OSWER Directive 9360.4-16
EPA xxx/x-xx/xxx
PBxx-xxxxxx
December 1995

SUPERFUND PROGRAM

REPRESENTATIVE SAMPLING GUIDANCE

VOLUME 5: WATER AND SEDIMENT

PART II -- Ground Water

Interim Final

Environmental Response Team

Office of Emergency and Remedial Response
Office of Solid Waste and Emergency Response

U.S. Environmental Protection Agency
Washington, DC 20460

Notice

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication.

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For more information on Ground-Water Sampling procedures, refer to the U.S. EPA *Compendium of ERT Ground-Water Sampling Procedures*, OSWER Directive 9360.4-06. Topics covered in this compendium include: sampling equipment decontamination; ground-water monitoring well installation, development, and sampling; soil gas sampling; water level measurement; controlled pump testing; slug testing.

Please note that the procedures in this document should be used only by individuals properly trained and certified under a 40-hour hazardous waste site training course that meets the requirements set forth in 29 CFR 1910.120(e)(3). This document should not be used to replace or supersede any information obtained in a 40-hour hazardous waste site training course.

Questions, comments, and recommendations are welcomed regarding the *Superfund Program Representative Sampling Guidance, Volume 5 -- Water and Sediment, Part II -- Ground Water*. Send remarks to:

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1.0 INTRODUCTION

1.1 OBJECTIVE AND SCOPE

This is Part II of the fifth volume in a series of guidance documents that assist Superfund Program Site Managers, On-Scene Coordinators (OSCs), Remedial Project Managers (RPMs), and other field staff in obtaining representative samples at Superfund sites. The objective of representative sampling is to ensure that a sample or a group of samples accurately characterizes site conditions.

Most hazardous waste site investigations utilize some form of a ground-water sampling or monitoring program to fully characterize the nature and extent of contamination. Because site conditions may differ, experienced hydrogeologists and geochemists should be consulted to establish the most suitable types of sampling and monitoring for each site.

The purpose of this document is to address representative ground-water sampling. Ground-water modeling and monitoring well installation are briefly introduced but are not addressed in detail in this document. References on these topics are provided in Section 1.6

The representative ground-water sampling principles discussed in this document are applicable throughout the Superfund Program. The following chapters will help field personnel to assess available information, select an appropriate sampling approach and design, select and utilize field analytical/geophysical screening methods and sampling equipment, incorporate suitable types and numbers of quality assurance/quality control (QA/QC) samples, and interpret and present the site analytical data.

As the Superfund Program has developed, the emphasis of the response action has expanded beyond addressing emergency response and short-term cleanups. Each planned response action must consider a variety of sampling objectives, including identifying threat, delineating sources of contamination, and confirming the achievement of clean-up standards. Because many important and potentially costly decisions are based on the sampling data, Site Managers and other field personnel must characterize site conditions accurately. To that end, this document emphasizes the use of cost-effective field analytical and geophysical screening techniques to characterize the site and aid in the selection of sampling locations.

1.2 UNIQUE CHARACTERISTICS OF GROUND WATER

The following are media-specific variables of ground water that should be considered when performing representative ground-water sampling:

- Homogeneity - Ground water, as a medium, is usually homogeneous, especially when compared to other media such as soil, air, or waste.

- Seasonal and Localized Variation in Flow - Seasonal and localized variations in ground-water flow should be considered when developing a ground-water assessment program. Seasonal variations are generally controlled by weather. Surface streams gain or lose water to the subsurface when flood or drought conditions are present. Localized variations in flow are caused by nearby, outside influences, as when a production well creates a cone of depression in the water table.

- Inaccessibility for Investigation - Ground water is often inaccessible to standard grab sampling techniques. Because ground water is subsurface, wells must often be drilled and completed for sampling if no existing wells are available. Sampling ground water is generally more complicated, labor-intensive, time-consuming, and expensive than sampling other media.

- Natural Background Composition - Knowledge of the natural background composition is necessary in order to determine the effects of a site on the ground water. Background or control monitoring wells are necessary to determine ambient composition.

- Water Treatment - Ground-water samples are often extracted from existing residential or commercial wells that have been treated with softeners or have been filtered or altered in other ways. Sampling (times, parameters, methods, preservatives, etc.) may have to be altered in order to compensate for or avoid treatment variables.

- Reproducibility of Sampling Results - Ground water is a flowing water body below the earth's surface. Physical and chemical characteristics may vary over time and space because of the factors listed above (e.g., seasonal variation). Contaminants tend to flow through ground water in a plume or plug of varying concentration; contamination sources may discharge in pulses or as a continuous flow; and contaminants may react with ground water to chemically transform over time. Because of this flowing nature, contaminant or natural constituent concentrations can vary. This variation could affect duplicating sample results over an extended time period. Contaminants will most often continue to be detected in ground water, but sample concentration ranges may be altered, either by an increase or a decrease, or contaminant by-products may be detected.

1.3 REPRESENTATIVE SAMPLING

Representative ground-water sampling ensures that a sample or group of samples accurately reflects the concentration of the contaminant(s) of concern at a given time and location. Analytical results from representative samples reflect the variation in pollutant presence and concentration throughout a site.

In addition to the variables introduced due to the characteristics of the sample media (as discussed in Section 1.2), this document concentrates on those that are introduced in the field. These latter variables relate to site-specific conditions, the sampling design approach, and the techniques for collection and preparation of samples. The following variables affect the representativeness of samples and subsequent measurements:

- Media variability - The physical and chemical characteristics of ground water.

- Contaminant concentration variability - Variations in the contaminant concentrations throughout the site and/or variables affecting the release of site contaminants into ground water on or away from the site.

- Collection and preparation variability - Deviations in analytical results attributable to bias introduced during sample collection, preparation, and transportation (for analysis).

- Analytical variability - Deviations in analytical results attributable to the manner in which the sample was stored, prepared, and analyzed by the on-site or off-site laboratory. Although analytical variability cannot be corrected through representative sampling, it can lead to the false conclusion that error is due to sample collection and handling procedures.

1.4 REPRESENTATIVE SAMPLING OBJECTIVES

Representative sampling objectives for ground water include the following:

- Identify the presence of contamination, including source, composition, and characteristics. Determine if it is hazardous.

- Establish the existence of an imminent or substantial threat to public health or welfare or to the environment.

- Establish the existence of potential threat requiring long-term actions.

- Develop containment and control strategies.

- Evaluate treatment options.

Note: Clean-up goals are generally established for ground water and are not considered a sampling objective.

1.4.1 Identify Contamination and Determine Hazard

One of the first objectives during a response action at a site is to determine the presence, identity, and potential threat of any hazardous materials. Field screening techniques can be used for rapid detection of contaminants. Upon confirming the presence of hazardous materials, sample and/or continue screening to identify their compositions and determine their concentrations.

1.4.2 Establish Imminent or Substantial Threat

Establishing threat to the public or environment is a primary objective during any response action. The data obtained from characterizing the contaminants will help the Site Manager to determine whether an imminent or substantial threat exists and whether a response action is necessary. The type and degree of threat determines the rate at which a response action is taken.

1.4.3 Determine Long-Term Threat

Site conditions may support a long-term threat that is not imminent or substantial. Characterization of the contaminants can assist the Site Manager to determine the need for long-term remediation and response. Samples should be collected in a manner that enables their use for evaluating the site under the Hazard Ranking System.

1.4.4 Develop Containment and Control Strategies

Once the chemical constituents and threat have been determined, many strategies for ground-water containment and control are available. Analytical data indicating the presence of chemical hazards are not in themselves sufficient to select a containment or control strategy. Site reconnaissance and historical site research provide information on site conditions and the physical state of the contaminant sources; containment and control strategies are largely determined by this information. For example, trenching and pump and treat systems can prevent spread of contamination in an aquifer.

1.4.5 Evaluate Treatment Options

The contaminants should be identified, quantified, and compared to action levels (e.g., maximum contaminant levels (MCLs) for drinking water). Where regulatory action levels do not exist, site-specific clean-up levels are determined by the Region (often in consultation with the Agency for Toxic Substances and Disease Registry (ATSDR)) or by State identification of Applicable or Relevant and Appropriate Requirements (ARARs). If action levels are exceeded, a series of chemical and physical tests may be required to evaluate possible treatment options.

1.5 CONCEPTUAL SITE MODEL

A conceptual site model is a useful tool for selecting sampling locations. It helps ensure that sources, migration pathways, and receptors throughout the site have been considered before sampling locations are chosen. The conceptual model assists the Site Manager in evaluating the interaction of different site features. Risk assessors use conceptual models to help plan for risk assessment activities. Frequently, a conceptual model is created as a site map (see Figure 1) or it may be developed as a flow diagram which describes potential migration of contaminants to site receptors (See Appendix A).

A conceptual site model follows contaminants from their sources, through migration pathways (e.g., air, ground water), and eventually to the assessment endpoints. Consider the following when creating a conceptual site model:

- The state(s) of each contaminant and its potential mobility
- Site topographic features
- Meteorological conditions (e.g., wind direction/speed, average precipitation, temperature, humidity)
- Human/wildlife activities on or near the site

The conceptual site model in Figure 1 is an example created for this document. The model assists in identifying the following site characteristics:

> *Potential Sources*: Site (waste pile, lagoon); drum dump; agricultural activities.
>
> *Potential Migration Pathway (Ground Water)*: Leachate from the waste pile, lagoon, drum dump, or agricultural activities.
>
> *Potential Migration Routes*: Ingestion or direct contact with water from the aquifer (e.g., ingestion of drinking water, direct contact when showering).
>
> *Potential Receptors of Concern*:
>
> > Human Population (Residents/Workers): Ingestion or direct contact with contaminated water from the aquifer.

Preliminary site information may provide the identification of the contaminant(s) of concern and the level(s) of the contamination. Develop a sampling plan based upon the receptors of concern and the suspected sources and pathways. The model may assist in the selection of on-site and off-site sampling locations.

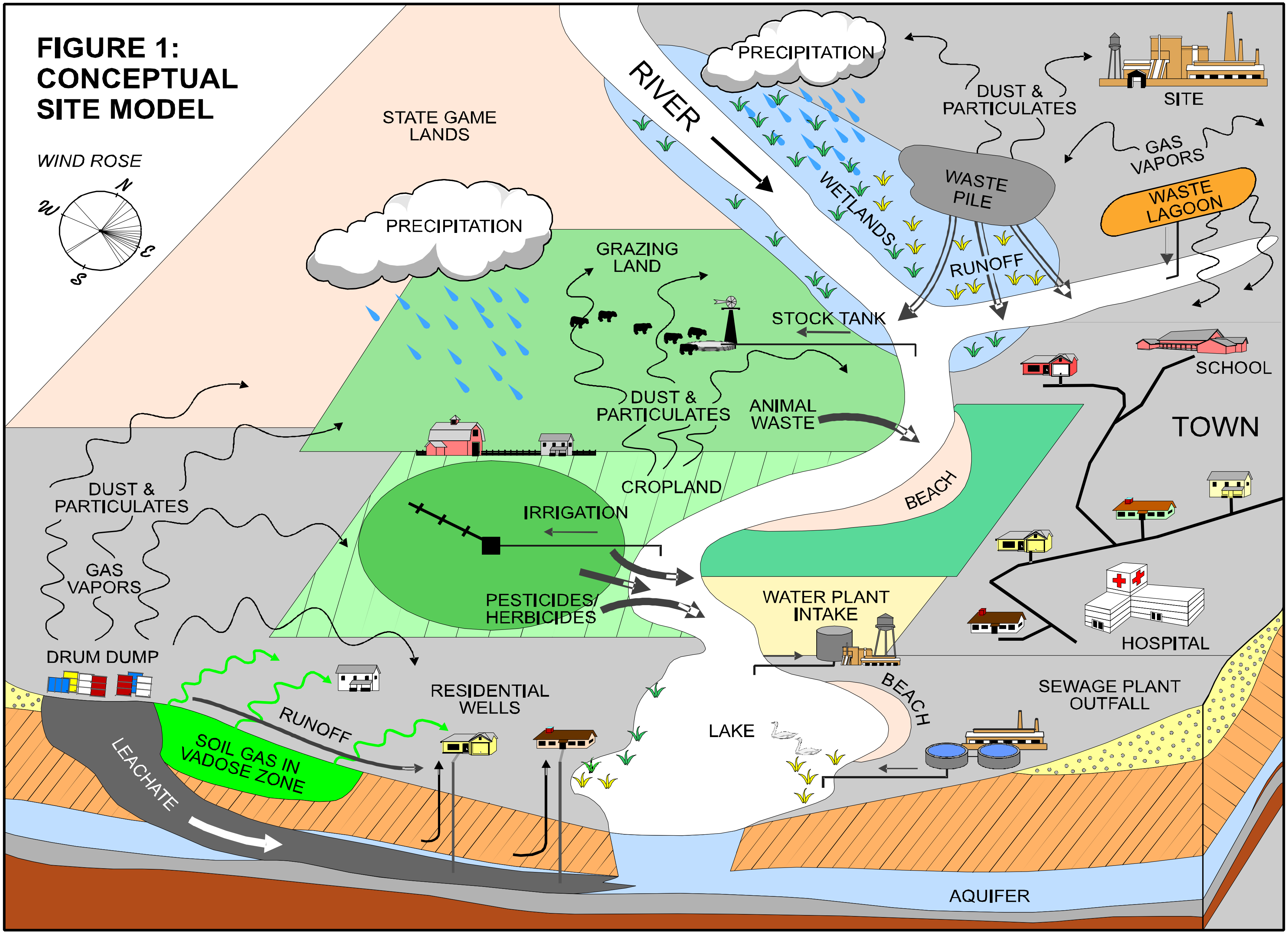


FIGURE 1: CONCEPTUAL SITE MODEL

1.6 OVERVIEW OF GROUND-WATER MONITORING WELL INSTALLATION AND GROUND-WATER MODELING

Ground-water monitoring well installation and ground-water modeling are complex issues which fall outside the scope of this document. Many standard operating procedures (SOPs) covering ground-water monitoring well installation techniques have been published. Monitoring well installation and ground-water modeling are briefly introduced here with several specific items for consideration. Refer to existing SOPs and other reference documents for more in-depth study.

1.6.1 Ground-Water Monitoring Well Installation

For most Superfund response actions where ground-water sampling is performed, existing ground-water production wells (commercial or residential) are used, if available, to obtain samples. Chemical data obtained from this type of well depict the general quality of water that is being delivered to the user community. Ground water is usually a composite of multiple aquifer strata which may mask the presence of narrow or small contaminant plumes from a single stratum. For this reason, production wells are not suitable for detailed source, case-preparation, or research types of monitoring. Such detailed monitoring efforts require wells designed to determine the geologic and hydrologic quality at specific locations and depths. The following items must be considered for ground-water sampling from monitoring wells:

- Drilling method
- Monitoring well components
- Monitoring well location
- Well diameter
- Well depth
- Well screen location

Refer to the U.S. EPA *A Compendium of Superfund Field Operations Methods*, OSWER Directive 9355.0-14; *Compendium of ERT Ground-water Sampling Procedures*, OSWER Directive 9360.4-06; *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*, OSWER Directive 9950.1; and *RCRA Ground-Water Monitoring: Draft Technical Guidance*, EPA/530-R-93-001, for specific details on monitoring well installation. The latter two documents should be referenced for information on locating, installing, and developing monitoring wells.

Locating Monitoring Wells

Often, one well is sited near the center of the contaminant plume just downgradient from the contamination source. Another well is installed downgradient of the contaminant source, outside the limits of the plume. For background data, one well may be placed outside of the contaminant plume, upgradient of the contaminant source. Additional wells may be installed to track the amount of contaminant dispersion taking place.

Determining the depth to sample is critical for successful ground-water monitoring. Sampling depth depends on the contaminant density, the aquifer characteristics, and the slope of the water table or potentiometric surface. The number of wells necessary to monitor ground water varies depending on many factors. For example, if an impoundment contamination source is higher than the surrounding landscape, leachate may flow locally in all four downgradient directions. In this case, at least four wells are needed to monitor plume movement, plus a background well may be desired in an unaffected area. In addition, some wells may be installed at more than one depth in a contaminant plume to verify vertical flow or spread of contamination at different depths.

See Driscoll, 1986, pp. 715-16 for more information on locating monitoring wells.

Well Casing and Well Screen

Select a well casing material based on water quality, well depth, cost, borehole diameter, drilling procedure, and Federal, state, and local regulations. Types of casing materials include: steel, polyvinyl chloride (PVC), fiberglass, and Teflon®. Common well casing diameters range from 2 inches to 12 inches or greater, and depend on well type, well size, well depth, and subsurface geology. Often a series of progressively smaller-diameter well casings are used from the ground surface to the well depth.

A well screen is a filtering device which permits water to enter the well from the saturated aquifer while preventing sediment from entering the well. A well screen has slots or perforations and attaches to the well casing. It can be constructed of metal, plastic, or other material. Important criteria for selecting a well screen include: a large percentage of open area, nonclogging slots, resistance to corrosion, and a sufficient column and collapse strength.

See Driscoll, 1986, pp. 413-431, and Fetter, 1993, pp. 339-344 for more information regarding well casing. See Driscoll, 1986, pp. 395-405, and Fetter, 1993, pp. 345-346 for more information regarding well screens. See U.S. EPA, November 1992, pp. 6-16 - 6-38 for advantages and disadvantages of selecting well casing and screen materials.

1.6.2 Ground-Water Modeling

Ground-water models, like conceptual site models, can be useful when selecting sampling approaches, objectives, and locations. Ground-water models developed for Superfund sites attempt to provide an estimation of how the actual ground-water system functions.

There are many types of ground-water models available (e.g., physical, analog, mathematical). The International Ground-Water Modeling Center (IGWMC) has developed a ground-water model definition which emphasizes the importance of describing a ground-water system mathematically. The IGWMC defines a ground-water model as "a non-unique, simplified, mathematical description of an existing ground-water system, coded in a programming language, together with a quantification of the ground-water system the code simulates in the form of boundary conditions, system parameters, and system stresses."

A ground-water model may be useful throughout site investigation activities because it can be adjusted as conditions in the actual ground-water system become better defined. The data which are generated by the model can be used to refine sampling approaches and locations as necessary. Typically, a ground-water modeling report will include data (results), along with a discussion of activities such as model calibration and conceptual model development. A suggested format for a ground-water modeling report can be found in U.S. EPA *Ground-Water Issue: Fundamentals of Ground-Water Modeling* (EPA/540/S-92/005).

1.7 EXAMPLE SITE

An example site, presented at the end of each chapter, illustrates the development of a representative ground-water sampling plan that meets Superfund Program objectives for early actions or emergency responses.

2.0 GROUND-WATER SAMPLING DESIGN

2.1 INTRODUCTION

The purpose of ground-water sampling is to provide technical information relative to the nature and condition of subsurface water resources at a specific time and place. Designs to monitor the status of ground water range from the studies of naturally occurring geochemical constituents to the detection or assessment of contamination within a ground-water system.

Ground-water sampling objectives include identifying threats, delineating sources and extent of contamination, determining treatment and disposal options, and confirming the attainment of targeted clean-up levels. Representative sampling designs are developed to most accurately characterize the hydrogeologic system and its interaction with the environment. Sampling protocols must integrate detailed sampling methodology, techniques and practices to ensure valid assessment. Sampling methodology and practice may be the most common source of assessment error. Consequently, sampling methodology and practice collectively demand careful preparation, execution, and evaluation to accurately characterize the hydrogeologic system or its subsystems. (For additional information see: U.S. EPA *Ground Water, Volume II: Methodology,* EPA/625/6-90/016b; and Palmer, Christopher M., *Principles of Contaminant Hydrogeology*.)

There are many methods and types of equipment useful for site characterization and sample collection. Selection of these factors is a critical component of a site-specific sampling design.

A properly developed ground-water sampling design defines the sampling purpose, protects site worker health and safety, effectively utilizes resources, and minimizes errors. The sampling design will vary according to the characteristics of the site. When developing a sampling design, consider:

- Prior actions at the site (e.g., sampling events, compliance inspections)
- Regional ground-water properties and characteristics
- Potential on-site waste sources (e.g., impoundments, waste piles, drums)
- Topographic, geologic, hydrologic, and meteorologic conditions of the site
- Flora, fauna, and human populations in the area

2.1.1 Pre-Sampling Plan Investigation

The pre-sampling plan investigation provides the planner with information critical to the development of a sound ground-water sampling design. Integration of all pertinent facts regarding the site history, the population(s) affected, and concentrations of substances on a site must be reviewed. After all of the pertinent information has been processed and incorporated into a thorough site pre-evaluation, the sampling plan can be developed. Considerations for sampling plan modification should be reviewed as necessary in light of the complex nature of ground-water resource dynamics.

Site History

Review of the site's history helps assess the natural and man-made impacts on a site. Geographic, geologic, tax, and fire insurance maps can indicate the status of the site. These maps can usually be found at local and collegiate libraries or municipal and county tax offices. Aerial photographs are helpful in reviewing operational use of the site. Archival aerial photographs may show changes in operation and site condition over time. This information can be correlated with information from potentially responsible parties.

Hydrogeologic information is critical to developing a sampling plan. A ground-water system is site specific, depending upon local geology, land and subsurface use, precipitation and water use, proximity to water bodies, and hydrogeologic parameters affecting contaminant transport. Hydrologic and hydrogeologic information can be found in libraries or requested from the U.S. Geological Survey (USGS), Water Resources Division, or state geological agencies and their water branches. Inspection histories can be used to determine prior health status of the site in view of possible trends. Local, state, and federal agencies dealing with health or environmental inspection can provide such historical information about a site.

Affected Populations

Human population statistics for the selected area can establish the number of people threatened by the contaminant exposure. Include populations affected by projected migration of contaminants within the ground-water system. Knowing the interaction of the contaminant within a ground-water system and the potential regional populations exposed to the contaminant will focus the sampling plan to the source and possible pathways of the contaminant. Wildlife populations in the area must be studied as well. Wildlife in ponds, lakes, streams, rivers, and bays is often affected by contaminants transported by ground water discharging into surface water. Information regarding regional wildlife populations and susceptibility to hazardous substances can be obtained from federal and state wildlife and conservation agencies.

Detection Levels versus Maximum Contaminant Levels

Sampling plan development must also address the concentration level of the contaminant within the ground-water system in relation to the maximum contaminant levels (MCLs) allowed within a public water system. Refer to the Federal Register for the levels requiring enforceable action. Knowledge of the chemical contaminant interaction within the ground-water system can add insight into the fate of the contaminant (soluble or insoluble in water; less or more dense than water; the nature of reactivity with sediment or geology of the subsurface). Correlate the concentration level versus the location of these concentrations. A sequence of order can then be applied to the locations. Ideally, a pattern may develop that can be related to the ground-water system and its dynamics. In the case of a single location, investigate potential sources in the surrounding area either by working backwards from an identified contaminant spot to a potential source, or from a potential source to an identified contaminant spot. Also consider source-to-current-location pathways and projected pathways when developing a sampling plan.

2.1.2 Types of Information Provided by Ground-Water Sampling Assessment

There are several types of information that a ground-water sampling assessment provides. These include but are not limited to: measure of ground-water quality, contaminant concentrations compared to action levels, selection of the appropriate response action, and determination of ground-water flow and contaminant plume movement.

Measure of Ground-Water Quality

Ground-water sampling assessments provide information concerning measure of ground-water quality of a site or region. Water quality is classified according to many categories and its intended use. Drinking water is especially subject to guidelines. A sampling assessment of ground water can determine whether the quality of the water has been maintained, upgraded, or allowed to degrade. The natural and artificially induced characteristics of ground water from a specific site or region can be established by ground-water sampling assessments -- specifically, the chemical, biological, and physical characteristics of the ground water.

Contaminant Concentrations Compared to Action Levels

Ground-water sampling assessments provide a single contamination level for a particular sampling location, or a set of contamination levels for several sampling locations within a site. Comparison to action levels in ARARs determines the basis for further action. Thus, sampling can evaluate potential hazards and represent a condition of ground-water character requiring enforceable action procedures.

Selection of Appropriate Response Action

The level of contaminant concentration as determined through sampling assessments is a critical factor in selecting a site response action. Depending upon the degree or level of contaminant concentration, contaminant frequency, or number of locations established as contaminated, and the site's potential threat to human health or the environment, a rapid or extensive clean-up program can be formulated, as well as temporary or short-term responses (e.g., provision of bottled water).

A sampling assessment may not always indicate contamination of the site. Careful examination of sampling protocol must consider the range of explanations. A miscalculation of suspected source sites; gross procedure error in sampling, laboratory analysis, or documentation; or error at many other points in sampling protocol could be the source of assessment error. These errors are addressed more extensively in Chapter 5.

If quality assurance/quality control (QA/QC) procedures have been followed for ground-water sampling assessment, then it is possible that sources of contamination may originate from above ground systems (e.g., lead entering tap water in the proximity of the facility). In any case, a sampling assessment at the least can characterize the natural ground-water conditions, which can be used as a control or comparison.

Determination of Ground- Water Flow and Contaminant Plume Movement

Knowing the direction of ground-water flow is important when evaluating a contaminated aquifer. When contamination enters the ground at a higher head (gradient) than exists at nearby shallow wells, these wells may become contaminated. Ground water flows from higher head to lower head. The direction of water movement may be determined using water-elevation data from a minimum of three wells. See Driscoll, 1986, pp. 79-85 and Freeze and Cherry, 1979, pp. 168-236 for more information regarding ground-water flow.

Ground-water tracers, such as dye or salt may be used to track ground-water flow velocities and contaminant plume movement. A tracer is placed in one well and the time of its arrival in a second well downgradient from the first well is noted. The dilution of the tracer detected in the second well can indicate the contaminant dilution rate and help determine the contaminant source concentration as well as the width, depth, and spreading velocity of the plume. Tracers also may be used to help determine aquifer porosity, hydraulic conductivity, and dispersivity.
The tracer selected must be detectable in extremely low concentrations and must not react chemically or physically with the ground-water or aquifer composition. See Driscoll, 1986, pp. 84-85 for more information regarding ground-water tracers.

2.1.3 Site Reconnaissance

A site reconnaissance can be conducted at an earlier date or immediately prior to sampling activities. It allows field personnel to assess actual, current site conditions, evaluate areas of potential contamination, evaluate potential hazards associated with sampling, and finalize a sampling plan. Site reconnaissance activities for a ground-water assessment include: observing and photographing the site; noting site access and potential evacuation routes; noting potential safety hazards; inventorying and recording label information from drums, tanks, or other containers; mapping process and waste disposal areas such as landfills, impoundments, and effluent pipes; mapping potential contaminant migration routes such as drainage, streams, and irrigation ditches; noting the condition of animals and/or vegetation; noting topographic and/or structural features; noting and mapping existing ground-water monitoring or other types of wells for potential sampling; and siting potential locations for new monitoring wells if necessary. Field personnel should use appropriate personal protective equipment when engaged in any on-site activities. Consider the following site-specific factors while performing a site reconnaissance:

- Sampling Objectives - Sampling is conducted typically to comply with regulations for the detection or assessment of suspected contamination within the subsurface. The information gathered aids in the identification of known and unknown substances present within the site and the level and extent of contamination of the environment. The information is used to document the condition of the ground-water system as an initial assessment, a record of development, or as evidence of remediation efficiency and compliance.

- Sample Collection and Toxicity - The samples collected are intended to document the absence or measure the presence of contaminants. The measure of acute or chronic toxicity is evaluated by assessing the site's extent of contamination, the time period in relation to the extent, and health hazards associated with the contaminant exposure time frame.

- Statistical Concerns - A site visit will familiarize the sampling planner with the environment to be sampled. Conspicuous indicators of potential contamination sources or contamination effects may suggest use of a judgmental or bias sampling design. A geostatistical sampling method can be cost-effective and time-efficient when compared to strictly random or random-stratified procedures. When using less random methods, the choice of sampling locations should be documented and justified. Employ random sampling in addition to bias sampling and include background or control samples for a thorough representation of the ground-water character. (See Section 2.3 for a discussion of sampling approaches.) (For additional information see Keith, Lawrence H., *Principles of Environmental Sampling*.)

- Timing of the Response - Consider seasonal variation when evaluating a site. Predictions of bad weather can influence technique and design. The urgency of the action weighed against seasonal constraints may dictate the options available within the targeted budget.

- Site-Specific Factors Affecting Ground-Water Flow Many factors of a site control the path or direction of ground-water flow. A combination of geologic survey information with the site reconnaissance can better familiarize the planner with the dynamics of the hydrogeologic system. The local geology of a site can determine the direction and rate of ground-water movement by means of its orientation and composition (e.g., horizontal, tilted or vertical structures, and confining clay versus unconfining sand and gravel). The degree of development of a site and its local topography can affect the ground-water flow (e.g., parking lot runoff disproportionally delivers water quantities to the subsurface and greater slopes afford less infiltration of water to the subsurface). The extent and type of vegetation can affect the amount of rainfall that actually recharges an aquifer system. Dense vegetation and high evapo-transpiration from vegetation allows very little water to descend to the subsurface. Seasonal variations can cause reversal of ground-water flow direction. This is usually associated with water bodies such as streams, rivers, ponds, and lakes. Water may flow to or from streams depending upon its surface elevation in relation to adjacent water table surfaces. During flood conditions, water usually flows from rivers toward the surrounding subsurface. During drought, water moves toward the lower level of the stream surface from higher ground-water surfaces. (Consult U.S. EPA *Handbook, Ground Water*, EPA/625/6-87/016, Chapter 4: Basic Hydrogeology.)

- Analytical Parameters - The site reconnaissance can help develop the list of analytical parameters. For example, a reconnaissance may indicate the presence of battery casings. Lead would then be a substance of concern. The site may contain constraints that may or may not allow a variety of tests to be performed. The cost-effectiveness of testing within the site's constraints can lead to limited options available to properly analyze the ground-water system. Testing methods may vary within one site (e.g., monitoring well sampling, hydroprobe extraction, etc.) in order to evaluate multiple criteria vital to the site assessment.

- Degradation (or Transformation) Products - Sites may contain degradation (or transformation) products, or by-products, of the contaminant that are detectable and potentially as hazardous as the contaminant itself. Sampling for the product can lead to clues of the source substance location and its reactive status within the subsurface.

- Sampling Order - The sampling plan should address a specific order of sampling locations (and depths at a single location) to be developed. In order to use equipment efficiently, the plan should attempt to sample from "clean" to "dirty" locations, reducing the potential for contaminants to affect relatively less contaminated locations. Typically, the background or "clean" location of a site is hydrologically upgradient from the suspected contaminant "hot spot." Depending upon the nature of the contaminant (e.g., a "sinker" or "floater"), the sampling at different depths within a column of water in a monitoring well should also follow a sequence.

2.2 PARAMETERS OF CONCERN, DATA QUALITY OBJECTIVES, AND QUALITY ASSURANCE MEASURES

2.2.1 Parameters of Concern

Drinking water populations, contaminants, and migration pathways are additional parameters that should be considered when developing a sampling plan. Often, ground-water contamination goes undetected because it is not directly visible. Drinking water odor or taste complaints by residents close to the site are usually the initial indication of ground-water contamination and potential health hazards. The sampling data should accurately delineate the extent of ground-water contamination, determine the impact on drinking water populations, and indicate potential migration pathways to such populations. It is important to design the sampling plan to determine where contaminants are most highly concentrated, and to locate areas of decreasing detectable concentrations and those not yet contaminated.

2.2.2 Data Quality Objectives

Data quality objectives (DQOs) state the level of uncertainty that is acceptable for data collection activities and define the certainty of the data necessary to make decisions. The overall goal of DQOs for a representative ground-water sampling plan are to acquire thorough and accurate information about subsurface water conditions at a site. DQOs are unique and site specific and should address the contaminant's interaction with the immediate site environment. When establishing DQOs for a particular project, consider:

- Decision(s) to be made or question(s) to be answered
- Why analytical data are needed and how the results will be used
- Time and resource constraints on data collection
- Descriptions of the analytical data to be collected
- Applicable model or data interpretation method used to arrive at a conclusion
- Detection limits for analytes of concern
- Sampling and analytical error

2.2.3 Quality Assurance Measures

To ensure that analytical samples are representative of site conditions, quality assurance measures must be associated with each sampling and analysis event. The sampling plan must specify QA measures, which include, but are not limited to, sample collection, laboratory SOPs, sample container preparation, equipment decontamination, field blanks, replicate samples, performance evaluation samples, sample preservation and handling, and chain-of-custody requirements. Quality assurance components are defined as follows:

- Precision - Measurement of variability in the data collection process

- Accuracy (bias) - Measurement of bias in the analytical process; the term "bias" throughout this document refers to (QA/QC) accuracy measurement

- Completeness - Percentage of sampling measurements which are judged to be valid

- Representativeness - Degree to which sample data accurately and precisely represent the characteristics and concentrations of the source/site contaminants

- Comparability - Evaluation of the similarity of conditions (e.g., sample depth, sample homogeneity) under which separate sets of data are produced

Refer to Chapter 5, Quality Assurance/Quality Control (QA/QC), for more detailed ground-water QA/QC information.

2.3 REPRESENTATIVE GROUND-WATER SAMPLING APPROACHES AND SAMPLE TYPES

Judgmental sampling is the primary representative sampling approach used for ground water. Other representative sampling approaches for ground water such as random, systematic grid, and systematic random sampling are described below. For information on the other types of sampling approaches, refer to U.S. EPA, *Superfund Program Representative Sampling Guidance*, Volume 1 -- *Soil*, OSWER Directive 9360.4-10.

2.3.1 Judgmental Sampling

Judgmental sampling is the biased selection of sampling locations at a site, based on historical information, visual inspection, sampling objectives, and professional judgment. A judgmental approach is best used when knowledge of the suspected contaminant(s) or its origins is available. Judgmental sampling includes no randomization in the sampling strategy, precluding statistical interpretation of the sampling results. Criteria for selecting sampling locations are dependent on the particular site and level of contamination expected.

Once a contaminant has been detected in the ground water, the source and extent must be identified. To do this, an understanding of the contaminant characteristics and the local geologic and hydrogeologic conditions is needed. Characteristics of the contaminant and any daughter (degradation) products must be known in order to understand how the material may be transported (both vertically and laterally) from the contamination source. Knowledge of the local hydrogeology is needed in order to identify areas or zones that would facilitate contaminant migration, such as water bodies and gravelly or sandy soils. The permeability of the underlying rock type should be analyzed, as well as its depth, which will help to narrow the potential sampling area. For example, if the underlying bedrock strikes northeast to southwest, then sampling of an aquifer should also be in this direction, unless cross-contamination between aquifers has already been identified.

When appropriate (based on sampling objectives, availability, sampling parameters, and budget), sample available local residential or commercial wells following a relatively systematic pattern based on the geology of the area. In the example given in the paragraph above, wells would be sampled along a line northeast to southwest. If the number of wells available is not sufficient to adequately identify the extent of contamination, then additional monitoring wells could be installed.

During a ground-water assessment, the selection of locations for monitoring well installation is done with a judgmental approach. This is generally because monitoring wells are complex, expensive, and time-consuming to install. In order to best determine the nature of a suspected contaminant plume, monitoring wells need to be placed in areas most likely to intercept the plume. Using a random, systematic grid or a systematic random approach would likely result in too many wells that miss the contaminant plume. Even placement of background or control monitoring wells favors a judgmental approach. Locations are selected based on the site reconnaissance and the planner's knowledge of the suspected contaminants, site geology, and hydrology.

2.3.2 Random, Systematic Grid, and Systematic Random Sampling

Random, systematic grid, and systematic random sampling are generally not used for ground-water sampling because sampling points are pre-determined from either existing wells or monitoring wells which are placed by judgment. However, these approaches may be useful for soil gas testing to assist in the siting of new monitoring wells. They can also be useful for conducting Geoprobe® sampling, if necessary. For additional information on these sampling approaches, refer to U.S. EPA, *Superfund Program Representative Sampling Guidance*, Volume 1 -- *Soil*, OSWER Directive 9360.4-10.

2.3.3 Grab versus Composite Sample Types

Grab samples are essentially the only type of samples collected for ground water. Unlike surface water, ground water is not composited. Each ground-water sample is representative of a discrete location and horizon in the subsurface.

2.4 SAMPLING PLAN

To develop a successful and practical representative ground-water sampling plan, the following site-specific information is required:

- Site Location - The location of the site will often influence the size of the sampling area and whether sampling should be conducted on or off site or a combination of both.

- Local Geology and Hydrology - Local geology and hydrology can determine whether off-site sampling is necessary and defines ground-water sampling boundaries and locations. For example, if an aquifer is very deep or there is a confining layer between the ground surface and the aquifer, then sampling within a small area may be all that is necessary in order to determine the extent of contamination within that aquifer.

- Topography - Topography will control the direction of surface runoff and may give clues to subsurface conditions. For example, wells in valleys may not be of the same aquifer as wells on a hill.

- Analytical Parameters - If contaminants are initially unknown, then a broad spectrum of analytical parameters is usually collected. As more information about the site becomes available (through screening or laboratory analysis), the number of parameters can be streamlined or altered in order to more effectively characterize the site. If the contaminant is known, then concentrate on sampling for it and its degradation products.

- Sampling Budget - Budget constraints inevitably affect operations. A combination of screening and analytical techniques minimizes expenses while still providing an acceptable level of quality for the sampling data.

- Physiochemical Nature of Suspected Contamination When designing the sampling plan, take into account the physical and chemical nature of the suspected contaminants, then design the sampling plan to facilitate efficient detection of the contaminants through sampling methodology, equipment, and analyses. For example, the water density or solubility of a contaminant may provide an indication of the contaminant's physical location within the water column.

Water has a specific gravity of one. Some chemical compounds, such as many complex petrochemicals, have a specific gravity of greater than one, and are therefore more dense than water. These substances tend to sink and include chlorinated solvents, wood preservatives, other coal tar wastes, and pesticides. These compounds are referred to as *dense nonaqueous phase liquids* (DNAPLs), or "sinkers". On the other hand, a specific gravity of less than one will allow a contaminant to float on or near the water table, and includes many fuel oil products and byproducts (e.g., gasoline, benzene, toluene, ethyl benzene, xylene (BTEX), and other straight chain hydrocarbons). These compounds are referred to as *light nonaqueous phase liquids* (LNAPLs), or "floaters". Nonaqueous phase liquids (NAPLs) tend to exist as separate layers in the water column. A substance with a specific gravity value near to or equal to one will generally dissolve in the water column (e.g., acetone, phenols, and creosote). Because of the potential stratification in the water column due to NAPL substances, sampling location with respect to the suspected contaminant location within the well should always be considered.

LNAPLs commonly occupy the capillary fringe zone above the water table. In a confined aquifer, these compounds are found along the upper surface of the permeable unit and also within the overlying confining layer.

DNAPLs cause additional representative sampling concerns. These compounds move downward under the influence of gravity until reaching a less permeable formation where they may either accumulate, move downslope along the bedrock, or penetrate fractures. Special precautions should be taken during drilling at sites suspected of DNAPL contamination; ensure that the drilling does not induce the spread of free-phase DNAPL contaminants. Monitoring well installation should be suspended when a DNAPL or low permeability lithogic unit is encountered. Fine-grained aquitards (e.g., silt or clay) should be assumed to permit downward DNAPL migration. For guidance on sites with potential DNAPL contamination, see U.S. EPA *Estimating the Potential for Occurrence of DNAPL at Superfund Sites*, OSWER Directive 9355.4-07.

Additional elements which should be addressed in a representative ground-water sampling plan include:

- Sample Number - The number of samples collected depends on the number of sample locations. Normally one sample is taken at each location, except for QA/QC requirements (e.g., replicates, and matrix spike/matrix spike duplicates). If there are multiple, discreet aquifers at the site, then samples of each may be necessary. Splitting samples also requires an increase in the number of samples.

- Sample Volume - The sample volume is dependent on the analytical parameters. It is also dependent on whether the contaminant is known or unknown. A greater volume is generally needed when the contaminant is unknown because a larger suite of parameters is usually selected.

- Sample Location - Sample location is generally dictated by the availability of existing monitoring, residential, or commercial wells. New monitoring wells are located by judgmental methods.

- Sample Depth - Sampling depth is typically the bottom or screened zone of a well. However, there may be times when certain stratigraphic horizons within the water column may need to be discreetly sampled (e.g., capturing "floaters" or "sinkers"). (Procedures for addressing stratified samples are discussed in Section 4.4.)

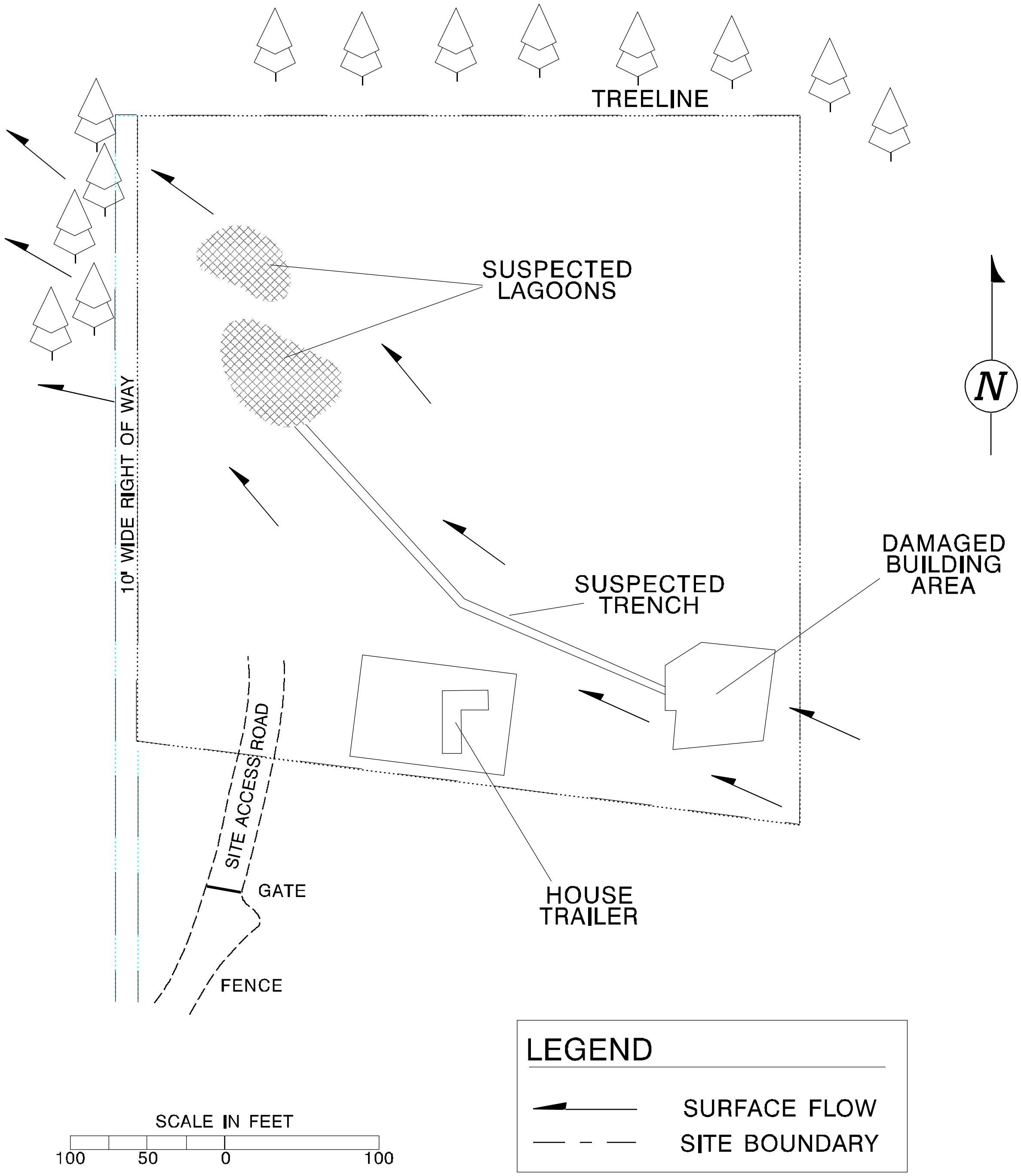
- Sample Order - Sampling order is from the least contaminated to the most contaminated wells or areas (if known).

2.5 EXAMPLE SITE

2.5.1 Background

The ABC Plating Site is located in northeastern Pennsylvania approximately 1.5 miles north of the town of Jonesville. Figure 2 provides a layout sketch of the site and surrounding area. The site covers approximately four acres and operated as a multi-purpose specialty electroplating facility from 1947 to 1982. During its years of operation, the company plated automobile and airplane parts with chromium, nickel, and copper. Cyanide solutions were used in the plating process. ABC Plating deposited electroplating wastes into two unlined shallow surface settling lagoons in the northwest portion of the site. Pennsylvania Department of Environmental Resources (PADER) personnel cited the owner/operator for the operation of an unpermitted treatment system and ordered the owner to submit a remediation plan for state approval. Before PADER could follow up on the order, the lagoons were partially backfilled with the wastes in place. The process building was later destroyed by a fire of suspicious origin. The owner abandoned the facility and could not be located by

Figure 2: Site Sketch
ABC Plating Site



enforcement and legal authorities. Several vats, drums, and containers were left unsecured and exposed to the elements. The state contacted EPA for an assessment of the site for a possible federally funded response action; an EPA On-Scene Coordinator (OSC) was assigned to the task.

2.5.2 Site History and Reconnaissance

The EPA OSC reviewed the PADER site file. In 1974 the owner was cited for violating the Clean Streams Act and for storing and treating industrial waste without a permit. The owner was ordered to file a site closure plan and to remediate the settling lagoons. The owner, however, continued operations and was then ordered to begin remediation in 90 days or be issued a cease and desist order. Soon after, a follow-The OSC obtained copies of aerial photographs of the site area from the local district office up inspection revealed that the lagoons had been backfilled without removing the waste.

The OSC and a sampling contractor (Team) arrived on site to interview local and county officials, fire department officers, neighboring residents (including a former facility employee), and PADER representatives regarding site operating practices and other site details. The former employee sketched facility process features on a map copied from state files. The features included two settling lagoons and a feeder trench which transported plating wastes from the process building to the lagoons. The OSC obtained copies of aerial photographs of the site area from the local district office of the U.S. Soil Conservation Service. The state provided the OSC with copies of all historical site and violation reports. These sources indicated the possible presence and locations of chromium, copper, and zinc plating process areas.

The Team mobilized to the site with all the equipment needed to perform multi-media sampling. The OSC and Team made a site entry, utilizing appropriate personal protective equipment and instrumentation, to survey the general site conditions. They observed 12 vats, likely containing plating solutions, on a concrete pad where the original facility process building once stood. Measurements of pH ranged from 1 to 11. Fifty drums and numerous smaller containers (some on the concrete pad, others sitting directly on the ground) were leaking and bulging because of the fire. Some rooms of the process building could not be entered due to unsafe structural conditions caused by the fire. The Team noted many areas of stained soil, which indicated container leakage, poor waste handling practices, and possible illegal dumping of wastes.

2.5.3 Identification of Parameters of Concern

During the site entry, the OSC and Team noted that several areas were devoid of vegetation, threatening wind erosion which could transport heavy metal- and cyanide-contaminated soil particulates off site. These particulates could be deposited on residential property downwind or be inhaled by nearby residents.

Erosion gullies located on site indicated surface soil erosion and stormwater transport. Surface drainage gradient was toward the west and northwest. The Team observed stressed, discolored, and necrotic vegetation immediately off site along the surface drainage route. Surface drainage of heavy metals and cyanide was a direct contact hazard to local residents. Surface water systems were also potentially affected. Further downgradient, site runoff entered an intermittent tributary of Little Creek, which in turn feeds Barker Reservoir. This reservoir is the primary water supply for the City of Jonesville and neighboring communities, which are located 2.5 miles downgradient of the site.

The site entry team observed that the site was not secure and there were signs of trespass (confirming a neighbor's claim that children play at the facility). These activities could lead to direct contact with cyanide and heavy metal contaminants, in addition to the potential for chemical burns from direct contact with strong acids and bases as might be found in leaking or unsecured drums or containers.

After interviewing residents, it was established that the homes located to the south and nearest to the site rely upon private wells for their primary drinking water supply. Ground water is also utilized by several small community production systems which have wells located within 2 miles of the site. The on-site settling lagoons were unlined and therefore posed a threat to ground water, as did precipitation percolating through contaminated soils. Contamination might have entered shallow or deeper aquifers and potentially migrated to off-site drinking water wells.

During Phase 1 sampling activities, full priority pollutant metals and total cyanide analyses were conducted on all soil and ground-water samples sent to the laboratory. These parameters were initially selected based on a study of plating chemistry:

plating facilities generally use either an acid or basic cyanide bath to achieve the desired coating on their metal products. Since Phase 1 samples were collected from the areas of highest suspected contaminant concentration (i.e., sources and drainage pathways), Phase 2 samples (all media types) were analyzed for total chromium, hexavalent chromium (in water only), and cyanide, the only analytes detected consistently during the Phase 1 analyses. During Phase 3, the samples sent to the laboratory for definitive analysis were analyzed for total chromium and cyanide.

2.5.4 Sampling Objectives

The OSC initiated an assessment with a specific sampling objective, as follows:

- Phase 1 -- Determine whether a threat to public health, welfare, and the environment exists. Identify sources of contamination to support an immediate CERCLA-funded activation for containment of contaminants and security fencing (site stabilization strategies) to reduce direct contact concerns on site. Sample the nearby drinking water wells for immediate human health concerns.

Once CERCLA funding was obtained and the site was stabilized:

- Phase 2 -- Define the extent of contamination at the site and adjacent residential properties. Estimate the costs for early action options and review any potential long-term remediation objectives. For example, install and sample soil borings and monitoring wells on site to evaluate potential impact on subsurface soils and ground water.

- Phase 3 -- After early actions are completed, document the attainment of goals. Assess that the response action was completed to the selected level and is suitable for long-term goals.

2.5.5 Selection of Sampling Approaches

The OSC, Team, and PADER reviewed all available information to formulate a sampling plan. The OSC selected a judgmental sampling approach for Phase 1. Judgmental sampling supports the immediate action process by best defining on-site contaminants in the worst-case scenario in order to evaluate the threat to human health, welfare, and the environment. Threat is typically established using a relatively small number of samples (fewer than 20) collected from source areas or suspected contaminated areas based on the historical data review and site reconnaissance. For this site, containerized wastes were screened to categorize the contents and to establish a worst-case waste volume, while soil samples were collected to demonstrate whether a release had already occurred, and nearby residential drinking water wells were sampled for immediate human health concerns.

For Phase 2, a stratified systematic grid design was selected to define the extent of contamination in soils. The grid could accommodate analytical screening and geophysical surveys. Based on search sampling conducted at sites similar to ABC Plating, a block grid with a 50-foot grid spacing was selected. This grid size ensured a 10 percent or less probability of missing a "hot spot" of 45 feet by 20 feet. The grid was extended to adjacent residential properties when contaminated soil was identified at grid points near the boundary of the site.

Based on the results of soil sampling and geophysical surveys, a judgmental approach was used to select locations for installation of 15 monitoring wells: at "hot spots"; along the perimeter of the suspected plume established from analytical results and geophysical survey plots; and at background ("clean") locations. Subsurface soil and ground- water samples were collected from each of the 15 monitoring well locations for laboratory analysis to establish the presence and, if applicable, the degree of contamination at depth.

2.5.6 Sampling Plan

During Phase 1, containerized wastes were evaluated using field analytical screening techniques. Phase 1 wastes-screening indicated the presence of strong acids and bases and the absence of volatile organic compounds. The Team collected a total of 12 surface soil samples (0-3 inches) and 3 ground-water samples during this phase and sent them to a laboratory for analysis. The soil sampling locations included stained soil areas, erosion channels, and soil adjacent to leaking containers. Background samples were not collected during Phase 1 because they were unnecessary for activating immediate action response funding. Ground-water samples were collected from three nearby residential wells. Based on Phase 1 analytical results, chromium was selected as the target compound for determination of extent of contamination in soil and ground water.

During Phase 2 sampling activities, the OSC used a transportable X-ray fluorescence (XRF) unit installed in an on-site trailer to screen soil samples for total chromium in order to limit the number of samples to be sent for laboratory analysis. Soil sampling was performed at all grid nodes at the surface (0-4 inches) and subsurface (36-40 inches). The 36-40 inch depth was selected based on information obtained from state reports and local interviews, which indicated that lagoon wastes were approximately 3 feet below ground surface. Once grid nodes with a contamination level greater than a selected target action level were located, composite samples were collected from each adjoining grid cell. Based on the XRF data, each adjoining grid cell was either identified as "clean" (below action level) or designated for response consideration (at or above action level).

Also during Phase 2, the OSC oversaw the performance of ground penetrating radar (GPR) and electromagnetic conductivity (EM) geophysical surveys to help delineate the buried trench and lagoon areas, any conductive ground-water plume, and any other waste burial areas. The GPR and comprehensive EM surveys were conducted over the original grid. Several structural discontinuities, defining possible disturbed areas, were detected. One GPR anomaly corresponded with the suspected location and orientation of the feeder trench. The EM survey identified several high conductivity anomalies: the suspected feeder trench location, part of the lagoon area, and a small area west of the process building, which may have been an illegal waste dumping area. (Field analytical screening and geophysical techniques are further discussed in Chapter 3.)

Using the data obtained during soil sampling and the geophysical surveys, a ground-water assessment plan for Phase 2 was prepared. The Team collected depth soundings and water level measurements of the nearby residential wells to assess aquifer usage and location (depth). With these data and the analytical results from Phase 1, a work plan for monitoring well installation and testing on site was developed. The plan consisted of:

- Installation of overburden, bedrock contact and bedrock (open borehole) monitoring wells in order to evaluate the shallow water table and aquifer conditions

- Analysis of subsurface soils retrieved during borehole/well drilling in order to evaluate the extent of contamination in overlying soils

- Collection of depth soundings and water level measurements of the newly installed monitoring wells to map aquifer and water table gradients

- Collection of ground-water samples from each monitoring well

- Performance of hydraulic tests in order to evaluate aquifer characteristics

The monitoring wells were located in areas shown, during soil sampling, to be heavily contaminated; along the outer perimeter of a contaminant plume based on soil XRF results and the geophysical surveys; and an apparent upgradient location for background conditions comparison. Fifteen wells were located at grid nodes corresponding to the above results. (Section 4.6.1 provides details on the performance of well installation (drilling), testing and surveying, and ground-water sampling procedures.)

Upon monitoring well installation and sampling, a hydraulic (pumping) test was completed of the bedrock monitoring wells to gather information about aquifer characteristics. These data characterize contaminant transport through the ground-water aquifer. The hydraulic test provided transmissibility, hydraulic conductivity, and storativity values. Utilizing these values with ground-water level data, the estimated vertical and horizontal ground-water gradient and velocity could be calculated. All monitoring wells installed were surveyed for elevation above mean sea level, needed to determine accurate depth to ground water (piezometric surface) and relative gradients.

Phase 3 activities are discussed in Section 6.8.

3.0 FIELD ANALYTICAL SCREENING, SAMPLING EQUIPMENT, AND GEOPHYSICAL TECHNIQUES

3.1 FIELD ANALYTICAL SCREENING

Field analytical screening techniques can provide valuable information in ground-water sampling. Field analytical screening for ground water is used primarily as a tool for siting monitoring wells and for on-site health and safety assessment during well drilling activities. When used correctly, screening techniques can help to limit the number of "non-detect" monitoring wells installed. Some of the commonly used screening methods for ground-water assessment are presented in this chapter in the general order that they would initially be used at a site, although site-specific conditions may mandate a different sequence. For more information on ground-water field screening devices, refer to the U.S. EPA *Compendium of ERT Field Analytical Procedures*, OSWER Directive 9360.4-04, and *Compendium of ERT Ground-Water Sampling Procedures*, OSWER Directive 9360.4-06. Refer to Standard Operating Safety Guides for each instrument, and the U.S. Department of Health and Human Services *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities* (NIOSH Pub. 85-115) for site entry information.

3.1.1 Flame Ionization Detector

The flame ionization detector (FID) detects and measures the level of total organic compounds (including methane) in the ambient air in proximity to a well or in a container headspace. The FID uses the principle of hydrogen flame ionization for detection and measurement. It is especially effective as an ethane/methane detector when used with an activated charcoal filter because most organic vapors are absorbed as the sample passes through the filter, leaving only ethane and methane to be measured.

The FID operates in one of two modes: the survey mode, or the gas chromatography (GC) mode. In the survey mode, the FID provides an approximate total concentration of all detectable organic vapors and gases measured relative to the calibration gas (usually methane). The GC mode identifies and measures specific components, some with detection limits as low as a few parts per million (ppm), using known standards analyzed concurrently in the field. Since the GC mode requires standards to identify classes of compounds, it is necessary to have an idea of which compounds might be present on site before sampling. Advantages of the FID are that it is portable, relatively rugged, and provides real-time results.

During a ground-water assessment, the FID is used in the survey mode for monitoring the borehole during drilling and in the survey or GC mode for health and safety screening.

The FID does not respond to inorganic substances. It has positive or negative response factors for each compound depending on the selected calibration gas standard. Ambient air temperatures of less than 40 degrees Fahrenheit will cause slower responses; relative humidity of greater than 95 percent can cause inaccurate and unstable responses. Interpretation of readings (especially in the GC mode) requires training and experience with the instrument.

3.1.2 Photoionization Detector

Another portable air monitoring instrument frequently used for field screening during ground-water assessments is the photoionization detector (PID). Like the FID, the PID provides data for real-time total organic vapor measurements, identifying potential sample locations and extent of contamination, and supporting health and safety decisions. The PID is useful in performing soil gas screening, health and safety monitoring during well drilling activities, and headspace screening analysis. The PID works on the principle of photoionization. Unlike the FID, the PID can be used to detect gross organic and some inorganic vapors, depending on the substance's ionization potential (IP) and the selected probe energy. It is portable and relatively easy to operate and maintain in the field.

The PID detects total concentrations and is not generally used to quantify specific substances. PIDs cannot detect methane; however, methane is an ultraviolet (UV) light absorber, and false negative instrument readings may register in methane-rich environments. The PID cannot detect substances with IPs greater than that of the UV light source. (Interchangeable UV lamps are available.) Readings can be affected by high wind speeds, humidity, condensation, dust, power lines, and portable radios. Dust particles and water droplets (humidity) in the sample may collect on the light source and absorb or deflect UV energy, causing erratic responses in PIDs not equipped with dust and moisture filters.

3.1.3 Gas Chromatograph

Although many FIDs are equipped with a GC mode, an independent, portable GC (gas chromatograph) can also be used on site to provide a chromatographic profile of the occurrence and intensity of unknown volatile organic compounds (VOCs) in ground water. The GC is useful as a soil gas screening tool to determine "hot spots" or plumes, potential interferences, and semi-quantitation of VOCs and semi-volatile organic compounds (semi-VOCs) in ground-water samples. For example, when installing a monitoring well, the GC might be used to screen water samples during drilling in order to indicate when a target contaminated aquifer zone is encountered.

Compounds with high response factors, such as benzene and toluene, produce large response peaks at low concentrations, and can mask the presence of compounds with lower response factors. However, recent improvements in GCs, such as pre-concentrator devices for lower concentrations, pre-column detection with back-flush capability for rapid analytical time, and the multi-detector (PID, FID, and electron capture detector (ECD)), all enable better compound detection. The GC is highly temperature-sensitive. It requires set-up time, many standards, and operation by trained personnel.

3.1.4 Hydraulic Probe

The hydraulic probe (Geoprobe® is one brand) is a truck-mounted device used to collect screening ground-water, soil, and soil gas samples at relatively shallow depths. The probe is mounted on the back of a small truck or van and is operated hydraulically using the vehicle's engine. Small diameter hardened steel probes are driven to depths of up to 40 feet or more, depending on soil conditions. Soil gas samples can then be collected using a vacuum pump. Soil or water samples can also be collected using a small-diameter shelby tube or slotted well point and foot valve pump.

The hydraulic probe can be used in ground-water investigations to assess vertical and horizontal extent of contamination. Shallow samples can be collected relatively quickly and easily. It is useful in a ground-water assessment to assist in siting monitoring wells and to install shallow wells if necessary. It can also collect undisturbed ground-water samples without installing wells. The hydraulic probe is only effective in unconsolidated geologic materials, however. In general, probing is possible under conditions amenable to hollow stem auger drilling.

3.1.5 Soil Gas Technique

Soil gas testing is a quick method of site evaluation. For ground-water assessments, soil gas testing is used to track contaminant plumes and determine appropriate locations for installing monitoring wells. For this technique, a thin stainless steel probe is inserted into a hole made in the soil with a special slam bar. The hole is sealed around the probe and a sampling pump is attached. Samples are then collected in Tedlar bags, sorbent cartridges, or SUMMA canisters. The samples are analyzed using an FID, PID, or GC. A disadvantage of the soil gas technique is that its ability to detect contaminants diminishes the further it is from the source (as contaminant concentration diminishes).

3.1.6 Field Parameter Instruments

Field parameters measured during ground-water sampling include pH, specific conductivity, temperature, salinity, and dissolved oxygen. Specific conductivity, pH, and temperature are often used as standard indicators of water quality. Instruments that measure these three indicators are used during ground-water assessments to determine if a well has been purged sufficiently (stabilized) prior to sampling (see Section 4.3).

3.1.7 X-Ray Fluorescence

Field analytical screening using X-ray fluorescence (XRF) is a cost-effective and time-saving method to detect and classify lead and other heavy metals in a sample. XRF screening provides immediate semi-quantitative results. The principle behind XRF is the detection and measurement of the X-rays released from an atom when it is excited by the absorption of source X-rays. The energy released (fluorescent X-rays) are characteristic of the atoms present.

Results of XRF analysis help determine the presence of metals and are often used to assess the extent of soil contamination at a site. For ground-water assessment, XRF may be used on subsurface soil samples collected during drilling or with surface soils when selecting locations for monitoring well installation. XRF use requires a trained operator and may require numerous site-specific calibration samples.

3.2 GROUND-WATER SAMPLING EQUIPMENT

Conducting representative ground-water sampling requires an understanding of the capabilities of the equipment used for sampling, since the use of inappropriate equipment may result in biased samples. Select appropriate sampling equipment based on the sampling objectives, the analytical parameters, the type of well being sampled (e.g., monitoring well or drinking water well), and other site-specific conditions. Follow SOPs for the proper use and decontamination of sampling equipment. This section presents various types of ground-water sampling equipment and information to assist in selecting appropriate materials.

The ground-water sampling devices discussed below are covered in greater detail in many SOPs and references on the various types of available ground-water sampling devices. Refer to U.S. EPA *A Compendium of Superfund Field Operations Methods*, OSWER Directive 9355.0-14, and *Compendium of ERT Ground-Water Sampling Procedures*, OSWER Directive 9360.4-06, for details on the equipment listed. Also refer to Driscoll, Fletcher G., *Ground-Water and Wells*, 2nd ed., and the 1985 "Proceedings of the Fifth National Symposium and Exposition on Aquifer Restoration and Ground-Water Monitoring," for additional comparisons of the various types of sampling equipment.

3.2.1 Bailer

A bailer is a simple purging device for collecting samples from monitoring wells. It usually consists of a rigid length of tube with a ball check-valve at the bottom. A line is used to mechanically lower the bailer into the well to retrieve a volume of water. Because bailers are portable and inexpensive, they can be dedicated to monitoring wells at a site, thus avoiding the need to use a bailer for sampling more than one well (and avoiding cross-contamination). Bailers are available in a variety of sizes and construction materials (e.g., polyvinyl chloride (PVC), Teflon®, and stainless steel).

Bailers are best suited for purging shallow or narrow diameter monitoring wells. Deeper, larger diameter, and water supply wells generally require mechanical pumps to evacuate a large volume of water.

For VOC analysis, a positive-displacement volatile sampling bailer is most effective. Bottom-fill bailers, which are more commonly used, are suitable provided that care is taken to preserve volatile constituents. Fill sample containers directly from the bailer, filling samples for VOC analysis first.

3.2.2 Hydraulic Probe

The hydraulic probe can be used to collect shallow (generally 40 feet or less) ground-water samples using a mill-slotted well point or retractable screen drive point. After the well point is driven to the desired depth, the probe rod is connected to a vacuum pump for purging. (Since ground water is sampled in situ and is not exposed to the atmosphere, extensive purging is not required.)

Water samples are collected using dedicated polypropylene tubing fitted with a small diameter foot-valve pump. Samples are collected in 40-ml vials or other containers for laboratory analysis. See Section 3.1.4 for more information on the hydraulic probe.

3.2.3 Air-Lift Pump

An air-lift pump operates by releasing compressed air via an air line lowered into the well. The air mixes with the water in the well to reduce the specific gravity of the water column and lift the water to the surface.

Air-lift pumping is used in well development and for preliminary testing. For sampling, air-lift pumping is less efficient than other pumping methods which follow; it may be selected for use when aeration is needed to remove gas or corrosive water which can be destructive to a well pump. Because an air-lift pump aerates the water, it is not applicable for VOC sample collection.

3.2.4 Bladder Pump

A bladder pump consists of a stainless steel or Teflon® housing that encloses a Teflon® bladder. The bladder pump is operated using a compressed gas source (bottled gas or an air compressor). Water enters the bladder through a lower check valve; compressed gas moves the water through an upper check valve and into a discharge line. The upper check valve prevents back flow into the bladder.

The bladder pump can be used to purge and sample to a depth of approximately 100 feet. It is recommended for VOC sampling because it causes minimal alteration of sample integrity as compared with other ground-water sample methods. The bladder pump requires a power supply and a compressed gas supply or air compressor. The pump is somewhat difficult to decontaminate and should thus be dedicated to a well (or dedicated tubing should be used).

3.2.5 Rotary Pump

A rotary pump is a positive displacement pump which discharges the same volume of water regardless of the water pressure. The rate of discharge is the same at both low and high pressure, but the input power varies in direct proportion to the pressure. The rotary pump consists of a housing with inlet and outlet ports and rotating gears or vanes. As water is discharged from the pump, a replacement supply of equal volume is taken in.

Rotary pumps are useful for well purging and general sample collection at shallow to deep sampling depths. Because of water agitation, they may not be suitable for sampling VOCs, and they are difficult to decontaminate between sampling stations.

3.2.6 Peristaltic Pump

A peristaltic pump is a suction lift pump consisting of a rotor with ball-bearing rollers. Dedicated Teflon® tubing is threaded around the rotor. Additional lengths of dedicated Teflon® tubing are attached to both ends of the rotor tubing: one end is inserted into the well; the other end is a discharge tube. The sample makes contact with the tubing only, not with the pump. The tubing should be equipped with a foot valve to avoid having aerated water from the tubing fall back into the well.

A peristaltic pump is suitable for sampling small diameter wells (e.g., 2 inches). Cross-contamination is not of concern because dedicated tubing is used and the sample does not come into contact with the pump or other equipment. The peristaltic pump has a depth limitation of 25 feet and its use can result in a potential loss of the volatile fraction due to sample aeration.

3.2.7 Packer Pump

A packer pump is used to isolate portions of a well or water column for sampling. The pump consists of two expandable parts that isolate a sampling unit between them. The parts deflate for vertical movement within the well and inflate when the desired sampling depth is reached. The packers are constructed of rubber and can be used with various types of pumps.

An advantage of the packer pump is it allows the isolation of a portion of the water column in order to sample at a discrete depth. Disadvantages relate to the rubber construction of the packers which may deteriorate over time allowing cross contamination. The rubber also poses potential contaminant compatibility concerns. A packer pump should not be used if the contaminants are unknown, or where well casing or contaminant characteristics interfere or interact with the pump construction materials.

3.2.8 Syringe Sampler

Syringe samplers are a relatively new and less commonly available sampling device. Syringe samplers were developed by research groups to obtain ground water samples over a period of time. The device consists of a syringe (15 to 1500 ml in volume) which is lowered into the well to the desired sampling depth. The syringe plunger is then pulled open by a remote method, either mechanical or pneumatic, allowing the syringe to fill.

The remote operation allows the collection of a sample at a discrete depth. In addition, the interior of the sampler (i.e., the syringe) is not exposed to the water column. Disadvantages to this device include the small volume of sample that can be collected, it cannot be adapted for evacuation/purging uses, and it is not readily commercially available.

3.2.9 Ground-Water Sampling Equipment Selection Factors

The following factors should be considered when selecting ground-water sampling equipment.

- Composition - Select the composition of the sampling equipment based on the sampling parameters and objectives. For example, use samplers made of Teflon®, glass, or stainless steel instead of PVC when sampling for VOCs. Consider well composition when selecting sampling equipment. For example, select a stainless steel bailer when bailing a well with stainless steel casing to avoid the introduction of organic constituents. When sampling a PVC-cased well, PVC, stainless steel, or Teflon® bailers may be used.

- Physical Constraints - Physical constraints of the monitoring well location, power availability, and topography are factors that affect selection of ground-water sampling equipment. For example, a small diameter or particularly deep well may require the use of different purging and sampling equipment than that used for other wells at the site. Site accessibility may hinder the use of large or vehicle-mounted equipment.

- Sample Analysis - Equipment should be chosen based on its impact on the samples. For example, sampling equipment selected for collecting VOCs should agitate the water as little as possible. This is not as critical for metals or other non-volatile analyses.

- Ease of Use - Generally, the more complicated the sampling equipment is, the greater the chance for some form of failure in the field. Utilize the simplest effective sampling devices available. Adequate training in equipment safety and use is critical to personnel safety as well as to sample representativeness. Consider ease of decontamination when using non-dedicated equipment.

3.3 GEOPHYSICAL METHODS

Geophysical methods can be useful in conjunction with screening and sampling activities to help delineate subsurface features and boundaries, contaminant plumes, and bedrock types. Geophysical data can be obtained relatively rapidly, often without disturbing the site. The data are helpful in selecting well locations and screen depths. The following sections discuss surface and borehole geophysics and preferable geophysical techniques for ground-water investigations.

3.3.1 Surface Geophysics

The following surface geophysical techniques may be useful in ground-water investigations. As implied by the name, these techniques are performed above ground. For more detailed information on each of these techniques (with the exception of gravimetric surveys), see ERT SOP #2159 and Driscoll, 1986. For more information on gravimetric surveys, see Driscoll, 1986.

- Ground Penetrating Radar (GPR) - Uses a high frequency transmitter that emits radar pulses into the subsurface. These waves are scattered at points of change in the dielectric permittivity of the subsurface material and are reflected back to an antenna. (Dielectric permittivity is a function of bulk density, clay content, and water content of the subsurface.) The returning energy wave is then plotted as a function of time on an analog plot. Interpretation of the analog plot identifies anomalies, clay layers, and water content in the substrate.

  GPR works best in dry, sandy soil above the water table, and at depths between 1 and 10 meters (although the full instrument depth range is less than one meter to tens of meters). When properly interpreted, GPR data can indicate changes in soil horizons, fractures, and other geological features, water-insoluble contaminants, man-made buried objects, and hydrologic features such as water table depth. Uneven ground surfaces or cultural noise affect GPR results.

- Electromagnetic Conductivity (EM) - Relies on the detection of induced electrical current flow through geologic strata. This method measures bulk conductivity (inverse of resistivity) of subsurface materials below the transmitter and receiver. EM is commonly used in the detection of ground-water pollution, as well as to locate pipes, utility lines, cables, trenches, buried steel drums, and other buried waste.

  EM has limited applications in areas of cultural noise, including above-ground power lines and metal fences, and lateral geologic variations which might be misinterpreted as contaminant plumes.

- Electrical Resistivity - Used to map subsurface structures through differences in their resistance to electrical current. Material resistivities are measured as functions of porosity, permeability, water solution, and concentrations of dissolved solids in pore fluids. Bulk resistivity is measured in the subsurface by measuring electrical currents injected through electrodes placed in the soil.

  Electrical resistivity surveys are limited by electrical noise, such as occur in industrial areas. Resistivity surveys should ideally be conducted in areas removed from pipelines and grounded metallic structures such as metal fences and railroad tracks. This requirement precludes use of electrical resistivity surveys on many sites. Resistivity can often be used off site to map area stratigraphy. Resistivity surveys are labor intensive, requiring ground setup and removal of electrodes for each station measurement. Use extreme care during rain or wet ground conditions.

- Seismic Investigations - Conducted by two methods: refractive and reflective. In the refractive method, the travel time of acoustic waves is measured as they move through and are refracted along an interface of the subsurface. The reflective method measures travel time of acoustic waves as they are reflected off an interface. Seismic refraction is typically used when bedrock is within 500 feet of the ground surface.

  Seismic refraction is useful for mapping discrete stratigraphic layers and therefore can help in selecting monitoring well locations and depths. A seismic refraction survey can provide subsurface stratigraphic and structural data in areas between existing wells or boreholes. Seismic reflection is used less often in ground-water investigations, but is more commonly used for deeper and larger-scale stratigraphic mapping (e.g., petroleum exploration).

- Magnetic Investigations - Rely on local variations in the earth's magnetic field to detect ferrous or magnetic objects. By mapping variations in the concentrations of the local magnetic fields, detection of buried objects such as drums or tanks may be accomplished. Magnetic surveys are limited by cultural noise such as power lines, utilities, and metal structures.

- Gravimetric Surveys - Measure small localized differences in the earth's gravity field caused by subsurface density variations, which may be produced by changes in rock type (porosity and grain type), saturation, fault zones, and varying thickness of unconsolidated sediments overlying bedrock. This method is useful in identifying buried valleys, particularly in glaciated areas.

  Gravimetric surveys use a portable gravity meter which can survey a large area relatively quickly. The accuracy of the readings is dependent upon the accuracy of the elevation determination of each station. (Most altimeters are accurate only to plus or minus 2 ft (0.6 m), so gravity stations should be surveyed.) A gravimetric survey can provide a quick preliminary screening of an area. Other geophysical methods or test drilling can then be used to help identify stratigraphy and aquifer characteristics.

Table 1 illustrates the applicability of various surface geophysical techniques to ground-water investigations. Table 2 lists some advantages and disadvantages of surface geophysical techniques to ground-water investigations.

3.3.2 Borehole Geophysics

The following borehole geophysical techniques may be useful in ground-water investigations. Borehole geophysics may be used alone or to supplement surface geophysical techniques. Site terrain is an important factor when conducting borehole geophysical surveys. Much of the equipment is mounted or housed inside a truck but can be carried to well locations if necessary. Some borehole logs can be run in a cased as well as open hole.

Often several of the following tests are run at the same time for comparative purposes. Borehole geophysical logs can be interpreted to determine the lithology, geometry, resistivity, formation factor, bulk density, porosity, permeability, moisture content, and specific yield of water-bearing formations as well as the chemical and physical characteristics of ground water. The operating principles of the various borehole geophysical techniques are similar. A sonde (a cylindrical tool containing one or more sensors) is lowered to the bottom of the borehole, activated, and slowly withdrawn. Signals or measurements at various depths are recorded at the surface. Instruments vary from hand-held portable gear to truck-mounted, power-driven equipment. For more detailed information on each of these techniques, see Driscoll, 1986.

- Resistance Logs - Electric logs measuring the apparent resistivity of the rock and fluid surrounding a well. They are good indicators of subsurface stratigraphy and water quality. Electric current is measured as it flows from electrodes in the probe to other electrodes in the probe or on the ground surface.

  Resistance logs have a small radius of investigation and are very sensitive to conductivity of borehole fluid and changes in borehole diameter. Increases in formation resistivity produce corresponding increases in resistance measurements on the log. Deflections on the log are interpreted as changes in lithology. Because of its excellent response to lithology changes, the resistance log is very useful for geological correlation. Formation fluids are perhaps the most important variable in interpreting resistance logs. For example, dry sands and clays have high resistivities, but their resistivities decrease with water saturation.

Dissolved minerals also affect resistivity. (Fresh water is a poor conductor whereas salt water is a good conductor; water in saturated clays contains dissolved minerals from the clay, which results in high conductivities.)

A limitation of resistance logs is that they can be run only in uncased boreholes that are filled with drilling fluid and water. Resistance logging is therefore most appropriately conducted before monitoring well completion.

- <u>Spontaneous Potential (SP) Logs</u> - Used in conjunction with resistivity logs to show the naturally occurring electric potentials of the chemical and physical changes at contacts between differing types of geologic materials. The electric current is measured between an electrode placed in an uncased borehole and one placed at the surface.

  SP response is due to small voltage differences caused by chemical and physical contacts between the borehole fluid and the surrounding formation. Voltage differences appear at lithology changes or bed boundaries and their response is used to quantitatively determine bed thickness or formation fluid resistivity. Qualitative interpretation of the data can be used to identify permeable beds.

  Buried cables, pipelines, magnetic storms, and the flow of ground water can all cause anomalous readings. Caution must be exercised when using SP data in a quantitative fashion. Mathematical formulas are structured for oil well logging and incorporate assumptions which may not apply to fresh water wells. As with resistance logs, SP logs can be run only in uncased, liquid-filled boreholes.

- <u>Gamma Logs</u> - Measure the naturally occurring gamma radiation emitted from the decay of radioisotopes normally found in the substrate. Elements that emit natural gamma radiation are potassium-40 and daughter products of the uranium and thorium decay series. Changes in radiation levels are commonly associated with differences in substrate composition.

  Gamma logs can be run in open or cased boreholes filled with water or air. The sensing device can be part of the same sonde that conducts SP and resistance logs. Gamma rays or photons are measured and plotted as counts per minute. This method is useful in identifying clay layers or other naturally radioactive geologic units.

  Gamma logging is used to identify the lithology of detrital sediments, where the finer-grained units have higher gamma intensity. (Fine-grained materials also tend to have lower permeability and effective porosity, important for evaluating aquifer zones.) A limitation with gamma and other nuclear logs is that they are affected by changes in borehole diameter and borehole media (e.g., air, water, or mud). Gamma logs record the sum of the radiation emitted from the formation and do not distinguish between radioactive elements. For use in stratigraphic correlation however, specific element identification is not critical. Interpretation of gamma logs is difficult where sandstone and other strata contain volcanic rock fragments with radioactive minerals (e.g., rhyolite). Interpretation is also difficult in sandstone containing a large proportion of feldspar (which contains radioactive potassium-40).

- <u>Gamma-Gamma Logs</u> - Similar to gamma logs except that a radioactive gamma source is attached to the gamma sonde and the gamma particles reflected back from the geologic formation are measured. Gamma-gamma logs measure the differing bulk densities of geologic materials. They can be used to identify lithology and also to calculate porosity when fluid and grain density are known.

- <u>Neutron Logs</u> - Also utilize a radiation source in the sonde. The neutron source is a europium-activated, lithium iodide crystal enriched in lithium-6. The neutron logging tool bombards the formation with neutrons and measures the returning radiation. Neutrons, when ejected from a nucleus, have great penetrating power and may travel through several feet of subsurface formation. All free neutrons are eventually captured by the nuclei of some element. Neutron logs respond primarily to hydrogen density. The high energy neutrons from the source are slowed by collision with hydrogen ions in the formation. This response to hydrogen ion content is then cross-calibrated to porosities for water-saturated rocks. Neutron logs respond to the hydrogen content in the borehole and surrounding formation and indicate the porosity of the various geologic units in the survey. Neutron logs can be run in cased or open holes which are dry or filled with fluid.

Neutron logs are typically used to determine moisture content above the water table and total porosity below the water table. Neutron logs are effective for identifying perched water tables. Neutron log information can also be used to determine lithology and conduct stratigraphic correlation of aquifers and associated formations as well as to help determine the effective porosity and specific yield of unconfined aquifers.

- Acoustic (Sonic) Logs - Measure the travel time and attenuation of an acoustic signal created by an electromechanical source in the borehole. A transmitter in the borehole converts the electrical energy to acoustic (sound) energy which travels through the formation as an acoustic pulse to one or more receivers. The acoustic energy is then converted back to electrical energy, which is measured at the surface. The acoustic wave velocity is affected by the type of material through which it passes (rock or sediment is more conductive than is pore fluid), hence it is useful in determining porosity.

  Acoustic logs can help determine fracture patterns within semiconsolidated and consolidated bedrock such as sandstone, conglomerate, and igneous rocks. Knowledge of fracture patterns in an aquifer is helpful in estimating ground-water flow, and thereby estimating the rate of plume movement. Acoustic logs can be used to locate the static water level and to detect perched water tables.

- Temperature Logs - Used to measure the thermal gradient of the borehole fluid. The sonde measures changes in temperature of the fluid surrounding it, and the log records resistivity as a function of temperature. Borehole fluid temperature is influenced by fluid movement in the borehole and adjacent strata. In general, the temperature gradient is greater in low permeability rocks than in high permeability rocks, likely due to ground-water flow. Temperature logs provide information regarding ground-water movement and water table elevation. Temperature logs are useful for detecting seasonal recharge and subsurface infiltration of irrigation and industrial wastewater runoff, and quantitative interpretation of resistivity logs.

  Temperature logs are designed to be operated from the top to the bottom of the borehole, in order to channel water past the sensor. Repeat temperature logs should be delayed until the borehole fluid has had time to reach thermal equilibrium.

Table 3 illustrates the applicability of various borehole geophysical techniques to ground-water investigations. Table 4 lists some advantages and disadvantages of borehole geophysical techniques to ground-water investigations.

3.3.3 Geophysical Techniques for Ground-Water Investigations

The following situations illustrate uses for geophysical techniques in ground-water assessment.

- To define the location, extent, and the movement of a contaminant plume, several geophysical techniques may be utilized, including EM, electrical resistivity, and possibly GPR. Resistivity and spontaneous potential (SP) logs could also be utilized as borehole geophysical methods.

- To locate faults and fracture systems, seismic refraction and reflection and EM are the preferred methods, but GPR, electrical resistivity and acoustic logs could also be used.

- The mapping of grain size distribution in unconsolidated sediments is not possible with any geophysical technique. It is possible, however, to identify different soil types of different grain sizes (e.g., sand, silt, and clay). Seismic reflection and refraction, GPR, and gravimetric surveys may be used to identify differing formations. Several borehole geophysical techniques could also be utilized in this type of analysis, including gamma, gamma-gamma, neutron porosity, resistivity, and SP logs.

- Definition of lithologic boundaries may be accomplished with seismic reflection and refraction and with GPR techniques. When using borehole geophysics, resistivity, SP, and acoustic logs are useful.

- For mapping water tables, GPR and electrical resistivity are preferred but seismic refraction and reflection and gravimetric surveys may also be used. If using borehole geophysics, direct measurement or temperature logs would be the method of choice. Resistivity and SP logs could also be used.

- To define the bedrock topography, seismic refraction and reflection, GPR and gravimetric surveys may be used.

- For delineating stratigraphic layers or subsurface features, such as buried stream channels and lenses, seismic refraction and reflection, electrical resistivity, gravimetric surveys, and possibly GPR could be used.

3.4 EXAMPLE SITE

3.4.1 Selection of Field Analytical Screening Techniques

Phase 1 sampling identified the sources and types of on-site contaminants in order to establish a threat. Hazard categorization techniques, organic vapor detecting instruments (FID and PID), and radiation and cyanide monitors were utilized to tentatively identify containerized liquid wastestreams in order to select initial judgmental soil sampling locations. During Phase 2 sampling, a portable XRF unit was used to determine the extent of soil contamination and to identify additional "hot spots." A FID and PID continued to be utilized throughout all field activities for health and safety monitoring during Phases 1 through 3.

The portable XRF for soil screening was also used during monitoring well installation. Continuous split spoon samples were collected during advancement of the boreholes. Each spoon was sampled and screened in the field using the XRF unit. Selected samples (one per borehole location) were submitted to the laboratory for confirmation analysis. One off-site sample was selected by the field geologist based on field observations and professional judgment.

Ground-water samples were screened in the field for pH, specific conductivity, and temperature using a three-in-one monitoring instrument. The instrument probe was placed into a clean glass jar containing an aliquot of the ground-water sample. The instrument was decontaminated prior to and after each sample screening.

3.4.2 Selection of Sampling Equipment

Dedicated plastic scoops were used for Phase 1 soil sampling. Phase 1 ground-water samples were collected directly from the residential taps into sample containers. For Phase 2, soils were collected from the near surface (0-4 inches) and at depth. Stainless steel trowels were used to retrieve shallow soil samples. Subsurface samples were collected by advancing boreholes using a hand-operated power auger to just above the sampling zone and then using a stainless steel split spoon to retrieve the soil. The split spoon was advanced with a manual hammer attachment.

Monitoring wells were installed using a dual-tube, air percussion drill rig. Borehole soil samples were retrieved using 2-foot stainless steel split spoon samplers. Soil from the split spoons was transferred to sample containers using disposable plastic scoops. Monitoring well installation is described further in Section 4.6.1.

Ground water was sampled in Phase 2 from the monitoring wells installed on site. First, monitoring wells were purged using a 1.5 gallon per minute (gpm) submersible rotary pump with flexible PVC outflow hose and safety cable. The pump and hose were decontaminated between well locations by pumping deionized water through the system. A similar pump and hose system was used to perform the hydraulic (pumping) test. The pumps are operated by a gas-powered generator placed near the well location.

The ground-water samples were obtained using dedicated bottom-fill Teflon® bailers. The bailer was attached to nylon rope, which was selected because less material would be adsorbed onto the nylon and brought out of the well. Residential ground-water samples were collected directly into the sample containers from the kitchen sink tap. Water level and depth measurements were obtained from monitoring wells using decontaminated electronic measuring equipment.

3.4.3 Selection of Geophysical Methods

The GPR instrument delineated buried trench and lagoon boundaries. The EM meter detected subsurface conductivity changes, thereby identifying buried metal containers and contaminants. The EM-31D, a shallower-surveying instrument than the EM-34, was selected because of the instrument's maneuverability and ease of use, and because the expected contaminant depth was less than 10 feet.

Table 1: Applicability of Surface Geophysical Techniques to Ground-Water Investigations

	Seismic Reflection	Seismic Refraction	Electromagnetic Conductivity	Magnetic Investigations	Ground Penetrating Radar	Electrical Resistivity	Gravi-metric Surveys
Contaminant Plume Delineation			P		A	P	
Faults/Fracture Detection	P		P		A	A	A
Lithologic Boundary Delineation	P	P			A		
Bedrock Topography Delineation	P	P			A		A
Stratigraphic Mapping	P	P			A	P	P
Water Table Mapping	A	A			P	P	A
Soil Type of Unconsolidated Sediments	P	P			P		P
Metallic Detection			P	P	P	A	
Non-Metallic Detection						P	
Seepage Detection			A		P	A	
Buried Structure Detection				A	A		

P - Preferred Method

A - Applicable Method (in most cases)

Table 2: Advantages and Disadvantages of Surface Geophysical Techniques to Ground-Water Investigations

	Advantages	Disadvantages
Seismic Reflection	• Ability to discern discrete layers • Less offset space is required than for refraction	• Velocities 10-20% of true velocities • Data collection and interpretation are more labor intensive and complex than for refraction • Depth data not as precise as refraction • Signal enhancement needed to identify reflected waves
Seismic Refraction	• Relatively precise depth can be determined • Provide subsurface data between boreholes • Ability to map water table and top of bedrock	• Data collection can be labor intensive • Large geophone line lengths needed
Electromagnetic Conductivity	• Lightweight, portable equipment • Continuous or quick scan survey • Rapid data collection	• Interference from cultural noise and surface metal objects • Limited use where geology varies laterally
Magnetic Investigations	• Can survey large area quickly and cost effectively • Little site preparation needed	• Interference from cultural noise, and large metal objects • Unable to differentiate between steel anomalies
Ground Penetrating Radar	• Can survey large area quickly • Continuous real-time data display • Quick data processing	• Interference from cultural noise, uneven terrain, and vegetation • Clay content and shallow water table inhibit radar penetration
Gravimetric Surveys	• Can survey large area quickly • Little site preparation	• Accurate elevations require surveying • Should be used only as preliminary screening tool
Electrical Resistivity	• Quantitative modeling can estimate depth, thickness, and resistivity of subsurface layers	• Interference from cultural noise, surface metal objects, and industry • A minimum of two to three crew members is required • Surveys are labor intensive

Table 3: Applicability of Borehole Geophysical Techniques to Ground-Water Investigations

	Resistance Logs	Spontaneous Potential Logs	Gamma Logs	Gamma-Gamma Logs	Neutron Logs	Temperature Logs	Acoustic Logs
Contaminant Plume Delineation	P	P	P			P	
Faults/Fracture Detection							P
Lithologic Boundary Delineation	P	P	P	P	A		A
Bedrock Topography Delineation	P	P	P	P	A		P
Stratigraphic Mapping	P	P	P	P	P		P
Water Table Mapping	A	A			P	P	A
Soil Type of Unconsolidated Sediments	P	P	P	P	P		
P - Preferred Method			A - Applicable Method (in most cases)				

Table 4: Advantages and Disadvantages of Borehole Geophysical Techniques to Ground-Water Investigations

	Advantages	Disadvantages
Resistance Logs	• Indicates lithologic changes • Indicates amount and type of subsurface fluid (water quality)	• Can only be run in uncased borehole • Difficult to interpret lithology when using drilling fluid with clay additives
Spontaneous Potential Logs	• Can be run in conjunction with resistance log • Indicates lithologic changes and permeable beds	• Can only be run in uncased borehole • Interpretation for water well often more difficult than for oil well
Gamma Logs	• Easy to operate • Can be run in open or cased borehole • Qualitative guide for stratigraphic correlation and permeability	• Affected by changes in borehole diameter and borehole media • Feldspar and volcanic rock fragments make interpretation difficult
Gamma-Gamma Logs	• Can identify lithology and calculate porosity when fluid and grain density are known	• Porosity readings of low density materials can be erroneously high
Neutron Logs	• Can determine total porosity in saturated zone • Can determine moisture content in unsaturated zones • Can be run in open or cased borehole	• Radioactive source requires special handling by trained personnel • Logging can be somewhat complex
Acoustic Logs	• Useful for determining relative porosity • Indicates fracture patterns in aquifer • Can indicate static water level and perched water tables	• Clays may distort readings
Temperature Logs	• Can indirectly measure permeability • Provides information regarding ground-water movement and water table elevation	• Delay repeat logs until borehole fluid reaches thermal equilibrium

4.0 GROUND-WATER SAMPLE COLLECTION AND PREPARATION

4.1 INTRODUCTION

During a response action, proper field sample collection and preparation is as important as proper sampling equipment selection. Sample collection refers to the physical removal of an aliquot of ground water from its source (i.e., aquifer) for the purpose of either screening or laboratory analysis. Ground-water sample collection procedures should be selected so that the resultant sample is representative of the aquifer or particular water zone being sampled. Field sample preparation refers to all aspects of sample handling from collection to the time the sample is received by the laboratory. This chapter provides information on sample collection and preparation for ground water.

The representativeness of a ground-water sample is greatly influenced by the sampling device used and the manner in which the sample is collected. Proper training and use of SOPs will limit variables and enhance sample representativeness. Selection of ground-water sampling devices such as bailers and pumps should be site-specific and dependent on well diameter, yield, lift capacity, and the analytes being sampled. Excessive aeration should be minimized to preserve volatile constituents. Where possible, the bailer or pump used should be compatible with the analyte(s) of concern.

4.2 STATIC WATER LEVEL

Prior to sampling, the static water level elevation in each well should be measured. All measurements should be completed prior to the sampling event so that static water levels will not be affected. The water level measurements are necessary to establish well purging volumes. These measurements can also be used to construct water table or potentiometric surface maps and hence determine local ground-water flow gradient. Measure the depth to standing water and the total depth of the well to calculate volume of stagnant water in the well for purging. See ERT SOP #2151 for detail on collecting static water level measurements.

4.3 WELL PURGING

There is little or no vertical mixing of water in a nonpumping well, therefore stratification occurs. The well water in the screened section mixes with the ground water due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant. The stagnant water may contain foreign material inadvertently or deliberately introduced from the surface, resulting in unrepresentative data. Adequate well purging prior to sample withdrawal will safeguard against collecting nonrepresentative stagnant water samples.

Well purging techniques are specific to the following well types.

- <u>Residential, Commercial, and Public Supply Wells</u> - Sample residential, commercial, and public supply wells as near to the wellhead as possible and at a point before treatment, such as filtering and water softening units, whenever possible. Open the tap to a moderate flow and purge for approximately 15 minutes. If this is not possible, a 5-minute purge is considered a minimum. As an alternative to a minimum volume, purging can be conducted until the field parameters pH, temperature, and specific conductivity have stabilized (see Section 4.3.1).

- <u>Monitoring Wells</u> - To obtain a representative sample from a monitoring well, it is necessary to evacuate the standing water in the well casing prior to sampling. The minimum recommended amount that should be purged from a monitoring well is one casing volume, but three to five casing volumes of standing water should be evacuated where possible in order to obtain a ground-water sample representative of the aquifer. In a high yield aquifer where there is no standing water above the screened section of the well casing, purging three volumes is not as critical as in lower yield aquifers. (The faster recharge rate limits the amount of time that the water has to interact with the atmosphere and casing materials.) If the well is purged dry, it should be considered sufficiently purged for sampling (refer to Section 4.3.2 for additional information).

The amount of purging a well receives prior to sample collection depends on the intent of the sampling as well as the hydrogeologic conditions. When the sampling objective is to assess overall water resource quality, long pumping periods may be required to obtain a sample that is representative of a large volume of the aquifer. The pumped volume is determined prior to sampling, or the well is pumped until the stabilization of parameters such as temperature, specific conductivity, and pH has occurred.

Monitoring to define a contaminant plume requires a representative sample of a small volume of the aquifer. These circumstances require that the well be pumped enough to remove the stagnant water but not enough to induce flow from other areas. Generally, three well volumes are considered effective. Otherwise, the appropriate volume to be removed prior to sampling can be calculated, based on aquifer parameters and well dimensions.

Well purging devices include bailers, submersible pumps (rotary-type), non-gas contact bladder pumps, suction pumps, and hand pumps. See ERT SOP #2007 for specific guidelines on purging wells prior to sampling and for more detail on each purging device.

4.3.1 Stabilization Purging Technique

The stabilization technique is an alternative to volume purging. This method requires that several field parameters be continuously monitored during purging. When these parameters stabilize, begin sampling. The parameters used for this method are pH, temperature, and specific conductivity. Stabilization of these parameters indicates that the standing water in the monitoring well has been removed and that a representative sample of the aquifer water may now be collected. This method of purging is useful in situations where it is not feasible to evacuate three casing volumes from the well prior to sampling (e.g., large casing diameter, extremely deep, and active supply wells). See ERT SOP #2007 for specific volume and stabilization purging techniques.

4.3.2 Wells that Purge Dry

A well that is purged dry should be evacuated and allowed to recover prior to sample withdrawal. If the recovery rate is fairly rapid and time allows, evacuation of more than one volume of water is desirable. If the recovery rate is slow, the first recharge can be considered suitable for sample collection.

4.4 GROUND-WATER SAMPLE COLLECTION

In order to maintain sample representativeness, dedicated samplers should be used for each well whenever possible. When not possible, the sampler should be decontaminated after each sample collection and sufficient QA/QC blank samples should be collected to assess potential cross-contamination.

After well purging is complete, collect and containerize samples in the order of most volatile to least volatile, such as:

- Volatile organic analytes (VOAs)
- Purgeable organic carbon (POC)
- Purgeable organic halogens (POX)
- Total organic halogens (TOX)
- Total organic carbon (TOC)
- Extractable organic compounds
- Total metals
- Dissolved metals
- Phenols
- Cyanide
- Sulfate and chloride
- Turbidity
- Nitrate and ammonia
- Radionucliides

See ERT SOP #2007 for specific detail on filling sample containers, with special considerations for VOA sampling.

If the contaminants in the water column are stratified (e.g., DNAPLs, LNAPLs), be certain to use an appropriate sampling device. Modify, where possible, standard sampling procedures to collect the sample from the suspected depth for the contaminant layer. It may be necessary to lower the bailer used for sample collection to a particular depth in the well, or to use a point-source bailer or other discrete-depth sampling device.

After a monitoring well is initially constructed, it should be developed and purged to remove invaded water. The well should sit idle for at least two weeks to allow the water level to fully stabilize and the suspected stratified layers to settle out. Measurement of the thickness of a floating (LNAPL) layer may be accomplished in several ways. An indicator gel, chalk or paste may be applied to an incremented steel tape.

The indicator changes color in the presence of water or the immiscible layer, depending on the specific use of the indicator compound. For example, water-level indicator gel is used to determine the depth to the water surface. A weighted float is then used to determine the depth to the top of the LNAPL layer. The difference between these two readings is the thickness of the floating layer.

An electronic monitoring device called an interface probe is also available for the LNAPL layer measurement. This device, like an electric water-level sounder, is lowered into the well along an electronic wire/line. When the probe contacts the surface (the LNAPL layer) a sound is generated. As the sampler continues to lower the probe, a different electronic sound is emitted when the water surface, or water/oil interface, is reached. The line of the device is incremented, like a water-level sounder, so the layer thickness can be determined. Standard electric water-level sounding devices, however, will not work properly for these measurements. The interface probe is a specialized instrument which is commonly available and used at fuel oil/ground-water contamination sites.

A sample of a floating layer may be obtained using a bottom-fill bailer. Care should be taken to lower the bailer just through the floating layer, but not significantly down into the underlying ground water. (A clear bailer is preferable for this activity.)

For sampling sinking layers, a discrete-depth-capable sampling device, such as a packer pump or syringe sampler, is best suited. When these specialized devices are not available, depending on the sampling parameters, standard devices may be used. For example, samples at the bottom of the screen or at some intermediate location may also be obtained with a standard bailer and a second well casing. In order to avoid mixing the waters, a separate casing is temporarily lowered inside the permanent well casing. The temporary casing is equipped with an easily removed cap on the bottom so that no fluid enters the casing until it has reached the desired sampling depth. The cap is then freed from the bottom of the inner casing, allowing water to enter to be sampled by a bailer. At significant depths below the nonaqueous layer, several bailers full of water may need to be withdrawn and discarded before the sample is obtained from a fresh formation sample.

When a temporary casing and all other specialized equipment is unavailable, a standard bailer alone may be used. Collect a water sample from the well and transfer it to the sample container. Allow the sample to settle in the sample container into the separate stratified layers. The analytical laboratory may then decant, as appropriate, to obtain a sample of the desired layer. More commonly, the parameters of concern in the stratified layers are simply included in the laboratory analysis of the sample as a whole without the need to separate into unique layers. In this last example, care must be taken to allow the bailer to reach the desired depth in the water column to insure collecting any dense layers at the bottom of the well. (See Section 2.4 for additional discussion on sampling concerns and the physiochemical nature of contaminants.)

4.5 GROUND-WATER SAMPLE PREPARATION

This section addresses appropriate ground-water sample preparation and handling techniques. Proper sample preparation and handling maintain sample integrity. Improper handling can render samples nonrepresentative and unsuitable for analysis.

The analyses for which a sample is being collected determines the type of bottles, preservatives, holding times, and filtering requirements. Samples should be collected directly into appropriate containers that have been cleaned to EPA or other required standards. Check to see that a Teflon® liner is present in the sample bottle cap, if required.

Samples should be labeled, logged, and handled correctly, including appropriate chain-of-custody documentation. Place samples in coolers to be maintained at 4EC. Ship samples to arrive at the designated analytical laboratory well before their holding times are expired. It is preferable that samples be shipped or delivered daily to the analytical laboratory in order to maximize the time available for the laboratory to do the analysis.

Certain conditions may require special handling techniques. For example, treatment of a sample for VOAs with sodium thiosulfate preservative is required if there is residual chlorine in the water (e.g., a public water supply) that could cause free radical chlorination and change the identity of the original contaminants. (The preservative should not be used if there is no chlorine in the water.) All such special requirements must be determined prior to conducting fieldwork.

Sample preparation for ground water may include, but is not limited to:

- Filtering
- Homogenizing/Aliquotting
- Splitting
- Final Preparation

4.5.1 Filtering

Samples may require filtering, such as for total metals analysis. Samples collected for organic analyses should not be filtered. Two types of filters may be used, which must be decontaminated prior to use. A barrel filter works with a bicycle pump, which builds up positive pressure in the chamber containing the sample and then forces it through the filter into a container placed underneath. A vacuum filter has two chambers; the upper chamber contains the sample, and a filter divides the chambers. Using a hand pump or a Gilian®-type pressure pump, a vacuum is created in the upper chamber and the sample is filtered into the lower chamber. Preservation of the sample, if necessary, should be done after filtering.

See ERT SOP #2007, Section 2.7.5, for more detail on filtering ground-water samples.

4.5.2 Homogenizing/Aliquotting

Homogenizing, or aliquotting, is the mixing or blending of a grab sample to distribute contaminants uniformly. Ideally, proper homogenizing ensures that all portions of the sample are equal or identical in composition and are representative of the total sample collected. Incomplete homogenizing can introduce sampling error. Homogenizing disturbs the ground-water sample, so it is not appropriate for VOC sampling.

Homogenizing is done during only one sampling event per well location, and only after the VOC sample portions have first been filled. It may be utilized for wells with extremely low yield and potentially insufficient sample volume to fill all sample containers provided by the laboratory. In some low yielding wells, the percentage of suspended material in a bailer-full of sample will increase as sampling proceeds. Homogenizing ensures that at least a minimum volume is aliquotted per analytical parameter, and the percentage of suspended material is equitably divided among all containers (excluding VOCs).

4.5.3 Splitting

Split samples are created when the samples have to be separated into two or more equivalent parts and analyzed separately. Split samples are most often collected in enforcement actions to compare sample results obtained by EPA with those obtained by the potentially responsible party. Split samples also provide measures of sample variability and analytical error. Fill two sample collection jars simultaneously, alternating the sample stream or bailer full of sample between them.

4.5.4 Final Preparation

Final preparation includes preserving, packaging, and shipping samples.

Sample preservation is used to retard chemical breakdown of the sample. Preservation of ground-water samples includes controlling pH with chemical preservatives, refrigerating samples, and protecting samples from light.

Select sample containers on the basis of compatibility with the material being sampled, resistance to breakage, and capacity. Appropriate sample volumes and containers will vary according to the parameters being analyzed. Actual sample volumes, appropriate containers, and holding times are specified in the U.S. EPA *Compendium of ERT Ground-Water Sampling Procedures*, OSWER Directive 9360.4-06. Package all samples in compliance with current International Air Transport Association (IATA) or U.S. Department of Transportation (DOT) requirements, as applicable. Packaging should be performed by someone trained in current DOT shipping procedures.

See ERT SOP #2007, Section 2.3 for more detail on ground-water sample preparation.

4.6 EXAMPLE SITE

4.6.1 Sample Collection

During Phase 1 and Phase 2, surface soil samples were collected from shallow locations. The samples were collected as grab samples. The sample locations were cleared of surface debris, then samples were retrieved with disposable plastic scoops and placed directly into sample containers. During Phase 2, subsurface soil samples were collected at the soil boring/well installation locations, using stainless steel split spoon samplers. The split spoon samples were collected using a hand-held power auger to advance the hole. A 2-foot stainless steel split spoon sampler with hammer attachment was then pushed into the hole. The soil sample was retrieved from the split spoon sampler using a disposable plastic scoop to transfer the soil into a stainless steel bowl. Several scoopfuls were collected along the length of the split spoon sampler and composited in the bowl. The composite sample was then transferred directly into the sample container using the disposable plastic scoop.

Phase 1 and Phase 2 residential well ground-water samples were collected directly from the kitchen taps of homes using private wells near to the site. The configuration of the residential system was noted in the logbook prior to sampling. If present, water softeners were taken off line. Any screen or filter was first removed from the tap, which was allowed to run for a minimum of five minutes prior to sampling. The samples were collected directly into the sample containers.

Fifteen monitoring wells were installed at the site at locations described in Section 2.5.6. The wells were drilled with a dual-tube, air percussion rig. Each boring was completed to a 9.5-inch diameter. After completion of the boring, 4-inch Schedule 40 PVC casing and 0.010 slot screen were installed in lengths appropriate to each well. Shallow wells were drilled to approximately 40 feet below grade surface (BGS) and bedrock contact wells were drilled to approximately 55 to 60 feet BGS. Continuous split spoon sampling was performed at each well location from 4 feet BGS to well completion depth. The boreholes were grouted from the bottom to the top of the lower confining layer, then 10 feet of screen were set above the grouted portion. PVC casing was set above the screen to above the ground surface. Casing was extended to accommodate a 2-foot stick-up above grade, and then capped. A 6-inch diameter metal outer casing with locking cover was installed over the well casing stick-up and secured 2 feet BGS in concrete. A concrete spill pad was then constructed around each well outer casing to prevent re-infiltration at the well point. Upon completion, all monitoring wells were developed by purging using a decontaminated rotary pump and flexible PVC disposable hose.

A Team geologist supervising the monitoring well installation logged each borehole soil lithology from the retrieved split spoon samplers collected during drilling of the boreholes. The geologist scanned each sampler with a PID immediately upon opening (into halves) for health and safety monitoring. All logging was accomplished utilizing the Unified Soils Classification System standard method. Figure 3 provides an example of a soil boring and monitoring well completion log.

Soil samples were then collected in wide-mouth clear glass jars by transferring a portion of each lithologic unit in the split spoon with a disposable plastic scoop and compositing the sample in the jar. At the completion of each borehole, each sample was screened in the field using the XRF unit. Select samples (one per borehole location) were forwarded to the laboratory for confirmation analysis. Split spoon samplers were decontaminated after each use.

Upon completion and development, the 15 on-site monitoring wells were sampled for ground-water analysis. The well caps were brushed and cleaned off prior to opening. Immediately upon removing the well cap, a PID was operated over the opening to determine VOC levels, if any, in the breathing zone. The VOC monitoring was performed to establish if a higher level of respiratory protection was required. Depth to water level measurements were then taken of each well to the nearest 0.01 ft. The total depth of the well was obtained with a depth sounder. The volume of water in the well was then calculated using the formula below. For a four-inch well, well volume would equal 0.632 gallon/ft.:

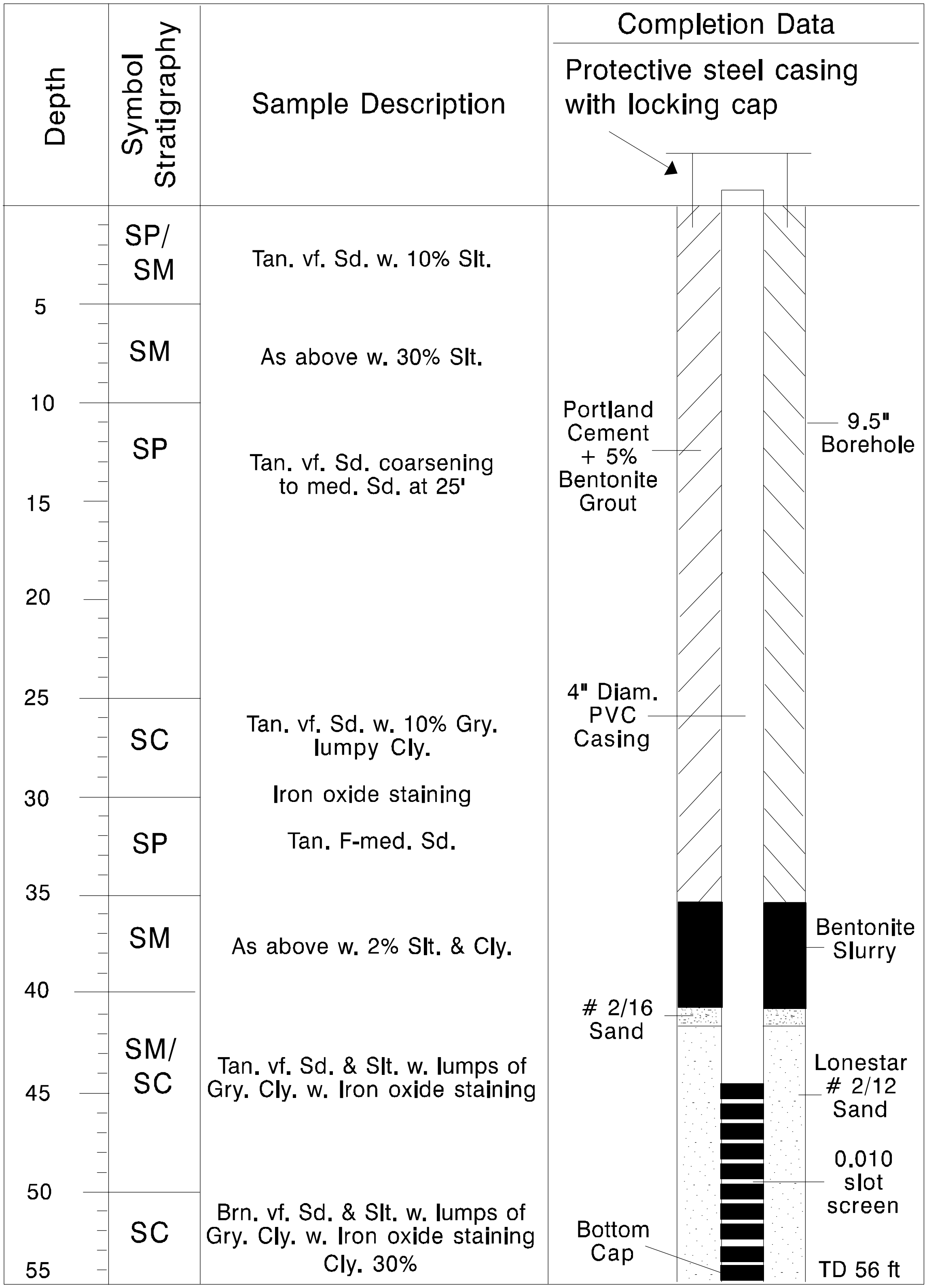
$$\text{Well volume} = B \times (\text{radius of well})^2 \times \text{height of water column} \times 7.48 \text{ gallon/ft}^3$$

(conversion factor for ft^3 to gallons)

Each monitoring well was purged prior to obtaining a representative sample. Wells with sufficient yield were purged three well volumes. Low-yielding wells were purged once to dryness. (Most wells on site are low-yielding.) Purging was completed using a 1.5 gpm decontaminated submersible (rotary-type) pump with flexible PVC outflow hose and safety cable. The pump was slowly lowered to a point approximately 3 feet above the bottom of the well. With the known flow rate, length of pumping required was calculated. Purge water was pumped into 55-gallon steel drums. (The drums were staged and later disposed of properly based on the results of analysis of their contents.) Low-yielding overburden wells were purged with a decontaminated stainless steel bottom-fill bailer and polypropylene rope until dry. All wells were allowed to recover overnightbefore sample collection, or until sufficient water was present to complete a sample set.

Each monitoring well was sampled after purging and recovery. Ground-water samples were collected using dedicated disposable Teflon® bailers. Each bailer was attached to a clean polypropylene rope and intro-

Figure 3: Soil Boring/Monitoring Well Completion Log



duced into the well. The bailer was lowered slowly to the approximate mid-point of the well. Once the sample was collected, care was taken not to agitate the water while pouring directly into the appropriate sample containers. An additional ground-water aliquot was placed into a large wide-mouth glass jar in order to obtain conductivity, temperature, and pH measurements. These measurements were recorded in the field logbook.

After well sampling, a hydraulic (pumping) test was performed to determine aquifer characteristics for mathematical modeling of potential contaminant plume migration. The hydraulic test was conducted using one well as a pumping well with three observation wells. The pumping well was purged at a rate of 22 gpm for 30 hours. All wells (observation and pumping) were monitored during pumping and for 4 hours after pumping ceased. Drawdown data from the wells were used to calculate the characteristics of the aquifer.

To generate accurate gradient and well location maps, the 15 newly installed monitoring wells were surveyed for vertical location using feet above mean sea level (MSL) units. Vertical elevations were taken at a mark on the top of the inner casing of each monitoring well, to establish a permanent location for all future water level measurements and elevations. A permanent benchmark was located near to the site by the survey team to determine all the well elevations. Elevations were then measured against the benchmark and mapped in MSL units.

All non-disposable equipment, including drill rig and equipment, stainless steel bailers, pumps, water level indicators, and depth sounders, were decontaminated between each location and prior to the first sampling event each day.

4.6.2 Sample Preparation

All sample containers were supplied by the contracted analytical laboratory. Chemical preservation was also provided by the laboratory through pre-preserved bottleware. Sample containers for ground-water samples consisted of:

- 1-liter polyethylene bottles for total chromium, pre-preserved with reagent-grade nitric acid lowering the pH to less than 2 after addition of the sample

- 1-liter polyethylene bottles for hexavalent chromium

- 1-liter polyethylene bottles for cyanide, pre-preserved with sodium hydroxide

Sample containers for soils consisted of 8-ounce glass jars with Teflon® caps for all parameters.

All samples were preserved to 4E C by placing them in coolers packed with "blue ice" immediately after collection and during shipment. (The laboratory was responsible for cooling and refrigeration of samples upon arrival.)

The samples were packaged in compliance with IATA requirements for environmental samples. Chain-of-custody paperwork was prepared for the samples. Laboratory paperwork was completed as appropriate and the samples were shipped to the predesignated laboratories for analysis. Holding times for total chromium and cyanide are less than six months, but hexavalent chromium has a holding time of less than 24 hours. This was coordinated in advance with the analytical laboratory and required daily ground delivery of samples to the laboratory.

Because many of the ground-water samples from the on-site wells were extremely turbid, the non-volatile portions of samples were filtered in the laboratory prior to analysis. Filtering was accomplished using a barrel filtering device with a minimum pore size of 0.45 microns. Samples for chromium analysis were split and filtered so that dissolved and particulate chromium could be differentiated. Dissolved chromium is of concern because of its ability to be transported in ground water.

5.0 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

5.1 INTRODUCTION

The goal of representative sampling is to obtain analytical results that accurately depict site conditions during a defined time interval. The goal of quality assurance/quality control (QA/QC) is to implement correct methodologies which limit the introduction of error into the sampling and analytical procedures, and ultimately into the analytical data.

QA/QC samples evaluate three types of information: 1) the magnitude of site variation; 2) whether samples were cross-contaminated during sampling and sample handling procedures; and 3) whether a discrepancy in sample results is a result of laboratory handling and analysis procedures.

5.2 DATA CATEGORIES

EPA has established data quality objectives (DQOs) which ensure that the precision, accuracy, representativeness, and quality of environmental data are appropriate for their intended application. Superfund DQO guidance defines two broad categories of analytical data: *screening* and *definitive*.

Screening data are generated by rapid, less precise methods of analysis with less rigorous sample preparation than definitive data. Sample preparation steps may be restricted to simple procedures such as dilution with a solvent, rather than elaborate extraction/digestion and cleanup. At least 10 percent of the screening data are confirmed using the analytical methods and QA/QC procedures and criteria associated with definitive data. Screening data without associated confirmation data are not considered to be data of known quality. To be acceptable, screening data must include the following: chain-of-custody, initial and continuing calibration, analyte identification, and analyte quantification. Streamlined QC requirements are the defining characteristic of screening data.

Definitive data are generated using rigorous analytical methods (e.g., approved EPA reference methods). These data are analyte-specific, with confirmation of analyte identity and concentration. Methods produce tangible raw data (e.g., chromatograms, spectra, digital values) in the form of paper printouts or computer-generated electronic files. Data may be generated at the site or at an off-site location, as long as the QA/QC requirements are satisfied. For the data to be definitive, either analytical or total measurement error must be determined. QC measures for definitive data contain all of the elements associated with screening data, but also may include trip, method, and rinsate blanks; matrix spikes; performance evaluation samples; and replicate analyses for error determination.

For further information on these QA/QC objectives, please refer to U.S. EPA *Data Quality Objectives Process for Superfund*, pp. 42-44.

5.3 SOURCES OF ERROR

There are many potential sources of data error in ground-water sampling. The following is a list of some of the more common potential sources of error:

- Sampling design
- Sampling methodology
- Analytical procedures
- Seasonal variations

See U.S. EPA *Data Quality Objectives Process for Superfund*, pp. 29-36, for more information on error.

5.3.1 Sampling Design

The sampling design should utilize approved SOPs and previously approved sampling designs to ensure uniformity and comparability between samples. The actual sample collection process should be determined prior to sampling. Sampling equipment and techniques must be standardized for like sampling situations.

The sampling design should fulfill sampling and data quality objectives. The quality assurance objectives selected should be built into the sampling design, including all necessary QA/QC samples.

Sampling design errors for ground water include: well selection, well location, well construction and development, background sample location, and equipment (material and type).

5.3.2 Sampling Methodology

Sampling methodology and sample handling procedures have possible sources of error, including: cross-contamination from inappropriate use of sample collection equipment; unclean sample containers; improper sampling equipment decontamination; and improper shipment procedures. Procedures for collecting, handling, and shipping samples should be standardized to allow easier identification of any source(s) of error, and to minimize the potential for error. Use approved SOPs to ensure that all given sampling techniques are performed in the same manner, regardless of the sampling team, date, or location of sampling activity. Use field blanks, replicate samples, trip blanks, and rinsate blanks (discussed in Section 5.4) to identify errors due to improper sampling methodology and sample handling procedures. An example of a sampling methodology error for ground water is inappropriate purging.

5.3.3 Analytical Procedures

Analytical procedures may introduce errors from laboratory cross-contamination, inefficient extraction, and inappropriate methodology. Matrix spike, laboratory duplicate, performance evaluation, and laboratory control samples help to distinguish analytical error from sampling error.

5.3.4 Seasonal Variations

Seasonal variations are not controllable but must be taken into consideration as a source of error during ground-water assessments. Changes in flow direction or volume can redistribute contaminants throughout a site, making assessment difficult. Plan sampling events in order to minimize the effects of seasonal variations, if possible.

5.4 QA/QC SAMPLES

QA/QC samples are collected at the site or prepared for or by the laboratory. Analysis of the QA/QC samples provides information on the variability and usability of sampling data, indicates possible field sampling or laboratory error, and provides a basis for future validation and usability of the analytical data. The most common field QA/QC samples are field replicate, background, and rinsate, field, and trip blank samples. The most common laboratory QA/QC samples are performance evaluation (PE), matrix spike (MS), matrix spike duplicate (MSD), and laboratory duplicate samples. QA/QC results may suggest the need for modifying sample collection, preparation, handling, or analytical procedures if the resultant data do not meet site-specific quality assurance objectives.

Ground water is typically characterized by low or trace concentrations of contaminants, making precision and accuracy more important than for samples with higher concentrations (e.g., waste). Frequent field blanks are thus appropriate in ground-water sampling.

The following sections briefly describe the most common types of QA/QC samples appropriate for ground-water sampling.

5.4.1 Field Replicate Samples

Field replicates, also referred to as field duplicates and split samples, are field samples obtained from one sampling point, homogenized (where appropriate), divided into separate containers, and treated as separate samples throughout the remaining sample handling and analytical processes. Use replicate samples to assess error associated with sample methodology and analytical procedures. Field replicates can also be used when determining total error for critical samples with contamination concentrations near the action level. In such a case, a minimum of eight replicate samples is recommended for valid statistical analysis. Field replicates may be sent to two or more laboratories or to the same laboratory as unique samples. For total error determination, samples should be analyzed by the same laboratory. Generally, one field replicate per 20 samples per day is recommended.

5.4.2 Background Samples

Defining background conditions may be difficult because of natural variability and the physical characteristics of the site, but it is important in order to quantify true changes in contaminant concentrations due to a source or site. Defining background conditions is critical for avoiding false positives and for enforcement purposes in naming responsible parties. Background sampling is often required in ground-water sampling to verify plume direction, ambient conditions, and attribution of sources. A properly collected background sample serves as the baseline for the measure of contamination throughout the site. Ground-water background sample locations should be chosen carefully, usually upgradient from the suspected source of contamination where there is little or no chance of migration of contaminants of concern. Collect at least one background sample for comparison, although additional samples are often warranted by site-specific factors such as natural variability of local geology and multiple sources. Background samples may be collected to evaluate potential error associated with sampling design, sampling methodology, and analytical procedures. Refer to U.S. EPA "Establishing Background Levels" fact sheet, OSWER Directive 9285.7-19FS, for detailed discussion on the proper selection and considerations of a background sample location.

5.4.3 Rinsate Blank Samples

A rinsate blank, also referred to as an equipment blank, is used to assess cross-contamination from improper equipment decontamination procedures. Rinsate blanks are samples obtained by running analyte-free water over decontaminated sampling equipment. Any residual contamination should appear in the rinsate sample data. Analyze the rinsate blank for the same analytical parameters as the field samples collected that day. Handle and ship the rinsate like a routine field sample. Where dedicated sampling equipment is not utilized, collect one rinsate blank per type of sampling device per day.

5.4.4 Field Blank Samples

Field blanks are samples prepared in the field using certified clean water (HPLC-grade water (carbon-free) for organic analyses and deionized or distilled water for inorganic analyses) which are then submitted to the laboratory for analysis. A field blank is used to evaluate contamination or error associated with sampling methodology, preservation, handling/shipping, and laboratory procedures. Handle, ship, and analyze a field blank like a routine field sample. Submit one field blank per day.

5.4.5 Trip Blank Samples

Trip blanks are samples prepared prior to going into the field. They consist of certified clean water (HPLC-grade) and are not opened until they reach the laboratory. Utilize trip blanks for volatile organic analyses only. Handle, transport, and analyze trip blanks in the same manner as the other volatile organic samples collected that day. Trip blanks are used to evaluate error associated with shipping and handling and analytical procedures. A trip blank should be included with each shipment.

5.4.6 Performance Evaluation/ Laboratory Control Samples

A performance evaluation (PE) sample evaluates the overall error contributed by the analytical laboratory and detects any bias in the analytical method being used. PE samples contain known quantities of target analytes manufactured under strict quality control. They are usually prepared by a third party under an EPA certification program. The samples are usually submitted "blind" to analytical laboratories (the sampling team knows the contents of the samples, but the laboratory does not). Laboratory analytical error may be evaluated by the percent recoveries and correct identification of the components in the PE sample. *Note: Even though they are not available for all analytes, analyses of PE samples are recommended in order to obtain definitive data.*

A blind PE sample may be included in a set of split samples provided to the potentially responsible party (PRP). The PE sample will indicate PRP laboratory accuracy, which may be critical during enforcement litigation.

A laboratory control sample (LCS) also contains known quantities of target analytes in certified clean water. In this case, the laboratory knows the contents of the sample (the LCS is usually prepared by the laboratory). PE and LCS samples are not affected by matrix interference, and thus can provide a clear measure of laboratory error.

5.4.7 Matrix Spike/Matrix Spike Duplicate Samples

Matrix spike and matrix spike duplicate samples (MS/MSDs) are field samples that are spiked in the laboratory with a known concentration of a target analyte(s) in order to determine percent recoveries in sample extraction. The percent recovery from MS/MSDs indicates the degree to which matrix interferences will affect the identification of a substance. MS/MSDs can also be used to monitor laboratory performance. When four or more pairs of MS/MSDs are analyzed, the data obtained may be used to evaluate error due to laboratory bias and precision. Analyze one MS/MSD pair to assess bias for every 20 samples, and use the average percent recovery for the pair. To assess precision, analyze at least eight matrix spike replicates from the same sample, and determine the standard deviation and the coefficient of variation. MS/MSDs are recommended for screening data and are required as one of several methods for determining analytical error for definitive data. Since the MS/MSDs are spiked field samples, provide sufficient volume for three separate analyses (triple volume). When selecting a well for spiked samples, choose a well capable of providing steady volume.

5.4.8 Laboratory Duplicate Samples

A laboratory duplicate is a sample that undergoes preparation and analysis twice. The laboratory takes two aliquots of one sample and analyses them as separate samples. Comparison of data from the two analyses provides a measure of analytical reproducibility within a sample set. Discrepancies in duplicate analyses may indicate poor homogenization in the field or other sample preparation error, either in the field or in the laboratory.

5.5 EVALUATION OF ANALYTICAL ERROR

The acceptable level of error in sampling data is determined by the intended use of the data and the sampling objectives, including the degree of threat to public health, welfare, or the environment; response action levels; litigation concerns; and budgetary constraints.

Error may be determined with replicate samples. To evaluate the total error of samples with contaminant concentrations near the response action level, prepare and analyze a minimum of eight replicates of the same sample. Analytical data from replicate samples also serve as a quick check on errors associated with sample heterogeneity, sampling methodology, and analytical procedures. Different analytical results from two or more replicate samples could indicate improper sample preparation, or improper sample handling, shipment, or analysis.

Although a quantified confidence level may be desirable, it may not always be possible. A 95% confidence level (5 percent acceptable error) should be adequate for most Superfund activities. Note that the use of confidence levels is based on the assumption that a sample is homogeneous.

5.6 CORRELATION BETWEEN FIELD SCREENING RESULTS AND DEFINITIVE LABORATORY RESULTS

One cost-effective approach for delineating the extent of site contamination is to correlate inexpensive field screening data and other field measurements with definitive laboratory results. The relationship between the two methods can then be described by a regression analysis. The resulting equation can be used to predict laboratory results based on field screening measurements. In this manner, cost-effective field screening results may be used in conjunction with off-site laboratory analysis.

Statistical regression involves developing an equation that relates two or more variables at an acceptable level of correlation. In this case, the two variables are field screening results and definitive laboratory results. The regression equation can be used to predict a laboratory value based on the results of the screening device. The model can also be used to place confidence limits around predictions. Additional discussion of correlation and regression can be found in most introductory statistics textbooks. A simple linear regression equation can be developed on many calculators or computer databases. Consult a statistician to check the accuracy of more complex models.

Evaluation of the accuracy of a model relies in part on statistical correlation, which involves computing an index called the correlation coefficient (r) that indicates the degree and nature of the relationship between two or more sets of values. The correlation coefficient ranges from -1.0 (a perfect inverse or negative relationship), through 0 (no relationship), to +1.0 (a perfect, or positive, relationship). The square of the correlation coefficient, called the coefficient of determination, or simply R^2, is an estimate of the proportion of variance in the dependent variable. The value of an acceptable coefficient of variation depends on the sampling objectives and intended data uses. As a rule of thumb, statistical relationships should have an R^2 value of at least 0.6 to determine a reliable model. However, for health assessment purposes, the acceptable R^2 value may be more stringent (e.g., 0.8). Analytical calibration regressions have an R^2 value of 0.98 or greater.

Field screening data can be used to predict laboratory results if there is an acceptable correlation between them. The predicted values can be located on a base map and contoured. These maps can be examined to evaluate the estimated extent of contamination and the adequacy of the sampling program.

5.7 EXAMPLE SITE

5.7.1 Data Categories

Screening data which generate non-definitive, unconfirmed results were used to select analytical parameters and samples to be sent for laboratory confirmation analysis. Samples were sent to the analytical laboratory under protocols which provided definitive data. The rigorous laboratory analyses provided definitive identification and quantitation of contaminants.

5.7.2 Sources of Error

All direct reading instruments were maintained and calibrated in accordance with their instruction manuals. Many of these instruments are class-specific (e.g., volatile organic vapors) with relative response rates that are dependent on the calibration gas selected. Instrument response to ambient vapor concentrations may differ by an order of magnitude from response to calibration standards. If compounds of interest are known, site-specific standards may be prepared.

The number and location of initial field samples were based on observation and professional judgment (as outlined in Section 2.5.5). Field standard operating procedures, documented in the site sampling plan, established consistent screening and sampling procedures among all sampling personnel, reducing the chances for variability and error during sampling. Site briefings were conducted prior to all sampling and screening events to review the use of proper screening and sampling techniques.

Other steps taken to limit error included proper sample preparation, adherence to sample holding times, and the use of proper IATA shipment procedures. All off-site laboratory sample analyses were performed using approved EPA standard methods and protocols.

5.7.3 Field QA/QC Samples

Field QA/QC samples were collected during soil and ground-water sampling at the ABC Plating site. Two field replicate samples were collected for subsurface soils; two wells (one overburden and one bedrock) were selected for replicate collection and analysis of ground water. Rinsate blanks were collected from split spoon samplers, a bailer, and the submersible rotary pump after decontamination by pouring deionized water through the respective piece of equipment and then into a sample container. The field replicates and blanks were preserved and prepared as "regular" field samples. A trip blank for VOC analysis and a performance evaluation (PE) sample for metals were sent to the laboratory. (The PE sample is not affected by matrix interferences.) The trip blank was provided by the laboratory (pre-filled and preserved) and sent with the sample containers prior to sample collection. One trip blank per day was submitted to the laboratory. Additional volume was collected and provided to the laboratory for matrix spike/matrix spike duplicate analyses for one per 20 sample locations for each medium.

5.7.4 Laboratory QA/QC

Instructions on matrices, target compounds, and QA/QC criteria of particular interest were provided to the laboratory to help ensure that analytical results met the required quality assurance objectives. The laboratory analyzed for metals using the methods of inductively coupled plasma (ICP) spectrometry and atomic absorption (AA). Two SW-846 methods were employed for hexavalent chromium analysis: Method 7196, a colorimetric method, and Method 2185, a chelation method. These two methods were utilized in an attempt to better quantify hexavalent results. The presence of cyanide was confirmed in the laboratory using total and amenable cyanide analyses (colorimetric manual Method 9010).

6.0 DATA PRESENTATION AND ANALYSIS

6.1 INTRODUCTION

Data presentation and analysis techniques are performed with analytical, field screening, or geophysical results. The techniques discussed below can be used to compare analytical values, to evaluate numerical distribution of data, and to reveal the location of "hot spots," contaminant plumes, and the extent of contamination at a site. The appropriate methods to present and analyze sample data depend on the sampling objectives, the number of samples collected, the sampling approaches used, and other considerations.

6.2 DATA POSTING

Data posting involves placement of sample values on a site base map or cross-section. Data posting is useful for displaying the distribution of sample values, visually depicting the location of contamination with associated assessment data. Data posting requires each sample to have a specific location (e.g., *x*, *y*, and sometimes *z* coordinates). Ideally, the sample coordinates are surveyed values facilitating placement on a scaled map. Data posting is useful for depicting concentration values of ground-water and plume migration.

6.3 CROSS-SECTION/FENCE DIAGRAMS

Cross-section diagrams (two-dimensional) and fence diagrams (three-dimensional) depict subsurface features such as stratigraphic boundaries, aquifers, plumes, impermeable layers, etc. Two-dimensional cross-sections may be used to illustrate vertical profiles of ground-water concentrations on a site. Both cross-sections and fence diagrams can provide useful visual interpretations of contaminant concentrations and migration.

6.4 CONTOUR MAPPING

Contour maps are useful for depicting ground-water contaminant concentration values throughout a site. Contour mapping requires an accurate, to-scale basemap of the site. After data posting sample values on the basemap, insert contour lines (or isopleths) at a specified contour interval, interpolating values between sample points. Contour lines can be drawn manually or can be generated by computer using contouring software. Although the software makes the contouring process easier, computer programs have a limitation: as they interpolate between data points, they attempt to "smooth" the values by fitting contour intervals to the full range of data values. This can result in a contour map that does not accurately represent general site contaminant trends. If there is a big difference in concentration between a "hot spot" and the surrounding area, the computer contouring program, using a contour interval that attempts to smooth the "hot spots," may eliminate most of the subtle site features and general trends.

6.5 WELL LOCATION MAP

A well location map should be prepared using surveyed data for all features at the site. This map serves as a basemap onto which other data may be plotted (e.g., data posting, contaminant plume contours, water elevation contours). The map is drawn to scale and incorporates all wells located, installed, and sampled, including residential and monitoring wells. The surveyed coordinates for each monitoring well location could also be posted onto the map (in feet above mean sea level (msl)) to illustrate topography and surface gradient.

6.6 STATISTICAL GRAPHICS

The distribution or spread of the data set is important in determining which statistical techniques to use. Common statistical analyses, such as the t-test, rely on normally distributed data. The histogram is a statistical bar graph which displays the distribution of a data set. A normally distributed data set takes the shape of a bell curve, with the mean and median close together about halfway between the maximum and minimum values. A probability plot depicts cumulative percent against the concentration of the contaminant of concern. A normally distributed data set, when plotted as a probability plot, appears as a straight line. A histogram or probability plot can be used to see trends and anomalies in the data from a ground-water site prior to conducting more rigorous forms of statistical analysis.

6.7 RECOMMENDED DATA INTERPRETATION METHODS

The data interpretation methods chosen depend on project-specific considerations, such as the number of sampling locations and their associated range in values. Data which are dissimilar in composition should not be compared using statistical interpretation methods. Data posting, screening, and sampling data sheets, and cross-section/fence diagrams may be appropriate. A site feature showing extremely low data values (e.g., non-detects), with significantly higher values (e.g., 5,000 ppm) from neighboring "hot spots" and little or no concentration gradient in between, does not lend itself to contouring software.

6.8 EXAMPLE SITE

A water table contour map was generated with the water level data for the shallow overburden monitoring wells. This indicated a westward flow direction, which generally coincides with the surface topography. The deep bedrock wells lie nearly on a straight line, and therefore a confident determination of flow direction was not possible. A westward component of flow direction is evident in the data, however. The bedrock contact wells provided inconsistent water level data, most likely due to the presence of discontinuous perched water zones at the well locations.

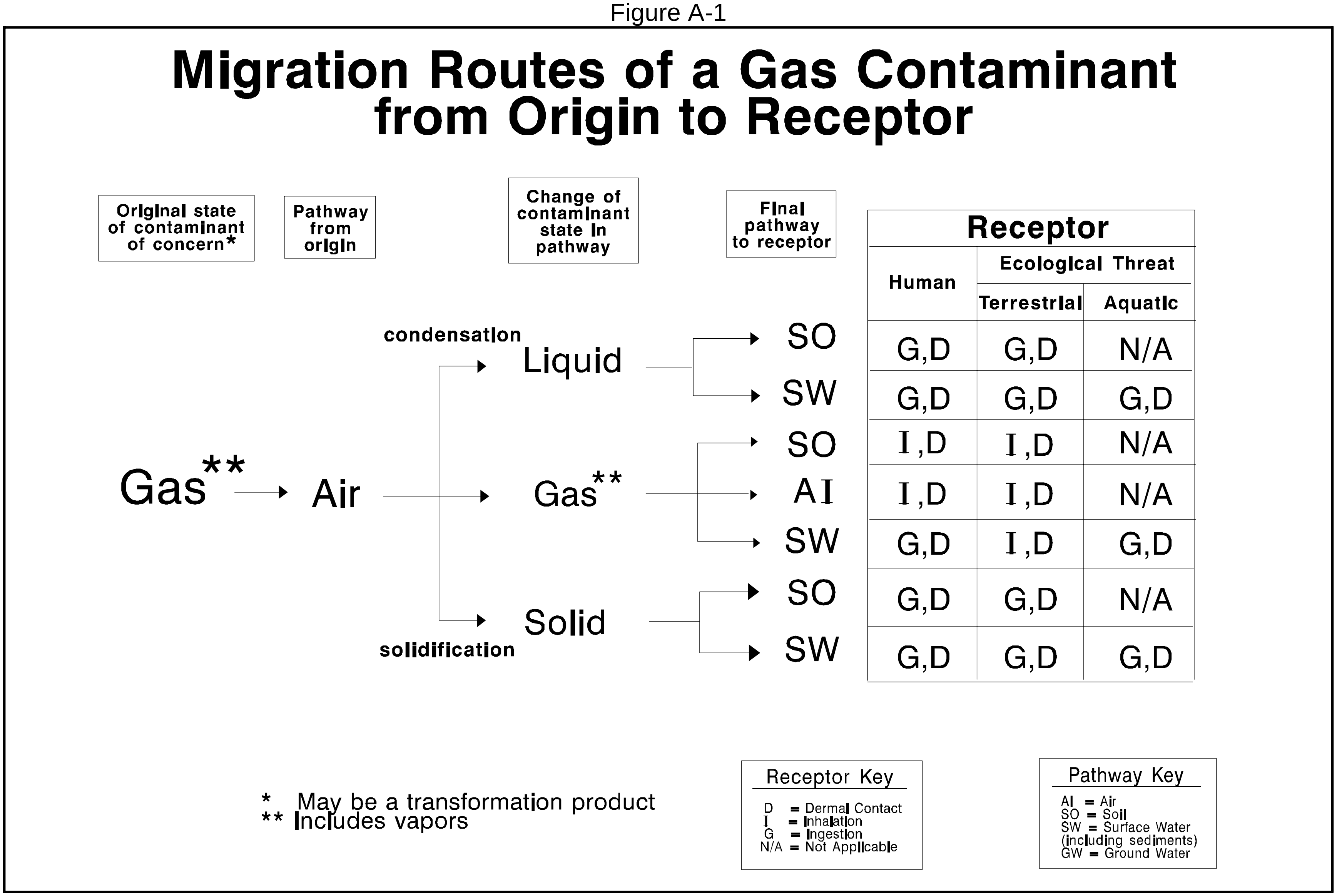
All ground-water samples were analyzed for total chromium and cyanide. Cyanide was not found in any of the samples above the 50 µg/l detection limit. Using a detection limit of 50 µg/l for chromium, three filtered samples were found to be contaminated at two locations (3OB, and 6OB/6AW). Five of the unfiltered ground-water samples (Wells 2SA, 3OB, 4SA, 6OB, and 6AW) exceeded the detection limit. These data were posted on a site/well location map to illustrate well proximities, as well as a map indicating the contours of contamination.

The rate of chromium contaminant migration in ground water and the potential long-term impact to nearby residential wells were estimated using a mathematical model which included worst case assumptions and evaluated attenuation of contaminants through soil and ground water. The OSC concluded that the potential for residential well contamination was minimal. Removal of soil, the source of contamination, was recommended. This decision met the Phase 2 objective of establishing early action options and consideration of long-term remediation requirements for ground water.

All containers of wastes were removed from the site. Soil treatment/disposal was completed using the existing grid design. Cells were sampled and designated as clean or excavated. Excavated material was stockpiled while treatment/disposal options were evaluated. Excavated cells were filled with stone and clean soil. Composite sampling in each cell verified cleanup, using an action level of 100 mg/kg chromium in the soil composite. (The clean-up level was established based on the earlier mathematical model and soil attenuation calculations.) The soil response served as an early action to meet the Phase 3 objective originally established for the site.

APPENDIX A -- Example of Flow Diagram For Conceptual Site Model

Figure A-1



Migration Routes of a Gas Contaminant from Origin to Receptor

	Receptor		
	Human	Ecological Threat	
		Terrestrial	Aquatic
SO	G,D	G,D	N/A
SW	G,D	G,D	G,D
SO	I,D	I,D	N/A
AI	I,D	I,D	N/A
SW	G,D	I,D	G,D
SO	G,D	G,D	N/A
SW	G,D	G,D	G,D

* May be a transformation product
** Includes vapors

Receptor Key

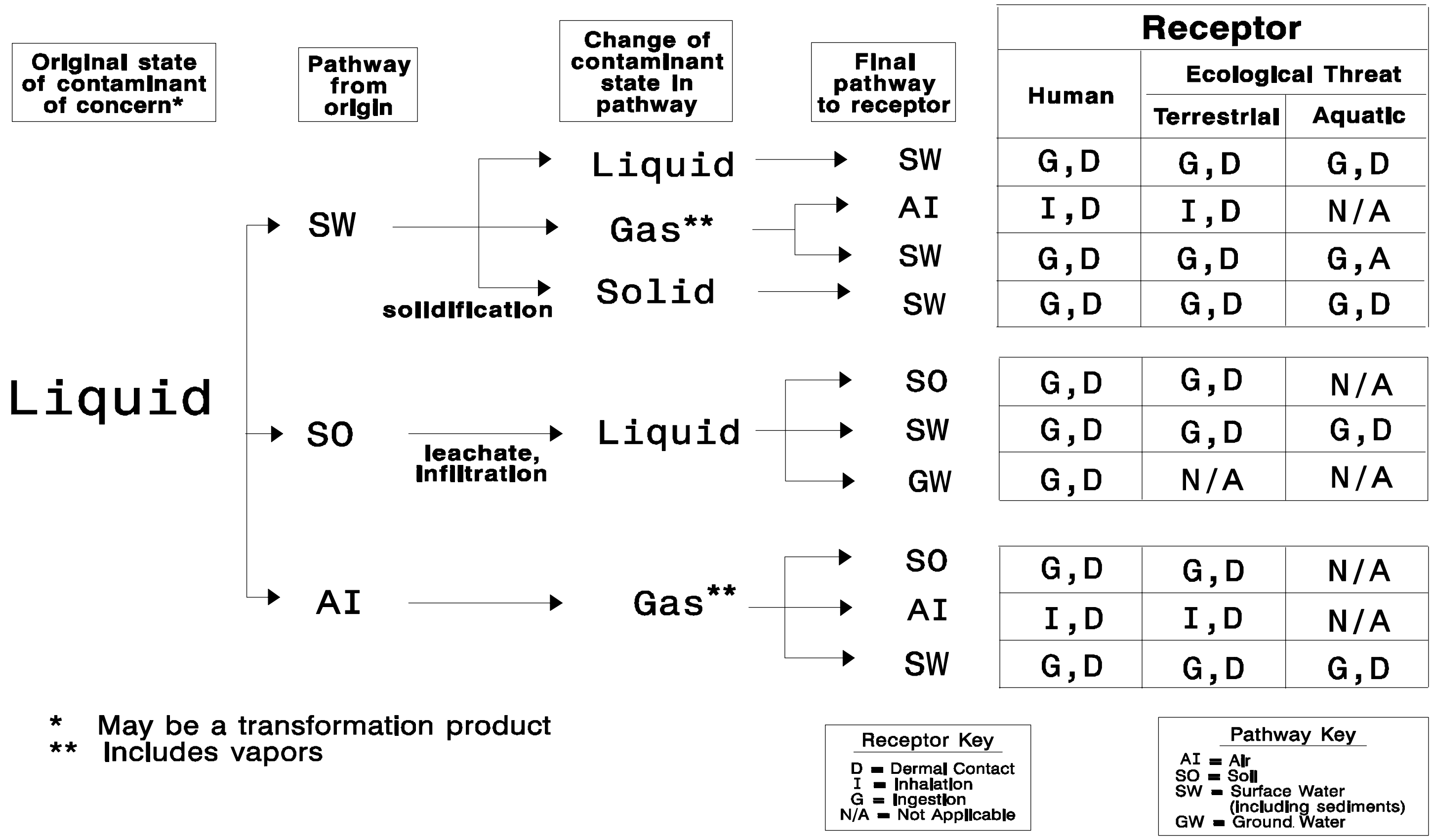
D = Dermal Contact
I = Inhalation
G = Ingestion
N/A = Not Applicable

Pathway Key

AI = Air
SO = Soil
SW = Surface Water (including sediments)
GW = Ground Water

Figure A-2

Migration Routes of a Liquid Contaminant from Origin to Receptor



Original state of contaminant of concern*	Pathway from origin	Change of contaminant state in pathway	Final pathway to receptor	Receptor		
				Human	Ecological Threat	
					Terrestrial	Aquatic
Liquid	SW	Liquid	SW	G,D	G,D	G,D
		Gas**	AI	I,D	I,D	N/A
			SW	G,D	G,D	G,A
	solidification	Solid	SW	G,D	G,D	G,D
	SO	leachate, infiltration → Liquid	SO	G,D	G,D	N/A
			SW	G,D	G,D	G,D
			GW	G,D	N/A	N/A
	AI	Gas**	SO	G,D	G,D	N/A
			AI	I,D	I,D	N/A
			SW	G,D	G,D	G,D

* May be a transformation product

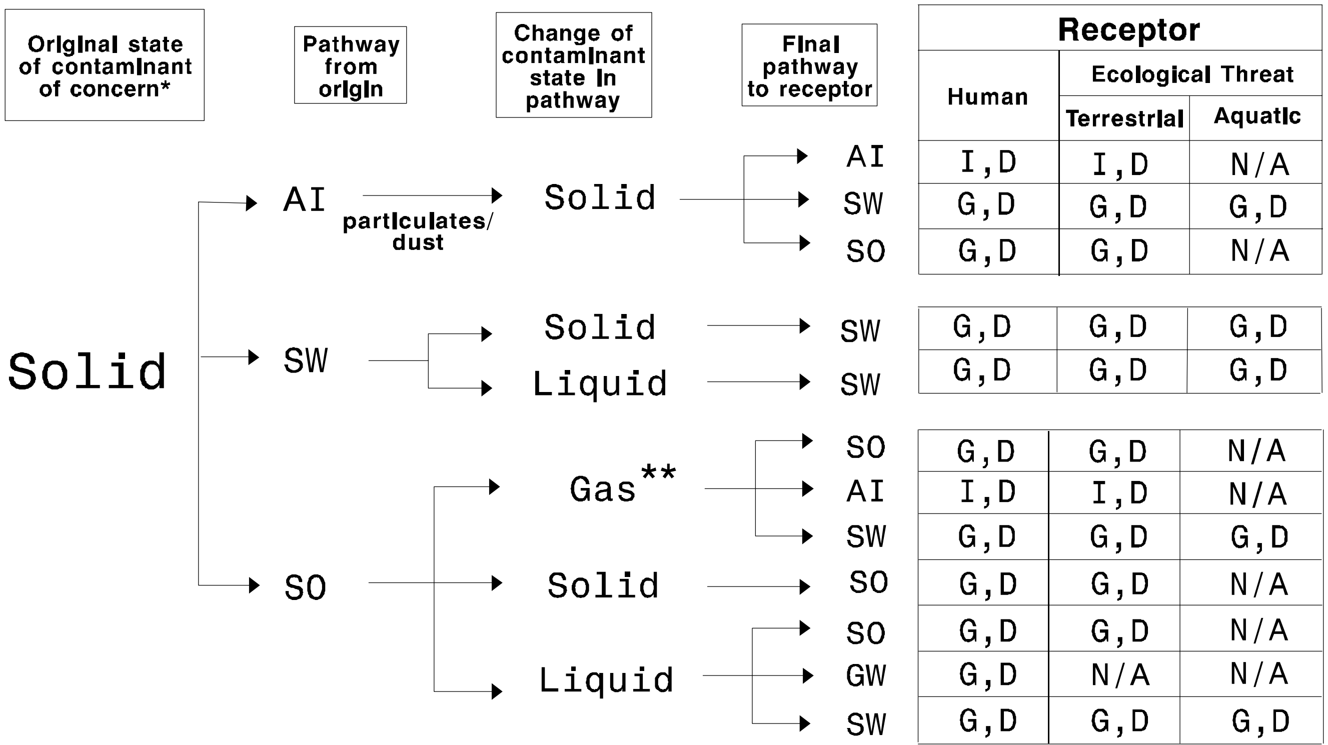
** Includes vapors

Receptor Key
D = Dermal Contact
I = Inhalation
G = Ingestion
N/A = Not Applicable

Pathway Key
AI = Air
SO = Soil
SW = Surface Water (including sediments)
GW = Ground Water

Figure A-3

Migration Routes of a Solid Contaminant from Origin to Receptor



Original state of contaminant of concern*	Pathway from origin	Change of contaminant state in pathway	Final pathway to receptor	Receptor: Human	Receptor: Ecological Threat: Terrestrial	Receptor: Ecological Threat: Aquatic
Solid	AI	Solid	AI	I,D	I,D	N/A
			SW	G,D	G,D	G,D
			SO	G,D	G,D	N/A
	SW	Solid	SW	G,D	G,D	G,D
		Liquid	SW	G,D	G,D	G,D
	SO	Gas**	SO	G,D	G,D	N/A
			AI	I,D	I,D	N/A
			SW	G,D	G,D	G,D
		Solid	SO	G,D	G,D	N/A
		Liquid	SO	G,D	G,D	N/A
			GW	G,D	N/A	N/A
			SW	G,D	G,D	G,D

* May be a transformation product

** Includes vapors

Receptor Key

D = Dermal Contact
I = Inhalation
G = Ingestion
N/A = Not Applicable

Pathway Key

AI = Air
SO = Soil
SW = Surface Water (including sediments)
GW = Ground Water

References

Aller, Bennett, Hackett, et al. 1989. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*. National Water Well Association, Dublin, Ohio.

Code of Federal Regulations (CFR), Title 40 - Protection of Environment. Part 136 - Guidelines Establishing Test Procedures for the Analysis of Pollutants.

Custodio, Gurgui, Ferreira. 1987. *Ground-Water Flow and Quality Modelling*. D. Reidel Publishing Company, Dordrecht, Holland.

Driscoll, Fletcher G. 1986. *Ground Water and Wells* (2nd edition).

Fetter, C.W., Jr. 1980. *Applied Hydrogeology*. Charles E. Merrill Publishing Company, Columbus, Ohio.

Garrett, Peter. 1988. *How to Sample Ground Water and Soils*. National Water Well Association, Dublin, Ohio.

Keith, Lawrence, H. 1988. *Principles of Environmental Sampling*.

New Jersey Department of Environmental Protection. February 1988. *Field Sampling Procedures Manual*.

Palmer, Christopher, M. 1992. *Principles of Contaminant Hydrogeology*.

Proceedings of the Fifth National Symposium and Exposition on Aquifer Restoration and Ground-Water Monitoring. 1985.

U.S. Department of Health and Human Services. 1985. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*. NIOSH Pub.85-115.

U.S. Environmental Protection Agency. 1995a. "Establishing Background Levels." Office of Solid Waste and Emergency Response Directive 9285.7-19FS.

U.S. Environmental Protection Agency. 1995b. *Superfund Program Representative Sampling Guidance*, Volume 1 -- *Soil*. Office of Solid Waste and Emergency Response Directive 9360.4-10.

U.S. Environmental Protection Agency. 1995c. *Superfund Program Representative Sampling Guidance*, Volume 4-- *Waste*. Office of Solid Waste and Emergency Response Directive 9360.4-14.

U.S. Environmental Protection Agency. September 1993. *Data Quality Objectives Process for Superfund*. Office of Solid Waste and Emergency Response Directive 9355.9-01.

U.S. Environmental Protection Agency. 1993. *Project Summary- Compilation of Ground-Water Models*. Office of Research and Development. EPA/600/SR-93/118.

U.S. Environmental Protection Agency. November 1992. *RCRA Ground-Water Monitoring: Draft Technical Guidance*. EPA/530-R-93-001.

U.S. Environmental Protection Agency. September 1992. *Guidance for Performing Site Inspections Under CERCLA*. Office of Solid Waste and Emergency Response Directive 9345.1-05

U.S. Environmental Protection Agency. February 1992. *Estimating the Potential for Occurrence of DNAPL at Superfund Sites*. Office of Solid Waste and Emergency Response Directive 9355.4-07.

U.S. Environmental Protection Agency. January 1992. *Statistical Training Course for Ground-Water Monitoring Data Analysis*. EPA/530-R-93-003.

U.S. Environmental Protection Agency. 1992. *Ground-Water Issue- Fundamentals of Ground-Water Modeling*. Office of Research and Development and Office of Solid Waste and Emergency Response. EPA/540/S-92/005.

U.S. Environmental Protection Agency. January 1991a. *Compendium of ERT Field Analytical Procedures*. Office of Solid Waste and Emergency Response Directive 9360.4-04.

U.S. Environmental Protection Agency. January 1991b. *Compendium of ERT Ground-Water Sampling Procedures*. Office of Solid Waste and Emergency Response Directive 9360.4-06.

U.S. Environmental Protection Agency. January 1991c. *Compendium of ERTSurface Water and Sediment Sampling Procedures*. Office of Solid Waste and Emergency Response Directive 9360.4-03.

U.S. Environmental Protection Agency. 1990. *Ground Water, Volume II: Methodology*. EPA/625/6-90/016b.

U.S. Environmental Protection Agency. April 1989. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance*. Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency. September 1988. *Field Screening Methods Catalog -- User's Guide*. Office of Solid Waste and Emergency Response. EPA/540/2-88/005.

U.S. Environmental Protection Agency. December 1987. *A Compendium of Superfund Field Operations Methods*. Office of Solid Waste and Emergency Response Directive 9355.0-14.

U.S. Environmental Protection Agency. 1987. *Handbook, Ground Water.* EPA/625/6-87/016.

U.S. Environmental Protection Agency. September 1986. *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document* (TEGD). Office of Solid Waste and Emergency Response Directive 9950.1.

U.S. Geological Survey. 1991. *Concepts and Modeling in Ground-Water Hydrology - A Self-Paced Training Course.* Open File Report 90-707.