda_{b,ij}$ interpolated using Table 5 is 0.3495.

The mean, considering the less-than-detection limit values, is:

$$\bar{X}_{b,ij} = \bar{X}'_{b,ij} - g_{b,ij}\,(\bar{X}'_{b,ij} - DL_{b,ij})$$

$$= 15.53 - .3495(15.33 - 10)$$

$$= 13.60$$

TABLE 7
SUMMARY STATISTICS DESCRIBING THE REPLICATE MEASUREMENTS OF TOC (ppm) THAT WERE TAKEN DURING THE ESTABLISHMENT OF BACKGROUND CONCENTRATIONS

Well	Month	N	Prop <DL	Mean	Variance	Std. Dev.	C.V.
1	1	4	0	60.78	0.14	0.38	0.62
	3	4	0	63.45	0.14	0.38	0.60
	5	4	0	70.43	0.87	0.93	1.32
	7	4	0	68.85	0.12	0.34	0.50
	9	4	0	66.25	0.11	0.33	0.50
	11	4	0	62.53	0.17	0.41	0.66
2	1	4	0	58.23	0.03	0.17	0.29
	3	4	0	59.85	0.04	0.19	0.32
	5	4	0	62.23	0.11	0.33	0.53
	7	4	0	59.50	0.18	0.42	0.71
	9	4	0	57.78	0.01	0.10	0.17
	11	4	0	58.23	0.01	0.10	0.16
3	1	4	0	61.33	0.05	0.22	0.36
	3	4	0	61.63	0.11	0.33	0.54
	5	4	0	63.10	0.60	0.78	1.23
	7	4	0	61.38	0.08	0.28	0.45
	9	4	0	60.55	0.11	0.33	0.55
	11	4	0	60.38	0.08	0.29	0.48
4	1	4	0	63.68	0.25	0.50	0.78
	3	4	0	65.88	0.03	0.17	0.26
	5	4	0	65.35	0.06	0.24	0.36
	7	4	0	64.25	0.07	0.27	0.41
	9	4	0	63.48	0.03	0.17	0.27
	11	4	0	61.78	0.04	0.21	0.33

TABLE 8
SUMMARY STATISTICS DESCRIBING THE REPLICATE MEASUREMENTS OF TOX (ppb) THAT WERE TAKEN DURING THE ESTABLISHMENT OF BACKGROUND CONCENTRATIONS

Well	Month	N	Prop <DL	Mean	Variance	Std. Dev.	C.V.
1	1*	0	1.00	<10.0	--	--	--
	3**	2	0.50	10.12	3.09	1.76	17.37
	5**	2	0.50	10.30	3.05	1.75	16.99
	7**	1	0.75	8.26	4.00	2.00	24.21
	9**	3	0.25	11.55	1.85	1.36	11.78
	11**	2	0.50	10.58	10.89	3.30	31.19
2	1**	3	0.25	13.58	15.95	3.99	29.40
	3	4	0	13.55	4.47	2.11	15.57
	5	4	0	15.53	8.00	3.00	19.32
	7	4	0	17.75	4.92	2.22	12.49
	9	4	0	14.88	0.72	0.85	5.71
	11	4	0	14.55	0.03	0.17	1.19
3	1	4	0	17.60	8.63	2.94	16.70
	3	4	0	18.63	1.55	1.25	6.68
	5	4	0	21.15	0.22	0.47	2.23
	7	4	0	17.95	0.64	0.80	4.47
	9	4	0	16.60	5.22	2.29	13.76
	11	4	0	21.53	0.02	0.13	0.59
4	1	4	0	13.60	0.17	0.41	3.00
	3	4	0	13.48	0.20	0.44	3.28
	5**	2	0.50	10.66	13.73	3.71	34.76
	7**	2	0.50	10.56	10.37	3.22	30.49
	9**	3	0.25	11.88	3.38	1.84	15.48
	11	4	0	12.58	0.68	0.83	6.57

*All values were LT the limit of detection.
**Cohen's method was used to calculate the summary statistics.

TABLE 9
SUMMARY STATISTICS DESCRIBING THE REPLICATE MEASUREMENTS TAKEN DURING THE FIRST MONITORING PERIOD FOLLOWING THE ESTABLISHMENT OF BACKGROUND

Well Location	Chemical Parameter	N	Prop <DL	Mean	Variance	Std. Dev.	C.V.
1/Up	TOX (ppb)	4	0	12.68	3.75	1.89	14.91
	TOC (ppm)	4	0	71.83	0.48	0.69	0.96
2/Up	TOX	4	0	24.43	7.00	2.65	10.83
	TOC	4	0	63.45	0.71	0.84	1.33
3/Up	TOX	4	0	19.05	0.12	0.34	1.79
	TOC	4	0	63.50	0.29	0.54	0.84
4/Up	TOX	4	0	8.96	2.69	1.64	0.18
	TOC	4	0	64.68	0.06	0.25	0.39
5/Down	TOX	4	0	18.18	0.10	0.01	0.53
	TOC	4	0	68.53	0.58	0.34	0.85
6/Down	TOX	4	0	12.38	0.06	0.25	2.02
	TOC	4	0	75.98	0.08	0.29	0.38
7/Down	TOX	4	0	16.23	9.75	3.12	19.24
	TOC	4	0	68.65	8.80	2.97	4.32
8/Down	TOX	4	0	28.08	5.69	2.39	8.50
	TOC	4	0	88.78	0.19	0.44	0.49
9/Down	TOX	4	0	16.23	0.02	0.13	0.78
	TOC	4	0	59.55	0.73	0.85	0.35
10/Down	TOX	4	0	22.85	13.94	3.73	16.34
	TOC	4	0	62.15	0.02	0.13	0.21

2.2.3 Transformation of pH Measurements to Hydrogen Ion Concentration

It may also be valuable in the case of interim status detection monitoring parameters to consider transformation of the pH scale to hydrogen ion concentration. This methodology is explained in Table 10. The hydrogen ion concentration scale can be used for statistical comparisons rather than pH scale measurements.

2.3 Data Summary

One of the most important initial steps is to review and evaluate the ground-water data using summary statistics, tables, data plots, and maps. The background data should be considered collectively and on a well-by-well basis. Also, it is informative to consider whether there are seasonal influences on the concentration measurements from particular wells.

Most statistical software packages offer procedures that provide univariate summary statistics of data and subsets of data. Table 11 is an example of output that describes the background TOC and TOX averaged replicate data. These are quite informative with respect to the mean background concentration, the variability of the background concentration, percentile estimates, the presence of outliers, and the distributional shape of the concentration measurements. Chapter Six also discusses the use of summary statistics.

Another informative display of data involves plotting replicate average concentrations over time. This permits a visual comparison among the upgradient wells and indicates whether there appear to be seasonal or unusual, extreme events. Figures 1A and 2B are plots of the averaged replicate TOC and TOX data measured in the upgradient wells during the year of background characterization.

TABLE 10
METHODOLOGY FOR TRANSFORMING THE pH MEASUREMENTS TO HYDROGEN ION CONCENTRATIONS

The pH is equal to the negative base ten logarithm of the hydrogen ion concentration:

$$pH = -\log_{10}|H_3O^+|$$

Where: $|H_3O^+|$ = moles/liter of H_3O^+

The hydrogen ion concentration is therefore equal to:

$$|H_3O^+| = 10^{-pH}$$

TABLE 11
A SUMMARY DESCRIPTION OF THE TOC (ppm) AND TOX (ppb) AVERAGED REPLICATE DATA COLLECTED FROM THE UPGRADIENT WELLS DURING THE BACKGROUND CHARACTERIZATION PERIOD

TOC

MOMENTS

N	24	SUM WGTS	24
MEAN	62.5344	SUM	1500.82
STD DEV	3.18651	VARIANCE	10.1538
SKEWNESS	0.761381	KURTOSIS	0.534888
USS	94086.7	CSS	233.539
CV	5.09561	STD MEAN	0.650444
T:MEAN=0	96.1411	PROB>|T|	0.0001
SGN RANK	150	PROB>|S|	0.0001
NUM ^= 0	24		
W:NORMAL	0.953103	PROB<W	0.38

QUANTILES(DEF=4)

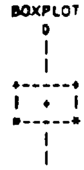
100% MAX	70.425	99%	70.425
75% Q3	64.1062	95%	70.0312
50% MED	62	90%	67.5499
25% Q1	60.4187	10%	58.225
0% MIN	57.775	5%	57.8875
		1%	57.775
RANGE	12.65		
Q3-Q1	3.6875		
MODE	58.225		

EXTREMES

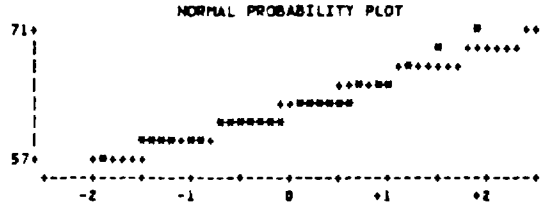
LOWEST	HIGHEST
57.775	65.35
58.225	65.875
58.225	66.25
59.5	68.85
59.85	70.425

STEM	LEAF	#
70	4	1
68	8	1
66	2	1
64	239	3
62	251457	6
60	4583468	7
58	2258	4
56	8	1

BOXPLOT



NORMAL PROBABILITY PLOT



FREQUENCY TABLE

VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM
57.775	1	4.2	4.2	60.775	1	4.2	33.3	62.525	1	4.2	58.3	65.35	1	4.2	83.3
58.225	2	8.3	12.5	61.325	1	4.2	37.5	63.1	1	4.2	62.5	65.875	1	4.2	87.5
59.5	1	4.2	16.7	61.375	1	4.2	41.7	63.45	1	4.2	66.7	66.25	1	4.2	91.7
59.85	1	4.2	20.8	61.625	1	4.2	45.8	63.475	1	4.2	70.8	68.85	1	4.2	95.8
60.375	1	4.2	25.0	61.775	1	4.2	50.0	63.675	1	4.2	75.0	70.425	1	4.2	100.0
60.55	1	4.2	29.2	62.225	1	4.2	54.2	64.25	1	4.2	79.2				

TOX

MOMENTS

N	24	SUM WGTS	24
MEAN	14.035	SUM	336.84
STD DEV	3.65708	VARIANCE	13.3742
SKEWNESS	0.517442	KURTOSIS	-0.569072
USS	5035.16	CSS	307.608
CV	26.0569	STD MEAN	0.746499
T:MEAN=0	18.8011	PROB>|T|	0.0001
SGN RANK	150	PROB>|S|	0.0001
NUM ^= 0	24		
W:NORMAL	0.946531	PROB<W	0.3

QUANTILES(DEF=4)

100% MAX	21.525	99%	21.525
75% Q3	17.35	95%	21.4312
50% MED	13.565	90%	19.8875
25% Q1	10.6	10%	10.06
0% MIN	8.26	5%	8.695
		1%	8.26
RANGE	13.265		
Q3-Q1	6.74999		
MODE	8.26		

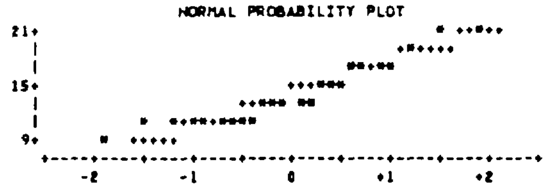
EXTREMES

LOWEST	HIGHEST
8.26	17.75
10	17.95
10.12	18.625
10.3	21.15
10.56	21.525

STEM	LEAF	#
20	15	2
18	6	1
16	6689	4
14	595	3
12	65566	5
10	01366759	8
8	3	1

BOXPLOT

NORMAL PROBABILITY PLOT

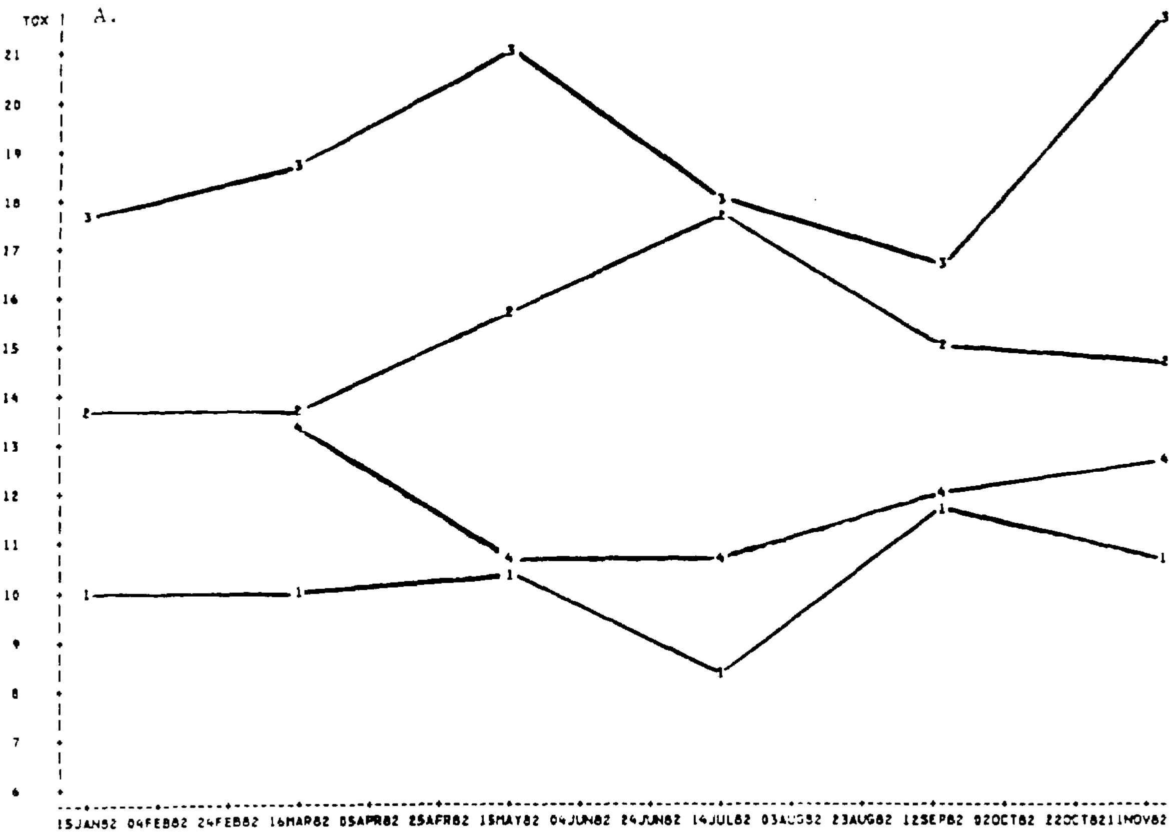


FREQUENCY TABLE

VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM	VALUE	COUNT	PERCENTS CELL	PERCENTS CUM
8.26	1	4.2	4.2	10.66	1	4.2	29.2	13.58	1	4.2	54.2	17.4	1	4.2	79.2
10	1	4.2	8.3	11.55	1	4.2	33.3	13.6	1	4.2	58.3	17.75	1	4.2	83.3
10.12	1	4.2	12.5	11.88	1	4.2	37.5	14.55	1	4.2	62.5	17.95	1	4.2	87.5
10.3	1	4.2	16.7	12.575	1	4.2	41.7	14.875	1	4.2	66.7	18.625	1	4.2	91.7
10.56	1	4.2	20.8	13.475	1	4.2	45.8	15.525	1	4.2	70.8	21.15	1	4.2	95.8
10.58	1	4.2	25.0	13.55	1	4.2	50.0	16.6	1	4.2	75.0	21.525	1	4.2	100.0

FIGURE 1

PLOTS OF TOX (ppb) AND TOC (ppm) CONCENTRATIONS VERSUS TIME IN THE FOUR UPGRADIENT WELLS THAT WERE USED TO CHARACTERIZE BACKGROUND CONCENTRATIONS



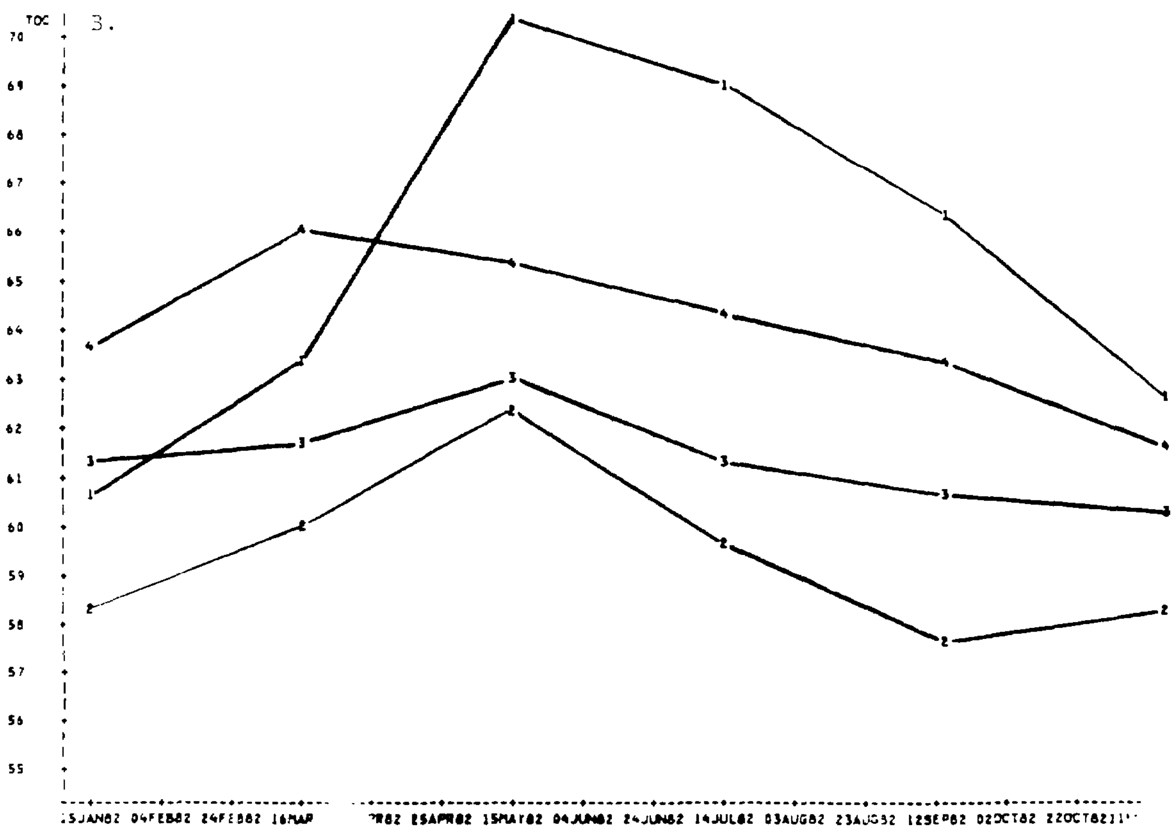
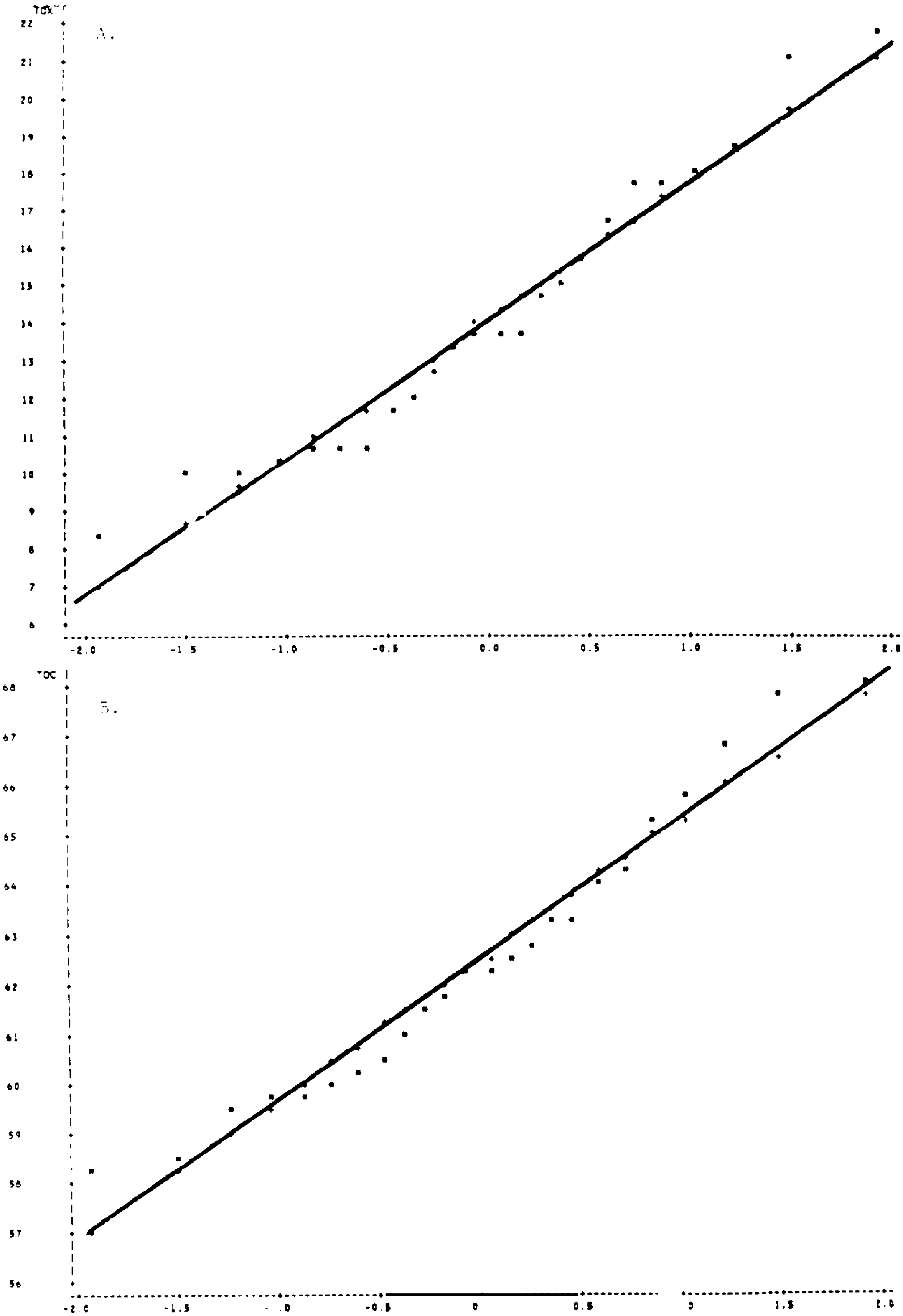


FIGURE 2

NORMAL PROBABILITY PLOTS OF TOX (ppb) AND TOC (ppm) CONCENTRATION VERSUS THE NORMAL SCORES FROM THE DATA WHICH ARE PLOTTED AS STARS (*) AND FROM DISTRIBUTION WITH THE SAME MEAN AND VARIANCE AS THE DATA WHICH ARE REPRESENTED BY THE LINE.



3.0 SEASONAL TRENDS

3.1 Characterization of Seasonality

During the analysis of interim status detection monitoring data, it is important to consider seasonal trends in concentration. The presence of time or seasonal effects introduces a factor that may obscure the presence of, or falsely indicate, leakage from the hazardous waste unit. This is because there are times of the year when concentrations are normally higher or lower than the average. In such a situation, if a downgradient well is sampled during a period when concentrations are high, the statistical test may suggest the presence of contamination when actually the high values are the result of normal seasonal concentration increase.

In order to evaluate whether seasonal influences are reflected in the ground-water concentration measurements, one should plot the data plotted over time. Figures 1A and 1B indicate that the TOC data for all wells in the system appear to increase during mid-year and decrease during the winter. In contrast, the TOX data reveal no clear seasonal trends.

3.2 Methods for Reducing the Adverse Effects of Seasonally Influenced Data

Two methods are available for considering seasonal fluctuations in interim status ground-water monitoring data. The first method can be applied when one year of background data are used in the analysis and simply calls for the seasonal effect to be included in the variance estimate used for the averaged replicate t-test. Essentially, this method includes the additional variability caused by seasonality in the t-test error term. As a result, comparisons of monitoring well data with the background data will not lead to inaccurate contamination assessments because the seasonal variability will have been accounted for in the error term. Under this method, the difference between the upgradient and downgradient mean must exceed the differences expected by seasonal change in order to indicate contamination.

The other method uses a seasonal correction methodology. Under this approach, the background and monitoring data are corrected to reduce the tendency for the data values to become seasonally large or small, but retain their original error structure. This method requires that the upgradient wells have been monitored for more than one year (Chapter Five discusses the situations and considerations that may lead to a modification of the background data set).

The seasonal correction is performed separately for each well and chemical parameter. Table 12 presents an example application of the seasonal correction methodology. First, monthly averages of the average replicate values are calculated by averaging across years for each month. Then, an overall average is calculated for all the averaged replicate values across all years and months. Finally, the adjusted means are calculated by taking an averaged replicate value then subtracting the monthly mean and adding the overall background mean.

The data from subsequent monitoring events must also be corrected if seasonally adjusted data have been used to establish the background statistics. The monitoring data are corrected in a similar fashion by subtracting the monthly averages from the background data and then adding the overall average from the background data to the averaged replicate monitoring data values.

Several problems may arise in the use of seasonal correction. If monitoring data were collected on an even month, say April (4), then, because the background data are only available for odd numbered months, the monthly averages from the two adjacent months (March and May) could be averaged to estimate a monthly average for correcting the April monitoring event.

Finally, after the background data have been corrected, it is useful to replot the data for summary and review purposes.

TABLE 12
AN ILLUSTRATION OF HOW TO PERFORM A SIMPLE SEASONAL CORRECTION
USING TOC (ppm) DATA FROM MONITORING WELL NO. 1

The seasonal correction can only be performed if more than one year of background data are available. Consult Chapter Five for when and how to update background data.

Month	Averaged Replicate Values			Monthly Means**	Adjusted Means***		
	1982	1983	1984*		1982	1983	1984
1	60.78	58.23	61.33	60.11	66.59	64.04	67.14
3	63.45	69.85	61.47	64.92	64.45	71.30	62.47
5	70.43	82.23	79.10	77.25	59.10	70.90	67.77
7	68.85	79.41	69.27	72.51	62.26	72.82	62.68
9	66.25	54.78	60.41	60.48	71.69	60.22	65.85
11	62.53	58.13	60.00	60.22	68.23	63.83	65.70

Overall Background Mean $\bar{X}_{b,i}$ = 65.92

*The data from 1983 and 1984 have not been discussed elsewhere in Appendix B. These are included because the seasonal correction methodology requires more than one year of data.

**Monthly means are calculated by averaging for a particular month all of the measurements taken during the month over the prior monitoring.

***The adjusted means are calculated by taking an averaged replicate value then subtracting the monthly mean and adding the overall background mean. For example, the adjusted monthly mean for May 1983 was calculated as follows:

$$82.23 - 77.25 + 65.92 = 70.90$$

4.0 GOODNESS-OF-FIT

Before applying the t-test to the data, it is also important for owner/operators to evaluate whether their replicate average data have been sampled from a normally distributed population of concentration measurements. Many background data sets will be too small to reasonably evaluate with respect to distributional shape; for example, a single-well upgradient system sampled quarterly only yields four replicate average values.

4.1 Graphical Methods

One simple method for evaluating data distributions is to plot the data on a normal probability plot and overlay a plot of the data expected from a normal distribution that has the same mean and variance as the data. If the sampling data deviate substantially from the data expected from a normal distribution, then the data may not have been sampled from a normal distribution. The methodology for developing normal probability plots is well documented (e.g., Neter and Wasserman, 1974; and Shapiro, 1980) and will not be described.

Figures 2A and 2B are normal probability plots of the replicate averages of the TOC and TOX data, respectively. In these instances, the data approximate a reasonably normal distribution. The replicate averages, because of a fundamental statistical principle referred to as the central limit theorem, will tend to approach a normal distribution. However, in some instances, the normal distribution will not be appropriate and lognormal estimates of the mean and variance may be useful. Aithchison and Brown (1957) present methodologies for estimating lognormal distribution parameters. Enforcement officers should not, however, allow owner/operators to simply take the natural logarithms of their data prior to analysis because this will reduce the ability of the statistical procedure to detect contamination.

4.2 Hypothesis Testing Methods

Another set of methods that can be used to evaluate the distributional shape of replicate averages uses statistical tests. One problem with statistical goodness-of-fit hypothesis testing is that few tests are useful with small sample sizes. The benefit is that unlike the visual comparison of a line with data points, there is no subjectivity associated with a statistical goodness-of-fit hypothesis test. The null hypothesis that the data follow a normal distribution is either accepted or rejected. If the hypothesis is rejected, then the lognormal theory referenced above may be useful.

One statistical goodness-of-fit test, which performs well on small sample sizes and tests the null hypothesis that the data values are random samples from a normal distribution against an unspecified alternative distribution, is the Shapiro-Wilk, W statistic (Shapiro and Wilk, 1965).

The enforcement officer should respond to complaints regarding the non-normality of data by insisting that owner/operators evaluate, either graphically or via a statistical test, the goodness-of-fit of their data distributions. Enforcement officers should also understand that parametric methods such as the t-test are robust to departures from normality and that the outcome of the statistical evaluation is not altered by small deviations from normality, particularly when larger sample sizes are available (Harris, 1975). Finally, interim status facilities are required by 40 CFR §265 to use a Student's t-test and therefore cannot use a nonparametric statistical procedure to circumvent the requirement for normally distributed data.

5.0 ANALYSIS OF MONITORING WELL DATA COLLECTED AFTER CHARACTERIZATION OF THE BACKGROUND GROUND-WATER QUALITY

After development of the background ground-water concentrations interim status, owner/operators must sample their entire well systems semiannually. The purpose is to determine whether any well in the monitoring system has concentrations that are larger than (or in the case of pH, different from) those established during the characterization of the background water quality.

Data collected during May 1983 from the four upgradient and six downgradient wells are presented in Table 2. The data consist of four replicate measurements of TOC and TOX from each of the ten wells. The replicate measurements are averaged prior to analysis using the methodology described earlier in Appendix B. Table 9 presents the averaged replicate monitoring data.

6.0 THE AVERAGED REPLICATE T-TEST

6.1 Calculation Methodology

Once the replicates are averaged and summary statistics, which describe the background data, are developed, the calculation of the test statistic is straightforward. Table 13 describes the methodology for calculating the required input statistics and test statistics. Table 14 presents example calculations that compare the background TOX data with data from downgradient Well 6.

Observe that Cohen's method is also used in these calculations. This is because during background characterization, all four replicates from Well 1 measured during the first month of monitoring were less than the limit of detection. Therefore, as described earlier, the replicate average was also <10.0 ppb of TOX. Cohen's method was needed to estimate the background summary statistics from the replicate average data.

6.2 Control of the False Positive Rate

The test statistics from the calculations described in Table 13 are compared with critical values from the t-distribution that have been adjusted to control the overall false positive probability for the waste

TABLE 13
A DESCRIPTION OF THE METHODOLOGY USED TO CALCULATE THE TEST STATISTIC FOR THE AVERAGED REPLICATED T-TEST

The notation assumes that data were obtained from every upgradient well every time they were sampled during the background characterization period. Alternative and more complicated methods which require estimating the contribution from several components of variance, fractional degree of freedom estimates, and linear combinations of mean square estimates can also be used to provide unbiased estimates of the background variance.

WITHOUT LESS THAN DETECTION LIMIT VALUES

Background Mean

$$\bar{X}_b = \sum_{i=1}^{n_b} \sum_{j=1}^{o_b} \bar{X}_{b,ij}/n_b \cdot o_b$$

Background Variance

$$s_b^2 = \sum_{i=1}^{n_b} \sum_{j=1}^{o_b} (\bar{X}_{b,ij} - \bar{X}_b)^2/((n_b \cdot o_b) - 1)$$

WITH LESS THAN DETECTION LIMIT VALUES

Background Mean of All Nondetection Limit Values

$$\bar{X}_b' = \sum_{i=1}^{n_b} \sum_{j=1}^{o_b} \bar{X}_{b,ij}'/n_b'$$

Where: n_b' = Number of averaged replicate values greater than or equal to the limit of detection in the background data set.

$\bar{X}_{b,ij}'$ = Average replicate values greater than or equal to the limit of detection in the background data set.

(Continued)

TABLE 13 (Continued)
A DESCRIPTION OF THE METHODOLOGY USED TO CALCULATE THE TEST STATISTIC FOR THE AVERAGED REPLICATED T-TEST

Background Variance of All Nondetection Limit Values

$$s_b^{2\prime} = \sum_{i=1}^{n_b} \sum_{j=1}^{o_b} (\bar{X}'_{b,ij} - \bar{X}'_b)^2/(n'_b - 1)$$

Cohen's Adjustment

$$T_b = s_b^{2\prime}/(\bar{X}'_b - DL_b)^2$$

h_b = proportion of values less than a limit of detection

λ_b = from Table 5 based on values of h_b and T_b.

Adjusted Background Mean

$$\bar{X}_b = \bar{X}'_b - \lambda_b(\bar{X}'_b - DL_b)$$

Adjusted Background Variance

$$s_b^2 = s_b^{2\prime} + \lambda_b(\bar{X}'_b - DL_b)^2$$

AVERAGED REPLICATE TEST STATISTIC

$$t^*_{m,i} = \frac{\bar{X}_{m,i} - \bar{X}_b}{s_b \sqrt{1 + 1/(n_b \bullet o_b)}}$$

TABLE 14
EXAMPLE CALCULATIONS OF THE METHODOLOGY DESCRIBED IN TABLE 13, WHICH COMPARE THE TOX AVERAGED REPLICATE BACKGROUND DATA WITH THE TOX DATA FROM DOWGRADIENT WELL 6

<u>Background Mean, Variance, and Standard Deviation of All Averaged Replicates Above a Limit of Detection</u>

$$\bar{X}_b' = (10.12 + 10.30 + \cdots + 11.88 + 12.58)/23$$
$$= 14.21$$

$$s_b^{2'} = ((14.21-10.21)^2 + \cdots + (14.21 - 12.58)^2)/(23-1)$$
$$= 13.22$$

$$s_b' = \sqrt{13.22} = 3.64$$

<u>Cohen's Adjustment</u>

$$T_b = 14.21/(\text{~~14.21~~ } 13.22 \text{ (var)} - 10.0)^2$$
$$= 0.746$$

$$h_b = 1/24 = 0.042$$

$$\lambda_b = 0.061 \text{ (From Table 5)}$$

<u>Adjusted Background Mean, Variance and Standard Deviation of the Averaged Replicates</u>

$$\bar{X}_b = 14.21 - 0.61(14.21 - 10.0)$$
$$= 13.95$$

$$s_b^2 = 13.22 + 0.61(14.21 - 10.0)^2$$
$$= 14.30$$

$$s_b = \sqrt{14.30} = 3.78$$

(Continued)

TABLE 14
EXAMPLE CALCULATIONS OF THE METHODOLOGY DESCRIBED IN TABLE 13, WHICH COMPARE THE TOX AVERAGED REPLICATE BACKGROUND DATA WITH THE TOX DATA FROM DOWGRADIENT WELL 6

The Averaged Replicate Value from Monitoring Well No. 6

$$\bar{X}_{m,6} = (12.4 + 12.7 + 12.3 + 12.1)/4$$
$$= 12.38$$

The Averaged Replicate Test t-Statistic

$$t^*_{m,6} = (12.38 - 13.95)/\left(3.78\sqrt{1+1/24}\right)$$
$$= -0.407$$

management unit. The probability depends on the monitoring event under evaluation and considers that multiple downgradient wells are being tested and that the concentrations of four indicator parameters are being measured. Critical values based on Bonferroni t-statistics are used for each individual comparison to control the false positive rate at one percent for the entire facility. Miller (1981) discusses Bonferroni t-statistics and methods for estimating critical values. Tables 15 and 16 include tabulations of critical values (one and two tailed, respectively) to use for individual comparisons that control the overall facility false positive rate at one percent.

6.3 Evaluation of Whether There Is a Suggestion of Contamination

The test statistics (t^*) calculated for each well using the methodology described in Table 13 are presented in Table 17. The test statistics are compared with the Bonferroni critical test statistics (t_c) using the following decision rules:

- If specific conductivity, TOC, or TOX are being evaluated and if t^* is less than t_c, then there is no statistical indication that the concentrations are higher in the well under comparison than in the background data. If t^* is larger than t_c then there is a statistical indication that the concentrations are higher in the well under investigation.

- If pH is being evaluated and if $|t^*|$ (absolute value of t^*) is less than t_c, then there is no statistical indication that pH has changed. If $|t^*|$ is larger than t_c, then there is a statistical indication that pH has changed. If t^* is negative, then pH increased; if t^* is positive, then pH decreased relative to background.

6.4 Evaluation of the Power and False Negative Rate

The false negative rate and power for each chemical parameter can be evaluated after characterization of the background ground-water quality. As described in Chapter Five, this is an important evaluation procedure because it allows evaluation of the false negative rate, that is, the probability that a difference in mean concentration of a specified

TABLE 15
ONE TAILED CRITICAL (t_c) VALUES WHICH CONTROL THE
OVERALL SIGNIFICANCE LEVEL AT ONE PERCENT

Total No. of Wells	Degress of Freedom Associated with the Averaged Replicate Test Statistic								
	3	7	11	15	19	23	27	31	35
4	6.297	4.543	4.065	3.841	3.712	3.628	3.568	3.524	3.490
5	6.534	4.609	4.175	3.939	3.803	3.714	3.651	3.604	3.569
6	6.729	4.793	4.265	4.019	3.876	3.783	3.718	3.669	3.569
7	6.896	4.889	4.342	4.086	3.939	3.842	3.774	3.724	3.388
8	7.041	4.972	4.408	4.145	3.992	3.893	3.823	3.771	3.490
9	7.169	5.045	4.466	4.196	3.039	3.937	3.865	3.812	3.569
10	7.285	5.111	4.518	4.242	4.082	3.977	3.904	3.849	3.632
11	7.390	5.171	4.566	4.283	4.120	4.013	3.938	3.882	3.685
12	7.487	5.225	4.609	4.321	4.154	4.046	3.969	3.912	3.731
13	7.576	5.276	4.648	4.356	4.186	4.076	3.998	3.940	3.771
14	7.657	5.322	4.685	4.388	4.216	4.103	4.024	3.966	3.807
15	7.736	5.366	4.719	4.418	4.243	4.129	4.049	3.989	3.839

TABLE 16
TWO TAILED CRITICAL (t_c) VALUES WHICH CONTROL THE OVERALL SIGNIFICANCE LEVEL AT ONE PERCENT

Total No. of Wells	Degress of Freedom Associated with the Averaged Replicate Test Statistic								
	3	7	11	15	19	23	27	31	35
4	7.041	4.972	4.408	4.145	3.992	3.893	3.823	3.771	3.731
5	7.285	5.111	4.518	4.242	4.154	4.046	3.969	3.912	3.869
6	7.487	5.225	4.609	4.321	4.154	4.046	3.969	3.912	3.869
7	7.659	5.322	4.685	4.388	4.216	4.103	4.024	3.966	3.920
8	7.808	5.406	4.751	4.446	4.269	4.153	4.072	4.012	3.965
9	7.941	5.481	4.810	4.496	4.315	4.197	4.114	4.052	4.004
10	8.061	5.547	4.862	4.542	4.357	4.236	4.151	4.088	4.039
11	8.169	5.608	4.909	4.583	4.394	4.271	4.185	4.120	4.071
12	8.269	5.663	4.952	4.621	4.429	4.304	4.215	4.150	4.100
13	8.361	5.714	4.992	4.655	4.460	4.333	4.244	4.177	4.126
14	8.446	5.761	5.029	4.687	4.489	4.360	4.270	4.202	4.150
15	8.525	5.805	5.063	4.717	4.516	4.386	4.294	4.226	4.173

TABLE 17
THE RESULTS OF THE AVERAGED REPLICATE T-TEST WHICH COMPARE BACKGROUND TOC AND TOX DATA WITH THE DATA COLLECTED DURING THE SUBSEQUENT MONITORING PERIOD

This analysis assumes that pH and specific conductance were also monitored.

Monitoring Well	TOC (ppm)			TOX (ppb)		
	$\bar{X}_m$	$\bar{X}_m - \bar{X}_b$	t*	$\bar{X}_m$	$\bar{X}_m - \bar{X}_b$	t*
1	71.83	9.29	2.857	12.68	-1.27	-0.329
2	63.45	0.91	0.280	24.43	10.48	2.716
3	63.50	0.96	0.295	19.05	5.10	1.322
4	64.68	2.14	0.658	8.96	-4.99	-1.293
5	68.53	5.99	1.842	18.18	4.23	1.096
6	75.98	13.44	4.133*	12.38	-1.57	-0.407
7	68.85	6.11	1.879	16.23	2.28	0.597
8	88.78	26.24	8.070*	28.08	14.13	3.663
9	59.55	-2.99	-0.920	16.23	2.28	0.591
10	62.15	-0.39	-0.120	22.85	8.90	2.307

t_c(overall alpha=0.01, k=40, df=23) = 3.98

TOX $\bar{X}_b$ = 13.95 ppb, TOC $\bar{X}_b$ = 62.54 ppm

TOX $s_b\sqrt{1+1/24}$ = 3.858, TOC $s_b\sqrt{1+1/24}$ = 3.252

*The concentrations measured in the well are statistically larger than the concentrations measured during the background characterization period.

magnitude will not be detected by the statistical procedure. The complement of the false negative rate is the power of the statistical test, which is the probability that the procedure will detect a difference.

A power and false positive evaluation should be performed at a concentration threshold which causes the test to indicate a statistically significant difference and at several concentrations that are less than the difference detected by the statistical test. The reason for performing this analysis is that smaller differences between the background and downgradient data concentrations than were detected by the statistical test may suggest contamination of the ground water by the unit being monitored. If the statistical procedure is only able to detect large differences as being statistically significant, then more samples or alternative approaches may be necessary.

Table 18 presents the results of such an analysis using the TOX and TOC data. Table 19 is a power table taken from Cohen (1969) that is required for the analysis. Table 18 indicates that the AR t-test as applied to these data performs well. Contamination would only be missed a large percentage of the time if the contamination resulted in only a 1 ppm for TOC or 1 ppb for TOX difference between upgradient and downgradient.

TABLE 18

A POWER ANALYSIS OF THE AVERAGED REPLICATE T-TEST CONDUCTED ON THE TOC AND TOX DATA USING THE METHODOLOGY DESCRIBED IN COHEN (1969)

Constants Required for the Analysis

	Difference Detected as Significant $s_b\sqrt{1+1/24} \cdot t_c = \bar{X}_m - \bar{X}_b$	Standard Deviation s_b	Background Sample Size n
TOC	3.252 • 3.977 = 12.93	3.186	24
TOX	3.858 • 3.977 = 15.34	3.780	24

Power and False Negative Rate Analysis as a Function of the Mean Difference Between the Background Data and Data from a Monitoring Well

	Difference	$\frac{\bar{X}_b - \bar{X}_m}{s_b} \cdot \sqrt{2} = d$	Power	False Negative Rate
TOC (ppm)	12.93	5.74	>.995	<.005
TOX (ppb)	15.34	5.74	>.995	<.005
TOC	10.0	5.56	>.995	<.005
TOX	10.0	4.30	>.995	<.005
TOC	3.0	1.33	0.96	0.04
TOX	3.0	1.12	0.86	0.14
TOC	1.0	0.44	0.14	0.86
TOX	1.0	0.37	0.09	0.91

TABLE 19

A POWER TABLE (Cohen, 1969)

Power of t test of m_1 m_2 at a .01

n	d_c	.10	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
8	1.49	01	02	02	03	05	07	09	12	21	33	46
9	1.38	01	02	02	04	05	08	11	15	25	39	54
10	1.28	01	02	03	04	06	09	12	17	29	45	61
11	1.21	01	02	03	04	07	10	14	20	33	50	67
12	1.15	01	02	03	05	07	11	16	22	38	55	72
13	1.10	01	02	03	05	08	12	18	25	42	61	77
14	1.05	01	02	03	06	09	14	20	27	46	65	81
15	1.01	01	02	04	06	10	15	22	30	50	70	85
16	.97	01	02	04	07	11	16	24	33	54	73	88
17	.94	01	02	04	07	12	18	26	35	57	77	90
18	.91	01	02	04	08	12	19	28	38	61	80	92
19	.88	01	02	05	08	13	21	30	41	64	83	94
20	.86	01	02	05	09	14	22	32	44	67	85	95
21	.83	01	03	05	09	15	24	34	46	70	87	96
22	.81	01	03	05	10	16	25	36	49	73	89	97
23	.79	01	03	06	10	17	27	38	51	75	91	98
24	.78	01	03	06	11	18	28	40	54	78	92	98
25	.76	01	03	06	11	19	30	42	56	80	93	99
26	.74	01	03	06	12	20	31	44	58	82	95	99
27	.73	01	03	07	12	21	33	46	60	84	95	99
28	.71	02	03	07	13	22	34	48	63	85	96	99
29	.70	02	03	07	14	23	36	50	65	87	97	*
30	.69	02	03	07	14	24	37	52	66	88	97	
31	.68	02	04	08	15	25	39	54	68	89	98	
32	.66	02	04	08	15	26	40	56	70	91	98	
33	.65	02	04	08	16	27	42	57	72	92	98	
34	.64	02	04	08	17	28	43	59	74	92	99	
35	.63	02	04	09	17	30	45	61	75	93	99	
36	.62	02	04	09	18	31	46	62	77	94	99	
37	.62	02	04	09	18	32	48	64	78	95	99	
38	.61	02	04	10	19	33	49	66	80	95	99	
39	.60	02	04	10	20	34	50	67	81	96	*	
40	.59	02	04	10	20	35	52	68	82	96		
42	.58	02	05	11	22	37	55	71	84	97		
44	.56	02	05	12	23	39	57	74	86	98		
46	.55	02	05	12	24	41	60	76	88	98		
48	.54	02	05	13	26	43	62	78	90	99		

n	d_c	.10	.70	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
50	.53	02	06	14	27	45	64	81	91	99	*	*
52	.51	02	06	14	28	47	67	82	92	99		
54	.50	02	06	15	30	49	69	84	93	99		
56	.50	02	06	16	31	51	71	86	94	*		
58	.49	02	06	16	32	53	73	87	95			
60	.48	02	07	17	34	55	75	88	96			
64	.46	02	07	18	36	58	78	91	97			
68	.45	02	08	20	39	62	81	93	98			
72	.44	02	08	21	42	65	84	94	98			
76	.42	03	09	23	44	68	86	95	99			
80	.41	03	09	24	47	71	88	96	99			
84	.40	03	10	26	50	74	90	97	99			
88	.39	03	10	27	52	76	91	98	*			
92	.38	03	11	29	54	78	93	98				
96	.38	03	11	30	57	80	94	99				
100	.37	03	12	32	59	82	95	99				
120	.34	04	15	39	69	90	98	*				
140	.31	04	18	47	77	94	99					
160	.29	05	21	54	84	97	*					
180	.27	05	25	60	88	98						
200	.26	06	29	66	92	99						
250	.23	07	36	78	97	*						
300	.21	09	45	86	99							
350	.20	10	53	92	*							
400	.18	12	60	95								
450	.17	14	66	97								
500	.16	16	72	98								
600	.15	20	81	*								
700	.14	24	88									
800	.13	28	92									
900	.12	33	95									
1000	.12	37	97									

* Power values below this point are greater than .995.

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APPENDIX C

DESCRIPTION OF SELECTED GEOPHYSICAL METHODS AND ORGANIC VAPOR ANALYSIS

APPENDIX C

SELECTED GEOPHYSICAL METHODS AND ORGANIC VAPOR ANALYSIS

This Appendix is a presentation of several investigative techniques capable of augmenting data gathered from boreholes and ground-water monitoring wells. The five methods are:

1. Ground Penetrating Radar (GPR)
2. Electromagnetic Conductivity (EM)
3. Resistivity
4. Seismic Refraction/Reflection
5. Organic Vapor/Soil Gas Analysis

The summaries of EM and resistivity focus on surficial and not borehole methods. Although surficial and borehole techniques operate under the same physical principles, the reader should be aware that surficial and borehole techniques have different characteristics. Surficial methods can be undertaken without regard to the number of location or boreholes therefore providing a great deal of flexibility to the investigation without disturbing the subsurface. Borehole EM and resistivity, however, offer a much higher degree of resolution at depth in the vicinity of a single borehole or between two or more.

The effectiveness of geophysical methods and organic vapor/soil gas analysis increases if several techniques are used conjunctively. For instance, EM, resistivity and organic vapor analysis are highly correlative in the field where organic contamination exists.

GROUND PENETRATING RADAR (GPR)*

Ground penetrating radar (GPR) uses high frequency radio waves to acquire subsurface information. From a small antenna which is moved slowly scross the surface of the ground, energy is radiated downward into the subsurface, then reflected back to the receiving antenna, where variations in the return signal are continuously recorded; this produces a continuous cross-sectional "picture" or profile of shallow subsurface conditions. These responses are caused by radar wave reflections from interfaces of materials having different electrical properties. Such reflections are often associated with natural geohydrologic conditions such as bedding, cementation, moisture and clay content, voids, fractures, and intrusions, as well as man-made objects. The radar method has been used at numerous HWS to evaluate natural soil and rock conditions, as well as to detect buried wastes.

Radar responds to changes in soil and rock conditions. An interface between two soil or rock layers having sufficiently different electrical properties will show up in the radar profile. Buried pipes and other discrete objects will also be detected.

Depth of penetration is highly site-specific, being dependent upon the properties of the site's soil and rock. The method is limited in depth by attenuation, primarily due to the higher electrical conductivity of subsurface materials. Generally, better overall penetration is achieved in dry, sandy or rocky areas; poorer results are obtained in moist, clayey or conductive soils. However, many times data can be obtained from a considerable depth in saturated materials, if the specific conductance of the pore fluid is sufficiently low. Radar penetration from one to ten meters is common.

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*GPR has been called by various names: ground piercing radar, ground probing radar and subsurface impulse radar. It is also known as an electromagnetic method (which in fact it is); however, since there are many other methods which are also electromagnetic, the term GPR has come into common use today, and will be used herein.

The continuous nature of the radar method offers a number of advantages over some of the other geophysical methods. The continuous vertical profile produced by radar permits much more data to be gathered along a traverse, thereby providing a substantial increase in detail. The high speed of data acquisition permits many lines to be run across a site, and in some cases, total site coverage is economically feasible. Reconnaissance work or coverage of large areas can be accomplished using a vehicle to tow the radar antenna at speeds up to 8 KPH. Very high resolution work or work in areas where vehicles cannot travel can be accomplished by towing the antenna by hand at much slower speeds. Resolution ranges from centimeters to several meters depending upon the antenna (frequency) used.

Initial in-field analysis of the data is permitted by the picture-like quality of the radar results. Despite its simple graphic format, there are many pitfalls in the use of radar, and experienced personnel are required for its operation and for the interpretation of radar data.

Radar has effectively mapped soil layers, depth of bedrock, buried stream channels, rock fractures, and cavities in natural settings.

Radar applications to HWS assessments include:

- Evaluation of the natural soil and geologic conditions.
- Location and delineation of buried waste materials, including both bulk and drummed wastes.
- Location and delineation of contaminant plume areas.
- Location and mapping of buried utilities (both metallic and non-metallic).

The radar system discussed in this document is a readily available impulse radar system. Continuous wave (CW) or other impulse systems exist, but they are generally one of a kind, being experimental instruments, and are not discussed here.

Figure C-1 shows a simplified block diagram of a radar system. The system consists of a control unit, antenna, graphic recorder, and an optional magnetic tape recorder. In operation, the electronics are typically mounted in a vehicle. The antenna is connected by a cable by hand. System power is usually supplied by a small gasoline generator. Various antennas may be used with the system to optimize the survey results for individual site conditions and specific requirements.

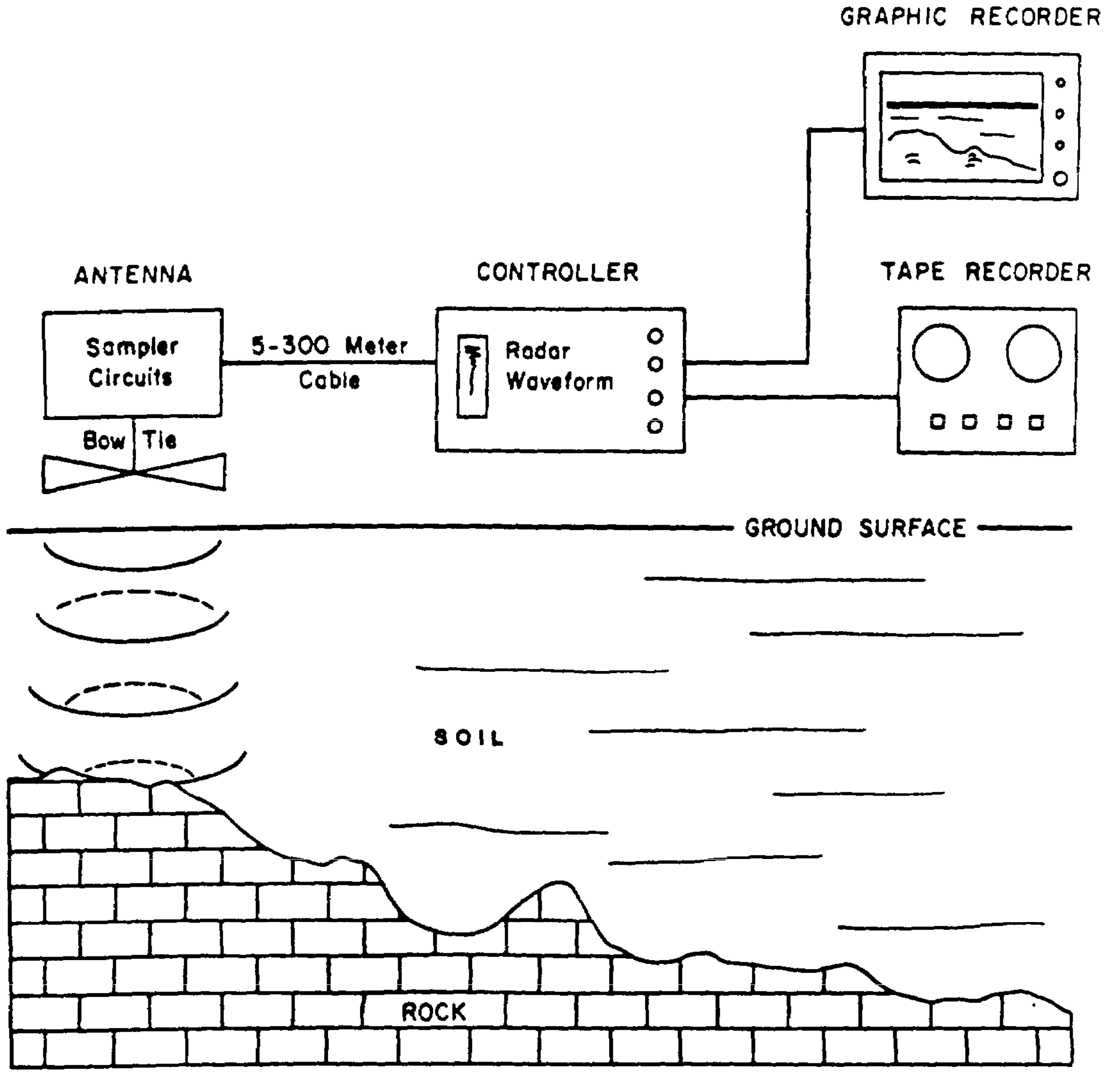

FIGURE C-1

BLOCK DIAGRAM OF GROUND PENETRATING RADAR SYSTEM.
RADAR WAVES ARE REFLECTED FROM SOIL/ROCK INTERFACE.

ELECTROMAGNETICS (EM)*

The electromagnetic (EM) method provides a means of measuring the electrical conductivity of subsurface soil, rock and ground water. Electrical conductivity is a function of the type of soil and rock, its porosity, its permeability, and the fluids which fill the pore space. In most cases, the conductivity (specific conductance) of the pore fluids will dominate the measurement. Accordingly, the EM method is applicable both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. Additionally, trench boundaries, buried wastes and drums, as well as metallic utility lines can be located with EM techniques.

Natural variations in subsurface conductivity may be caused by changes in soil moisture content, ground water specific conductance, depth of soil cover over rock, and thickness of soil and rock layers. Changes in basic soil or rock types, and structural features such as fractures or voids may also produce changes in conductivity. Localized deposits of natural organics, clay, sand, gravel, or salt rich zones will also affect subsurface conductivity.

Many contaminants will produce an increase in free ion concentration when introduced into the soil or ground water systems. This increase over background conductivity enables detection and mapping of contaminaed soil and ground water at HWS, landfills, and impoundments. Large amounts

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*The term electromagnetic has been used in contemporary literature as a descriptive term for other geophysical methods, including GPR and metal detectors which are based on electromagnetic principles. However, this document will use electromagnetic (EM) to specifically imply the measurement of subsurface conductivites by low-frequency electromagnetic induction. This is in keeping with the traditional use of the term in the geophysical industry from which the EM methods originated. While the authors recognize that there are many electromagnetic systems and manufacturers, the discussion in this section is based solely on instruments which are calibrated to read in electrical conductivity units and which have been effectively and extensively used at hazardous waste sites.

of organic fluids such as diesel fuel can displace the normal soil moisture, causing a decrease in conductivity which may also be mapped, although this is not commonly done. The mapping of a plume will usually define the local flow direction of contaminants. Contaminant migration rates can be established by comparing measurements taken at different times.

The absolute values of conductivity for geologic materials (and contaminants) are not necessarily diagnostic in themselves, but the variations in conductivity, laterally and with depth, are significant. It is this variation which enables the investigator to rapidly find anomalous conditions.

Since the EM method does not require ground contact, measurements may be made quite rapidly. Lateral variations in conductivity can be detected and mapped by a field technique called profiling. Profiling measurements may be made to depths ranging from 0.75 to 60 meters. Instrumentation and field procedures have been developed recently which make it possible to obtain continuous EM profiling data to a depth of 15 meters. The data is recorded using strip chart and magnetic tape recorders. This continuous measurement allows increased rates of data acquisition and improved resolution for mapping small geohydrologic features. Further, recorded data enhanced by computer processing has proved invaluable in the evaluation of complex hazardous waste sites. The excellent lateral resolution obtained from EM profiling data has been used to advantage in efforts to outline closely-spaced burial pits, to reveal the migration of contaminants into the surrounding soil, or to delineate fracture patterns.

Vertical variations in conductivity can also be detected by the EM method. A station measurement technique called sounding is employed for this purpose. Data can be acquired from depths ranging from 0.75 to 60 meters. This range of depth is achieved by combining results from a variety of EM instruments, each requiring different field application techniques. Other EM systems are capable of sounding to depths of 1,000 feet or more, but have not yet been used at HWS and are not adaptable to continuous measurements.

Profiling is the most effective use of the EM method. Continuous profiling can be used in many applications to increase resolution, data density, and permit total site coverage at critical sites.

At HWS, applications of EM can provide:

- Assessment of natural geohydrologic conditions;
- Locating and mapping of burial trenches and pits containing drums and/or bulk wastes;
- Locating and mapping of plume boundaries;
- Determination of flow direction in both unsaturated and saturated zones;
- Rate of plume movement by comparing measurements taken at different times; and
- Locating and mapping of utility pipes and cables which may affect other geophysical measurements, or whose trench may provide a permeable pathway for contaminant flow.

This document discusses only those instruments which are designed and calibrated to read directly in units of conductivity.

The basic principle of operation of the electromagnetic method is shown in Figure C-2. The transmitter coil radiates an electromagnetic field which induces eddy currents in the earth below the instrument. Each of these eddy current loops, in turn, generates a secondary electromagnetic field which is proportional to the magnitude of the current flowing within that loop. A part of the secondary magnetic field from each loop is intercepted by the receiver coil and produces an output voltage which (within limits) is linearly related to subsurface

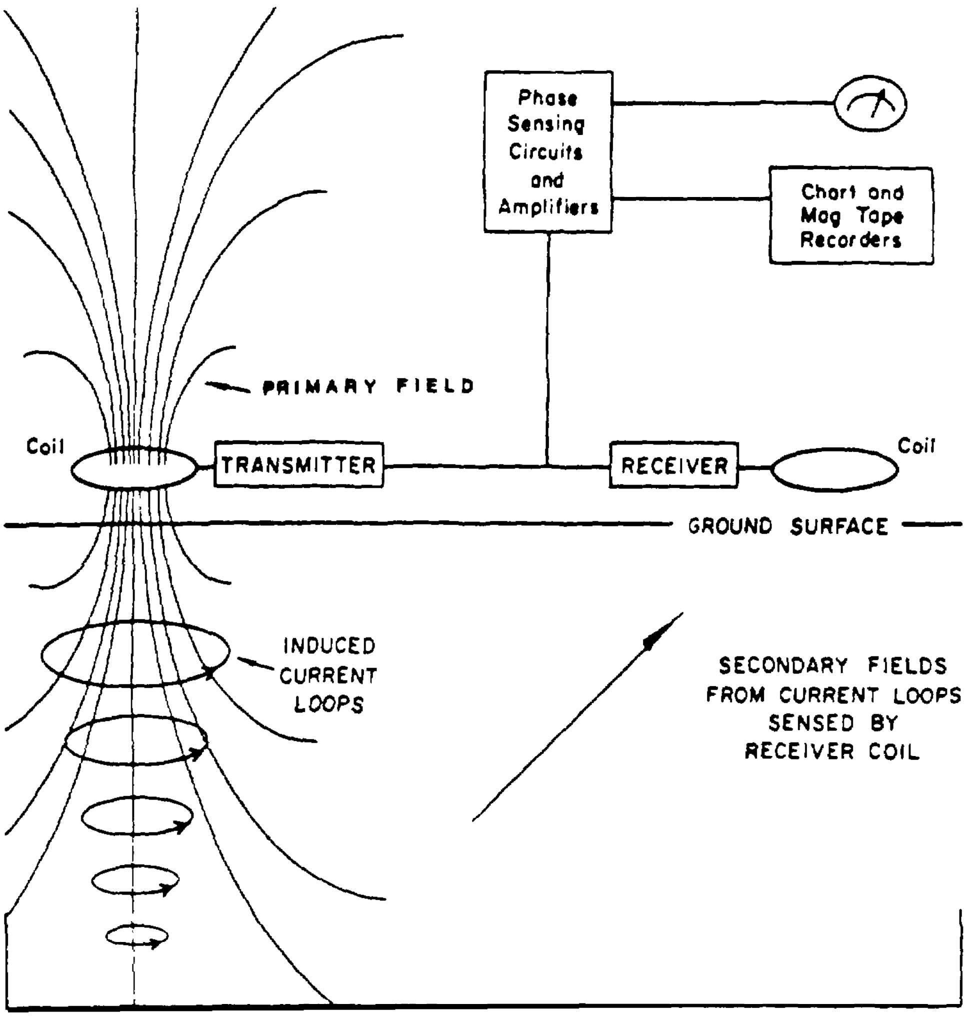


FIGURE C-2

BLOCK DIAGRAM SHOWING EM PRINCIPLE OF OPERATIONS conductivity. This reading is a bulk measurement of conductivity; the cumulative response to subsurface conditions ranging all the way from the surface to the effective depth of the instrument.

The sampling depth of EM equipment is related to the instrument's coil spacing. Instruments with coil spacings of 1, 4, 10, 20, and 40 meters are commercially available. The nominal sampling depth of an EM system is taken to be approximately 1.5 times the coil spacing. Accordingly, the nominal depth of response for the coil spacings given above is 1.5, 6, 15, 30, and 60 meters.

The conductivity value resulting from an EM insrument is a composite, and represents the combined effects of the thickness of soil or rock layers, their depths, and the specific conductivities of the materials. The instrument reading represents the combination of these effects, extending from the surface to the arbitrary depth range of the instrument. The resulting values are influenced more strongly by shallow materials than by deeper layers, and this must be taken into consideration when interpreting the data. Conductivity conditions from the surface to the instrument's nominal depth range contribute about 75 percent of the instrument's response. However, contributions from highly conductive materials lying at greater depths may have a significant effect on the reading.

EM instruments are calibrated to read subsurface conductivity in millimhos per meter (mm/m). These units are related to resistivity units in the following manner:

1000/(millimhos/meter) = 1 ohm-meter
1000/(millimhos/meter) = 3.28 ohm-feet
1 millimho/meter = 1 siemen

The advantage of using millimhos/meter is that the common range of resistivities from 1 to 1000 ohm-meters is covered by the range of conductivities from 1000 to 1 millimhos/meter. This makes conversion of units relatively easy.

Most soil and rock minerals, when dry, have very low conductivities (Figure C-3). On rare occasions, conductive minerals like magnetite, graphite and pyrite occur in sufficient concentrations to greatly increase natural subsurface conductivity. Most often, conductivity is overwhelmingly influenced by water content and the following soil/rock parameters:

- The porosity and permeability of the material;
- the extent to which the pore space is saturated;
- the concentration of dissolved electrolytes and colloids in the pore fluids; and
- the temperature and phase state (i.e., liquid or ice) of the pore water.

A unique conductivity value cannot be assigned to a particular material, because the interrelationships of soil composition, structure and pore fluids are highly variable in nature.

In areas surrounding HWS, contaminants may escape into the soil and the ground-water system. In many cases, these fluids contribute large amouns of electrolytes and colloids to both the unsaturated and saturated zones. In either case, the ground conductivity may be greatly affected, sometimes increasing by one to three orders of magnitude above background values. However, if the natural variations in subsurface conductivity are very low, contaminant plumes of only 10 to 20 percent above background may be mapped.

In the case of spills involving heavy nonpolar, organic fluids such as diesel oil, the normal soil moisture may be displaced, or a sizeable pool of oil may develop at the water table. In these cases, subsurface conductivites may decrease causing a negative EM anomaly. (A negative anomaly will occur only if substantial quantities of nonconductive contaminants are present.)

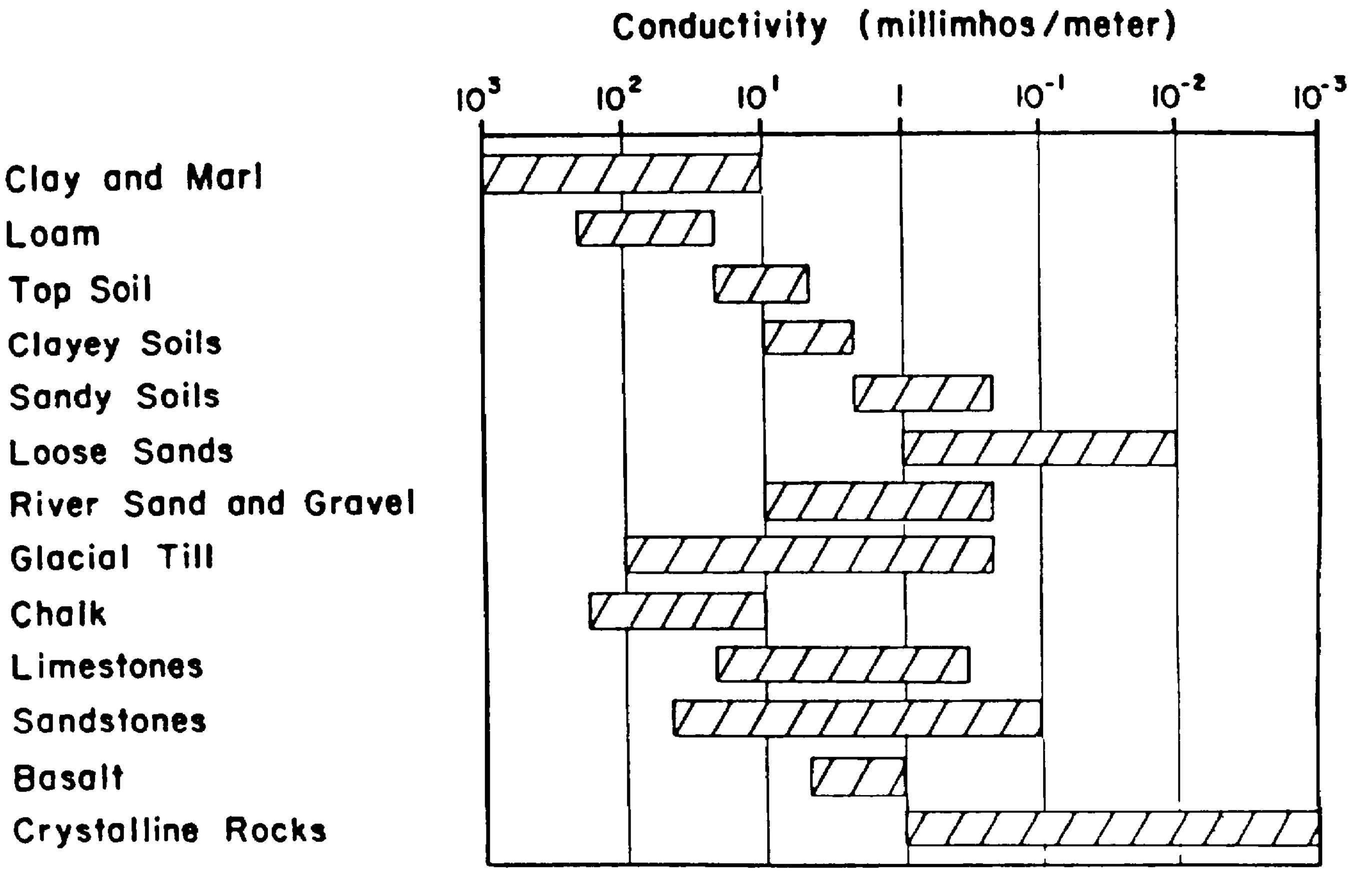


FIGURE C-3

RANGE OF ELECTRICAL CONDUCTIVTIES IN NATURAL SOIL AND ROCK.
(Modified After Culley et al.)

RESISTIVITY

The resistivity method is used to measure the electrical resistivity of the geohydrologic section which includes the soil, rock, and ground water. Accordingly, the method may be used to assess lateral changes and vertical cross sections of the natural geohydrologic settings. In addition, it can be used to evaluate contaminant plumes and locate buried wastes at hazardous waste sites.

Application of the method requires that an electrical current be injected into the ground by a pair of surface electrodes. The resulting potential field (voltage) is measured at the surface between a second pair of electrodes. The subsurface resistivity can be calculated by knowing the electrode separation and geometry of the electrode positions, applied current, and measured voltage. (Resistivity is the reciprocal of conductivity, the parameter directly measured by the EM technique.)

In general, most soil and rock minerals are electrical insulators (highly resistive); hence the flow of current is conducted primarily through the moisture-filled pore spaces within the soil and rock. Therefore, the resistivity of soils and rocks is predominantly controlled by the porosity and permeability of the system, the amount of pore water, and the concentration of dissolved solids in the pore water.

The resistivity technique may be used for "profiling" or "sounding." Profiling provides a means of mapping lateral changes in subsurface electrical properties. This field technique is well suited to the delineation of contaminant plumes and the detection and location of changes in natural geohydrologic conditions. Sounding provides a means of determining the vertical changes in subsurface electrical properties. Interpretation of sounding data provides the depth and thickness of subsurface layers having different resistivities. Commonly up to four layers may be resolved with this technique.

Applications of the resistivity method at hazardous waste sites include:

- Locating and mapping contaminant plumes;
- Establishing direction and rate of flow of contaminant plumes;
- Defining burial sites by
  - locating trenches,
  - defining trench boundaries,
  - determining the depths of trenches; and
- Defining natural geohydrologic conditions such as
  - depth to water table or to water-bearing horizons,
  - depth to bedrock, thickness of soil, etc.

Most dry mineral components of soil and rock are highly resistive except for a few metallic ore minerals. Under most circumstances, the amount of soil/rock moisture dominates the mesurement greatly reducing the resistivity value. Current flow is essentially electrolytic, being conducted by water contained within pores and cracks. A few minerals like clays actually contribute to conduction. In general, soils and rocks become less resistive as:

- Moisture or water content increases;
- Porosity and permeability of the formation increases;
- Dissolved solid and colloid (electrolyte) content increases; and
- Temperature increases (a minor factor, except in areas of permafrost).

Figure C-4 illustrates the range of resistivity found in commonly-occurring soils and rocks. Very dry sand, gravel, or rock as encountered in arid or semi-arid areas will have very high resistivity. As the empty pore spaces fill with water, resistivity will drop. Conversely, the resistivity of earth materials which occur below the water table but lack pore space (such as massive granite and limestone) will be relatively high and will be primarily controlled by current conduction along cracks

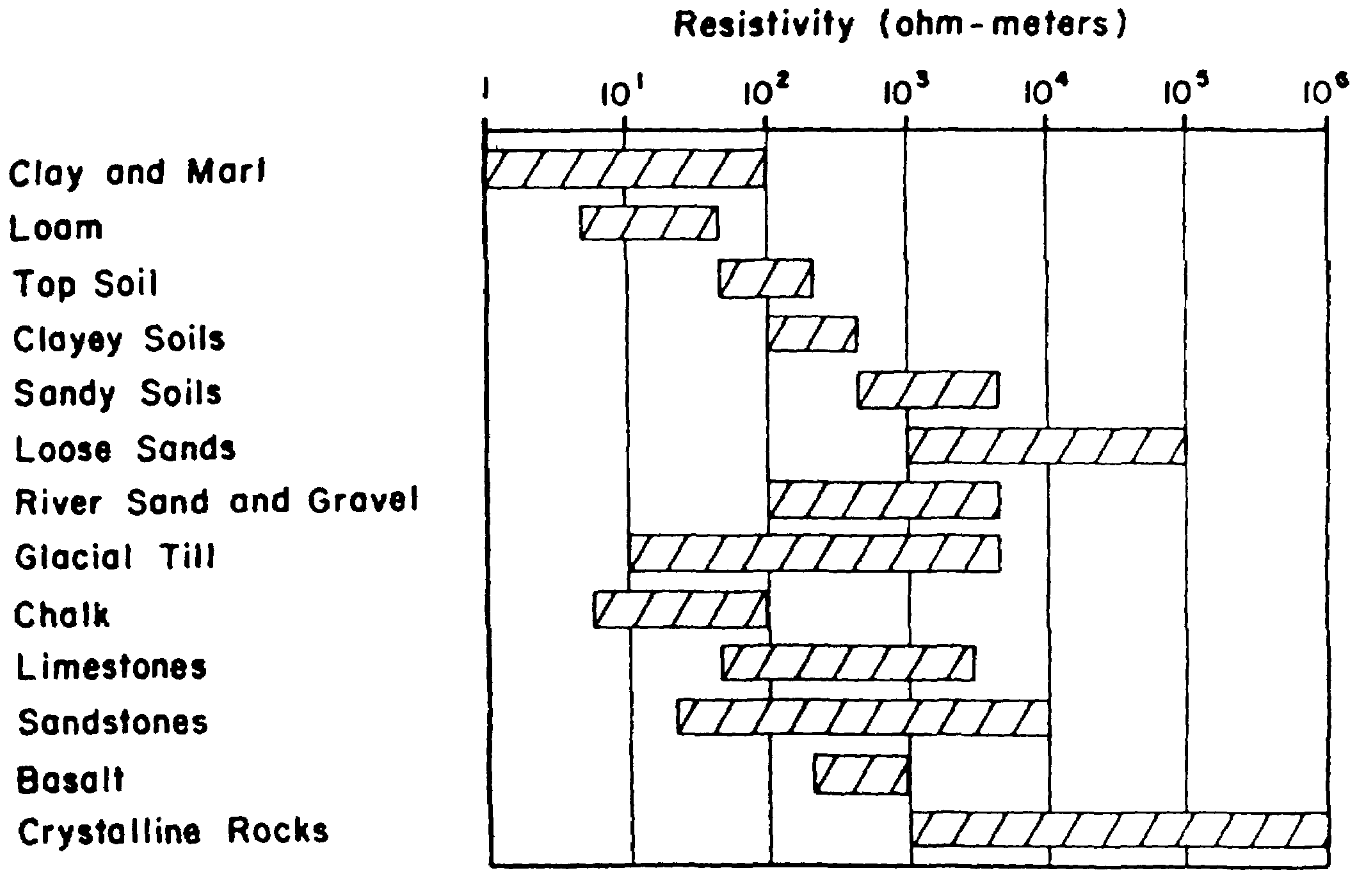


FIGURE C-4

RANGE OF RESISTIVITIES IN COMMONLY-OCCURRING SOILS AND ROCKS
(Modified after Culley et al.)

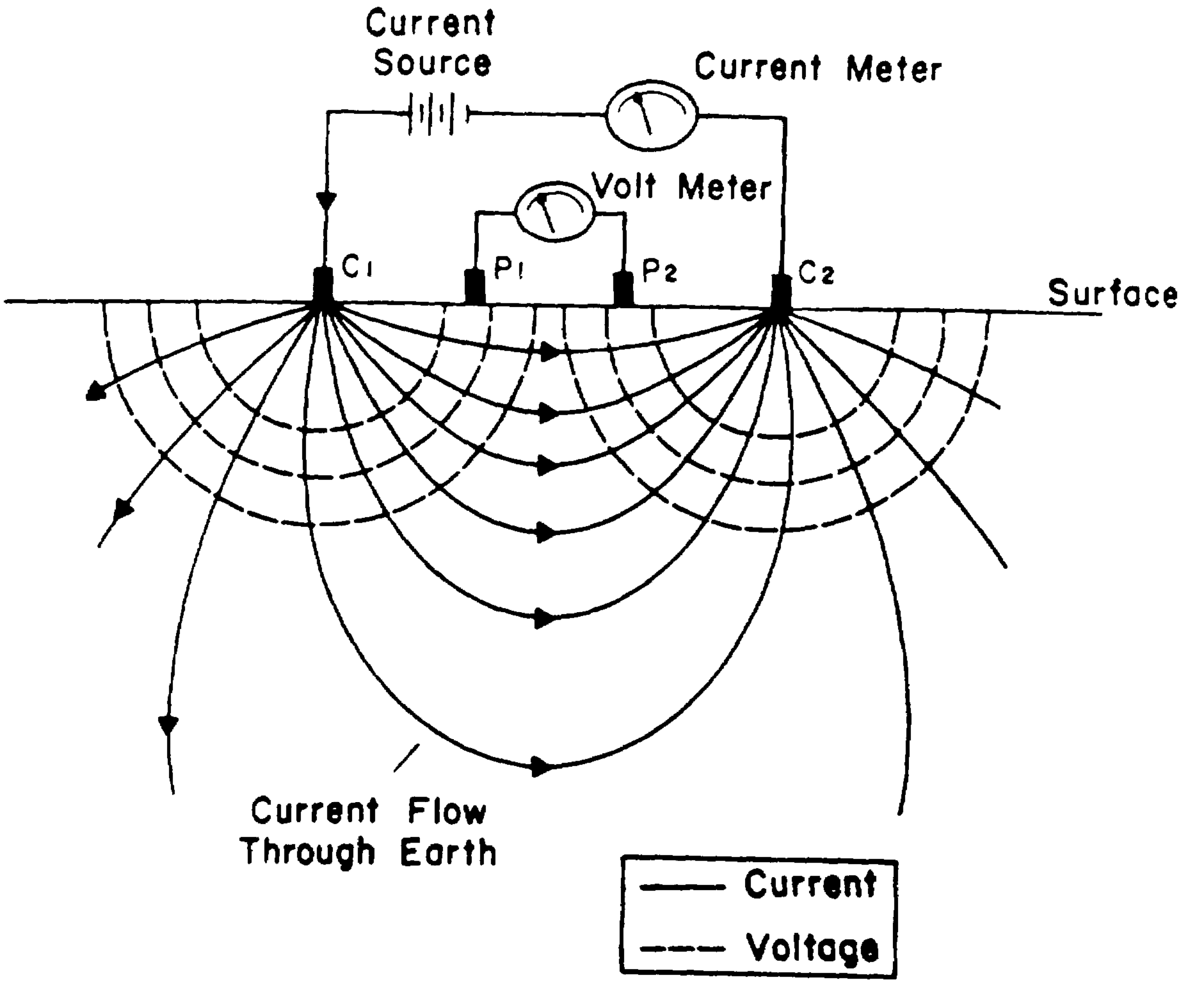
and fissures in the formation. Clayey soils and shale layers generally have low resistivity values, due to their inherent moisture and clay mineral content. In all cases, an increase in the electrolyte, total dissolved solids (TDS) or specific conductance of the system will cause a marked increase in current conduction and a corresponding drop in resistivity. This fact makes resistivity an excellent technique for the detection and mapping of conductive contaminant plumes.

It is important to note that no geologic unit or plume has a unique or characteristic resistivity value. Its measured resistivity is dependent on the natural soil and rock present, the relative amount of moisture, and its specific conductance. However, the natural resistivity value of a particular formation or unit may remain within a small range for a given area.

Figure C-5 is a schematic diagram showing the basic principles of operation. The resistivity method is inherently limited to station measurements, since electrodes must be in physical and electrical contact with the ground. This requirement makes the resistivity method slower than a noncontract method such as EM.

Many different types of electrode spacing arrays may be used to make resistivity measurements; the more commonly used include Wenner, Schlumberger, and dipole-dipole. Due to its simple electrical geometry, the Wenner array will be used as an example in the remainder of this section; however, its use is not necessarily recommended for all site conditions. The choice of array will depend upon project objectives and site conditions and should be made by an experienced geophysicist.

Using the Wenner array, potential electrodes are centered on a line between the current electrodes; and equal spacing between electrodes is maintained. These "A" spacings used during HWS evaluation commonly range from 0.3 meter to more than 100 meters. The depth of measurement is related to the "A" spacing and may vary depending upon the geohydrology.



Apparent resistivity values using the Wenner array are calculated from the measured voltage and current and the spacing between electrodes as shown in the following equation:

$$a = 2 \quad A\ V/I$$

where a = apparent resistivity (ohm-meters or ohm-feet)
A = "A" spacing (meters or feet)
V = potential (volts)
I = current (ampers)

FIGURE C-5

DIAGRAM SHOWING BASIC CONCEPT OF RESISTIVITY MEASUREMENT

Current is injected into the ground by the two outer electrtodes which are connected by cables to a DC or low-frequency AC current source. (If true DC is used, special nonpolarizing electrodes must be used.) The distribution of current within the earth is influenced by the relative resistivity of subsurface features. For example, homogenous subsurface conditions will have the uniform current flow distribution and will yield a resistivity value characteristic of the sampled section. On the other hand, current distribution may be pulled downward by a low-resistivity (lower than that of the surface layer, due to the influence of the lower resistivity material at depth.

The current flow within the subsurface produces an electric field with lines of equal potential, perpendicular to the lines of current (Figure C-5). The potential field is measured by a voltmeter at the two inner electrodes.

SEISMIC REFRACTION

Seismic refraction techniques are used to determine the thickness and depth of geologic layers and the travel time or velocity of seismic waves within the layers. Seismic refraction methods are often used to map depths to specific horizons such as bedrock, clay layers, and water table. In addition to mapping natural features, other secondary applications of the seismic method include the location and definition of burial pits and trenches at HWS.

Seismic waves transmitted into the subsurface travel at different velocites in various types of soil and rock and are refracted (or bent) at the interfaces between layers. This refraction affects their path of travel. An array of geophones on the surface measures the travel time of the seismic waves from the source to the geophones at a number of spacings. The time required for the wave to complete this path is measured, permitting a determination to be made of the number of layers, the thicknesses of the layers and their depths, as well as the seismic velocity of each layer. The wave velocity in each layer is directly related to its material properties such as density and hardness.

A seismic source, geophones, and a seismograph are required to make the measurments. The seismic source may be a simple sledge hammer with which to strike the ground. Explosives and any other seismic sources may be utilized for deeper or special applications. Geophones implanted in the surface of the ground translate the received vibrations of seismic energy into an electrical signal. This signal is displayed on the seismograph, permitting measurement of the arrival time of the seismic wave. Since the seismic method measures small ground vibrations, it is inherently susceptible to vibration noise from a variety of natural and cultural sources.

At HWS, seismic refraction can be used to define natural geohydrologic conditions, including thickness and depth of soil and rock layers, their composition and physical properties, and depth to bedrock or water table. It can also be used for the detection and location of anomalous features, such as pits and trenches, and for evaluation of the depth of burial sites or landfills. (In contrast to seismic refraction, the reflection technique, which is common in petroleum exploration, has not been applied to HWS. This is primarily because the method cannot be effectively utilized at depths of less than 20 meters.)

Although a number of elastic waves are inherently associated with the method, conventional seismic refraction methods that have been employed at HWS are concerned only with the compressional wave (primary or P-wave). The compressional wave is also the first to arrive which makes its identification relatively easy.

These waves move through subsurface layers. The density of a layer and its elastic properties determine the speed or velocity at which the seismic wave will travel through the layer. The porosity, mineral composition, and water content of the layer affect both its density and elasticity. Table C-1 lists a range of compressional wave velocities in common geologic materials. It can be seen from these tables that the seismic velocities for different types of soil and rock overlap, so knowing the velocities of these layers alone does not permit a unique determination of their composition. However, if this knowledge is combined with geologic information, it can be used intelligently to identify geologic strata.

In general, velocity values are greater for:

- dense rocks than light rocks.
- older rocks than younger rocks.
- igneous rocks than sedimentary rocks.
- solid rocks than rocks with cracks or fractures.

TABLE C-1

RANGE OF VELOCITIES FOR COMPRESSIONAL WAVES IN SOIL AND ROCK
(After Jakosky, 1950)

Material	Velocity (Meters/sec)
Weathered surface material	305 - 610
Gravel or dry sand	465 - 915
Sand (wet)	610 - 1,830
Sandstone	1,830 - 3,970
Shale	2,750 - 4,270
Chalk	1,830 - 3,970
Limestone	2,140 - 6,100
Salt	4,270 - 5,190
Granite	4,380 - 5,800
Metamorphic rocks	3,050 - 7,020

- unweathered rocks than weathered rocks.
- consolidated sediments than unconsolidated sediments.
- water-saturated unconsolidated sediments than dry unconsolidated sediments.
- wet soils than dry soils.

Figure C-6 shows a schematic view of a 12-channel seismic system in use and the compessional waves traveling through a two-layered system of soil over bedrock. A seismic source produces seismic waves which travel in all directions into the ground. The seismic refraction method, however, is concerned only with the waves shown in Figure C-6. One of these waves, the direct wave, travels parallel to the surface of the ground. A seismic sensor (geophone) detects the direct wave as it moves along the surface layer. The time of travel along this path is related to the distance between the sensor and the source and the material composing the layer.

If a denser layer with a higher velocity, such as bedrock, exists below the surface soils, some of the seismic waves will be bent or refracted as they enter the bedrock. This phenomenon is similar to the refraction of light rays when light passes from air into water and is described by Snell's law. One of these refracted waves, crossing the interface at a critical angle, will move parallel to the top of the bedrock at the higher velocity of the bedrock. The seismic wave travelling along this interface will continually release energy back into the upper layer by refraction. These waves may then be detected in the surface at various distances from the source (Figure C-6).

Beyond a certain distance (called the critical distance), the refracted wave will arrive at a geophone before the direct wave. This happens even though the refraction path is longer, because a sufficient portion of the wave's path occurs in the higher velocity bedrock.

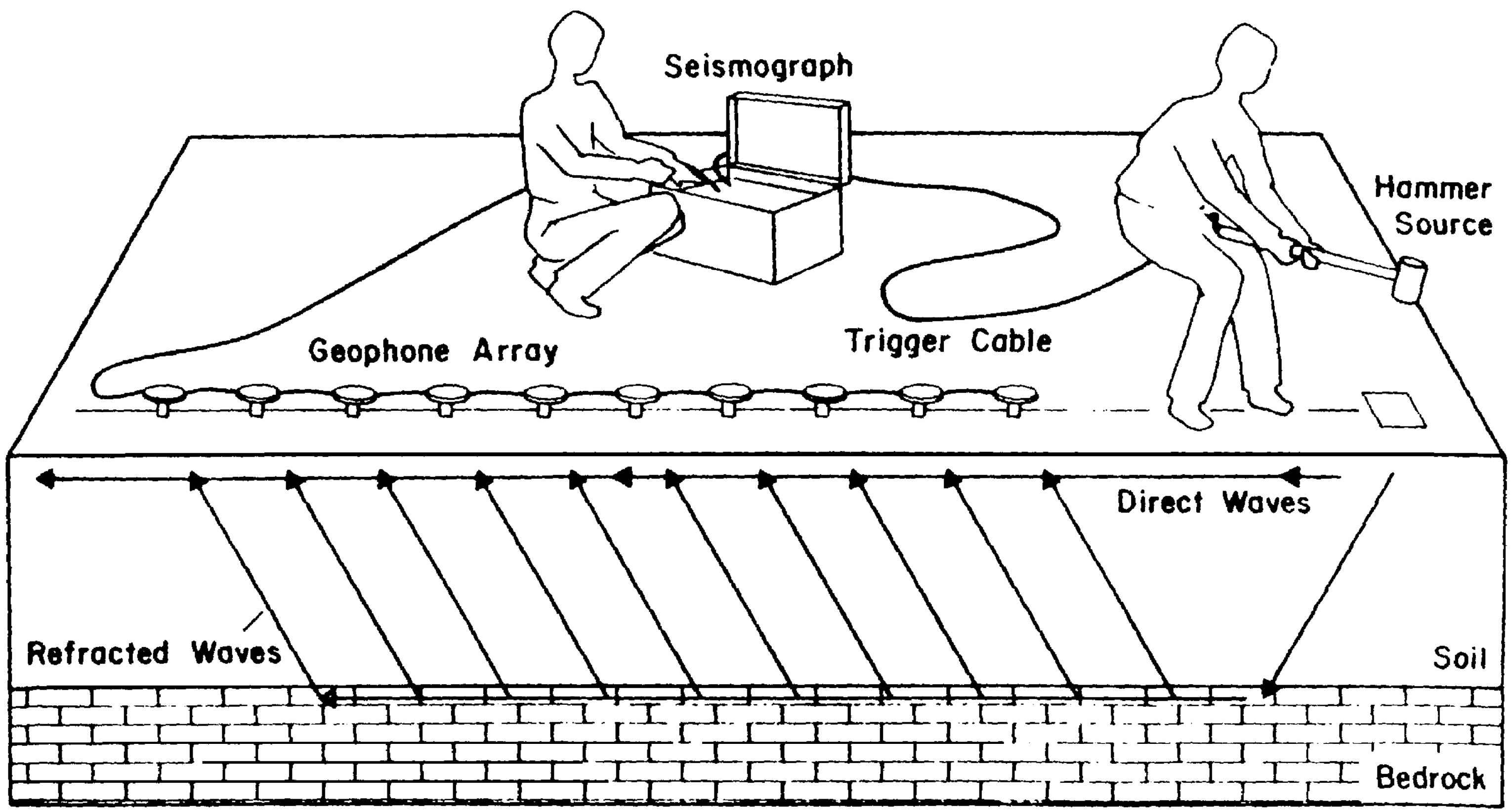


FIGURE C-6

FIELD LAYOUT OF A 12-CHANNEL SEISMOGRAPH SHOWING THE PATH
OF DIRECT AND REFRACTED SEISMIC WAVES IN A TWO-LAYER SOIL/ROCK SYSTEM

Measurement of these first arrival times and their distances from the source permits calculation of layer velocities, thicknesses and bedrock depth. Application of the seismic method is generally limited to resolving three to four layers.

The preceding concepts are based upon the fundamental assumptions that:

1. Seismic velocities of geologic layers must increase with depth. This requirement is generally met at most sites.

2. Layers must be of sufficient thickness to permit detection.

3. Sesimic velocities of layers must be sufficiently different to permit resolution of individual layers.

There is no way to establish from the seismic data alone whether a hidden layer (due to 1 and 2 above) is present; therefore, correlation to a boring log or geologic knowledge of the site must be used to provide a cross check. If such data is not available, the interpreter must take this into consideration in evaluating the data.

Variations in the thickness of the shallow soil zone, inhomogeneities within a layer, or irregularities between layers will often produce geologic scatter or anomalies in the data. This data scatter is useful information, revealing some of the natural variability of the site. For example, a zone containing a number of large boulders in a glacial till deposit will yield inconsistent arrival times, due to variable seismic velocities between the boulders and the clay matrix. An extremely irregular bedrock surface as is often encountered in karst limestone terrain, likewise, will produce scatter in the seismic data.

The seismic refraction technique uses the equipment shown in Figure C-6. The seismic source is often a simple ten-pound sledge hammer or drop weight which strikes the ground, generating a seismic impulse. Explosives and a variety of other excitation sources are also used for the greater energy levels rquired for information at deeper layers.

Seismic waves are detected by geophones implanted in the surface of the ground at various distances from the source. The geophone converts the seismic wave's mechanical vibration into an electrical signal in a manner similar to that of a microphone. This signal is carried by cable to the seismograph.

The seismograph is an instrument which electronically amplifies and then displays the received seismic signal from the geophone. The display may be a cathode ray tube, a single-channel strip chart, or a thermal printer, commonly used on multi-channel systems. The identification and measurement of the arrival time of the first wave from the seismic source is obtained from this presentation. The time is measured in milliseconds, with zero time or start of trace intitiated by the source, which provides a trigger signal to the seismograph.

Travel time is plotted against source-to-geophone distance producing a time/distance (T/D) plot.

- The number of line segments indicates the number of layers.
- The slope of each line segment is inversely proportional to the seismic velocity in the corresponding layer.
- Break points in the plot (critical distance, X) are used with the velocities to calculate layer depth.

The seismic line must be centered over the required information area and overall line length must be three to five times the maximum depth of interest. Resolution is determined by the geophone spacing. Spacings of 3 to 15 meters are commonly used; however, closer spacings may be necessary for very high resolution of shallow geologic sections.

ORGANIC VAPOR/SOIL GAS ANALYSIS

Organic contaminant vapors present in the vadose zone may be assessed using a variety of techniques. One method is the use of organic vapor detectors such as OVAs, explosimeters and Draeger tubes to detect volatile organics. Two major strategies may be adopted, jointly or separately, depending on whether wells are in place at the time of investigation:

1. Monitoring the well head space.
2. Monitoring the vadose zone directly by lowering a probe into shallow, hand-augurred holes.

Gaseous sample constituents can be identified in detail using a portable gas chromatograph. An alternative methodology is an analysis of soil gas. Under this methodology, a ten-liter sample of soil gas is drawn through a probe which is mechanically driven into the ground to a depth of about ten feet. Two cubic centimeters of gas are injected into a portable gas chromatograph to ascertain its organic constituents. It is useful to know what class of organics is present in order to choose the gas chromatography method which provides the highest resolution, i.e., photoionization/aromatics, electron-capture/halogenated hydrocarbons. The 2 cc sample is injected by syringe to the gas chromatograph through a dewatering napthalon tubing. This method is limited in two major ways:

1. Coarse, pebbly/cobbly strata prevent penetration of the probe, in which case holes may be hand-augured.
2. The presence of shallow, saturated zones, especially low permeability formations severely restricts the development of a gas envelope and thus limits the applicability of the method. Soil gas analysis is a vadose zone monitoring technique and cannot be used effectively where the water table or saturation is shallow.

Organic vapor/soil gas analysis is most effective when used in conjunction with other investigative methods. Although it provides an analysis of the volatile organics and thus provides a preliminary characterization of the subsurface contamination, it is limited to a fraction of the total hazardous constituents and needs augmentation.

* U.S. GOVERNMENT PRINTING OFFICE 1986; 621-735/60541