CHAPTER 5

HYDROGEOLOGIC SITE INVESTIGATIONS

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5.1 INTRODUCTION

The purpose of hydrogeologic site investigations is to characterize soil and ground water pollution problems in sufficient detail to facilitate design of a cost-effective corrective action program. For this purpose, the site investigation entails measurement of the physical parameters that control subsurface contaminant transport at a given site. Geologic, hydrologic, and chemical data must be acquired and integrated to define the nature and extent of soil and ground water contamination and the potential for migration of contaminants within the natural ground water flow system. To the extent practical, the remedy should be anticipated at the outset of an investigation so that design-basis information necessary for development of the corrective action program is obtained in a timely and cost-effective manner.

The preceding chapters of this book have reviewed the general principles of ground water occurrence and flow within geologic formations and the nature of the most common ground water contaminants. In this chapter, the engineering procedures involved in the acquisition and interpretation of ground water flow and contaminant information will be addressed. The following sections outline a systematic approach to planning and implementing soil and ground water contamination studies and summarize engineering standards for data evaluation and presentation.

5.2 DEVELOPMENT OF CONCEPTUAL SITE MODEL

Hydrogeologic processes are, by nature, complex, due to the heterogeneities of geologic formations and the transient effects of aquifer recharge and discharge phenomena. Additional complexity arises from the presence of contaminants that may be irregularly distributed in, and reacting with, subsurface formations and ground water. Consequently, detailed characterization of contaminant distribution and transport patterns throughout every inch of an aquifer system is impractical. From an engineering perspective, our objective is therefore to define subsurface contaminant transport processes to the degree necessary to allow us to design effective measures for control or reversal of these processes, as needed to protect public health and the environment.

Ultimately, protection of drinking water resources may require us to extract or "mine" the contaminated ground water mass from the affected aquifer. Therefore, it is helpful to approach a ground water contaminant delineation study in much the same manner as prospecting for hydrocarbons or precious metals. We do not need to know each twist and turn of every minor "ore" seam, but we do want to know how wide and how deep the play runs and, because our "ore" is a fluid, which way it is moving and how fast.

The hydrogeologic site investigation is the procedure by which we develop our understanding or our "working model" of contaminant plume migration within the ground water flow regime. In all cases, this model of the subsurface environment is constructed of three principal components of information:

1. **Geology**: the physical framework within which subsurface fluids collect and flow;
2. **Hydrology**: the movement of fluids through this physical framework; and
3. **Chemistry**: the nature of the chemical constituents that are entrained in this flow system and the chemical and physical interactions between the contaminants and the subsurface formation and ground water that may be occurring.

We build our model of the site by systematically addressing each of these principal components in turn. First, we must characterize the stratigraphic profile beneath the site and identify those strata serving as potential conduits for fluid flow and the geologic features that may influence the movement and accumulation of nonaqueous phase liquids (NAPLs). Second, we must measure the fluid hydraulic head distribution within the zone of saturation to determine the actual rate and direction of ground water movement through these conduits. Third, water samples are collected and analyzed to map the lateral and vertical extent of contaminant migration within the ground water flow regime.

There is significant overlap in the acquisition of these three classes of data, and in practice, they are collected simultaneously. For example, a soil boring may be drilled to characterize the geology of the site; it provides soil samples for laboratory analysis of contaminant concentration; and it may be converted to a monitoring well to permit collection of ground water samples and hydrologic data. A well designed site investigation will maximize the relevant information collected during each step of the work program. It is then the job of the project engineer or scientist to sort this information into a meaningful and accurate picture of subsurface ground water flow and contaminant transport processes.

5.3 STRATEGY FOR HYDROGEOLOGIC SITE INVESTIGATIONS

5.3.1 Overview and General Considerations

As a practical matter, site investigation workplans usually represent a compromise between the ideal of knowing as much as possible about a site and the realities imposed by a finite budget. For the purpose of economy and efficiency, every field and laboratory measurement conducted during the investigation must contribute to the conceptual model of the site. The key is to design a work program that provides the necessary data by making the maximum use of the available resources.

To achieve project objectives in a cost-effective manner, a clear strategy for mapping the contaminant zones must be established prior to commencement of field or laboratory work. At the outset, all available site information concerning subsurface geology, ground water flow, and the nature, extent, and timing of the contaminant release should be assembled to guide the selection of sampling locations. Data quality objectives and appropriate sampling and testing technologies must be identified to ensure collection of data that meet not only the engineering, but also the regulatory requirements of the project.

As a basis for a site investigation strategy, all subsurface contaminant problems should be viewed as two distinct zones of contamination: (1) contaminant source materials and contaminated soils in the unsaturated soil (or rock) zone; and (2) nonaqueous phase liquids (NAPLs) and/or ground water containing dissolved contaminants within the zone of saturation (Figure 5.1). For practical purposes, we can define the vertical boundary between these two zones as the surface of the uppermost water bearing unit beneath the site (e.g., a water-saturated stratum with hydraulic conductivity, $K \geq 1 \times 10^{-4}$ cm/sec). These two zones differ significantly in terms of their operant mechanisms of contaminant transport and the requisite corrective actions, and therefore should be addressed individually in the course of the hydrogeologic site investigation.

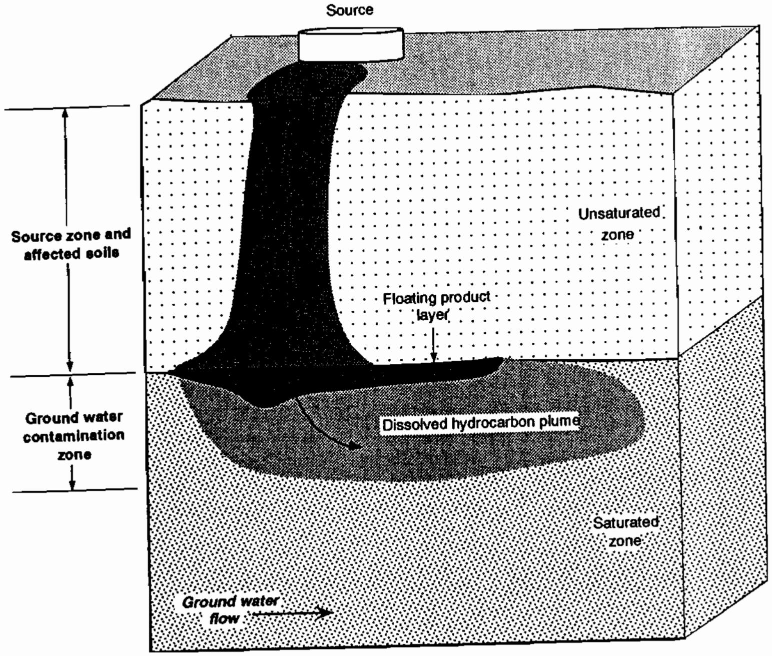


Figure 5.1 Zones of contamination for two-stage site investigation approach.

5.3.2 Unsaturated Source Zone Characteristics

Most incidents of hazardous chemical release to the subsurface environment occur as surface spills of products or wastes or leachate percolation from the base of waste landfills, surface impoundments, or material stockpiles. As the wetting front percolates downward through the unsaturated soil (or rock) zone underlying the source area, a significant portion of the contaminant mass may be retained in the unsaturated soil matrix due to the effects of filtration, sorption, or capillary retention. For many years thereafter, this contaminated soil can serve as a source of continuing contaminant release to stormwater flowing across the site surface or percolating downward through the unsaturated soil zone to the depth of underlying ground water.

Depending on the size and geological characteristics of this residual source zone and the nature and concentration of the contaminants, protection of surface water and ground water resources could involve either complete excavation and removal of the contaminated soils, capping of the site to minimize rainfall contact and precipitation, or contaminant extraction by means of in-situ soil venting or rinsing. To support design of appropriate corrective measures, the hydrogeologic site investigation must therefore address the full lateral and vertical extent of residual contaminants within the unsaturated soil zone and the potential for future release of contaminants to local water resources.

5.3.3 Ground Water Plume Characteristics

Dissolved contaminants contained in waste leachate fluids penetrating to the depth of ground water occurrence will become entrained in the natural ground water flow system and spread laterally and vertically in accordance with local ground water flow gradients (Figure 5.1). Free-phase liquid contaminants may be subject to an additional "density gradient" with light non-aqueous phase liquids (LNAPLs, such as gasoline) floating atop the zone of saturation and collecting in the structural highs of confined water-bearing units. Alternatively, dense non-aqueous phase liquids (DNAPLs) can percolate downward through the water-bearing stratum to perch and spread atop underlying confining units (Chapter 11).

In all cases, ground water contamination problems are fluid problems. The contaminant enters the ground water system as a fluid and can therefore be removed or controlled as a fluid. Unlike contamination within the unsaturated soil zone, excavation and removal of the soil or rock mass from the zone of ground water contamination is neither practical nor necessary. The hydrogeologic site investigation must therefore provide definitive information on the current lateral and vertical extent of dissolved and free-phase contaminants within the ground water, as well as the hydraulic processes controlling contaminant migration.

5.3.4 Two-Stage Site Investigation Approach

In practice then, the hydrogeologic site investigation proceeds as a two-stage process: (1) delineate the unsaturated source zone, comprised of the chemical waste or product mass and the associated contaminated soils within the unsaturated soil column, and (2) investigate the presence and extent of contaminant migration within the underlying ground water system. Step-by-step strategies for implementation of these source zone and ground water contamination delineation studies are outlined below and illustrated on Figures 5.2 – 5.4.

Procedures for Unsaturated Source Zone Characterization. The objectives of the source zone characterization study are to locate the site of the release, identify the contaminants of concern and determine their concentrations, and delineate the source material or unsaturated soil mass that may act as a continuing source of contaminant release to surface water or underlying ground water. The principal steps required for delineation of the source zone are illustrated in Figure 5.2 and listed below.

As shown on the task flowchart, to commence the delineation study, available chemical information regarding the suspected source of the subsurface release (e.g., waste or product spill) must be compiled to provide a basis for design of the laboratory testing program. If

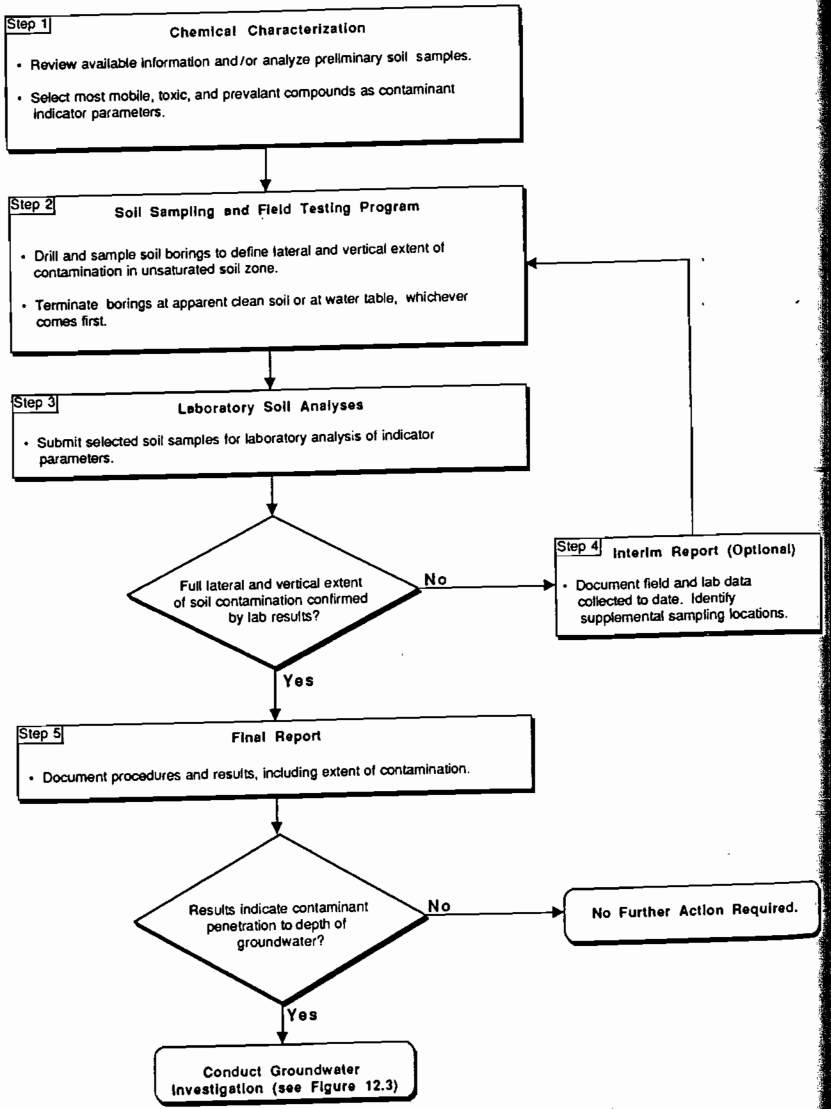


Figure 5.2 Procedures for source zone characterization.

such information is unavailable or inadequate, representative contaminated soil samples should be collected from the release site and analyzed for a broad suite of chemical compounds, as appropriate, to identify the principal contaminants of concern. Appropriate laboratory indicator parameters and field testing procedures should then be selected on the basis of the prevalence, mobility, and toxicity of the principal constituents identified.

In Step 2 of the source delineation, a field sampling and testing program is conducted to define the apparent lateral and vertical extent of contamination within the unsaturated soil zone. At each soil sampling location, sampling and field testing should be conducted continuously with depth until either clean soil or ground water infiltration is encountered. As discussed in Section 5.4, typical field test methods for hydrocarbon contamination include organic vapor headspace analyses and various colorimetric indicator tests.

To confirm the apparent lateral and vertical extent of contamination observed in the field, samples of the uppermost "clean" soils encountered at each sampling location should be submitted for laboratory analysis of indicator parameter content (see Step 3, Figure 5.2). Representative samples from within the contamination zone should also be submitted for analysis of total and leachable contaminant indicator concentrations in order to characterize contaminant mass and mobility.

Delineation of the contaminated soil zone is an iterative process, often requiring two or more field and laboratory cycles for completion. Should the results of the source zone investigation show contaminants to have penetrated to the depth of underlying ground water at concentrations exceeding relevant cleanup standards, a ground water contamination study will also be required.

Procedures for Ground Water Contaminant Plume Delineation. The objective of a ground water contaminant investigation is to determine the presence and extent of dissolved or free-phase contaminants, as well as the likely rate and direction of contaminant migration within the ground water flow system. Principal steps to be followed are shown on Figures 5.3 and 5.4.

As indicated on the task flowchart, the ground water investigation must be preceded by identification and characterization of all potential source zones in the study area. A detection monitoring program, involving installation of 1 to 3 ground water sampling points at each known or suspected source location, should then be completed to identify all sites of hazardous constituent release to ground water.

Ground water plume delineation should be conducted in a step-wise procedure in order to minimize the number of ground water sampling points required. First, based upon the suspected age of the release and the lateral ground water seepage velocity determined during the detection monitoring study, estimate the potential length of the contaminant plume (i.e., seepage rate × time = length) and space sampling points accordingly along the plume axis to locate the actual downgradient boundary. Second, to define the width of the contaminant plume, complete additional sampling points on 1 or 2 lines running transverse to the plume axis. Finally, to determine the vertical limit of contaminant migration, collect and analyze ground water samples from "nested" sampling points (i.e., samples collected in close lateral proximity, e.g., < 10 ft distance, but from different discrete depths within the water-bearing unit).

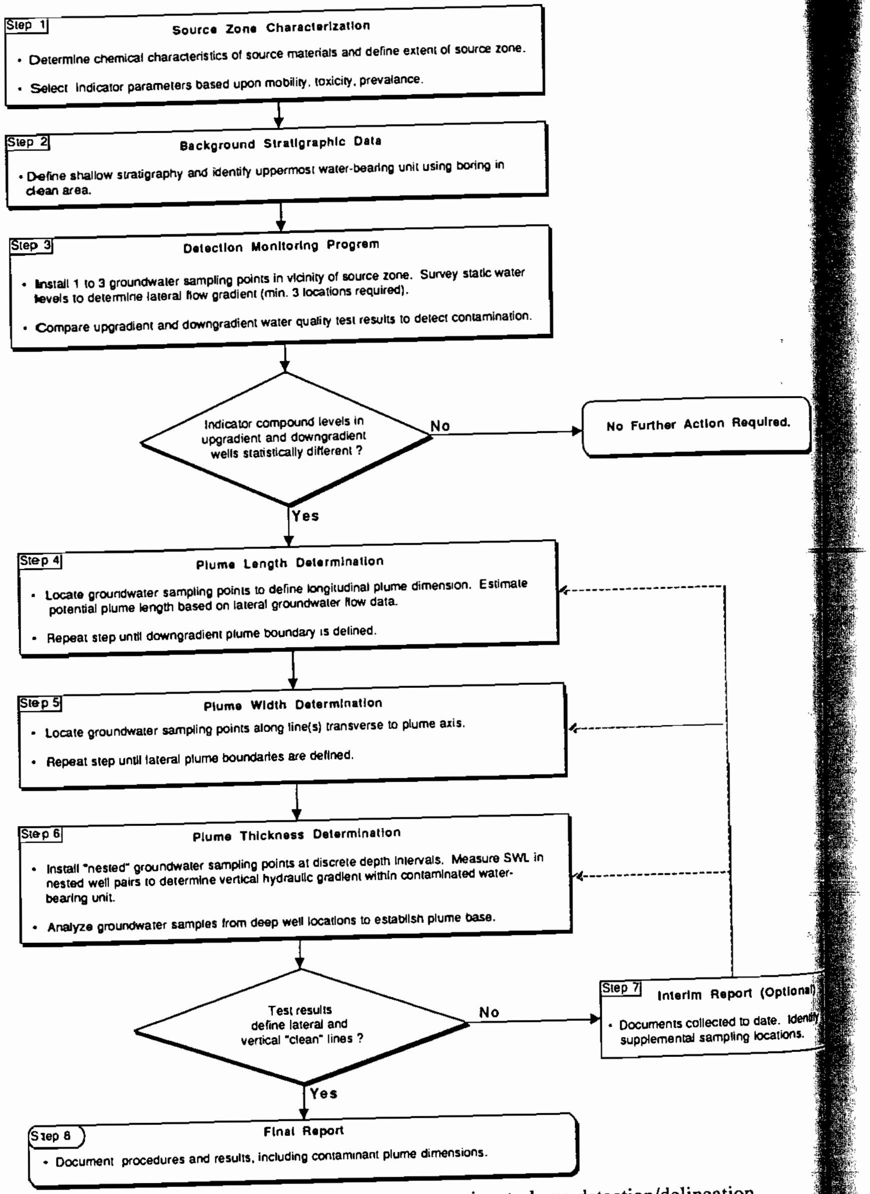


Figure 5.3 Procedures for ground water contaminant plume detection/delineation.

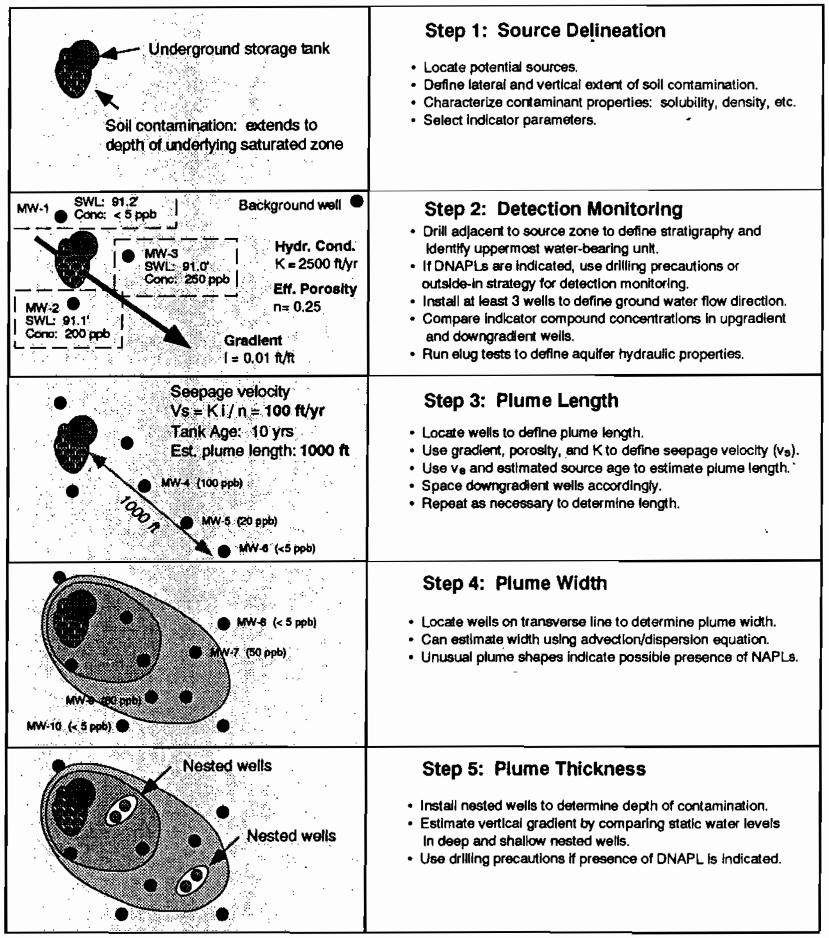


Figure 5.4 Typical work program for ground water plume delineation.

If the contaminant plume is found to extend through the full thickness of the uppermost water-bearing unit, sampling and analysis of ground water from the next underlying water-bearing stratum may be necessary to establish the vertical limit of contamination. In such case, it is critical that any observation points penetrating the confining layer separating the upper and lower water-bearing strata be completed in a manner not providing an artificial conduit for contaminant migration. Appropriate protective measures are discussed in Section 5.4.

5.4 DEVELOPMENT OF A DETAILED SITE INVESTIGATION WORKPLAN

Prior to commencing the hydrogeologic site investigation, the specific field and laboratory tasks required to implement the site investigation strategy described above should be identified and appropriate resources allocated. Preplanning activities should include specification of the number, location, and depth of soil and ground water samples to be collected; sampling procedures and associated equipment requirements; field safety protocol; and field and laboratory test methods. The proposed sampling plan should be reviewed in advance to ensure that the information obtained will be adequate to meet the geologic, hydrologic, and chemical data objectives of the source characterization or ground water plume detection/delineation study.

To provide a technical basis for planning of the site investigation, available site information must be compiled and reviewed to define the general location and duration of the suspected release, the probable contaminants of concern, and general stratigraphic conditions. Typical sources of information include site operating records, regulatory agency records, employee interviews, historical aerial photographs, published geologic references, prior foundation studies or hydrogeologic site investigation reports.

5.4.1 Project Objectives

Both the source zone investigation and the ground water plume investigation should be approached in a step-by-step manner. In addition, the project engineer or scientist must clearly anticipate the end point of the site investigation, as well as actions to be taken in the event that unexpected site conditions are encountered. For example, is the purpose of the sampling merely to confirm the presence or absence of a specific compound or to delineate its full extent? If ground water is encountered during a source characterization study, will a sample be collected for the purpose of contaminant detection?

It is not necessary or even advisable to complete a full hydrogeologic site investigation in one step. Rather, it will generally prove more economical to conduct the project in a phased manner with each work stage having a predefined objective and end point.

Based upon available information, a preliminary plan should be developed regarding the number, location, and depth of samples required to meet the project objectives. All proposed drilling locations should be staked and cleared in advance for the presence of buried utilities. Appropriate sample collection and handling procedures must be specified and relevant equipment provided in working order. Sample kits containing the sample containers and preservatives required for the specified analytical methods should be ordered from the laboratory.

The field supervisor should be provided with a written copy of the sampling plan and project safety plan, specifying project objectives, proposed sampling locations, field test procedures, and laboratory analyses, as well as the basis for modification of the proposed workplan during implementation. General guidelines for design of the field program are provided below.

5.4.2 Design of Unsaturated Source Zone Characterization Study

General guidelines regarding the number, location, and depth of sampling points required for a source zone characterization study are as follows:

Number and Location of Samples. For initial chemical characterization of the residual waste materials or affected soil zone, analysis of one to four samples collected from known contaminated areas will generally suffice. To define the lateral limits of the source zone, samples can either be located on a rough grid pattern across the suspected contaminant area or completed on a "step-out" pattern, whereby samples are collected at even distances along lines extending radially from the known source area until clean soil conditions are encountered.

To minimize the number of samples required for the source zone delineation, the field program should be focused on establishing the "clean line" (i.e., the perimeter of the contaminant area), rather than defining variations in contaminant concentrations within the source zone. In general, "clean" soil conditions will correspond either to (1) the natural background concentrations of the contaminant compounds occurring in site soils or (2) other cleanup standards established by the state or federal regulatory authority.

Sampling Depth. At each sampling location, soil samples should be collected continuously to the depth of clean soil conditions or to the depth of ground water occurrence, whichever comes first. However, care must be taken not to puncture confining layers (i.e., clay, shale, or other low-permeability strata) which might be serving as a "safety net" against downward migration of contaminants beneath the source zone. For this purpose, at sites where soil contamination may extend beyond the depth of the surface soil stratum, it is advisable to drill at least one "background" soil boring at a known clean location to define site stratigraphy prior to drilling through the contaminant zone.

Sampling and Field Testing Methods. Initial chemical characterization of the source zone materials will typically involve collection of wastes, spilled products, or affected soils for laboratory analyses of a broad range of hazardous chemical constituents potentially associated with the site. Thereafter, sample analyses may be limited to key indicator parameters, including the use of various field tests (such as organic vapor analyses or colorimetric methods). Hand augers may be used to collect soil samples at depths less than 5 ft below grade. For delineation of large contaminant areas or buried waste sites, backhoes are effective to depths of 10 to 15 ft. In general, direct-push soil probing devices or conventional drilling rigs represent the most cost-effective means of soil sample collection at depths greater than 10 ft.

measurements should be, at a minimum, calibrated against, and or confirmed by, "direct" data obtained from soil and ground water samples collected on site.

The following sections describe methods for the acquisition of geologic, hydrologic, and soil and ground water quality (chemical) data. The emphasis is on the more conventional techniques, employing direct observation and measurement of soil and ground water samples. Techniques employing indirect measurement of soil and water properties are treated more briefly, but their value should not be discounted. Use of indirect sampling methods in environmental assessments is an evolving field, and improvements in data quality and cost-effectiveness are likely to continue make such techniques increasingly common in the future.

5.5.2 Project Safety

Safety considerations should figure prominently into all drilling and sampling plans. A project health and safety plan meeting the requirements of 29 CFR §1910.120 is required by federal regulations (OSHA) for all investigations of hazardous waste sites. The plan should be distributed to and reviewed by all project personnel prior to project start-up. Prior to commencement of any drilling operation, the locations must be cleared for underground utilities.

5.5.3 Documentation of Site Conditions

Documentation of field sampling procedures and observations is a critically important aspect of the hydrogeologic site investigation. Without reliable records, the results of field sampling program may be of no value. Therefore, all measurements and relevant observations must be clearly and legibly recorded either in field logbooks or on data collection forms. Subjective observations, a necessary component of the field record should be made in the most precise, unambiguous language possible. In addition to the sample measurements and descriptions, the log should record any site conditions that could affect the observations or measurements, and any deviations from the established scope of work or sampling protocols.

5.6 GEOLOGIC DATA ACQUISITION

5.6.1 Direct Observation Methods

The essential geologic data required in all hydrogeologic site investigations is a description of the principal stratigraphic units underlying the site, including their thickness, lateral continuity, and water-bearing properties. This is most commonly assessed by direct examination of soil or rock samples collected from core borings. Soil samples collected during this process are also typically submitted for analysis of potential contaminants.

On sites underlain by unconsolidated materials and where drilling depths are shallow (100 ft or less), the collection of core samples from soil borings is a generally cost-effective method of collecting geologic data. In areas underlain by consolidated rock, where site conditions require investigation at greater depths, and where the cost of disposal of investigation-derived wastes (IDWs) is high due to classification of these materials as hazardous wastes, the collection of core samples is more costly and may be augmented or replaced in part by cone penetrometer testing, or surface or borehole geophysical methods, which are described below.

5.6.2 Drilling Methods

A variety of drilling methods are employed during hydrogeologic site investigations. Selection of the drilling method depends on such factors as drilling depth, nature of the geologic formations under investigation, and the specific purpose of the boring, that is, lithologic sampling, soil sampling for chemical analysis, and/or well installation. An additional consideration is the volume of drill cuttings and fluids that are produced, especially at sites where these investigation-derived wastes (IDWs) must be disposed as a hazardous waste.

This summary is intended to be only a brief introduction to the most common drilling methods used in the environmental industry. Driscoll (1986) presents detailed descriptions of drilling techniques used in the water well industry generally. Scalf et al. (1981) includes a description of drilling techniques which focuses on environmental applications.

In conducting environmental site investigations, the introduction of foreign materials into the borehole is generally undesirable due to the possibility of reaction with the geologic media or ground water, which may affect the results of laboratory analysis of soil or ground water samples. Even when a potable water source is used in the preparation of drilling fluids, chlorine may react with naturally occurring organic material in the soil to produce detectable concentrations of trihalomethane compounds (such as chloroform and dichlorobromomethane) in the ground water. Therefore, drilling is frequently performed "dry," that is, without the use of drilling fluids or "mud." Drilling dry also allows identification of the depth of the first occurrence of ground water. When ground water is first encountered, drilling operations should be halted long enough to observe whether or not water rises in the borehole, to determine whether ground water is confined or unconfined. Some drill rigs are equipped for both wet and dry drilling methods and can be switched from auger drilling above the water table to wet-rotary below it. Dry drilling is most commonly performed using either solid-flight or hollow-stem augers as described in the following paragraphs.

Solid Flight Auger Drilling. Solid flight augers consist of sections of solid rod with a continuous ramp of upward spiraling "flights" welded around it (Figure 5.5). The auger sections (each typically 5 ft in length) are pinned together as drilling proceeds. As the drill-stem is rotated, cutting teeth on the lead auger dig into the formation and the loosened soil rides up the flights to the ground surface. The "string" of auger sections is "tripped" out of the hole at each soil sample interval, and samples are collected by hydraulically pushing a thin-walled steel sampling tube ("Shelby tube") or driving "split-spoon" sampler with a percussion hammer, into the underlying undrilled formation. The drill string is then "tripped" back into the hole, and drilling proceeds to the next sample point.

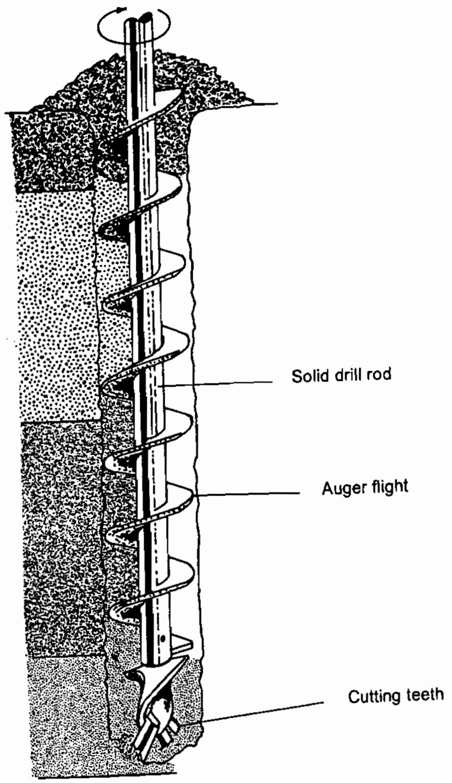


Figure 5.5 Solid-flight auger drilling equipment. Source: Scalf, et al., 1981.

Solid-flight augers are effective in cohesive soils above the saturated zone. Because of the tendency for borehole walls to collapse when the drill string is tripped in and out of the hole, solid flight augers are not useful in loose soils or below the water table and are not generally suitable for monitoring well installation.

Hollow Stem Auger Drilling. Hollow-stem augers are another type of flight auger, but instead of being welded to a solid rod, the flights are welded around a hollow pipe (Figure 5.6), The lead auger is fitted with cutting bits located around the circumference of its

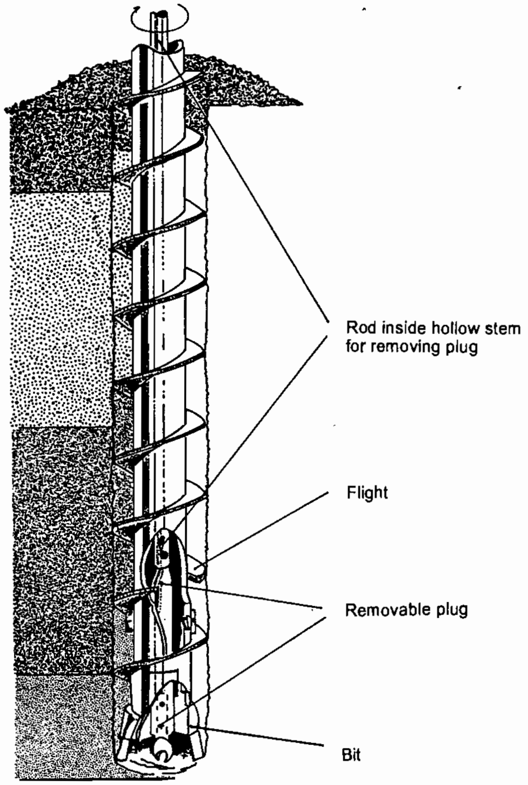


Figure 5.6 Hollow-stem auger drilling and soil sampling equipment. Source: Scalf, et al., 1981.

base. During drilling, a center rod equipped with a pilot bit is lowered inside the auger, and the center rod and hollow-stem are rotated together.

As drilling proceeds, loosened soil rides up the outer ramp of auger flights as with the solid flight auger. A plug, positioned above the bit, prevents soil from traveling up the inside of the hollow-stem. When the sample interval is reached, the center rod, plug, and bit are removed, and the soil sampling tool is lowered inside the hollow-stem, which remains in the borehole to prevent collapse of the walls. The sampling tool, typically a split-spoon or

Major Divisions			Graph symbol	Letter symbol	Typical descriptions
Coarse-grained soils More than 50% of material is larger than no. 200 sieve size	Gravel and gravelly soil More than 50% of coarse fraction **retained** on a no. 4 sieve	Clean gravels (little or no fines)	⁘	GW	Well-graded gravel-sand mixtures, little or no fines
			●	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
		Gravels with fines (appreciable amount of fines)	▥	GM	Silty gravels, gravel-sand-silt mixtures
			▨	GC	Clayey gravels, gravel-sand-clay mixtures
	Sand and sandy soils More than 50% of coarse fraction **passing** a no. 4 sieve	Clean sand (little or no fines)	░	SW	Well-graded sands, gravelly sands, little or no fines
			⁞	SP	Poorly graded sands, gravelly sands, little or no fines
		Sands with fines (appreciable amount of fines)	▥	SM	Silty sands, sand-silt mixtures
			▨	SC	Clayey sands, sand-clay mixtures
Fine-grained soils More than 50% of material is smaller than no. 200 sieve size	Silts and clays	Liquid limit **less** than 50%	▥	ML	Inorganic silts and very fine sands, rock flour silty or clayey fine sands or clayey silts with slight plasticity
			▨	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			⁞	OL	Organic silts and organic silty clays or low plasticity
	Silts and clays	Liquid limit **greater** than 50%	▩	MH	Inorganic silts, micaceous or diatomaceous fine sand or silty soils
			▨	CH	Inorganic clays or high plasticity, fat clays
			▨	OH	Organic clays of medium to high plasticity, organic silts
Highly organic soils			☰	PT	Peat, humus, swamp soils with high organic contents

Figure 5.12 Unified soil classification system.

organic material, root zones, burrows, calcareous or other mineralized zones, and desiccation features frequently provide avenues of contaminant migration through low-permeability soils into underlying aquifers.

Other descriptive features such as color should be noted to the extent that they can be used to distinguish strata of similar composition from one another and may sometimes provide consistent stratigraphic markers, such as a gray clay overlying a red clay.

Rock Classification and Description. Rocks are broadly classified in terms of their origin as igneous (those having formed from a molten fluid, or magma), metamorphic (those having formed by recrystallization of a pre-existing rock subjected to heat and/or pressure), and sedimentary (those having formed from deposition and consolidation of soil or rock particles or as chemical precipitates from mineral saturated water. Core samples should be logged in terms of their mineralogic composition, as well as their water-bearing (Hunt, 1984).

Sedimentary rocks that have formed by accumulation and consolidation of soil or rock fragments, ranging in size from fine powders to house-sized boulders, are referred to as clastic or detrital rocks. The most commonly encountered water-bearing varieties include sandstones and conglomerates (rocks composed of grains of variable sizes, e.g., gravel and sand). The porosity in these rocks may be primary (intergranular porosity, as encountered in well sorted, poorly cemented sandstones) or secondary (fracture porosity, as may be encountered in well-cemented, jointed rocks), or both. Rocks which formed by chemical precipitation from a mineral-saturated water body include carbonate rocks (limestones and dolomites) and the less common evaporites (halites, gypsum, and anhydrites). Porosity in these rocks is usually secondary, occurring as fractures or solution cavities. The water-bearing capacity of sedimentary rocks can also be influenced by the degree of weathering.

In igneous and metamorphic rocks, significant water flow is generally limited to within fractures. A notable exception to this rule is vesicular basalt, which may have significant primary porosity due to entrapment of gas bubbles in the molten lava as it cooled and hardened.

5.6.6 Cone Penetrometer Testing

Subsurface formations can also be logged or inferred from a variety of what may be referred to as indirect methods; methods in which soil or rock is characterized by instrumental measurement of geophysical properties, rather than direct examination of pieces of the formation. Such methods can dramatically speed up the investigation, limit the potential for exposure to hazardous constituents, and minimize the need to manage investigation-derived wastes, all of which help control investigation costs. However, by their nature, such data must be interpreted, and interpretations are not necessarily unique, since more than one subsurface condition may produce an identical instrument response. Therefore, indirect methods should be used in conjunction with direct observation methods and instrument response calibrated to subsurface conditions whenever possible.

Originally developed for geotechnical investigation, the cone penetrometer test (or CPT) can be useful for defining stratigraphy to depths of up to 100 ft (rarely more) in fine-grained soils and unconsolidated sands. In cone penetrometer testing, electronic strain gauges mounted in a steel cone-shaped probe are pushed at a constant rate into the subsurface by a

Apart from the inherent disadvantage of any indirect measurement (i.e., that the data are subject to interpretation), the major disadvantage of the cone rig is its size and weight, which can limit its mobility, particularly on unpaved sites.

5.6.7 Borehole and Surface Geophysical Methods

Subsurface geological conditions can also be evaluated indirectly using a variety of geophysical methods. Geologic strata or other buried features are differentiated by measuring the contrasting responses of differing geologic materials to physical forces such as electricity, magnetism, or seismic energy, or by measuring physical properties inherent in earth materials such as naturally occurring radioactivity. Geophysical methods are broadly divided into surface methods and borehole methods. Zohody et al. (1984) and Keys and MacCary (1971) provide guidelines for the applicability, acquisition, and interpretation of surface and borehole geophysical data, respectively.

In surface geophysical surveys, measurements are collected at regularly spaced intervals along a traverse or on a grid to produce a subsurface profile. Examples include conductivity surveys, most commonly used to identify salinity contrasts within an aquifer; magnetometer surveys, frequently used to identify buried drums, tanks, or ordnance, and ground penetrating radar (GPR), useful for identifying large scale buried geological or man-made features. The chief advantage of such methods is that broad regions of the subsurface can be surveyed rapidly in a noninvasive manner.

Borehole techniques utilize a variety of probes or sondes that measure physical properties of the soil or rock or contrasts between the drilling fluid and the fluids in the formation. Methods such as spontaneous potential and natural gamma ray logging are often used in lieu of core sampling to reduce costs, particularly when drilling conditions are difficult and required drilling depths are deep.

Application of surface and borehole geophysical methods to the environmental industry has been limited by the fact that a unique and definitive interpretation of the data is not generally possible. Because identical responses can be caused by a variety of conditions, the use of two or more types of measurements with interpretation by a highly knowledgeable specialist is frequently required to eliminate ambiguity. The need to run numerous tests, especially those employing the more sophisticated techniques, limits the ability of geophysical methods to compete cost-wise with drilling and sampling at shallow depths.

5.7 HYDROLOGIC DATA ACQUISITION

Assessment of the direction and rate of ground water flow beneath a site requires the following hydrologic data: lateral hydraulic gradient, hydraulic conductivity, and effective porosity. Of these, hydraulic gradient and conductivity are obtained by field measurements made in monitoring wells. Effective porosity (i.e., connected pore spaces through which ground water flows) is generally an estimated value (see Chapter 2). Because such determinations are most

commonly made from measurements in piezometers and monitoring wells, we begin with a description of monitoring well construction.

5.7.1 Monitoring Well Construction

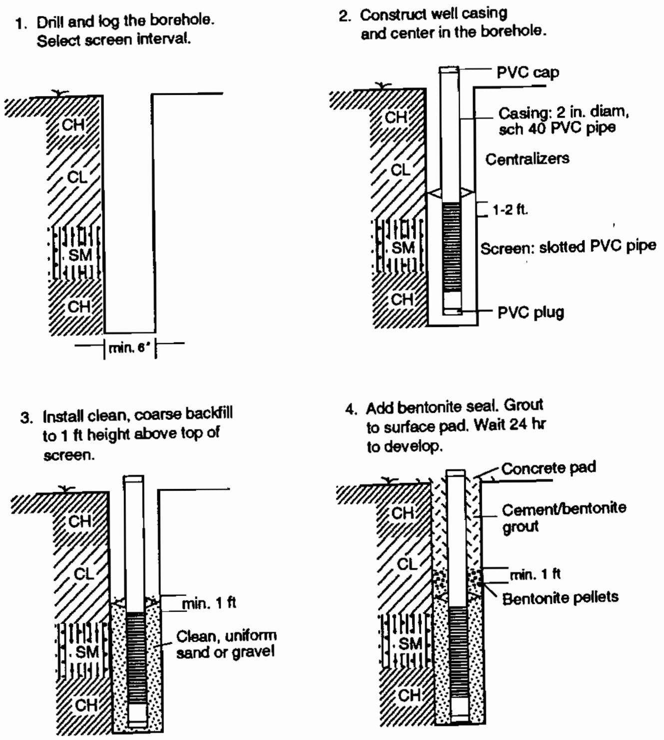
The monitoring well is the primary source of hydrologic and ground water quality data used in hydrogeologic site assessments. Most of the special requirements for monitoring well construction are due to their use in the collection of ground water quality data. For collection of hydrologic data, a piece of slotted pipe inserted into a borehole would be sufficient in most instances, but because of the dual purpose monitoring wells serve, careful attention must be paid to the materials used and the methods of construction. Many state environmental regulatory agencies have very particular construction specifications and require that well installation be performed by licensed drillers.

Hydrogeologic site investigations frequently require installation of a permanent monitoring well network to permit resampling and evaluation of changing site conditions. However, monitoring well installation is fairly expensive. To reduce the cost of a ground water plume delineation program, the use of temporary ground water sampling points is becoming increasingly common. A variety of configurations may be installed using a drill rig, direct-push soil probe rig, or cone penetrometer rig to provide samples for lateral and vertical plume delineation in a fraction of the time required to install a well. Following delineation, a relatively small number of permanent wells can be installed at strategic locations and depths to confirm plume boundaries and facilitate future monitoring.

The essential elements of a monitoring well are the well screen and riser, the filter pack, and the annular seal (Figure 5.15). The well screen, typically a section of slotted pipe, allows water to flow from the formation into the well while screening out coarse soil particles. The riser is a solid-walled or "blank" pipe that connects the well screen with the surface. The filter pack, also referred to as the sand or gravel pack, limits the influx of fine surface. The filter pack, also referred to as the sand or gravel pack, limits the influx of fine sediment from the formation. Above the gravel pack, a seal composed of low permeability material prevents fluids from above the screened interval (including percolating rainwater) from entering the well.

Well Design. Monitoring wells should be designed on the basis of the purpose of the well, the hydrogeologic setting, and the expected contaminants in the ground water, as well as cost. Monitoring objectives will determine such factors as the length and placement of the screen interval. Construction materials that are selected should minimize the potential for reaction with the formation fluids and the expected contaminants while providing adequate strength to withstand the pressures exerted by the formation.

For measuring the potentiometric surface, wells screens are positioned to intersect the top of the aquifer in confined flow systems, or to straddle the expected zone of water table fluctuation in unconfined aquifers. Placement of the screen across the top of the water-bearing zone permits detection of floating accumulations of light nonaqueous phase liquids (LNAPLs), while for investigation of dense nonaqueous phase liquids (DNAPLs), intersec-


1. Drill and log the borehole. Select screen interval.

2. Construct well casing and center in the borehole.

3. Install clean, coarse backfill to 1 ft height above top of screen.

4. Add bentonite seal. Grout to surface pad. Wait 24 hr to develop.

Figure 5.15 Typical monitoring well installation.

tion of the screen with the base of the aquifer is more appropriate. Long screen sections yield water samples representing an average of conditions across their length; shorter screens (10 ft or less) yield more depth-specific data and are generally preferred, since low levels of contamination present over a limited depth interval may be overlooked due to dilution of the sample by uncontaminated water from elsewhere in the screen interval. In general screens in excess of 15 ft are avoided. Well diameters of 2 in. and 4 in., installed in 6 in. and 10 in. diameter boreholes, are most common.

To establish the vertical extent of ground water contamination, it may be necessary to drill monitoring wells through a contaminated upper zone into an uncontaminated lower zone. In such cases, it is necessary to first install isolation casing, consisting of a length of blank pipe sealed in place with cement or grout to prevent entrainment of contaminants from the upper zone to the lower zone during drilling. Once the casing is installed, drilling and well installation are resumed within the casing.

Materials of Construction. Well screens and risers are most commonly constructed of PVC. Threaded joints are generally specified, since the use of glues that contain organic solvents is discouraged. However, PVC reacts with some contaminants and is not always suitable. For example, high concentrations of chlorinated solvents can attack PVC, compromising ground water samples or damaging the well. In addition, the strength of PVC may not be adequate for very deep installations. Stainless steel is frequently used under such conditions, at significantly greater expense. Materials such as Teflon minimize reaction with contaminants, but their use is usually cost-prohibitive. Information on compatibility of various well materials with common contaminants can be found in Driscoll (1986).

Filter packs should be composed of graded silica sand. Blasting sand and other general-use sands may contain minerals that adsorb dissolved metals, potentially compromising the integrity of the ground water sample. The grain size interval of the filter pack material should be selected based on analysis of aquifer grain size distribution as described by Driscoll (1986).

Annular seals are most often composed of bentonite, frequently in combination with other materials. A 1 ft. to 2 ft. thick layer of bentonite pellets is usually placed atop the filter pack to protect the filter pack from invasion by the grout, which completes the seal to the ground surface. Grout may be composed of neat Portland cement, a mixture of cement and powdered bentonite, or other specialty materials such as Volclay.

Installation Procedures. In monitoring well installation, both the drilling and sampling equipment and the well construction materials must be free of contamination to prevent contamination of collection of ground water samples. Drilling equipment should be cleaned with pressurized hot water or steam and detergent, as needed, prior to drilling at each location. Well screen and riser should be packaged and handled to prevent fouling prior to well installation. Drilling and sampling personnel should handle the well pipe with clean gloves.

When wells are drilled using hollow-stem augers, the well screen and riser are lowered within the augers. For rotary drilled wells, the well is lowered within the open borehole. Drilling mud should be thinned by dilution with potable water to the extent practical prior to well installation to facilitate well development. A bottom cap or plug at the base of the well pipe prevents the flow of sediment into the bottom of the well. Silt traps or sumps, consisting of a short section of riser are frequently installed beneath the well screen to prevent fine sediment entering the well from accumulating in and clogging the screened interval. In deeper wells, "centralizers" may be placed above the screen section to maintain distance from borehole wall and ensure proper filter pack placement. Proper placement of the screen should be verified by careful measurement.

Once the screen and riser are in position, the filter pack is installed within the annulus around the well screen (Figure 5.15). The filter pack is generally placed from the base of the well to 1 ft to 2 ft above the top of the screen. In wells drilled by hollow-stem, the filter pack material is usually poured down the inside of the augers. The auger sections are pulled from the hole one at a time as the annulus is filled with sand. In deeper wells and wells drilled by wet rotary methods, it is frequently placed using the tremie method. Potable water is used to wash the filter material down a pipe lowered to the base of the well.

Following placement of the filter pack, the well is sealed to the ground surface to prevent migration of fluids from the surface or water-bearing zones above the screened interval down the borehole. Grout is frequently placed using the tremie method to ensure even placement up the borehole.

Monitoring wells are completed at the surface with a locking caps and/or casing to prevent tampering and a concrete surface pad to protect the annular seal. The elevations of the ground surface and top of well casings should be surveyed relative to a common datum such as mean sea level or an arbitrary datum established by a site benchmark. Top of casing elevations are required to convert depth to water measurements to static water level elevations and should be surveyed to the nearest 0.01 ft, and the point of measurement marked on the top of the well casing.

Well Development Procedures. Following installation, wells are developed to remove fine sediment and drilling mud from the filter pack and ensure collection of ground water samples that are representative of formation conditions, and prevent clogging of the well screen and pump damage. If the well has been installed in a low permeability aquifer using a dry drilling method, bailing out three to ten casing volumes may be sufficient to permit collection of representative ground water samples. If fluids have been introduced during drilling, larger volumes of water must be removed.

Development usually consists of a combination of pumping and surging. Surging the well, by running a close fitting cylinder up and down the inside of the well over the screened interval, causes a back-flushing action in the gravel pack, loosening fine sediment. Pumping from the well (preferably at a rate higher than the expected normal pumping rate) pulls fine sediment through the well screen into the well where it can be pumped to the surface.

5.7.2 Determination of Ground Water Flow Gradients

Ground water flow gradients are determined by measurement of water level elevations in site wells. In addition to the lateral gradient, determined by measurement of wells within the same water-bearing zone, the vertical gradient may be determined by measurement of closely spaced "nested pairs" of wells screened in different aquifers or within the upper and lower portions of the same aquifer. The presence of surface water features should be noted and surface water elevations determined to evaluate possible recharge/discharge relationships. The presence and discharge rate of any pumping wells on site should also be noted.

The water level in each well is measured to the nearest 0.01 ft using an appropriate instrument such as a water-sensitive probe on a graduated tape. The elevation of the potentiometric surface is obtained by subtracting the depth to water from the top of casing elevation. Ideally, water level surveys represent the potentiometric surface at one instant in time. Therefore, measurements should be made in as short a time frame as possible, since water levels within wells respond to such factors as barometric pressure or tidal influence. On sites with large numbers of wells, requiring several hours to survey, the first well measured should be remeasured at the end of the survey to detect possible changes in the potentiometric surface during the period of the survey. If more than one instrument is to be used in the survey, a common well should be measured simultaneously using each instrument to confirm that all instruments give the same reading.

On sites with LNAPLs, the water level survey should also include inspection of wells for the presence floating free-phase layers. If an LNAPL accumulation atop the water column is found, the water level must be corrected for its presence. The thickness of the LNAPL layer, measured with minimal disturbance using an electric interface probe, is multiplied by the specific gravity of the LNAPL (e.g., 0.75 for a typical gasoline). This value is added to the *measured* water level elevation to obtain the *corrected* water level elevation. (Note that the thickness of an LNAPL layer in a well is influenced by a number of factors and typically does not reflect an equivalent accumulation in the adjacent formation).

Upon completion of the survey, water level elevations are plotted on a scaled site map and potentiometric surface contours are drawn, and lateral and vertical flow gradients are determined as described in Section 5.8.

5.7.3 Determination of Hydraulic Conductivity

Slug Tests. Single-well slug tests are a common, cost-effective method for the estimation of hydraulic conductivity in hydrogeologic site assessments. Two major varieties, rising-head tests and falling-head tests can be used. Falling-head tests are more difficult to perform and analyze, and require addition of water to the well. Therefore, rising-head slug tests are more commonly performed.

During a rising-head test, the static water level in the well is first measured and then a "slug," typically a solid cylinder, of known volume is lowered within the well to just below the static level. Following re-equilibration of the water level in the well with that in the aquifer, the slug is removed from the well instantaneously, causing a sudden drop in the water level or head. The return of the water level to static conditions is then monitored. The rising head can be measured by hand in low permeability systems. Higher yield systems may recover too quickly to permit manual collection of the most critical early data, and require the use of pressure transducers placed in the well and monitored with an electronic data logger.

The resultant change in head over time is plotted on semi-log paper, and the curve analyzed according to one of several methods, depending on aquifer and well conditions. The method of analysis will depend on such factors as whether the aquifer is confined or unconfined, and what percentage of the saturated interval is screened in the well. Analytical methods for slug tests are described in Chapter 3.

Slug tests evaluate only the portion of the aquifer immediately surrounding the tested well. Therefore, tests should be performed at a selection of site wells, to best represent the variability in hydraulic conductivity for the aquifer.

Constant-Rate Pump Tests and Well Performance Tests. While slug tests provide reasonable estimates of hydraulic conductivity, they evaluate only the portion of the aquifer immediately adjacent to the well and are generally not adequate for the detailed design of a ground water pumping system. Constant-rate aquifer pumping tests are used to characterize conditions over a larger portion of the aquifer by measuring the response of the aquifer to pumping at observation wells located some distance from the pumping well, typically over a period of 24 hrs. or more. Analysis of constant rate tests is performed by plotting water level drawdown in individual observation wells versus elapsed pumping time, or drawdown in two or more observation wells versus distance from the pumping well at a specific time. The resulting curves are used to calculate aquifer transmissivity and storativity, well efficiency, and radius of influence, all of which are necessary for design of an efficient ground water pumping system. The more common methods of analysis are summarized in Chapter 3. Because constant rate tests are expensive to conduct, they are usually deferred until the detailed design phase of a ground water remediation program.

Stepped-rate well performance tests provide a measure of the specific capacity (discharge rate, Q, divided by drawdown, s) of a pumping well, from which transmissivity, T, [gpd/ft] can be estimated from the empirical relationship $Q/s = T/2000$ for a confined aquifer, or $Q/s = T/1500$ for unconfined units. Small scale well performance tests can be conducted during well development at relatively little extra cost. A stepped-rate pumping test, also referred to as a step-drawdown test, is generally conducted before a constant-rate aquifer pump test to determine the optimal pumping rate for the latter test. During a stepped rate test, the well is pumped at a constant rate until the water level in the well stabilizes. The specific capacity of the well is calculated, and the pumping rate can then be increased (stepped up) and the water level observed until it stabilizes again.

5.8 ACQUISITION OF SOIL AND GROUND WATER QUALITY DATA

Chemical analysis of soil and ground water samples is required to identify the contaminants, quantify their respective concentrations, and delineate their lateral and vertical extent. This section describes procedures for collection and handling of soil and ground water samples. The following discussion is intended only as a general guide. The project workplan should specify sampling and analysis protocol based on project goals and applicable regulations or guidelines.

5.8.1 General Sampling Procedures

To assure collection of data that accurately represent site conditions, proper protocol must be followed during sample collection and handling. In addition to providing design basis information for site clean-up, the data must also be of a quality acceptable to regulatory agencies. Data may also be admitted as evidence in legal proceedings and must withstand the scrutiny of opposing legal counsel.

Measures must be taken to ensure sample integrity, for example, to prevent the loss of contaminant mass from the sample as by volatilization or biodegradation. Equipment and tools that contact the samples should be composed of stainless steel, Teflon, or other materials, which will not react with the contaminants in the sample. Samples should be sealed in appropriate sample containers with preservatives specified by the analytical method (often an acid to inhibit microbial activity). Samples are retained on ice pending delivery to the laboratory and there refrigerated until tested to prevent loss of volatile constituents.

Equally important is preventing the introduction of contaminants into the sample from some other source (cross-contamination). The use of disposable or "dedicated" equipment minimizes the potential for cross-contamination. Alternatively, sampling equipment should be thoroughly cleansed between sample locations. Where possible, locations should be sampled in order of increasing contamination to minimize the possibility of cross-contamination between locations.

Most analyses have a specified maximum holding time between sample collection and analysis. Samples should be transported to the laboratory as expeditiously as possible, generally within 24 hrs. of collection. The shipment of samples must be accompanied by a chain-of-custody form, which includes the signatures and affiliations of the personnel collecting, relinquishing and receiving the samples, as well as the date and time of the transfer. Essential sample collection data (sample identification number, date, and time of collection) and the specifications of the laboratory program must also be included.

Soil Sample Collection and Handling Procedures. Soil samples should always be collected using clean sample tools composed of inert materials, such as stainless steel, Teflon, or nonreactive plastics. Tools should be thoroughly cleansed using hot water, steam, and/or detergents and rinsed, preferably with deionized water prior to use and between sampling locations.

Soil samples should be collected in clean glass jars (unless otherwise specified by laboratory procedure) with tight-fitting lids, and identified with an appropriate label bearing the unique identification number of the sample. The outer surface of soil cores should be trimmed using a clean knife prior to shipment to the laboratory to ensure that soils that have been in contact with formation fluids above the sample point or with the inside wall of the sampler are not tested.

Ground Water Sample Collection and Handling. Ground water sampling is usually preceded by measurement of water level in the well. The well should also be inspected for the presence of NAPLs using a hydrocarbon interface probe or transparent bailer, if there is reasonable potential for them to be present, and any accumulation or sheen is noted. Because ground water samples containing "free product" may not accurately represent dissolved phase concentrations, samples from wells containing NAPLs are frequently not analyzed.

To ensure collection of ground water samples that are representative of formation conditions to the maximum extent practical, monitoring wells are usually "purged" of water that has been standing in the well by pumping or bailing. Removal of three to five saturated casing volumes is a generally accepted minimum purge. Alternatively, wells are purged until measurements of water quality parameters such as temperature, specific conductance, and pH have stabilized. Samples are then collected in appropriate containers and preserved as specified by the analytical method.

As an alternative method, so-called low-flow purging and sampling has been gaining wider acceptance in recent years. The pump intake is set within the screen interval and water is pumped at a rate as low as 0.1 L/min. so that minimal drawdown occurs. Water quality

Used in conjunction with a temporary ground water sampling installation, these methods can result in significant savings to the project budget by rapidly providing screening level data preventing the installation of an unnecessary number of monitoring wells. However, the cost of the test kit and time required to perform the extraction and analytical procedures, and the limited quality of the data must be weighed against the cost of a more definitive laboratory analysis to ascertain whether such tests are worth conducting. Field screening tests generally do not have detection limits sufficiently low to provide definitive ground water plume delineation. The quality control and repeatability of the data are also inadequate for regulatory purposes in most instances. Therefore, results are generally confirmed by laboratory analysis of duplicate samples.

5.9 DATA EVALUATION PROCEDURES

Upon completion of the field and laboratory programs, site data must be integrated to construct a working model of contaminant plume migration within the ground water flow regime. As discussed earlier in this chapter, the key components of this hydrogeologic site characterization are the geologic, hydrologic, and chemical data defining the occurrence and movement of fluids in the subsurface and the entrainment of contaminants in this natural flow system. Procedures for data organization and presentation are outlined below.

5.9.1 Geologic Data Evaluation

Available geologic data must be compiled to define the lateral and vertical configuration of permeable and impermeable strata comprising the framework within which subsurface fluids collect and flow. Conventional data presentation techniques include the following.

Scaled geologic logs should be prepared for each soil boring, monitoring well, or geophysical profile completed on the site. As shown in Figure 5.16, in addition to a description of the type and thickness of each stratum encountered, the log should indicate the drilling location, ground surface elevation, drilling method, depth of ground water occurrence, driller identification and date of completion (Hunt, 1984). For monitoring wells, as-built diagrams should be prepared showing well construction and static water elevation with respect to stratigraphy.

Cross-section diagrams should illustrate the bedding and lateral continuity of the principal stratigraphic units underlying the site. General guidelines for cross-section preparation are provided in Hunt, 1984 and Tearpock and Bischke, 1991. Given the extreme variability of shallow strata, care should be taken to avoid extrapolation of stratigraphic interpretations beyond the area of available geologic logs. An example is provided on Figure 5.17.

Structure maps and isopach drawings can be employed to characterize the physical constraints on ground water or contaminant flow through a water-bearing unit. Within a confined aquifer unit, a structure map (i.e., a topographic map of the upper surface of the water-bearing unit) can be used to identify topographic highs or "traps" wherein floating

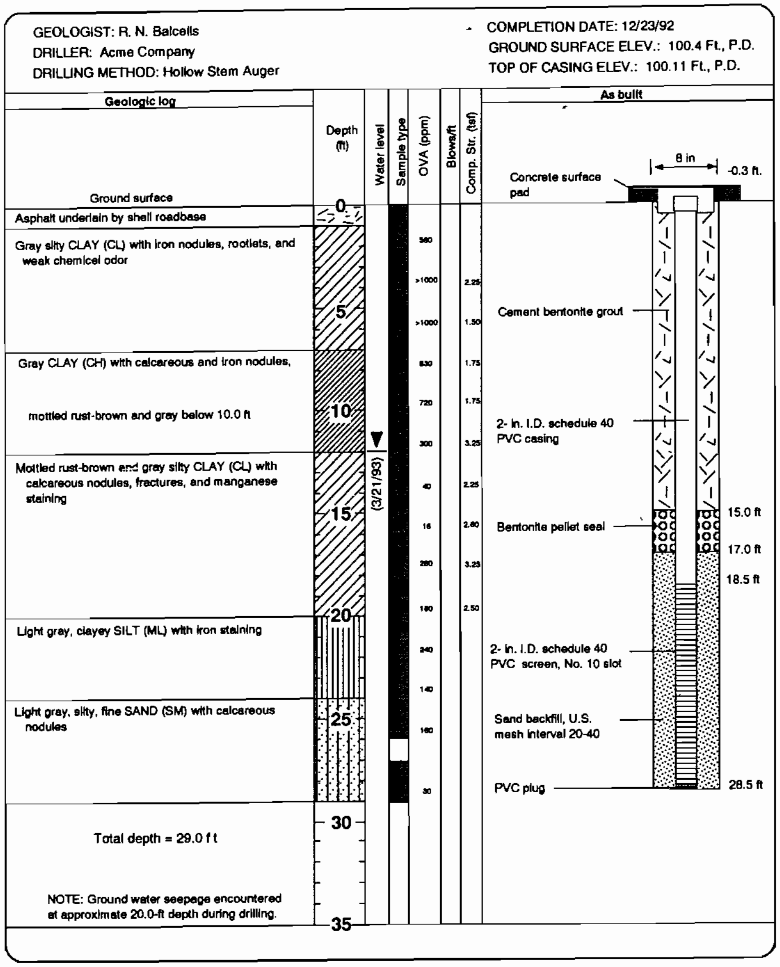


Figure 5.16 Typical drilling log and as-built diagram for monitoring well.

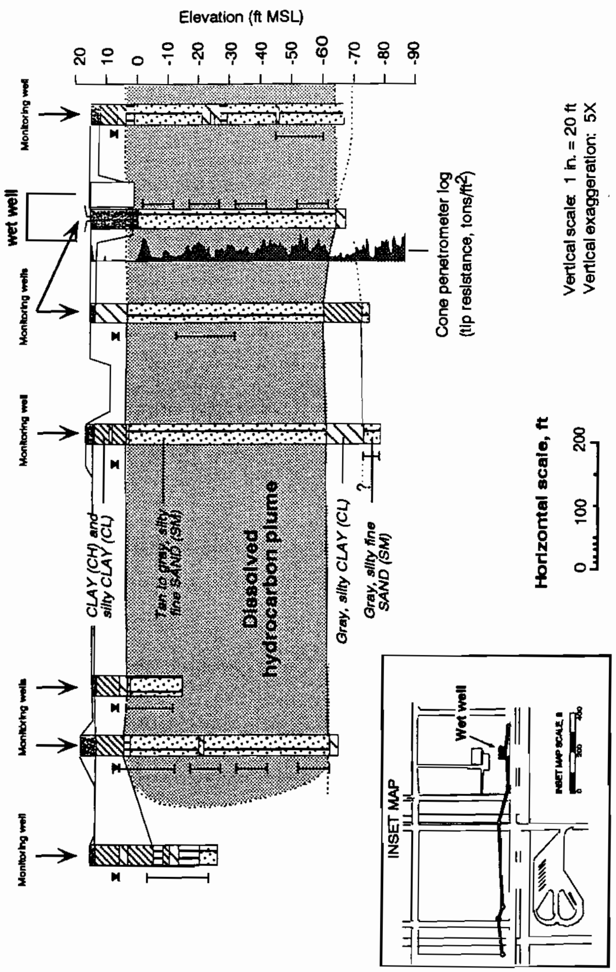


Figure 5.17 Geologic cross-section, west-east orientation, Case Study 1.

hydrocarbons might collect. Isopach drawings (i.e., contour maps of the thickness of the water-bearing stratum encountered at each drilling location) clearly illustrate lateral discontinuities or "pinch-outs" of the aquifer unit, as well as preferential flow paths.

5.9.2 Hydrologic Data Evaluation

Hydrologic data collected during the site investigation should be evaluated to define the direction and rate of natural ground water flow through the principal water-bearing strata underlying the study area. Data evaluation requirements include the following analyses.

Geologic logs and cross-sections should be reviewed to identify the uppermost water-bearing stratum underlying the site. Typically, this will be the first water-saturated stratum encountered beneath the site with sufficient hydraulic conductivity to yield water to wells (e.g., $K > 10^{-4}$ cm/sec). Static water levels should be superimposed on geologic log and cross-section diagrams to classify the aquifer unit as either confined (static water level above top of water-bearing unit), unconfined (static water level below top of water-bearing unit), or partially confined (confined at some locations and unconfined at other locations).

Within permeable strata, ground water movement is primarily horizontal, with a slight dip in the direction of flow. To define lateral ground water flow patterns, static water level elevations measured within monitoring wells or piezometers screened within the same water-bearing stratum should be plotted on a scaled site plan, and the values contoured to develop a potentiometric surface map of the water-bearing unit (Figure 5.18). Ground water flow is perpendicular to such equipotential lines, in the direction of lower hydraulic head. A potentiometric map calculates the lateral hydraulic flow gradient ($\Delta h/L$) is calculated as the change in head (Δh) divided by the lateral distance (L) between equipotential lines, and is commonly expressed as a dimensionless value (i.e., ft/ft). Alternatively, hydraulic gradient can be determined by means of triangulation between any three well locations as described in Heath, 1983.

The vertical hydraulic flow gradient within a single water-bearing stratum can be determined by comparison of static water level elevations from "nested" well pairs screened at different depths within the same unit. In such case, the vertical gradient is estimated as the difference in static water level elevations (Δh) divided by the vertical distance between the midpoints of the well screens. Vertical gradients between separate water-bearing strata can be determined either from nested well measurements or comparison of potentiometric surface maps at any one point.

The hydraulic conductivity of a water-bearing stratum can be measured by means of single-well slug tests or constant-rate aquifer pumping tests conducted on wells screened within that unit. Test procedures and calculation methods are discussed in Chapter 3. In the absence of direct field measurements, rough approximations of hydraulic conductivity can be made on the basis of aquifer soil or rock characteristics (see Chapters 2 and 3).

Finally, the lateral ground water seepage velocity within a water-bearing stratum, representing the actual rate of ground water movement, can be estimated using Darcy's Law. Note that hydraulic conductivity measurements are usually determined from field tests, while porosity is typically estimated on the basis of soil or rock type.

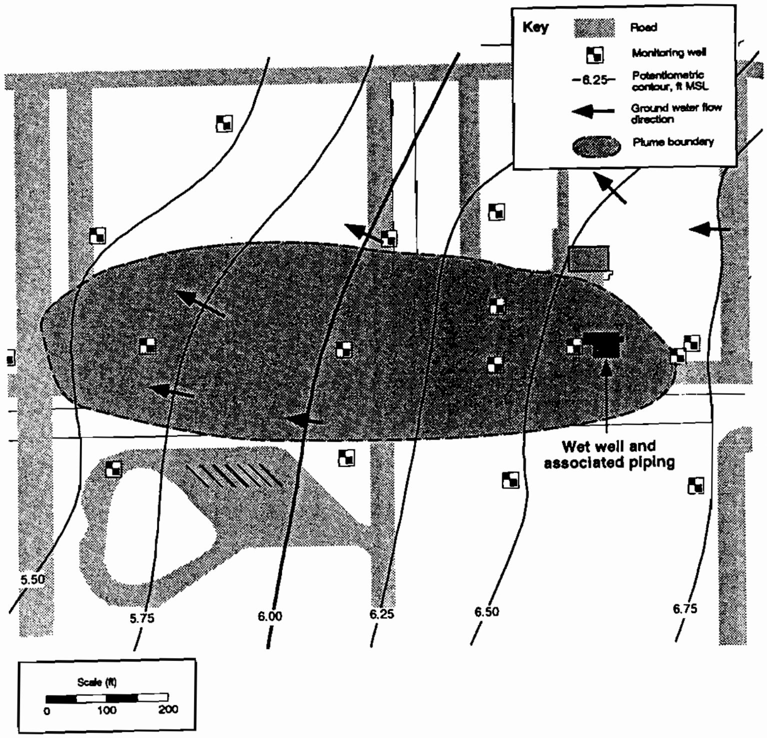


Figure 5.18 Potentiometric surface and plume location, Case Study 1.

5.9.3 Chemical Data Evaluation

Results of chemical analyses or indicator tests conducted on soil and ground water samples in either the field or laboratory must be plotted on scaled site plans and correlated with available geologic logs and cross-sections to define the lateral and vertical limits of contaminant migration. General procedures for laboratory data review and interpretation are as follows:

Data Validation Procedures. Upon receipt from the laboratory, all test results should be carefully reviewed to confirm laboratory accuracy and precision and compliance with relevant quality control standards. Formal data validation procedures are outlined in EPA, 1986, 1988, 1989a. Following confirmation of data validity, contaminant concentrations reported for soil and ground water samples should be corrected for those compounds detected in field, trip, or laboratory blank samples. Special attention should be paid to low concentrations of laboratory solvents (e.g., acetone, methylene chloride) or plasticizers (e.g., phthalate esters), which may represent inadvertent laboratory contamination of the soil or ground water samples.

Data Interpretation. Soil and ground water test results should be used to establish vertical and lateral "clean lines," the boundary beyond which contaminant concentrators are either less than natural background levels or less than the applicable cleanup standards specified by the regulatory authority. Various statistical methods can be employed to characterize background conditions and make comparisons to concentrations detected at individual sampling points (EPA, 1989b). Due to the variability of individual compound concentrations, it is usually instructive to define source zone or plume dimensions on the basis of the total organic or total inorganic contaminant levels detected at each sampling location. Data should be plotted on scaled site plans and cross-sections, and "clean lines" defined on the basis of clean sampling points. The delineation study is complete when a clean line can be drawn around all sides of the source zone or ground plume area, and the depth to clean soil or ground water has been established. These data should be sufficient to define the full volume of contaminated soil and ground water at the site.

Following completion of the delineation study, contaminant concentrations within the source zone or ground water plume should be inspected (and, if feasible, contoured according to lines of equal concentration) to confirm the location of the suspected contaminant source. In general, total contaminant concentrations should decrease with increasing distance from the point of release. Irregular concentration patterns may suggest (1) variable rates of contaminant release over time, or (2) the presence of multiple sources, or (3) complex hydrogeology. In such case, available site data should be carefully reviewed to confirm that all potential source areas have been identified and adequately outlined.

SUMMARY

This chapter summarizes field methods for collection of geologic, hydrologic, and water quality data. The geologic, hydrologic, and chemical data collected during the site investigation should fit together as an overall conceptual picture of a site. Geologic cross-sections and isopach maps should define stratigraphic conditions that are consistent with general depositional patterns observed in the site region. The apparent variability of ground water flow patterns indicated on potentiometric surface maps should correlate with actual stratigraphic variations or the locations of actual ground water recharge or discharge features (e.g., ponds, streams). Hydraulic conductivity measurements should be generally consistent with the soil or rock types observed during the drilling program. Dissolved contaminants should move in the direction of ground water flow, diminishing in concentration with distance from the source area. Geologic, hydrologic, and chemical data should be correlated in this manner, and