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REPRESENTATIVE SAMPLING GUIDANCE

VOLUME 5: WATER AND SEDIMENT

PART I -- Surface Water and Sediment

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

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For more information on water sampling procedures, refer to the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures,* OSWER Directive 9360.4-03. Topics covered in the compendium include sampling equipment decontamination, surface water and sediment sampling procedures, sampling equipment, and quality assurance/quality control (QA/QC) methods.

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 I - Surface Water and Sediment.* Send remarks to:

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1.0 INTRODUCTION

1.1 OBJECTIVE AND SCOPE

This is Part I 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. In the Superfund Program, surface water or sediment sampling can be conducted during: emergency responses, site assessments, and removal or early action activities. The representative sampling principles discussed in this document are applicable throughout the Superfund Program. This guidance document presents basic and general principles for sampling approaches, methods, and equipment. Surface water or sediment sampling specifically for remedial investigations and at remediation sites is not discussed directly in this guidance. However, general sampling decisions discussed in this document could be applicable to more detailed surface water or sediment sampling instances such as those performed for remedial investigations. More samples may be collected or more specific analytical parameters may be established for remedial investigations, but the sampling objectives and methods remain similar to those in this guidance.

The objective of representative sampling is to ensure that a sample or a group of samples accurately characterizes site conditions. The selected sample must possess the same qualities or properties as the location and source under investigation. In order to conduct representative sampling, proper sampling techniques and sample handling must be used to maintain the integrity of the sample (preserving the original form and chemical composition). The following chapters will help field personnel to assess available information, select an appropriate sampling approach, select and utilize field analytical screening methods and sampling equipment, incorporate suitable types and numbers of quality assurance/quality control (QA/QC) samples, and interpret and present site analytical data.

As the Superfund Program has developed, the emphasis has shifted beyond addressing emergency response and short-term cleanups. Each planned response action must consider a variety of sampling objectives, including identifying threat, determining the need for long-term action, 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. Inappropriate sample collection procedures can seriously bias the representativeness of a sample as well as its analytical results. This document emphasizes the use of cost-effective field analytical screening techniques in characterizing sites and aiding in the selection of sampling locations.

1.2 CHARACTERISTICS OF SURFACE WATER AND SEDIMENT

1.2.1 Surface Water

Surface waters are water bodies that rest or flow over land, with a surface that is open to the atmosphere. Surface water sampling consists of the collection of representative samples from streams, lakes, rivers, ponds, creeks, lagoons, estuaries, and surface impoundments. It includes samples collected from the depth of the water as well as the surface. Water sampling typically involves sampling low to medium-hazard wastes rather than the more concentrated high-hazard wastes found in drums or storage facilities. (For high-hazard waste sampling, see U.S. EPA *Superfund Program Representative Sampling Guidance, Volume 4 -- Waste*, OSWER Directive 9360.4-14, 1995.) Surface water sampling requires recognition of special properties and precautions. The following aspects of surface water should be considered in developing a representative sampling design:

- Stratification - Stratification in a water body can be thermally or chemically induced. The temperature profile is often the controlling force in the circulation of a water body. The warm, less dense surface water (epilimnion) and the deeper cold water mass (hypolimnion) become stratified and create a thermocline region where the temperature changes rapidly with depth. The position of the thermocline varies in surface water bodies, but is typically less than 30 meters below the surface. Chemically-induced stratification generally results when two levels of a water body are separated by a steep salinity gradient. Still water bodies,

such as lakes or reservoirs, have a much greater tendency to stratify than rivers or streams.

The epilimnion is exposed to the atmosphere, whereas the hypolimnion is a "confined" stratum which is vented only during seasonal overturn. These two zones may thus have very different concentrations of contaminants if: 1) the point of discharge is to one zone only; 2) the contaminants are volatile (thus vented in the epilimnion but possibly not in the hypolimnion); or 3) the surface stratum is influenced by short-term flushing due to inflow or outflow of shallow streams.

- Current - A current is a large portion of water moving in a certain direction. Currents can disturb mixing zones and reduce the chances of obtaining a representative sample. For example, a strong current may carry and distribute contamination over a larger area or move contaminated sediments further downstream, complicating source identification.

- Storm events - Storms may turn over strata in a water body and reduce the representativeness of the sample. Increased precipitation or runoff may increase or decrease representative concentrations of contaminants. For example, a large storm will dilute the concentration of contaminants present in a water body, possibly below detection levels. A water body which receives surface runoff may show a higher concentration of contaminants from the ensuing runoff than are representative of the water body under "normal" conditions.

  Precipitation may affect a field screening instrument's operation and accuracy through water or humidity interference during field use. This interference may affect screening for sample locations or put samplers at risk for health and safety concerns.

- Time of year - Temperate water bodies (usually lakes) experience two periods of overturn annually. As air temperature cools in the fall, the epilimnion becomes cooler and eventually isothermal conditions exist in the lake. Overturning and total mixing occurs. Similar overturning occurs again in the spring. The chemical composition of lakes and ponds can vary considerably depending on the season. Variations can occur during periods of increased water movement due to temperature variations, vegetation decay, freezing and thawing, as well as turnovers and inversions.

  The time of year also influences rainy and dry periods. For most areas of the United States, precipitation is greater in the late fall through spring with an accompanying increase in volume and flow in surface water bodies. In the spring, flowing water bodies may swell from upland headwaters receiving melting snow. By summer, water bodies may reduce in volume and velocity due to drying or drought conditions. Some water bodies, such as in intermittent streams, may actually be dry during certain times of the year.

- Circulation - Lakes shallower than 5 meters are subject to mixing by wind action. Large-scale water motion in lakes may be either wind driven or the result of density gradients. Sediment distribution may be dominated by either or both types of water motion. If a water body lacks stratification, the entire lake may be circulated or mixed by wind-generated motion.

- Velocity - The speed at which a surface water body flows can affect the selection of sampling locations, times, equipment, and techniques. Varying flow rates across or within the cross-section of the water body can lead to non-homogeneous mixing of contaminants, producing different phases, increasing the difficulty of collecting a representative sample.

- Turbidity - Surface water may contain suspended particles of fine sediments or solid contaminants. These particles may have a higher concentration of contaminants adhering to their surface area than is dissolved in the aqueous portion of the sample. Turbidity will vary due to mixing and settling in the water body.

- Salinity - The natural salt concentration, or salinity, of a water body may vary with its proximity to the ocean and seasonal gradients/stratification. An estuary is generally categorized as one of three types, depending upon fresh water inflow and

mixing properties: mixed estuary, salt wedge estuary, or oceanic estuary. Tidal phases of the water body must also be considered when sampling in saline waters. Salt concentration in the surface water may alter concentrations of contaminants due to chemical reaction/transformation. See Section 4.3.3 for additional details regarding estuaries.

1.2.2 Sediment

The characteristics of sediment are dependent on biological, chemical, and physical phenomena. Sediments consist of particles derived from rocks or biological materials that are either transported by flowing water bodies (e.g., rivers, streams) or situated beneath a static aqueous layer (e.g., lakes, ponds, impoundments). They include solids and sludges, suspended or settled in the water. Sediment types are classified by particle size, mineralogy, source materials, and other potential variables. Analysis of sediment can determine whether concentrations of specific contaminants exceed established threshold action levels or pose a risk to public health or the environment. Media-specific variables that can affect sediment sampling include:

- Particle size (grain size) - Particle size can affect sampling results because many pollutants adhere to particle surfaces and therefore occur in highest concentrations in small-grained material, where total surface area is greater, than in large-grained material.

- Terrigenous sediments - Sediments may consist of material eroded from a land surface, transported and deposited in the water body. The origin of the sediment may influence the selection of analytical methods to determine soil physical characteristics and the presence of chemical contaminants. Terrigenous sediments may exhibit a historical release not associated with the water body. For example, chemical reactions from sediments which originated in mining areas may result in changes in iron, sulfate, and pH concentrations in the surface water.

- Chemical constituents - Chemical constituents associated with sediments may reflect an integration of chemical and biological processes. Sediments may reflect the historical input with respect to time, application of chemicals, and land use. Bottom sediments, especially fine-grained particles, may act as a reservoir for adsorbed heavy metals and trace organic contaminants. Organic materials and metals are more concentrated and readily found in sediment than in water and can be detected in sediment analysis if they have not degraded. Ion exchange properties of certain clays may affect concentrations of soluble inorganic ions by removing them from solution. The clay-based sediments may remain suspended in water and thereby not provide a representative sediment sample. The clay or other suspended sediments may serve to transport contaminants that have adhered to the solid particles, to other locations in the water body.

- Depositional/erosional areas - Sediment accumulation depends on depth of water, water flow rate, and bottom configuration as well as temperature, rainfall, and latitude. Surface water velocity and flow characteristics can directly affect the distribution of substrate particle size and organic content. Contaminants are more likely to be concentrated in sediments typified by fine particle size and high organic content. This type of sediment is most likely to be collected from depositional zones. In contrast, coarse sediments with low organic content, found in erosional zones, do not typically concentrate pollutants. Identify depositional and erosional zones and plan the sampling design accordingly.

- Anaerobic/aerobic conditions - Deep sediments subject to no disturbance or mixing may exhibit anaerobic conditions, or lack of oxygen. The transformation/degradation of historical deposits of contaminants will be affected by either anaerobic or aerobic processes depending on the substrate conditions. Knowledge of whether anaerobic or aerobic conditions exist in the substrate at a specific sampling location will help to identify transformation products of suspected contaminants. Detection of these transformation products can be used to delineate the spread of contamination.

1.3 REPRESENTATIVE SAMPLING

Representative surface water and sediment 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 is discussed in Section 1.2), this document concentrates on those that are introduced in the field. These latter variables relate to the 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 their method of collection:

- Media variability - The physical and chemical characteristics of surface water and sediments, such as stratification, flow rate, particle size, and deposition. (Section 1.2 provides additional specifics of media variability.)

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

- Collection and preparation variability - Bias introduced during sample collection, preparation, and transportation (for analysis) can cause deviations in analytical results.

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

1.4 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 are 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. A conceptual model may be 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, surface water) 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; sewage plant outfall; agricultural activities.

Potential Migration Pathway (Surface Water): Runoff from the waste pile, lagoon, drum dump, or agricultural activities; outfall from the lagoon or sewage plant.

Potential Migration Routes: Ingestion or direct contact with water in the river, lake, or aquifer (e.g., ingestion of drinking water, direct contact with water at the public beach).

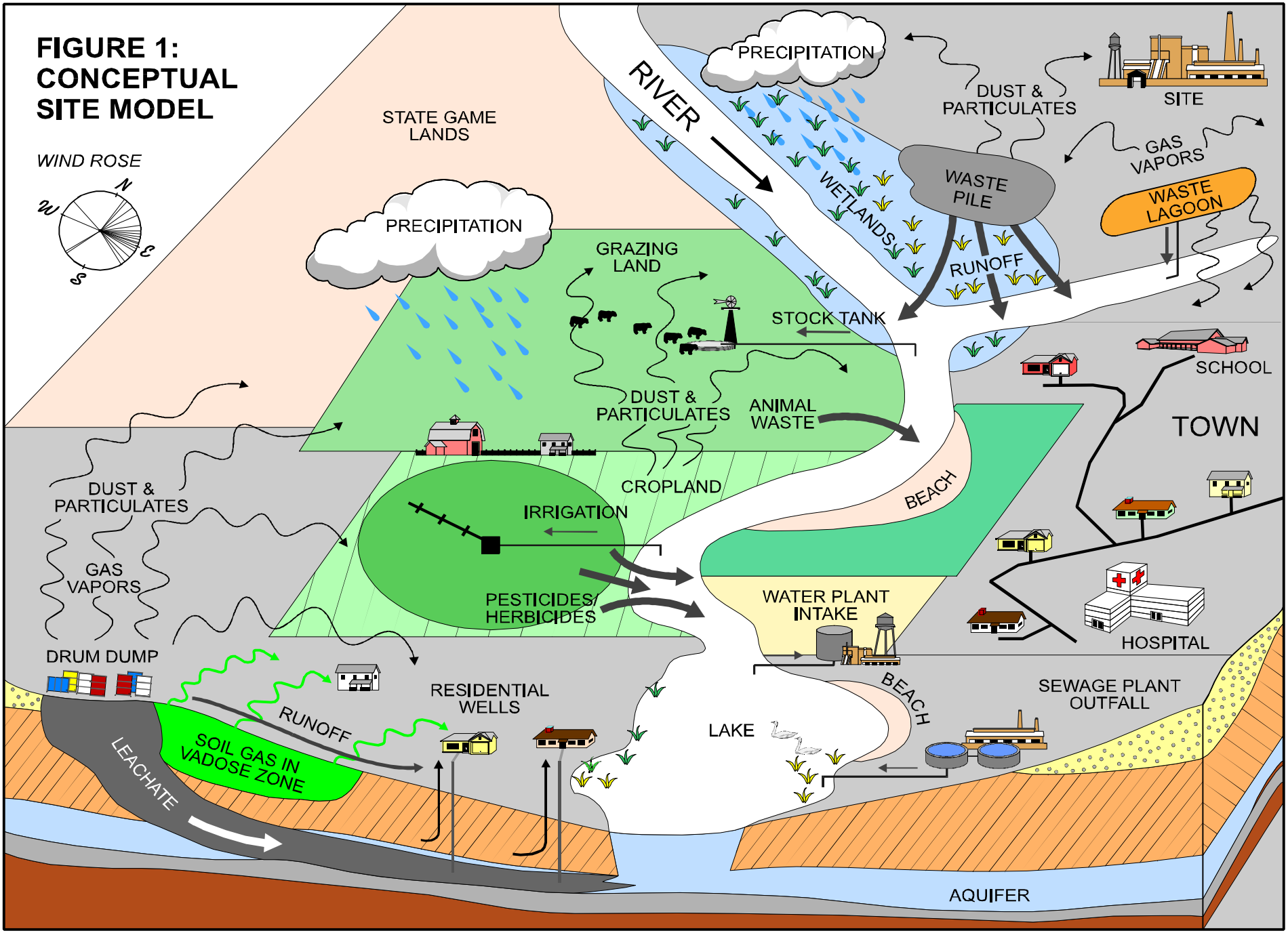


FIGURE 1:
CONCEPTUAL
SITE MODEL
WIND ROSE
N
E
S
W
STATE GAME
LANDS
RIVER
PRECIPITATION
DUST &
PARTICULATES
SITE
GAS
VAPORS
WETLANDS
WASTE
PILE
WASTE
LAGOON
RUNOFF
PRECIPITATION
GRAZING
LAND
STOCK TANK
SCHOOL
TOWN
DUST &
PARTICULATES
ANIMAL
WASTE
CROPLAND
BEACH
DUST &
PARTICULATES
IRRIGATION
GAS
VAPORS
PESTICIDES/
HERBICIDES
WATER PLANT
INTAKE
HOSPITAL
DRUM DUMP
RESIDENTIAL
WELLS
BEACH
SEWAGE PLANT
OUTFALL
RUNOFF
SOIL GAS IN
VADOSE ZONE
LEACHATE
LAKE
AQUIFER

Potential Receptors of Concern:

Human Population (Residents/Workers/Trespassers): Ingestion or direct contact with contaminated water in the river, lake, or aquifer (e.g., swimming, drinking).

Biota: Endangered/threatened species or human food chain organisms suspected of ingesting or being in direct contact with contaminated water.

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.

1.5 REPRESENTATIVE SAMPLING OBJECTIVES

Representative sampling applies to all phases of a Superfund response action. The following are representative sampling objectives for surface water and sediment:

- Determine if the contaminant is hazardous by identifying its composition and characteristics.
- Determine if there is an imminent or substantial threat to public health or welfare or to the environment.
- Determine the need for long-term action.
- Develop containment and control strategies.
- Evaluate appropriate disposal/treatment options.
- Verify treatment goals or clean-up levels.

1.5.1 Determine Hazard and Identify Contaminant

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 (discussed in Chapter 3) 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.

1.5.2 Establish Imminent or Substantial Threat

Establishing threat to the public or the environment is a primary objective during a 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.

1.5.3 Determine Long-Term Threat

Site conditions may establish 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 to support evaluating the site under the Hazard Ranking System.

1.5.4 Develop Containment and Control Strategies

Once the chemical constituents and threat have been determined, many strategies for surface water and sediment 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, harbor booms, sorbent booms, sorbent pad strings, and filter fences can prevent spread of contamination in a surface water body.

1.5.5 Identify Available Treatment/ Disposal Options

The contaminants should be identified, quantified, and compared to selected action levels. 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 and/or disposal options.

1.5.6 Verify Treatment Goals or Clean-up Levels

After treatment or disposal, representative sampling results should either confirm that the response action has met the site-specific treatment goals or clean-up levels, or indicate whether further treatment or response is necessary.

Sampling to verify cleanup requires careful coordination with demobilization activities. After treatment of a water body, verification sampling can begin by using field screening and on-site analysis. Lab confirmation of the screening performed can help ensure accuracy of subsequent screening to meet data quality objectives, as is discussed in Section 5.2. Sediment sampling can be conducted in phases before, during, and after cleanup. While verification sampling on a previously treated area is being conducted, treatment on other areas can begin.

1.6 EXAMPLE SITE

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

2.0 SURFACE WATER AND SEDIMENT SAMPLING DESIGN

2.1 INTRODUCTION

There is no universal sampling method to fully characterize surface water and sediment contaminants because site characteristics and sampling situations vary widely. The sampling methods and equipment must be suited to the specific sampling situation. A properly developed surface water/sediment 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 type and characteristics of the water body (e.g., river, estuary) being sampled, as well as the characteristics of the site. When developing a sampling design, consider:

- Prior actions at the site (e.g., prior sampling practices, compliance inspections)
- Properties and characteristics of the suspected contaminants
- Site waste sources (e.g., impoundments, waste piles, buried drums)
- Topographic, geologic, hydrologic, and meteorologic conditions of the site
- Flora, fauna, and human populations in the area

Surface water and sediment samples can vary greatly in composition, therefore making it difficult to obtain truly representative samples. Variation is due to both the location within the body of water being sampled and the time of collection. The change in composition of flowing waters such as streams or rivers is subject to the variance in flow and depth. Real-time field analytical screening techniques can be helpful throughout the response action. The results can be used to modify the site sampling plan as the extent of contamination becomes known. Emergency response sampling may require the use of a generic but media-specific sampling plan.

2.2 SAMPLING PLAN

The purpose of sampling is to obtain a small but representative portion of the medium of interest. Planning to ensure proper sample collection is essential. Many site-specific factors are important in the development of a good sampling plan, including: data use and quality assurance objectives, sampling objectives, sampling equipment and sampling methodology, sampling design, standard operating procedures (SOPs), field analytical screening, analytical method selection, decontamination, sample handling and shipment, and data validation. Each of these components should be addressed in one document, a site-specific sampling plan, to be used throughout the investigation. A sampling plan should be referred to throughout the field activities, along with the site-specific quality assurance/quality control plan, and the health and safety plan.

The U.S. EPA *Quality Assurance Sampling Plan for Environmental Response* software (QASPER), is a database that was designed to assist with the development of sampling plans for response actions. QASPER is menu driven software that prompts the user to input background information and to select prescribed parameters in order to develop a site-specific sampling plan. It also gives the user access to any previously developed site-specific sampling plans.

The following procedures are recommended for developing a thorough surface water/sediment sampling plan. Many steps can be performed simultaneously, and the sequence is flexible.

- Review the history of the site and adjoining areas, including regulatory and reported spill history; note current and former locations of buildings, tanks, and process, storage, and disposal areas.

- Perform a site reconnaissance; categorize physical/chemical properties and hazardous characteristics of materials involved.

- Identify topographic, geologic, and hydrologic characteristics of the site, including surface water, ground-water, and soil characteristics, as well as potential migration pathways and receptors.

- Determine geographic and demographic information, including population size and its proximity to the site (e.g., public health threats, source of drinking water); identify threatened environments (e.g., potentially contaminated wetlands or other sensitive ecosystems).

- Select sampling strategies considering field analytical screening and statistical applications when appropriate.

- Determine data quality and quality assurance objectives for field analytical screening, sampling, and analysis; as the extent of contamination becomes quantified, the sampling plan can be modified to better achieve sampling objectives throughout the response action.

It is recognized that many of these steps (described in detail below) may not be applicable during an emergency response because of the lack of advance notice. Emergency response sampling nevertheless requires good documentation of sampling events.

2.2.1 Historical Data Review

The first step in developing a sampling plan is a review of historical site data, examining past and present site operations and disposal practices to provide clues on possible contaminants and waste sources. Available sources of information include: federal, state and local agencies and officials; federal, state, and local agency files (e.g., site inspection reports and legal actions); deed or title records; current and former facility employees; potentially responsible parties (PRPs); local residents; and facility records or files. Where possible, data regarding adjoining properties should also be reviewed.

A review of previous sampling information should include sampling locations, matrices, methods of collection and analysis, and relevant contaminant concentrations. The reliability and usefulness of existing analytical data should be assessed, including data which are not substantiated by documentation or QA/QC controls, but which may still illustrate general site trends.

Information that describes specific chemical processes, raw materials used, products and wastes, and waste storage and disposal practices should also be collected. Information on materials handled at a site may provide guidance in the selection of analytical parameters. Review any available site maps, facility blueprints, and historical aerial photographs detailing past and present storage, process, and waste disposal locations. Areas on a site where particular processes occurred are good choices as sampling locations. U.S. Geological Survey (USGS) topographic maps should be reviewed to identify possible contamination overland flow or migration routes to surface water bodies. County property and tax records are also useful sources of information about the site and its surroundings.

2.2.2 Site Reconnaissance

A site reconnaissance can be conducted at an earlier date or on the same day immediately prior to sampling activities. It allows field personnel to assess site conditions, evaluate areas of potential contamination, evaluate potential hazards associated with sampling, and finalize a sampling plan. Site reconnaissance activities include: observing and photographing the site; noting site access routes and potential evacuation routes; noting potential safety hazards; recording label information from drums, tanks, or other containers; mapping effluent pipes or other point source discharges; mapping potential contaminant migration routes such as streams and irrigation ditches; noting the condition of animals and/or vegetation; and noting topographic and structural features (e.g., bridges or piers). Field personnel should use appropriate personal protective equipment when engaged in any site activities. A site reconnaissance for a surface water body should focus on collecting as much information as possible on the physical and chemical parameters of the water body. National Oceanic Atmospheric Administration (NOAA) tide tables and USGS freshwater surface water flow records are useful in determining the water body type. Common measurement tools and means for a surface water body reconnaissance include: boat, recording fathometer, salinometer, and conductivity and dissolved oxygen meters.

2.2.3 Physiographic and Other Factors

Other procedures, such as determining data quality and QA/QC objectives, utilizing field analytical screening techniques, identifying topographic, geologic, and hydrologic characteristics, and determining geographic and demographic information are important steps in an overall sampling plan. The remainder of this chapter includes a brief discussion of many of these procedures. Field analytical screening techniques and equipment are discussed in greater detail in Chapter 3; QA objectives are discussed in Chapter 5. For additional guidelines on preparing a sampling plan, please refer to the U.S. EPA *Superfund Program Representative Sampling Guidance, Volume 1 -- Soil,* OSWER Directive 9360.4-10.

2.3 MIGRATION PATHWAYS AND RECEPTORS

The historical data review and site reconnaissance are the initial steps in defining the source areas of contamination which could pose a threat to human health and the environment. Source areas could include waste impoundments, landfills, spills, contaminated soil, drums, tanks and other containers, and other waste management areas. Often these source areas are not directly located in or even adjacent to the surface water body. The contaminants are transported or migrate to the surface water or sediments. This section addresses how to delineate the spread of contamination away from the source areas. Included are pollutant migration pathways and the routes by which persons or the environment may be exposed to the on-site chemical wastes.

The fate of a contaminant is dictated by the source, the characteristics of the contaminant, and by the physical environment into which it is released. By defining the contaminants and the physical environment, the fate of contaminants can be predicted and the migration pathway can be identified. Knowing the migration pathway ensures that samples are collected in the most appropriate location(s).

Migration pathways are routes by which contaminants have moved or may be moved away from a contamination source. Pollutant migration pathways may include man-made pathways, surface drainage/topography, vadose zone transport, and wind dispersion. Human activity (such as foot or vehicular traffic) and animal activity also transport contaminants away from a source area. These five transport mechanisms are described below.

- Man-made pathways - A site located in an urban/suburban setting has the following man-made pathways which can aid contaminant migration to surface water bodies: storm and sanitary sewers, drainage culverts, sumps and sedimentation basins, French drain systems, and underground utility lines. A facility might utilize effluent pipes or point source discharges.

- Surface drainage/topography - Contaminants can be adsorbed onto sediments, suspended independently in the water column, or dissolved in surface water runoff. The runoff, following natural topography, can be rapidly carried into drainage ditches, streams, rivers, ponds, lakes, and wetlands. Historical aerial photographs can be invaluable for delineation of past surface drainage patterns. A search of historical aerial photographs can be requested through the U.S. EPA Regional Remote Sensing Coordinator. The U.S. Soil Conservation Service and local county planning offices are also excellent sources of historical aerial photographs.

- Vadose zone transport - Vadose zone transport is the vertical or horizontal movement of water and of soluble and insoluble contaminants within the unsaturated zone of the soil profile. Contaminants from a surface source or a leaking underground storage tank can percolate through the vadose zone and be adsorbed onto subsurface soil or reach ground water. Contaminants might migrate to surface water through a ground-water discharge area.

- Wind dispersion - Contaminants deposited over or adsorbed onto soil may migrate from a waste site as airborne particulates. Depending on the particle-size distribution and associated settling rates, these particulates may be deposited downwind or remain suspended, resulting in contamination of surface soils, surface waters, and/or exposure to nearby populations.

- Human and animal activity - Foot and vehicular traffic of facility workers, response personnel, and trespassers can move contaminants away from a source. Animal burrowing, grazing, and migration can also contribute to contaminant migration.

Once the migration pathways have been determined, identify all possible receptors (i.e., potentially affected human and environmental receptors) along these pathways. Human receptors include on-site and nearby residents, workers, and school children. Note the attractiveness and accessibility of site wastes to children and other nearby residents. Environmental receptors include edible aquatic species, federal- or state-designated endangered or threatened species, habitats for these species, wetlands, and other federal- or state-designated wilderness, critical, and natural areas.

2.4 SURFACE WATER AND SEDIMENT SAMPLE TYPES

Sampling procedures should be designed to be consistent with sampling objectives. The type of sample collected may depend on suspected contaminant types and characteristics; projected extent of water contamination; type of water body to be sampled (e.g., stream, impoundment); target analytes; and health and safety requirements. The following section describes and gives examples of the two types of surface water and sediment samples.

2.4.1 Grab Sample

A *grab* sample is a discrete aliquot from one specific sampling location at a specific point in time, and may be considered representative of homogenous conditions over a period of time and/or geographical area. When obtaining grab samples from a water body having stratified layers, sample each phase or stratum separately; the separate aliquots are representative of their respective stratum. When sampling stratified sources, determine as many properties as possible for the contaminants through historical data and site reconnaissance prior to sampling. Grab samples can be collected for both surface water and sediments, and are generally the preferred method for screening investigations. However, because the release of a contaminant in a surface water body is subject to variance over time and distance, a grab sample may not be a representative sample.

For many sampling situations grab sampling techniques are preferred over composite sampling. Grab sampling minimizes the amount of time and expense required for multiple samples; minimizes sampling personnel's exposure to potential hazardous substances; reduces risks associated with compositing unknowns; and eliminates physical and chemical changes that might occur due to compositing. Grab sampling also documents contamination at a specific point or location which can be easily identified and also re-located in later investigations for possible remedial or enforcement purposes.

2.4.2 Composite Sample

A *composite* sample is a non-discrete sample composed of two or more aliquots (of equal volume) collected at various sampling points or times. It can represent portions collected at various locations, various times, or a combination of both location and time variables. Composite samples are made by combining grab samples collected at defined intervals. There are four types of composite samples: *areal, vertical, flow proportional,* and *time.* The *areal composite* is composed of individual aliquots collected over a defined area. It is made up of aliquots (of equal volume) from grab samples collected in an identical manner (e.g., sediment aliquots collected along a streambed). A variation of this approach is the equal-width-increment (EWI) technique, in which equally-spaced vertical samples are collected across a stream with the sampling device passing through the water column at the same velocity at each location. This technique ensures that water and suspended particles are collected equally across the water body. Another variation is the equal-discharge-increment (EDI) technique, which positions the sampling locations across the stream based on incremental discharges rather than width (i.e., locations in deeper or higher velocity areas of the stream's cross-section are spaced more closely). This technique measures total discharge of contaminants in poorly mixed water bodies, but it requires knowledge of the cross-sectional stream flow distribution. Both techniques, however, are very time-consuming and expensive to employ. (Both techniques, as well as other depth integration approaches, are discussed in detail in ASTM standards, such as Standard D4411, in the *1989 Annual Book of ASTM Standards* - Volumes 11.01 and 11.02, Water and Environmental Technology.)

A *vertical,* also referred to as a *zonal, composite* is composed of individual aliquots collected at different depths but along the same vertical line. Like an areal composite, it is made up of aliquots collected in an identical manner. A *flow proportional composite* is a sample collected proportional to the flow rate during the compositing period by either a time-varying/constant volume or time-constant/varying volume method. A *time composite,* or *chronological sampling,* is composed of a varying number of discrete aliquots collected at equal time intervals during the compositing period. Both flow proportional and time composite samples are most appropriate for sampling flowing water bodies.

By design, composite samples reflect an "average" concentration within the composite area, flow, or interval. Compositing is appropriate when determining the general characteristics or the representativeness of certain sources for treatment or disposal. Samples collected along the length of the watercourse or at different times may reflect differing inputs or dilutions. It should be noted that compositing can mask problems by diluting isolated concentrations of some contaminants to below

detection levels. When compositing samples from a water body, note that resulting concentrations are representative of the water body's *average* concentration, but not of discrete areas within the water body. Compositing is not recommended where volatile compounds are a concern.

When compositing either surface water or sediment samples, specify in the sampling plan the method of selecting the aliquots that are composited and the compositing factor. The compositing factor is the number of aliquots to be composited into one sample (e.g., 3 to 1, 10 to 1). Determine this factor by evaluating detection limits for parameters of interest and comparing them with the selected action level for that parameter.

Compositing requires that each discrete aliquot be the same in terms of volume or weight and that they be thoroughly homogenized. Because compositing dilutes high concentration aliquots, the applicable detection limits should be reduced accordingly. If the composite value is to be compared to a selected action level, then the action level must be divided by the number of aliquots that make up the composite in order to determine the appropriate detection limit. The detection level need not be reduced if the composite area is assumed to be homogenous in concentration. Generally the number of samples to be taken for a composite depends upon the width, depth, discharge, and suspended sediments of the water body. The greater number of individual aliquots, the more likely the composite sample is truly representative of the overall characteristics of the water body.

2.5 SURFACE WATER AND SEDIMENT CHARACTERISTICS

The physical and chemical characteristics of the surface water and sediments, including stratification, current/flow rate, salinity, particle size, depositional/erosional areas, and degradation conditions, among other factors, influence the number and types of samples collected. These characteristics may also assist in determining sampling approaches and analytical parameters. Many of the characteristics of surface water and sediments are defined in Section 1.2.

2.6 SAMPLING CONSIDERATIONS

Factors to consider when designing a sampling plan include: hydrology, topography, water quality data, and water quality measurements such as pH, conductivity, temperature, dissolved oxygen, and salinity. Hydrology and morphometrics (e.g., measurements of volume, depth) of the surface water should be determined prior to sampling. Before sampling, identify the presence of phases or layers in impoundments and lakes, flow patterns in streams, and/or appropriate sample locations and depths.

Water quality data should be collected in impoundments and non-flowing (static) water bodies to determine if stratification is present. Measurements of dissolved oxygen, pH, temperature, conductivity, and oxidation-reduction potential can indicate if strata exist which would affect analytical results. Measurements should be collected at one-meter intervals from the substrate to the surface using an appropriate instrument (e.g., Hydrolab or equivalent). Knowing these variables assists in selecting locations and depths and interpreting analytical data.

2.7 QUALITY ASSURANCE CONSIDERATIONS

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

To ensure that the analytical samples are representative of site conditions, quality assurance measures must be associated with each sampling and analysis event. The sampling plan must specify these QA measures, which include, but are not limited to, sample collection, laboratory standard operating procedures (SOPs), sample container preparation, equipment decontamination, field blanks, replicate samples, performance evaluation samples, sample preservation and handling, and chain-of-custody requirements (see Chapter 5, Quality Assurance/Quality Control).

2.8 DATA QUALITY OBJECTIVES

Data quality objectives (DQOs) state the level of uncertainty that is acceptable for data collection activities and define the data quality necessary to make certain decisions. When establishing DQOs for a particular project, consider:

- Decision(s) to be made or question(s) to be answered by the data
- 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

In addition to these considerations, the quality assurance components of precision, accuracy (bias), completeness, representativeness, and comparability should also be considered. These components are defined in Section 2.7 and are discussed in further detail in Chapter 5, Quality Assurance/Quality Control.

2.9 ANALYTICAL SCREENING

There are two primary types of analytical data that can be generated during a response action: field analytical screening data and laboratory analytical data. Field analytical screening instruments and techniques provide real-time or direct (or colorimetric) reading capabilities. They include: flame ionization detectors (FIDs), photoionization detectors (PIDs), colorimetric tubes, portable X-ray fluorescence (XRF) units, portable gas chromatography (GC) units, immunoassay tests, and hazard categorization (hazcat) kits. These screening methods can assist with the selection of sample locations and depths or samples to be sent for laboratory analysis by narrowing the possible groups or classes of chemicals. They are effective and economical for gathering large amounts of site data. Once an area has been characterized using field screening techniques, a subset of samples can be sent for laboratory analysis to substantiate the screening results.

Under a limited sampling budget, analytical screening (with laboratory confirmation) will generally result in more analytical data from a site than will sampling for rigorous laboratory analysis alone. To minimize the potential for false negatives (not detecting contamination), use only those field analytical screening methods which provide detection limits below applicable action levels. If these methods are not available, field analytical screening can still be useful for detecting grossly contaminated areas, as well as for health and safety determination. Field analytical screening techniques to support surface water and sediment sampling are discussed in greater detail in Chapter 3.

Geophysical techniques (e.g., ground penetrating radar [GPR], magnetometry, electromagnetic conductivity [EM]) may be utilized during a response action to locate potential buried or disturbed waste source areas. These techniques are generally not used directly with representative surface water and sediment sampling. Please refer to U.S. EPA *Superfund Program Representative Sampling Guidance, Volume 1 -- Soil*, OSWER Directive 9360.4-10, for a discussion of geophysical techniques.

2.10 ANALYTICAL PARAMETERS

Designing a representative surface water and sediment sampling plan includes selecting analytical parameters and methods. Use data collected during the historical data review (e.g., past site operations and processes, materials stored on site, effluent discharges) to select appropriate analytical parameters and methods. If the historical data reveal little information about the possible types of contaminants on site, use applicable field analytical screening methods to narrow the parameters for analysis by ruling out the presence of high concentrations of certain contaminants. If the screening results are inconclusive, send a subset of samples from the areas of concern for a full chemical characterization by an off-site laboratory. These analyses can identify all contaminants of concern

(even at low detection levels). Methods often used for characterization include gas chromatography/mass spectrometry (GC/MS) for tentatively identified compounds (TICs) in the volatile and semivolatile organic fractions, infrared spectroscopy (IR) for organic compounds, and inductively coupled plasma (ICP) for inorganic substances.

After characterization, future sampling and analysis efforts can focus on substances identified above the action level. This will result in significant cost savings over a full chemical characterization of each sample. Utilize U.S. EPA-approved methodologies and sample preparation, where possible, for all requested off-site laboratory analyses. Knowledge of the analytical methodology and requirements is helpful when selecting sampling devices. Refer to the American Public Health Association *Standard Methods for the Examination of Water and Wastewater*, Seventeenth Edition, 1989, for detailed descriptions of analytical procedures/methodologies.

2.11 REPRESENTATIVE SAMPLING APPROACHES

Representative sampling approaches include judgmental, random, systematic grid, systematic random, transect, stratified, and three-dimensional (3D) sampling. The random and systematic random approaches are not very practicable for sampling water systems. When these two approaches are used, however, they are more appropriate to sediment samples than to surface water. The remaining approaches may be applied to both surface water and sediment sampling plans. Selection of a representative sampling approach must also consider the practicability of reaching sediments and obtaining a sample from a specific location, particularly difficult in surface waters. A representative sampling plan may use one or a combination of the approaches, each of which is described below.

2.11.1 Judgmental Sampling

Judgmental sampling is the biased selection of sampling locations based on historical information, visual inspection, and professional judgment. Judgmental sample collection is most appropriate when knowledge of the contaminant or its origin is available or when sampling non-static systems, such as flowing bodies of water. Judgmental sampling includes no randomization in the sampling strategy, precluding statistical interpretation of the sampling results. Criteria for selecting the sampling location depend on the sampling objectives and best professional judgment. Judgmental sampling does not necessitate sampling from the middle of the water body, but may consider factors such as source locations, tributaries, or depositional areas for more representative samples. Judgmental sampling also enables the investigator to select sampling locations with the fewest physical barriers impeding sample collection (e.g., docks, piers, stumps, dry stream beds). For surface water and sediment sampling for site assessments, emergency responses, and some early actions, judgmental sampling is often utilized.

Judgmental sampling allows no statistical analysis of error or bias. It is not always representative of site conditions, and tends to document "worst-case" scenarios. Judgmental sampling meets the objective to qualify hazardous substances on site, but not to quantify them. The judgmental approach is best used as a screening investigation to be followed with a statistical approach when determining extent of contamination or action alternatives. Judgmental approaches should be incorporated into sampling designs for remedial investigations and large-scale early and long-term response actions.

2.11.2 Random Sampling

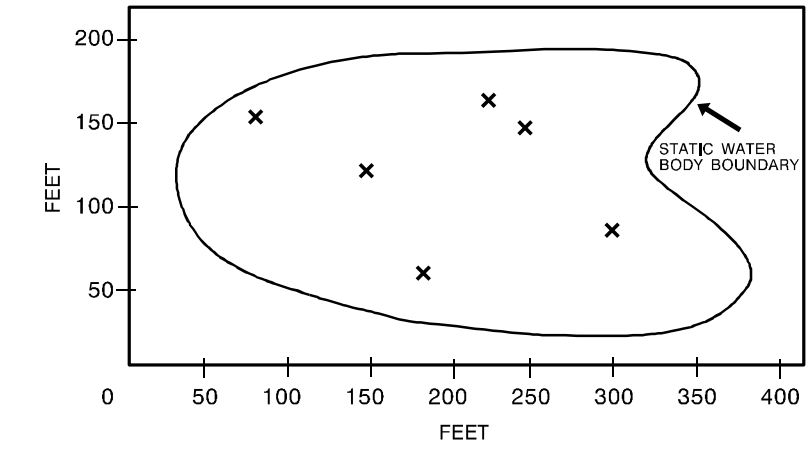
Random sampling, also referred to as simple random sampling, is the arbitrary collection of samples having like contaminants within defined boundaries of the area of concern (see Figure 2). Obtaining a representative sample depends on random chance probabilities. Random sampling is useful when there are many sampling locations available and no criteria for selecting one location over another. Choose random sampling locations using a random selection procedure (e.g., a random number table). (Refer to Ford and Turina, July 1984, for an example of a random number table.) The arbitrary selection of sampling points ensures that each sampling point is selected independently from all other points, so that all locations within the area of concern have an equal chance of being sampled. Randomization is necessary in order to make probability or confidence statements about the sampling results. The key to interpreting these statements is the assumption that the site or water body is homogeneous with respect to the parameters being sampled. The higher the degree of heterogeneity, the less the random sampling approach will adequately characterize true conditions. Random sampling is useful for sites with little background information available or for sites where obvious contaminated areas do not exist or are not evident. Random sampling is not recommended in flowing

water bodies and is only practicable for sediment bed sampling in non-flowing (static) water bodies.

2.11.3 Systematic Grid Sampling

Systematic grid sampling involves subdividing the area of concern by using a square or triangular grid and collecting samples from the nodes (intersections of the grid lines) (see Figure 3). Select the origin and direction for placement of the grid using an initial random point. From that point, construct a coordinate axis and grid over the area of concern. Generally, the more samples collected (and the smaller the grid spacing), the more reproducible and representative the results. Shorter distances between sampling locations improve representativeness. Systematic grid sampling can be used to characterize non-flowing (static) water bodies and their sediment beds.

Figure 2: Random Sampling



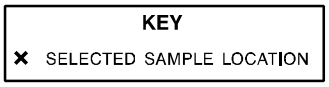
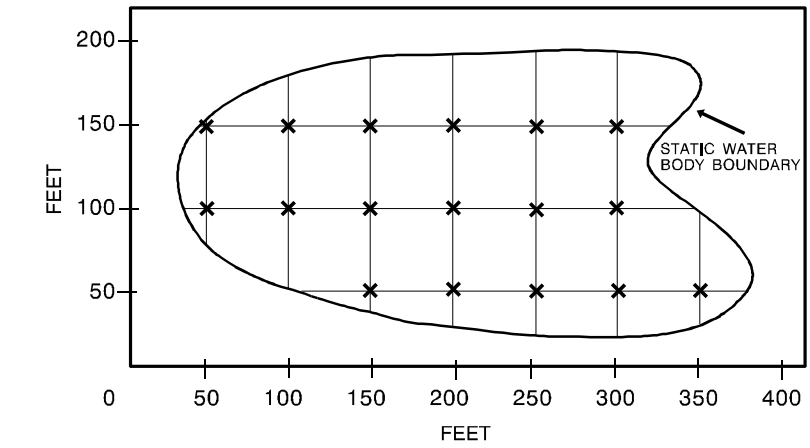
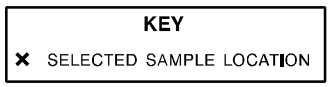


Figure 3: Systematic Grid Sampling



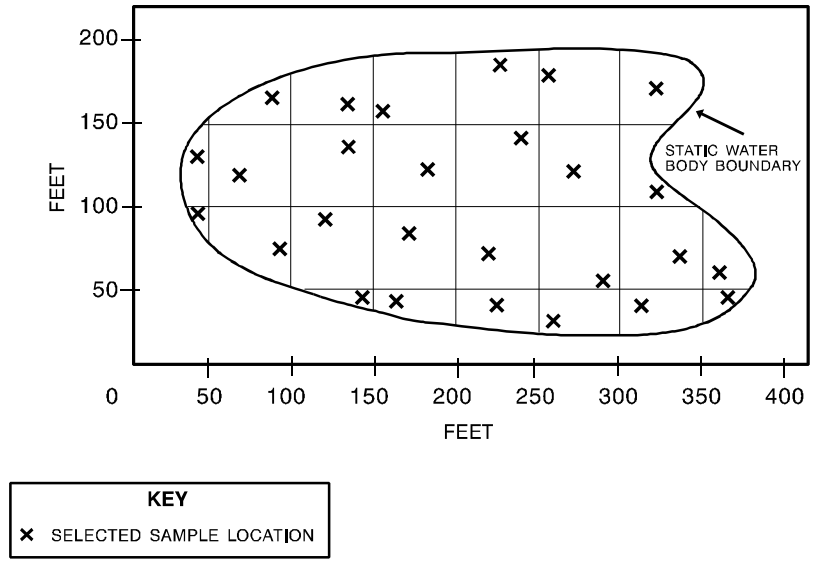


2.11.4 Systematic Random Sampling

Systematic random sampling is a flexible design for estimating the average pollutant concentration within grid cells (see Figure 4). Subdivide the area of concern using a square or triangular grid (as mentioned above) then collect samples from within each grid cell using random selection procedures.

Systematic random sampling allows for the isolation of cells that may require additional sampling and analysis. Like systematic grid sampling, systematic random sampling can be used to characterize sediment in an impoundment or non-flowing (static) water body; it is not recommended or practicable for surface water in any system.

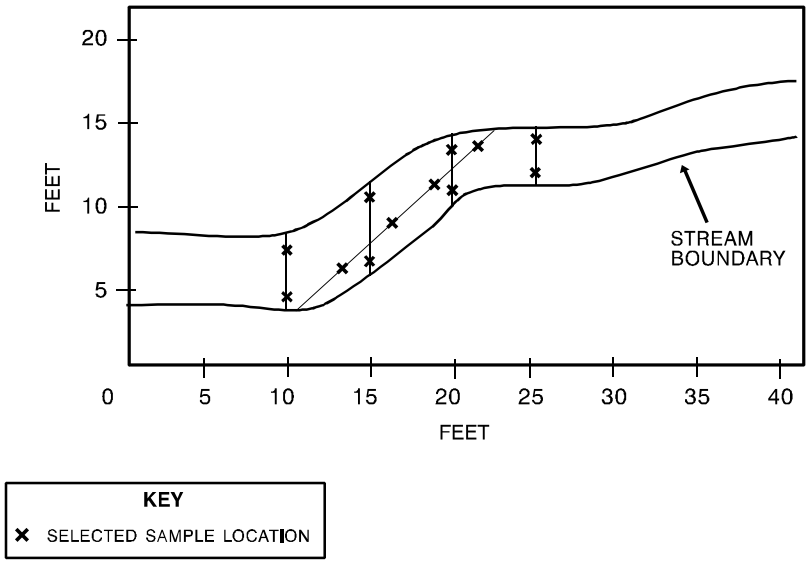
Figure 4: Systematic Random Sampling



2.11.5 Transect Sampling

Transect sampling involves establishing one or more transect lines across a surface (see Figure 5). Collect samples at regular intervals along the transect lines at the surface and/or at one or more given depths. The length of the transect line and the number of samples to be collected determine the spacing between sampling points along the transect. Transect sampling can best be accomplished when surface water bodies are small in size and the sampling locations within the transect grid boundaries are easily accessible. This is not the most desirable method in large lakes and ponds, or inaccessible areas where surface water samples can be obtained only by boat. Multiple transect lines may be parallel or non-parallel to one another, or may intersect. If the lines are parallel, the sampling objective is similar to systematic grid sampling. The primary benefit of transect sampling is the ease of establishing and relocating individual transect lines. Transect sampling is applicable to characterizing water flow and contaminant characteristics and contaminant depositional characteristics in sediments, such as distinguishing erosional versus depositional zones.

Figure 5: Transect Sampling



2.11.6 Stratified Sampling

Stratified sampling involves dividing the area to be sampled into mutually exclusive strata or areas where different sampling strategies may be employed in each stratum. Strata are chosen either based on areas where separate clean-up decisions need to be made or where variable strata contamination constituents or levels are expected. Where access is not a problem, stratified sampling is more appropriate for collecting representative sediment samples than surface water samples. Prior knowledge of stratification is required in order for this method to be most effective.

2.11.7 Three Dimensional (3D)

Three-dimensional (3D) sampling is similar to systematic sampling. First, the water body is divided along three axes (*x*, *y*, *z*), as opposed to the two horizontal axes in grid sampling. Then, a systematic approach (random or grid) is used to select sampling locations across the surface and at depth. Three-dimensional sampling is useful in static water bodies which exhibit distinct strata with depth but for which few data are available on contaminants and/or contaminant locations.

2.12 SAMPLING LOCATIONS AND NUMBERS

Selection of a surface water or sediment sampling location is based on many factors, including sampling objectives, surface water use, point source discharges, nonpoint source discharges, mixing zones, tributaries, changes in stream characteristics, stream depth, turbulence, presence of structures (e.g., dams, weirs), and accessibility to the sampling location. Tidal movement must also be considered when selecting sampling locations in tidal zones. Seasonal salinity ranges should be considered in estuaries.

The sampling objective can determine which characteristics of the surface water body warrant more attention. For example, when investigating a water body that serves as a source of water supply, factors such as accessibility, flow, and velocity are not as critical as they would be when determining contaminant impact on wetlands or sediments. This is because water supply intakes draw water from across the water body, also drawing in contaminants, while contaminants settle into wetlands by natural flow or mixing. When multiple sampling locations need to be investigated to determine pollution patterns or to obtain data for mathematical modeling purposes, several related factors may need to be considered. (See *A Practical Guide to Water Quality Studies of*

Streams, F.W. Kittrells, for additional guidelines on extensive or complicated sampling designs.)

The sampling objective will also influence the number of samples collected. When determining the presence/absence of a contaminant, few samples are required. More samples are needed if the objective is to identify the characteristic concentrations of a contaminant or the extent of contamination. Judgmental and statistical sampling techniques can be used together to thoroughly address an area. Some samples may be obtained from locations considered potentially affected areas by a judgmental approach (e.g., sediments downstream of a discharge outfall pipe). For areas less likely to be affected or with little available historic information, a random or grid approach may be used to adequately assess the entire water body or site.

To determine whether a water body has been affected by site contaminants, two sample sets are generally required: one surface water and sediment sample each from the point (or slightly downstream) where on-site contaminants are suspected to have entered the water body (also referred to as the probable point of entry [PPE]), and another surface water and sediment sample set from an upstream, unaffected background location. If multiple sources or contaminants from other sites upstream of the PPE are suspected in the water body, additional sample locations will be needed downstream of those alternate sources, upstream of the PPE.

Where the sampling objective is to delineate the extent of sediment contamination for response action alternatives, a greater number of samples and sampling locations will be required. In this situation, a systematic approach will be needed (e.g., transect or systematic grid) to accurately "map" the contamination. The exact number of samples required will be determined by the analytical parameters and the size of the line or grid and their intersects.

2.13 EXAMPLE SITE

2.13.1 Background

The ABC Plating Site is located in northeastern Pennsylvania approximately 1.5 miles north of the town of Jonesville. Figure 6 provides a layout sketch of the site and surrounding area. The site covers approximately 4 acres and was 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. Surface drainage from this area then entered a nearby stream.

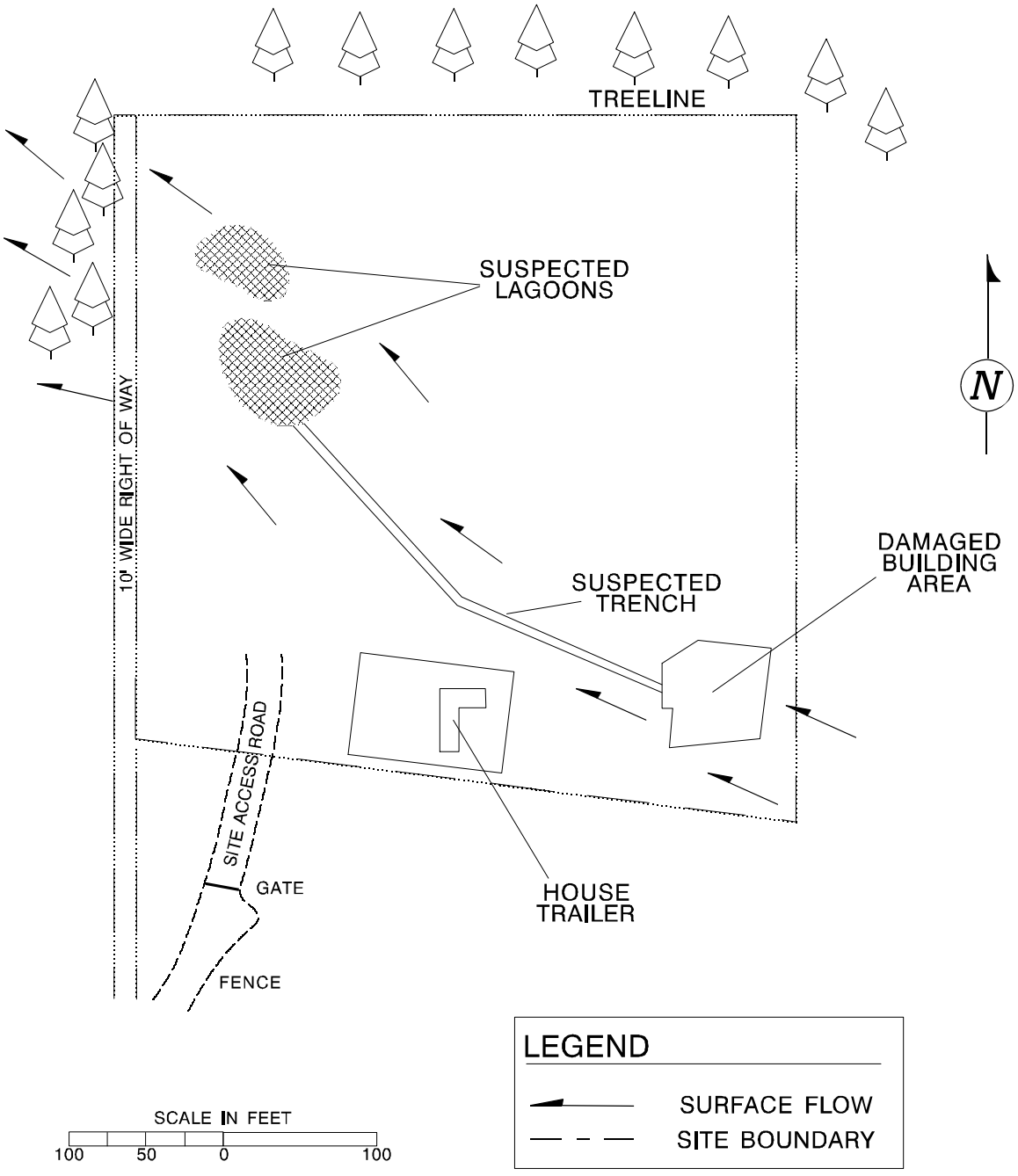
Pennsylvania Department of Environmental Resources (PADER) personnel cited the owner/operator for the operation of an unpermitted treatment system and ordered the owner to submit a remediation plan for state approval. Before PADER could follow up on the order, the lagoons were partially backfilled with 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 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.

2.13.2 Historical Data Review and Site 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-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 nickel plating process areas.

Figure 6: ABC Plating Site



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.

2.13.3 Identification of Migration Pathways, Transport Mechanisms, and Receptors

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.

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 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.

Erosion gullies located on site indicated soil erosion and water transport due to storms. Surface drainage sloped toward the west and northwest, including a distinct drainage path topographically downgradient of the former lagoon area. The Team observed stressed and discolored vegetation along the surface water drainage path. Surface runoff of heavy metals and cyanide was a direct contact hazard to local residents. Surface water systems were also potentially affected. Further downgradient, site runoff and the drainage path entered an intermittent tributary of Little Creek. The naturally eroded tributary flows west/southwest into a heavily wooded area off-site prior to its convergence with Little Creek. Little Creek in turn feeds Barker Reservoir, located southwest of the site. 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. Shallow ground-water discharges into the creek and reservoir at several locations, serving as another possible contaminant migration route.

2.13.4 Sampling Objectives

The OSC initiated a removal 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.

Once CERCLA funding was obtained and the site was stabilized:

- Phase 2 - Define the extent of contamination at the site and adjacent areas. Estimate the costs for early action options and review any potential long-term remediation objectives.

- 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.

2.13.5 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 bias-selected soil, ground-water, surface water, and sediment samples were collected to demonstrate whether a release had already occurred.

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. A block grid with 50-foot grid spacing was selected. This grid size ensured a 10 percent or less probability of missing a "hot spot." 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, a judgmental approach was used to locate sample locations along the drainage path. A judgmental approach was also used for the intermittent tributary and Little Creek. Based on the results of soil sampling and geophysical surveys, a judgmental approach was used to select locations for installation of 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 confirmatory analysis to establish the presence and, if applicable, the degree of contamination at depth.

A judgmental approach was selected for Phase 2 sampling in the surface water migration route. During Phase 1, samples were collected of soils along the drainage path and of surface water and sediments in the intermittent tributary. For purposes of EPA target and listing criteria, surface water at this site was considered to begin at Little Creek, the perennially flowing stream. Phase 1 samples exhibited limited site-related contamination along the drainage path. Because of Little Creek's distance from the site and the tributary traversing through the wooded area, detection of contamination in the surface water body had to be determined first. For this reason, during Phase 2 biased locations were selected for sampling in Little Creek, the intermittent tributary, and along the drainage path topographically downgradient of the former lagoons, to establish contaminant migration. A surface water and sediment sample set was collected along Little Creek upstream of the tributary PPE to determine background conditions.

2.13.6 Analytical Screening, Geophysical Techniques, and Sampling Locations

During Phase 1, containerized wastes were screened using hazard categorization techniques to identify the presence of acids, bases, oxidizers, and flammable substances. Following this procedure, photoionization detector (PID) and flame ionization detector (FID) instruments, a radiation meter, and a cyanide monitor were used to detect the presence of volatile organic compounds, radioactive substances, and cyanide, respectively, in the containerized wastes. Phase 1 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), 3 ground-water samples, one surface water sample, and one sediment sample 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. The surface water and sediment samples were collected from the observed PPE at the confluence of the unnamed intermittent tributary and the on-site surface water drainage pathway. Based on Phase 1 analytical results, chromium was selected as the target compound for determination of extent of contamination in all media/pathways.

During Phase 2 sampling activities, the OSC used a transportable X-ray fluorescence (XRF) unit installed in an on-site trailer to screen soil and sediment 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. Twenty-four surface and subsurface samples were sent for laboratory confirmation analysis following XRF screening. The analytical results from these samples allowed for site-specific calibration of the XRF unit. 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 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 survey was conducted over the original grid and run along the north-south grid axis across the suspected locations of the trench and lagoons. For the comprehensive EM survey, the original 50-foot grid spacing was decreased to 25 feet along the north-south grid axis. The EM survey was run along the north-south axes and readings were obtained at the established grid nodes. The EM survey was utilized throughout the site to detect the presence of buried metal objects (e.g., buried pipe leading to the lagoons) and potential subsurface contaminant plumes.

Using the data obtained during soil sampling and the geophysical surveys, a ground-water investigation plan for Phase 2 was prepared. Monitoring wells were located in areas shown to be heavily contaminated during soil sampling; along the outer perimeter of a contaminant plume based on soil XRF results and the geophysical surveys; and apparent upgradient locations for background conditions comparison. Fifteen wells were located at grid nodes established using the above data. Upon monitoring well installation and sampling, a hydraulic (pump) test was completed of the bedrock monitoring wells to gather information about aquifer characteristics, which help assess the ability of contaminants to migrate through ground water.

Three soil grid samples collected along the bank of the surface water drainage path, topographically downgradient of the former lagoon area, exhibited chromium contamination ranging from 772 to 2,060 mg/kg. The samples were from random locations according to the layout of the sampling grid. This chromium contamination suggests that a contaminant plume may have traveled topographically downgradient from the lagoons along the drainage path. (Contamination was not detected at depth in these samples.) Based on these results, it was decided that the surface water migration route should be further evaluated.

The tributary PPE sample set collected during Phase 1 did not exhibit any contamination at the time of sampling. However, the Team observed that the drainage path and tributary became very level and shallow prior to, and in, the heavily wooded area. Contaminants may settle out in this area due to its level terrain and many flow obstructions. Any contaminants here would be transported downstream only during heavy flow or storm events. It was decided to collect additional surface water and sediment sample sets along the drainage path and tributary using a judgmental approach during Phase 2 activities. If the site were to continue under Superfund remedial site evaluation for consideration of the surface water migration route, contamination must have been detected or suspected in the perennially flowing stream, Little Creek. A surface water and sediment sample set at the PPE for the tributary to Little Creek was collected to establish whether the contamination had migrated to the surface water body. The sediment sample would establish historical contamination, while the surface water aliquot would indicate current contamination migration. (Phase 2 sampling activities were scheduled to occur while the intermittent tributary was flowing.) A background sample set was collected in Little Creek by obtaining surface water and sediments upstream of the tributary confluence (PPE).

Phase 3 activities are discussed in Section 6.7.

2.13.7 Parameters for Analysis

During Phase 1 sampling activities, full priority pollutant metals and total cyanide analyses were conducted on all soil, ground-water, surface water, and sediment samples sent to the laboratory. These parameters were initially selected based on research of plating chemistry (plating facilities generally use either an acid bath 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.

3.0 FIELD ANALYTICAL SCREENING AND SAMPLING EQUIPMENT

3.1 INTRODUCTION

Sample collection requires an understanding of the capabilities of the sampling equipment, since using inappropriate equipment may result in biased or nonrepresentative samples. The limitations, uses, construction, and ease of use of the equipment or techniques must be understood prior to designing a sampling plan.

Section 3.2 provides an overview of the most commonly utilized field analytical screening equipment and techniques that are applicable to surface water and sediment sampling. Section 3.3 provides information for selecting sampling equipment. The example site synopsis continues at the end of the chapter.

3.2 FIELD ANALYTICAL SCREENING EQUIPMENT

Field analytical screening techniques and equipment may provide valuable information for developing sampling strategies. Field analytical screening can determine chemical classes of contaminants and in some cases can identify particular substances of concern. Real-time or direct-reading capabilities narrow the possible groups or classes of substances, which aids in selecting the appropriate laboratory analytical method. These screening techniques are useful and economical when gathering large amounts of site data. The screening techniques can also be utilized to select sample locations, as well as samples to be sent for off-site laboratory analysis or confirmation. The analytical screening methods provide on-site measurements of contaminants of concern, limiting the number of samples which need to be sent for off-site analysis. All screening equipment and methods described in this section are portable (the equipment is hand-held and generally no external power source is necessary). Screening techniques for surface water and sediment sample analysis are discussed in Table 1; the methods are presented in a general order of those most utilized and applied shown first. Field analytical screening methods are most often used to identify waste or contaminant source areas and may not be required during all surface water and sediment sampling events.

Field screening generally provides analytical data of suitable quality for site characterization, monitoring response activities, and health and safety decisions. Its application with surface water and sediment sampling may be more limited than with other sample media. For investigations of water bodies, these methods may assist with sample selection for laboratory analysis or for a preliminary determination of the extent of contamination in sediments or of a contaminant plume in a static water body. Screening methods can provide rapid, cost-effective, real-time data; however, results are often not compound-specific and not quantitative.

When selecting one screening method over another, consider relative cost, sample analysis time, potential interferences or instrument limitations, applicability to the sample medium, detection limit, QA/QC requirements, level of training required for operation, equipment availability and durability, and data bias. Also consider which elements, compounds, or classes of compounds the screening instrument is designed to analyze. As discussed in Section 2.9, the screening method selected should be sensitive enough to minimize the potential for false negatives. When collecting samples for screening analysis (e.g., portable gas chromatograph), evaluate the detection limits and bias of the screening method by sending a minimum of 10 percent of the samples for laboratory confirmation. For additional information on specific field screening analytical techniques and equipment, please refer to the U.S. EPA *Compendium of ERT Waste Sampling Procedures*, OSWER Directive 9360.4-07 or *Superfund Program Representative Sampling Guidance, Volume 4 - Waste*, OSWER Directive 9360.4-14.

3.3 SURFACE WATER AND SEDIMENT SAMPLING EQUIPMENT AND SELECTION

Sample collection requires an understanding of the capabilities of the sampling equipment, since the use of inappropriate equipment may result in nonrepresentative samples. Select approved sampling equipment based on the sample type and medium, matrix, physical location of the sample point, sampling objectives, and other site-specific conditions. Site-specific conditions may dictate that

only one method or type of equipment will work. Also consider the equipment design. For example, a device which aerates a sample during collection might release volatile organic compounds and thus not yield a sample representative of actual conditions.

Also consider the compatibility of the contaminants being sampled with the composition of the sampling device. All sampling devices should be of good quality. They should be made of material that will not affect the outcome of analytical results; they must not contaminate the sample being collected and must be able to be cleaned easily in order to reduce the risk for cross-contamination. Use of a device constructed of undesirable material may compromise sample quality by having components of its material leach into the sample or adsorb constituents of the sample. If a sampling device cannot be easily decontaminated, consider the cost-effectiveness of expendable equipment. Standard construction materials typically include Teflon®, polyvinyl chloride (PVC), glass, stainless steel, and steel. Selection is commonly determined by considering the substance to be sampled and the cost of sampling.

Select, when possible, equipment that is easy to operate, in order to decrease training requirements and when wearing cumbersome personal protective equipment. Complicated sampling procedures usually require increased training and introduce a greater likelihood of procedural errors; SOPs help to avoid such errors. Follow SOPs for the proper use and decontamination of all sampling equipment. The U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03, provides SOPs for some standard surface water and sediment sampling equipment and methods.

This section provides appropriate uses, advantages, and disadvantages of select examples of surface water and sediment sampling equipment. Representative sampling requires that appropriate sampling equipment be chosen for each sampling objective and location. The surface water sample collected may represent all phases or a specific stratum present in the water, as required by the sampling objective. Construction material, design and operation, decontamination procedures, and the procedures for proper use are factors to consider when selecting equipment. The following characteristics of surface water can affect the representativeness of a sample: density, analyte solubility, temperature, and currents. A sampling device should have a capacity of at least 500 milliliters, if possible, to reduce the number of times the liquid must be disturbed and to reduce sediment agitation.

When selecting sediment sampling equipment, consider the width, depth, flow, and the bed characteristics of the area to be sampled. Sediment may be sampled in both flowing and standing water. Samples may be recovered using a variety of methods and equipment, depending on the depth of the aqueous layer, the portion of the sediment profile required (surface vs. subsurface), the type of sample required (disturbed vs. undisturbed) and the sediment type. Sediment is collected from beneath an aqueous layer either directly using a hand-held device, or indirectly using a remotely-activated device. Selection of a sampling device is most often contingent upon the depth of water at the sampling location as well as the physical characteristics of the medium to be sampled. Take care to minimize disturbance and sample washing as the sample is retrieved through the aqueous layer. It is important to get a representative sample of all horizons present in the sediments. Maintain sample integrity by preserving the sample's physical form and thus its chemical composition.

Tables 2 and 3 provide examples of commonly used surface water and sediment sampling equipment, respectively, but the list is not exhaustive. The advantages and disadvantages listed represent only highlights of the equipment use. Additional details on surface water and sediment sampling equipment and procedures are provided in the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03.

3.4 EXAMPLE SITE

3.4.1 Selection of Analytical Screening Equipment

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, and radiation and cyanide monitors were utilized to tentatively identify containerized liquid wastestreams in order to select initial judgmental 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." Soil samples to be sent for laboratory analysis were placed into sampling jars. An organic vapor detecting instrument (PID) continued to be utilized throughout all field activities for health and safety monitoring during Phases 1 through 3.

The portable XRF was used during soil screening, monitoring well installation, and sediment sampling. Ground-water and surface water samples were screened in the field for pH, 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 water sample. The instrument was decontaminated prior to and after each sample screening.

3.4.2 Selection of Geophysical Equipment

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

3.4.3 Selection of Sampling Equipment

Disposable plastic scoops were used for Phase 1 soil and sediment sampling. Phase 1 ground-water and surface water samples were collected directly 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 collect shallow 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. Ground water was sampled in Phase 2 from the monitoring wells installed on site. 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.

As in Phase 1, Phase 2 sediment samples were collected using dedicated disposable plastic scoops. Surface water samples were collected directly into the sample containers. The shallow depth and narrow breadth of the intermittent tributary and Little Creek did not require any specialized equipment or remote sampling devices.

TABLE 1: SURFACE WATER AND SEDIMENT FIELD ANALYTICAL SCREENING EQUIPMENT

Instrument	Use(s)	Advantage(s)	Disadvantage(s)
Direct - Reading/ Real - Time Instruments	Portable monitoring instruments used to measure or identify specific parameters under field conditions including: pH, specific conductivity, temperature, salinity, and dissolved oxygen	• Portable and easy to operate and maintain in the field • Qualitative identification • May be used with probes placed directly into the sample medium	• May return a reading with a high degree of error
Field Test Kits and Colorimetric Indicator Tubes	Used for detecting specific compounds, elements, or compound classes in surface water and sediment	• Rapid results • Easy to use • Kits may be customized to user needs	• Limited number of kit types available • Interference by other analytes is common • Subjective interpretation is needed • Can be prone to error • May have limited shelf life • Colorimetric tubes may be used for ambient air only
Photoionization Detector (PID)	Detects and measures total concentration of volatile organic compounds (VOCs) and some non-volatile organic and inorganic contaminants in ambient air or container headspace; used to evaluate existing conditions, identify potential sample locations, or identify extent of contamination	• Immediate results • Easy to operate and maintain • Detects to parts per million (ppm) level for headspace analysis	• Limited use to quantify specific substances • Does not detect methane • Readings can be affected by high winds, humidity, condensation, dust, power lines, and portable radios • Probe should not be placed directly into sample medium
Flame Ionization Detector (FID)	Detects and measures the level of total organic compounds (including methane) in ambient air or container headspace; used to evaluate existing conditions, identify potential sample locations, or identify extent of contamination	• Immediate results • Detects to ppm level for headspace analysis • Rugged • Available with a GC mode to detect specific VOCs	• Does not respond to inorganic substances • Does not recognize and may be damaged by acids • Requires training and experience • Requires a hydrogen fuel source • Probe should not be placed directly into sample medium

TABLE 1: SURFACE WATER AND SEDIMENT FIELD ANALYTICAL SCREENING EQUIPMENT (Cont'd)

Instrument	Use(s)	Advantage(s)	Disadvantage(s)
Hazard Categorization (hazcat)	Performed as an initial screen for hazardous substances to provide identification of the classes/types of substances in the individual surface water or sediment sample	• Rapid categorization of unknown liquids • Good for screening and determining contaminant compatibility	• Not analyte-specific, yields only basic information (e.g., base vs. acid, chlorinated vs. non-chlorinated substance) • Requires numerous chemical reagents • Requires interpretation of results
Portable Gas Chromatograph (GC)	Used to measure occurrence and concentration of VOCs and some semi-VOCs	• Can screen "hot spots" • Determines potential interferences • Conducts headspace analysis • Semi-quantitation of VOCs and semi-VOCs	• Highly temperature sensitive • Requires set-up time, many standards, and extensive training
Radiation Detector	Detects the presence of selected forms of radionucliides in sediments	• Easy to use • Probes for one or combination of alpha, beta, or gamma emitters	• Units and detection limits vary greatly • Time intensive for detailed surveys • Experienced personnel required to interpret results
Portable X-ray Fluorescence (XRF)	Used to detect heavy metals in sediments	• Rapid sample analysis • Detects to ppm level (detection limit should be calculated on a site-specific basis)	• Requires trained operator • Sediment must be dried • Potential matrix interferences • Detection limit may exceed action level • Radioactive source • Cannot be used for surface water samples

TABLE 2: SURFACE WATER SAMPLING EQUIPMENT

Sampler	Uses	Advantages	Disadvantages
Laboratory-cleaned Sample Container (Direct Method)	Used to collect samples from surface and shallow depths of surface water bodies	• Quick and easy to use • No decontamination required • Disposable • Reduces risk of cross-contamination from sampling equipment • Reduces the loss of volatile fraction during transfer to a sample container • Preferred if there is an oily layer on the sample surface; the layer will not stick to a sampling device and thus miss being transferred to the sample container	• Cannot be used for other water bodies, such as waste impoundments, where contact with concentrated contaminants is a concern • Labelling can be difficult • May not be possible when containers are pre-preserved
Scoop, Ladle, Beaker (Transfer Devices)	Stainless steel, Teflon®, or other inert composition material devices to transfer the sample directly into a sample container at a near shore location	• Easy to use and decontaminate • Allows collection without a loss of preservative in the sample container	• Difficult to maneuver sample especially if placing into VOA vials • Avoid equipment with painted or chrome-plated surfaces • May aerate sample releasing VOCs, or some contaminants may adhere to the surface of the transfer device
Weighted Bottle Sampler	Used to collect samples in a water body or impoundment at predetermined depth	• Easy to decontaminate • Simple to operate • Sampler remains unopened until at desired sampling depth	• Cannot be used to collect liquids that are incompatible with the weight sinker, line or actual collection bottle • Sample container may not fit into sampler, thus requiring additional equipment • Sample container exposed to matrix
Pond Sampler	Used for near shore sampling where cross-sectional sampling is not appropriate and for sampling from outfall pipe or along a disposal pond, lagoon, or pit bank where direct access is limited	• Easy to fabricate using a telescoping tube; not usually commercially available • Can sample at depths or distances up to 3.5 meters (can sample areas difficult to reach with extension)	• Difficult to obtain representative samples in stratified water bodies • Sample container may not fit into sampler, thus requiring additional equipment
Peristaltic Pump	Used to extend the reach of sampling effort by allowing the operator to reach into the water body, sample at depth, or sweep the width of narrow streams through the use of Teflon® or other tubing	• Very versatile • Easy to carry and operate; fast • With medical-grade silicone, it is suitable to sample almost any parameter including most organic contaminants • Sample large bodies of water • Capable of lifting water from depths in excess of 6 meters	• Depth limited to 7.5 meters/25 feet • Cannot be used if volatile compounds are to be analyzed • Lift ability decreases with higher density fluids, increased wear on silicone pump tubing, and increases with altitude • Oil and grease contaminants may adhere to tubing and thus decrease concentration in sample • Must often change tubing between locations to decrease cross-contamination; must always have extra tubing on hand • At high flow, must weight tubing in stream

TABLE 2: SURFACE WATER SAMPLING EQUIPMENT (Cont'd)

Sampler	Uses	Advantages	Disadvantages
Bailer	Used for collecting samples in deep bodies of water where cross-sectional sampling is not appropriate	• Easy to use • No power source needed • Bailers can be dedicated to sample locations • Disposable equipment available • Can be constructed of a variety of materials	• Transfer of sample may cause aeration, thus not appropriate for VOCs • Inappropriate for strong currents or where a discrete sample at a specific depth is required
Kemmerer Bottle/Van Dorn Sampler	Used when access is from a boat or structure such as a bridge or pier, and where discrete samples at specific depths are required	• Can take discrete samples at specific depths • Can sample at great depths • Kemmerer Bottle lowers vertically; Van Dorn Sampler lowers horizontally, which is more appropriate for estuary sampling	• Sampling tube is exposed to material while traveling down to sampling depth • Transfer of sample into sample container may be difficult • May need extra weight • Often constructed of materials incompatible with sample
Bacon Bomb Sampler	Used to collect samples from discrete depths within a water body; generally used when access is from a boat or structure	• Remains unopened until the sampling depth • Can collect a discrete sample at desired depth/stratum • Widely used and available	• Difficult to decontaminate • Difficult to transfer sample to sample container • Tends to aerate sample thereby losing volatile organic constituents
Wheaton Dip Sampler	Useful for sampling liquids in shallow areas or from areas where direct access is limited; also useful when sampling from an outfall pipe	• Long handle allows access from a discrete location • Sample container is not opened until specified sampling depth • Sampler can be closed after sample is collected ensuring integrity • Easy to operate	• Depth of sampling is limited by length of extension poles • Exterior of sample container may come in contact with sample • Sample container may not fit into sampler
Depth-Integrating Samplers	Used to collect water and suspended sediment samples; used with the EWI and EDI composite sampling techniques	• Allows for collection of representative samples of suspended materials • Samples proportionate to the velocity of the water body	• Requires experienced operator
PACS Grab Sampler	Used to collect water samples from impoundments, or ponds with restricted work areas	• Allows discrete samples to be collected at depth	• Depth of sampling is limited by length of extension pole • Difficult to decontaminate

Note: Standard operating procedures and example figures of some of the equipment is available in the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03.

Abbreviations

EWI = equal-width-increment
EDI = equal-discharge-increment

TABLE 3: SEDIMENT SAMPLING EQUIPMENT

Sampler	Uses	Advantages	Disadvantages
Scoops, Trowels, Dippers, Shovels (Direct Method)	Used for surface sediments where water depth is shallow (limited to near surface)	• Quick and easy to use • Easy to decontaminate • Available in a variety of materials • Appropriate for consolidated sediments • Disposability reduces the risk for cross-contamination • Laboratory scoop is less subject to corrosion or chemical reactions than commercially available garden or household tools (less risk for sample contamination)	• Disturbs the water/sediment interface and may alter sample integrity; fine fraction is lost • Not efficient in mud or other soft substrates • Difficult to release secured undisturbed samples to readily permit subsurface sampling • Difficult to maneuver sample especially if placing into VOA vials • Limited by depth of aqueous layer • Avoid equipment with painted or chrome-plated surfaces (common with garden trowels)
Vertical-pipe, Core Sampler	Used to collect samples of most sediments to depths of 75 cm (30 in.)	• Easy to use • Can collect undisturbed sample (minimum loss of fine fraction) that can profile any stratification as a result of changes in deposition • Provides historical record of deposition	• When used in impoundments, penetration depths could exceed that of substrate and damage the liner material • A relatively small surface area and sample size result in the need for repetitive sampling to obtain an adequate amount for analysis
Ponar/Ekman/ Peterson Dredges	Ponar dredge is used to sample most types of sediments --- Ekman dredge is used where bottom material is unusually soft, such as thick organic sludges --- Peterson dredge is used when bottom is rocky, in deep water or in a stream with high velocity	• Ponar is easily operated by one person; light weight • Available in a "petite" size which can be operated without a winch or crane • Appropriate for most sediment types from silts to granular materials --- • Ekman can obtain samples of bottom fauna --- • Peterson can be used in rocky substrates and high velocity water bodies • Easily operated by one person	• Dredges are normally used from a boat, bridge or pier due to the weight of the equipment which may require a boom for lowering or raising • Penetration depths for Ponar and Ekman dredges do not exceed more than 4-6 inches • Not capable of collecting undisturbed sample and may cause agitation currents that may temporarily resuspend some settled solids --- • Ekman is not suitable for sandy, rocky, and hard bottoms, vegetation-covered bottoms, and streams with high velocities • Should not be used from a bridge more than a few feet high because spring mechanism could be damaged • Not capable of collecting an undisturbed sample and may cause agitation currents that may temporarily resuspend some settled solids --- • Peterson can displace and miss light materials if allowed to drop freely
Thin-Wall Tube Auger	Used to collect consolidated sediments at surface and at depth	• Easy to use • Preserves core sample	• Limited by the depth of the aqueous layer • May be difficult to remove core sample from auger • Possible washout during retrieval
Veihmeyer Sampler	Used for sampling most types of soil and sediments, except very wet or stony sediments	• Can achieve substantial depths with appropriate length of tubing • Various driveheads available for different sediment types	• Very difficult to clean • Parts needed for sampler are not appropriate for certain analyses • Not appropriate in rocky substrate

TABLE 3: SEDIMENT SAMPLING EQUIPMENT (Cont'd)

Sampler	Uses	Advantages	Disadvantages
PACS Grab Sampler/Sludge Getter	Used for collecting grab samples from ponds and impoundments at depth	• Allows discrete samples to be collected at depth • Can be used in heavy sediments or sludges, or moderately viscous materials	• Not useful in very viscous materials • Depth of sampling is limited by length of extension pole • Heavy, possibly requiring more than one person to operate
Sampling Trier	Used to collect sediments up to 40 inches depth from water surface	• Preferred for moist or sticky samples	• Difficult to use in stony or sandy substrates • May be difficult to remove sample from sampling device
Soil Coring Device/ Silver Bullet Sampler	Used when a core sample is required	• Contains a collection tube which holds core relatively intact • Bit of silver bullet sampler is replaceable	• Difficult to use in rocky or tightly packed substrates • Depth restrictions
Sludge Judge	Used to collect a core of sediments or water and sediments	• Easy to use • Core allows delineation of settled state of sediments or physical state of water body	• Use is limited due to possible reactivity of construction material • Difficult to decontaminate • Not useful in thick sediments
Hand Corer	Used for sediments in water that is very shallow (a few inches)	• Easy to use • Preserves sequential layer of deposit (useful for historical information) • Appropriate for trace organic compounds or metals analyses • May have a check valve on top to prevent wash-out during retrieval	• Can be disruptive to water/sediment interface • May cause disruption to sample integrity • Delivers small sample size requiring repetitive sampling
Gravity Corer	Collects core samples from most sediments; can be used in water deeper than 5 feet	• Collects undisturbed samples • Can collect to a depth of 75 cm (30 in.) within the sediment substrate • Preserves sequential layer of deposit (useful for historical information) • Has a check valve to prevent washout during retrieval	• May damage liners in impoundments if penetration is too deep • Not suitable for obtaining coarse-grained samples
Bucket and Posthole Augers	Used for direct method samples	• Direct sample recovery • Fast and easy to use • Provides a large volume sample	• Disturbs sediment horizons • May cause disruption to sample integrity • Posthole augers that are designed to cut through fibrous, rooted swampy areas have limited sample collection utility

Note: Standard operating procedures and figures of many of these equipment types are available in the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03.

4.0 FIELD SAMPLE COLLECTION AND PREPARATION

4.1 INTRODUCTION

When sampling a water body, the following critical factors must be considered to ensure that the sample is representative: points of sampling, frequency of sampling, and maintenance of integrity of sample prior to analysis. During a response action, proper field sample collection and preparation methods are as important as proper sampling equipment selection. Sample collection refers to the physical removal of water or sediments from a water body for the purposes of either screening or laboratory analysis, and includes sample quantity and sample volume. 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 various sample types and sources.

The collection of samples from water bodies presents unique challenges. Some samples involve merely collection by a direct method in shallow waters. Often however, site-specific conditions may dictate the use of special equipment to access the sample location, increased health and safety concerns, and proper timing to consider tidal fluctuations and/or flow rates.

4.2 SAMPLE VOLUME AND NUMBER

How a sample is collected can affect its representativeness. The greater the number of samples collected from a site and the larger the volume of each sample, the more representative the analytical results should be. However, sampling activities are often limited by sampling budgets and project schedules.

Sampling objectives and analytical methods are considerations in determining appropriate sample volume and number. The volume of a sample should be sufficient to perform all required laboratory analyses with an additional amount remaining to provide for analysis of QA/QC samples (including duplicate analyses). The volume of water samples can vary depending on the requirements of the laboratory and the analytical method(s). The minimum volume collected should be three to four times the amount required for the analysis. Typically, no more than 8 liters are required for each water sample. The amount of sediment required for analysis can also vary but will not usually exceed 16 ounces. Always consult the analytical laboratory during sampling design to determine the adequate volume required for each matrix and location. Sometimes site conditions may limit the available sample volume; creek waters may be shallow during a dry season or the sediments may consist of a rocky substrate. Review the site conditions when selecting laboratory analyses. Where sample volume may be limited, it may be necessary to reduce the number of analyses to those most critical to the investigation and its objectives.

The number of sample locations will depend upon site-specific requirements and must satisfy the investigation objectives. A few selected locations may be enough to identify the existence of contamination, or multiple location, systematic sampling may be required to delineate the full extent of contamination. Both strategies may be used during different phases of a site investigation. The physical characteristics of the water body might also dictate sample numbers. A complicated, well-developed system of tributaries, changes in flow, and sediment deposition will necessitate additional sample locations to ensure that samples are representative of site contaminant migration conditions. The number of samples may vary according to the particular sampling approach used at the site. Chapter 2 provides additional information on sampling approaches and sample locations and numbers.

4.3 SURFACE WATER SAMPLE COLLECTION

Sampling situations vary widely and therefore no universal sampling procedure can be recommended. Sampling considerations and guidelines, however, do apply to every case. Prior to sample collection, review the characteristics of the water body. When sampling surface waters and sediments, always collect the water samples before sediment samples to avoid disturbing sediments into the water and biasing the water sample. Avoid surface scum. Sampling should proceed from downstream to upstream locations to minimize disturbance. Determine tidal influences and flow rates, which can affect sample collection.

Surface water samples are generally collected as grab samples because of the natural mixing effect of flowing waters. However, compositing samples may assist in the attempt to document intermittent or sporadic contaminant discharges. This is particularly of concern with effluent releases which are highest during certain times of the day. Representative sampling would seek to obtain an average concentration from release and no release conditions. Section 2.4.2 describes composite samples and compositing approaches. Surface water compositing is generally completed using the surface water collection equipment described in Chapter 3. A programmable composite sampler is available for time compositing. This electronic pumping tool collects an aliquot of the sample water from a stationary location over designated time intervals (e.g., 30 or 60 minutes) for a certain study period (e.g., 24 hours). This equipment allows the collection of an "averaged," uniform, representative sample, but will not distinguish a particular interval when contaminant levels are high or low. The criteria for selection of the "automatic sampler" are the same as for other sampling equipment, including compatibility, sample integrity, etc. (Automatic sampling equipment is generally not used at EPA CERCLA sites prior to remedial investigations and is therefore not discussed in greater detail in this document; please refer to U.S. EPA, 1986 and Krajca, 1989 for further discussion of these devices.)

Fresh water environments are commonly separated into three groups: flowing waters, such as rivers, streams, and creeks; static water bodies, such as lakes, ponds, and impoundments; and estuaries. These waterways differ in characteristics, therefore sample collection must be adapted to each. A discussion of special considerations for sampling in wetlands is also included in this section. This section provides general information on sampling several types of water bodies. Table 4 compares advantages and disadvantages of sample method locations. For specific sampling information, refer to the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03.

TABLE 4: SURFACE WATER AND SEDIMENT SAMPLE METHOD LOCATION

Location	Water Body Type	Advantages	Disadvantages
Bridge, Pier	Rivers, streams, large ponds or impoundments	• Provide ready access; allow sampling at any point across water body • Little disturbance	• Structure can alter water flow and influence sediment deposition and scouring • Not always in ideal location
Wading, Shore	Lakes, ponds, slow-moving rivers and streams	• Ease of collecting sediment samples	• Disturbs bottom deposits; introduces particulate and sediments into water • Samplers must carry large amounts of equipment
Boat	Slow-moving, deep water, and estuaries	• Appropriate for locations where no other means are available	• Safety concerns • Difficult to decontaminate • Requires a means of launching and transporting boat • May affect flow of water • Depending on depth, may disturb sediments

4.3.1 Rivers, Streams, and Creeks

This group of water bodies includes outfalls and drainage features (e.g., ditches and culverts), as well as rivers, streams, and creeks. Methods for sampling flowing water bodies vary from the simplest direct methods to more sophisticated multipoint sampling techniques. The size of the stream or river and its amount of turbulence can affect the number and type of sampling locations. In small streams (less than 20 feet wide) it is possible to select a location with well-mixed water for grab sampling. A grab sample collected at mid-depth in moving water at the main flow line would represent the entire cross-section. (The main flow line is not necessarily the center of the stream; observe flow patterns across the surface to identify this area.) Slightly larger streams or rivers would require multiple samples at locations across the channel width. At the minimum, one vertical composite (consisting of grab locations from just below surface, mid-depth, and just above the bottom) collected at the main flow line would be necessary. Identifying sampling locations that are well mixed vertically or ones that are horizontally stratified is useful prior to sampling. When sampling rivers, streams, or creeks, locate the area that exhibits the greatest degree of cross-sectional homogeneity. Since mixing is primarily attributed to turbulence and water velocity, selecting a site immediately downstream of a mixing zone will ensure good vertical mixing. In the absence of mixing zones, the selection of a site without any immediate point sources, such as tributaries and industrial and municipal effluent, is preferred for the collection of representative water samples.

For fast flowing rivers and streams, it may be difficult to collect a mid-channel sample at a specific location; health and safety concerns must dictate where to collect the sample. For low flowing streams, health and safety concerns are reduced, but obtaining a specific representative location may be difficult. For low flow or intermittent streams, either locate an area where a pool has been created or, in the most extreme situations, use a cleaned trowel to create a pool in the sediments for water to accumulate.

When sampling a point source, two samples from channel mid-depth are typically drawn: one upstream and one adjacent to, or slightly downstream of, the site PPE or the point of discharge. Additional samples may be required if multiple discharges or additional tributaries are present. Structural features such as dams, weirs, and bridges can cause changes in the physical characteristics of a stream or river by creating shallow pools. When water travel times are long through these areas, sampling locations should be established in them. Some stream structures allow overflow that significantly re-aerates oxygen-deficient water. This requires locations to be close (both upstream and downstream) to the structures in order to measure the rapid and artificial increase in dissolved oxygen (DO), which may cause the sample to be non-representative. Also collect a sample at a location well away from the aeration effect of the obstacle.

4.3.2 Lakes, Ponds, and Impoundments

The number of samples collected in these three types of water bodies will vary according to the size and shape of the water body. Stratification from temperature differences is often present in these bodies and is more prevalent than in rivers or streams. Different layers can be detected visually as well as by compiling a temperature profile. In ponds and small impoundments, a single vertical composite at the deepest point would be adequate to characterize the water body. (The deepest point of a naturally formed pond is generally near the center (although this may need to be determined), and near the dam in an impoundment.) Measure DO, pH, and temperature in each aliquot of the vertical composite. Fewer mixing zones require more samples to be collected. One way to obtain representative samples is to divide the area into a grid and then perform systematic grid sampling at each node. If stratified, collect a sample from each stratum at each node location (three-dimensional or stratified sampling). Transect sampling may also apply.

Lakes and larger impoundments require several vertical aliquots to be collected which can then be composited. Sampling locations may be determined by a transect or grid. Separate composites of epilimnetic and hypolimnetic zones may be collected if desired; however, a composite should consist of several vertical aliquots collected at various depths. Irregularly shaped lakes may require additional separate composite samples to be collected. Lakes where discharges, tributaries, land use characteristics, and other such factors may affect mixing, water quality and/or the accuracy of representative water body sampling may also require additional composite samples. Compositing is discussed further in Section 2.4.2.

Surface impoundments (such as wastewater lagoons) which contain concentrated wastes are addressed in U.S. EPA *Superfund Program Representative*

Sampling Guidance, Volume 4 - Waste, OSWER Directive 9360.4-14. Precautions and concerns exist when dealing with waste impoundments which are not addressed in general surface water and sediment sampling.

4.3.3 Estuaries

Estuaries are areas where inland fresh water (both surface water and ground water) mixes with oceanic saline water. Estuaries are generally categorized as mixed, salt wedge, or oceanic, dependent upon inflow and mixing properties. Determining estuary category is critical to establishing sample locations. Estuaries may be classified as critical areas, wetlands, or fisheries, and therefore also present special target considerations.

Mixed estuaries are characterized by homogenous salinity in the water column and a gradual increase in salinity toward the sea. This type of estuary is typically shallow and well mixed. Locating specific sampling points, particularly in the vertical water column, is not critical due to this mixing. Location with respect to the open sea is more important in mixed estuaries.

Salt wedge estuaries are characterized by a significant vertical increase in salinity and stratified fresh-water flow along the surface. Density differential between fresh and saline waters overrides any vertical mixing; a salt wedge tapering inland moves horizontally with the tide. Contamination entering from upstream may be missed if sampling into the salt wedge.

Oceanic estuaries exhibit salinity levels near to full-strength ocean waters. Seasonally, fresh-water inflow is low compared to the fresh-saline water mixing occurring near, or at, the shoreline.

Sampling in estuary zones is typically performed on successive slack tides. Estuary studies can be complex and are usually performed in two phases, during both wet and dry periods. Estuary dynamics can be affected by fresh-water inflow sources and therefore cannot be studied in a single season. Samples are generally collected at mid-depth in areas where the depth is less than 10 feet, unless the salinity profile indicates the presence of salinity stratification. In those cases, samples are collected from each stratum. Measurements of dissolved oxygen and temperature should accompany the sampling. In estuaries where the depth is greater than 10 feet, water samples may be collected at the one-foot depth, mid-depth, and one foot from the bottom.

True salt-water bodies (e.g., oceans, salt lakes) are rarely sampled at Superfund sites. Salt-water bodies would be sampled according to the fresh water and estuary guidance above. Review stratification, flow/turbulence, and other site factors prior to developing the sampling plan. As with fresh water bodies, sampling in estuaries can demonstrate current and historical contamination through surface water and sediment samples, respectively. Be certain to evaluate the effect of the salt concentration on the contaminants of concern and their analytical methods in order to accurately document a contaminant plume or establish connection to a source or site. Also consider the salt concentration and its compatibility with sampling equipment. For estuarine sampling, the Van Dorn horizontal sampler is often utilized.

4.3.4 Wetlands

Wetlands are considered a sensitive environment and generally include swamps, marshes, bogs and similar areas. Wetlands can be natural or man-made. Wetlands can include fresh and estuarine water systems and are commonly contiguous to open waters (e.g., rivers, lakes, bays). As defined in 40 CFR Part 230.3, as part of Superfund's Hazard Ranking System (HRS), wetlands are those "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." Wetlands are also identified using other definitions, including a classification system of the U.S. Fish and Wildlife Service (USFWS) and the 1989 *Federal Manual for Identifying and Delineating Jurisdictional Wetlands*, as is used by the U.S. Army Corps of Engineers.

National Wetlands Inventory maps use the USFWS classifications. These maps serve as an excellent starting point for identifying wetlands at a site, but should not be used as the sole source of identification. (A detailed comparison of the relationship between the HRS and the USFWS definitions of wetlands is addressed in the U.S. EPA *Hazard Ranking System Guidance Manual*, OSWER Directive 9345.1-07, Section A.2.) Where possible, an attempt should be made to field verify and document (e.g., logbook, photograph) the wetlands location and area.

In some instances, historical data may document the presence of wetlands which no longer exist during the site reconnaissance. Attempt to determine whether the wetlands were eliminated or filled, particularly if the alteration was due to site activity. Dredged or

filled former wetlands may affect sampling design, methods, and results due to the potential effects from non-native soils, confined or void subsurface spaces, or buried organic layers and on-site contaminants.

Special care should be taken when sampling wetlands to collect surface water and sediment samples free of vegetation and other organic matter or detritus. As with other surface water and sediment samples, consider curves and bends, slow versus fast flow, and depositional areas when selecting locations. Due to the slow movement of water through the vegetated wetlands, contaminants may tend to collect in wetlands sediments. Wetlands may also serve as a valuable source to document historical contaminant releases. For some purposes (e.g., HRS documentation), an aqueous sample is preferred or required to document contamination within wetlands, therefore surface water samples should be collected where possible for all response action considerations. As with other water bodies, wetlands can demonstrate historical contamination through sediment samples, current contamination through surface water samples, and concern for future contamination if the wetlands can be documented to be the receiving body for a contaminant drainage pathway or surface water route, although not currently exhibiting any site-related contamination. The probable point of entry for a tributary or drainage path into a surface water body may be located within adjoining wetlands. As a sensitive environment, wetlands present special threat and target considerations beyond those of other water body systems.

Depending on the type of wetlands and the season, wetlands may contain fresh or salt water, and saturated or dry sediments. Follow the protocols and procedures discussed throughout this guidance document for sampling each medium, respectively, depending on the site-specific characteristics of the wetlands. Wetlands, if periodically dry, should be sampled during a wet period, if possible, to establish the wetlands sample as a sediment versus a surface soil. For complex sites with extensive surface water, sediment and wetlands concerns, a wetlands expert should be consulted for identification, delineation and sampling.

4.4 SEDIMENT SAMPLE COLLECTION

As with water sampling, determine tidal influence and its possible effect on sediment sample collection. Sediments are typically heterogenous in composition and are subject to variations in texture, bulk composition, water content, and pollutant content. Therefore, large numbers of samples may be required to characterize a small area. Many sediment samples along the cross-section of a river or stream need to be collected in order to accurately characterize the deposits. Generally, samples are collected at quarter points along the cross-section of the water body. Aliquots can usually be combined into a single composite sample except for those of unlike composition. For small streams, one single sediment sample can be collected at the main flow line of the water body. In most cases, a sediment sample is collected at the same location(s) as a surface water sample.

Sediments in low flowing waters are largely the products of erosion and may contain a variety of organic matter. Sediment samples from ponds, lakes, and reservoirs should be collected approximately in the deepest point of the water body. This is especially applicable to reservoirs formed by impoundments of rivers or streams. Coarser grain sediments are found near the headwaters of the reservoir, while bed sediments are composed of fine-grained materials which may have an increased concentration of contaminants. Sediment sampling locations can be influenced by the shape, flow pattern, depth distribution, and circulation of the water body.

Sediment samples from ponds and lakes can be collected from each node of the grid or transect set up for sampling surface water. For streams or rivers, collect a sediment sample in at least two locations: one upstream and one adjacent to, or slightly downstream of, the site PPE or at point of discharge. Consider depositional versus erosional areas against the objectives for sampling; contaminants tend to concentrate in the fine-grained sediments in depositional zones.

Take care to minimize disturbance and sample washing as the sediment is retrieved through the water column. Fine fractions lost during sample collection can result in a non-representative sample. Any liquid collected when sampling can be considered representative of sediment conditions. Wet sediments which are to be analyzed while still wet should be collected in rigid containers, not collected or stored in bags.

4.5 SAMPLE PREPARATION

Sample preparation depends on the sampling objectives and analyses to be performed. Proper sample preparation and handling maintain sample integrity. Improper handling can render samples unsuitable for analysis. For example, homogenizing and compositing samples result in a loss of volatile constituents and are thus inappropriate methods when volatile contaminants are of concern. The effective use of SOPs can ensure that the same methods are used for all samples and by all samplers. Where possible, the same person should sample all of one matrix per water body to ensure similar methodology in collection. Sample preparation for water and sediments may include, but is not limited to:

- Removing extraneous materials
- Homogenizing
- Splitting
- Compositing
- Final preparation

4.5.1 Removing Extraneous Materials

During sample collection, identify and discard materials from the sample which are not relevant or vital for characterizing the site. Avoid the collection of floating or suspended debris (e.g., leaves, paper trash, etc.) in the surface water flow or column. For sediments, avoid collecting decaying or other organic material, such as twigs, leaves, roots, and insects. Avoid trash and other unrelated materials. Remove the materials with the cleaned sampling tool, not with your hand or other instrument which might cross-contaminate the sample. The presence of extraneous materials may introduce an error into the sampling or analytical procedures.

Not all external materials are extraneous, however. For example, some contaminants may be adsorbed onto inert materials, such as fly ash or other industrial by-products or waste, which settle onto the bottom sediments. Collect samples of any material thought to be a potential source of contamination. Discuss any special analytical requirements for extraneous materials with the project team (e.g., project management, geologist, chemist), and notify the laboratory of any special sample handling requirements or method changes.

4.5.2 Homogenizing

Homogenizing is the mixing or blending of a grab or composite sample to distribute contaminants uniformly within the sample. 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 thus introduces sampling error. All samples to be composited or split should be homogenized after all aliquots have been combined.

Homogenizing generally does not apply to water samples; unless stratified, surface water is assumed to be homogenous due to natural mixing. If phases occur, treat each stratum as a unique homogenous medium and sample each separately. The mixing of sediments may release some contaminants into the water phase of the sediment sample. If homogenizing is required, manually mix the sediment sample using a spoon or scoop and a tray or bucket constructed of inert or compatible materials (stainless steel is preferred). Samples can also be homogenized using a mechanically operated stirring device as depicted in ASTM Standard D422-63. Do not homogenize samples for volatile compound analysis.

4.5.3 Splitting

After collection, samples are split into two or more equivalent parts when two or more portions of the same sample need to be 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 (field replicates). Homogenize the samples before splitting, when collecting only non-VOC sediment samples. For each parameter, split water samples by alternately filling sample collection jars for the sample and its split from the same sampling device. For sediment, alternate spoonfuls of homogenized sample between collection jars. Surface water and sediment samples for VOC analysis should not be homogenized; instead, collect two uniform samples concurrently from the same location (collocated samples).

4.5.4 Compositing

Compositing is the process of physically combining and homogenizing (if applicable) several individual aliquots of the sample. The field preparation technique of compositing of samples requires that each discrete aliquot be equal, and that the aliquots be

thoroughly homogenized. Compositing samples provides an "average" concentration of contaminants over a certain number of sampling points, which reduces both the number of required laboratory analyses and the sample variability. Compositing can be a useful technique but must always be implemented with caution. Compositing is not recommended where volatile organic compounds are of concern. Compositing may dilute an isolated contaminant to below detection limits, thus masking a possible problem. Additional information on compositing for surface water and sediment sampling is provided in Sections 2.4.2, Composite Sample, and 4.3, Surface Water Sample Collection.

4.5.5 Final Preparation

Obtain sample containers from a vendor that certifies their decontamination/cleanliness. Consider their compatibility with the material being sampled, resistance to breakage, volume, container color, storage and transport, and decontamination procedures (see U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures* OSWER Directive 9360.4-03). Additional information on containers and cleaning procedures is available in U.S. EPA's *Specifications and Guidance for Obtaining Contaminant-Free Sample Containers*, OSWER Directive 9240.0-05. Volume and containers will vary according to the parameter(s) to be analyzed. Glass is appropriate for most sampling because it is chemically inert to most substances, although some metals may adhere to the sides of glass containers. Glass is not recommended for samples containing strong alkali solutions and hydrofluoric acid. Polyethylene plastic bottles are suitable for metals, cyanide, and sulfide in water, but are not recommended for organic analyses since plasticizers may leach into the sample. Amber glass bottles help preserve sample integrity for extractable organic constituents in water which may degrade in light, such as hydrocarbons, pesticides, and petroleum residues. Sample containers must be tightly capped in order to prevent oxidation from the air and/or the loss of volatile components. Most sample aliquots for VOC analysis are stored in 40-milliliter glass Teflon® septum vials, which allow for easy syringe removal of the sample for analysis, without the loss of headspace gases. VOC sample containers must be completely filled to the top with no air pockets. Improper decontamination of sampling equipment may result in cross-contamination of samples.

Keep low and medium concentration surface water and sediment samples to be analyzed for organic constituents at not more than 4E C by using ice or "blue ice" when shipping. This cooling is to retard the transformation of contaminants through biodegradation or reaction while awaiting laboratory analysis. If required, add any preservatives to specific samples before shipping. The analytical laboratory will recommend or provide any chemical preservatives prior to sampling. Follow the laboratory's instructions for quantity and timing of preservative addition; many laboratories will provide the sample containers already chemically preserved. Refer to the laboratory, as well as 40 CFR 136, and the U.S. EPA *Compendium of ERT Surface Water and Sediment Sampling Procedures*, OSWER Directive 9360.4-03, for actual sample volumes, appropriate containers, and holding times. Label all sample containers in accordance with the analytical laboratory or Regional procedures and place them into reclosable plastic bags prior to packaging for shipment. Package all samples in compliance with current U.S. Department of Transportation (DOT) or International Air Transport Association (IATA) requirements. Be certain the sample container meets these requirements, and check the shipping/packing instructions about preservatives.

Packaging should be performed by someone trained in current DOT shipping procedures. Be certain all containers are packaged to prevent breakage or leakage. For all samples, be certain to maintain secure chain-of-custody from collection to shipment to the analytical laboratory.

4.6 EXAMPLE SITE

4.6.1 Sampling

During Phase 1, soil samples were collected as grab samples from shallow surface locations. The sample locations were cleared of surface debris, then the samples were retrieved with disposable scoops and placed directly into sample containers. During Phase 2, soil samples were collected using trowels and split spoon samplers. The shallow soil samples were collected in the same manner as the Phase 1 soil samples. The subsurface soil samples were retrieved from the split spoon sampler using a disposable plastic scoop which transferred 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 a disposable plastic scoop.

Phase 1 and Phase 2 residential well ground-water samples were collected directly from the taps of homes, which used private wells near the site. Fifteen monitoring wells were installed at the site with 4-inch Schedule 40 PVC casing and 0.010 slot screen in lengths appropriate to each well. Shallow wells were drilled to approximately 40 feet below ground surface, and bedrock contact wells were drilled to approximately 55 to 60 feet. Continuous split spoon sampling was completed at each well location from 4 feet to well completion depth. Upon completion, all monitoring wells were developed using a decontaminated submersible pump and flexible PVC hose.

After development, the 15 on-site monitoring wells were sampled for analysis of ground water. Each monitoring well was purged to obtain a representative sample. Wells with sufficient yield were purged three well volumes. Low-yielding wells were purged once to dryness.

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 nylon rope and introduced into the well. After well sampling, a hydraulic (pump) test was performed to determine aquifer characteristics for mathematical modeling of potential contaminant plume migration. To generate accurate gradient and well location maps, the fifteen newly installed monitoring wells were surveyed for vertical location using feet above mean sea level (MSL) units.

Surface water and sediment samples were also collected as grab samples during Phase 1 and Phase 2. Sampling activities occurred when the intermittent tributary was flowing in order to obtain water samples. Because of the shallow depth and narrow breadth of the tributary and Little Creek, samples could be obtained by reaching into the near center in the main flow line of the water body from the stream bank. The sampler stood downstream of the desired sampling location and created as little disturbance of the streambank and water body as possible. This caution reduced the potential for cross-contamination of the sample locations.

Sampling proceeded from the most downstream location in Little Creek, to upstream, and the surface water aliquot was sampled prior to sediment collection at each location to reduce entraining suspended material into the water samples. Cleaned and labeled surface water sample containers were placed directly into the flow of the water body for sample collection. The sediment samples were collected (using dedicated disposable plastic scoops) from the substrate directly beneath the location where the water sample was retrieved. The sample material was then transferred immediately into a clean, labeled sample container.

All non-disposable equipment, including drill rig and equipment, stainless steel bailers, submersible pumps, water level indicators, and depth sounders, were decontaminated between sampling at 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 surface water samples consisted of:

- 1-liter polyethylene bottles for total chromium, pre-preserved with reagent-grade nitric acid to result in, after sample addition, a pH of less than 2
- 1-liter polyethylene bottles for hexavalent chromium
- 1-liter polyethylene bottles for cyanide, pre-preserved with sodium hydroxide

Sample containers for sediments 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.

5.0 QUALITY ASSURANCE/QUALITY CONTROL

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. The QA/QC sample results are used to assess the quality of analytical results of environmental samples collected from a site.

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 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's *Data Quality Objectives Process for Superfund*, 1993, pp. 42-44.

5.3 SOURCES OF ERROR

Identifying and quantifying the error or variation in sampling and laboratory analysis can be difficult. However, it is important to limit their effect(s) on the data. The four most common potential sources of data error in surface water and sediment sampling are:

- Sampling design
- Sampling methodology
- Sample heterogeneity
- Analytical procedures

Refer to U.S. EPA's *Data Quality Objective Process for Superfund*, for further discussion on error.

5.3.1 Sampling Design

Site variation includes the variation both in the types and in the concentration levels of contaminants throughout a water body. Representative sampling should accurately identify and define this variation. However, error can be introduced by the selection of a sampling design which "misses" this variation. For example, a sampling grid with relatively large distances between sampling points or a biased sampling approach (i.e., judgmental sampling) may allow significant contaminant trends to go unidentified. Surface water might have multiple strata; failure to account for differences in composition of multiple phases can introduce sampling error. The sampling design must account for all phases and strata which might contain hazardous substances.

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. All samples should be collected using a uniform surface area and/or depth to ensure data comparability. Sampling equipment must be standardized for similar sampling situations.

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

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. Standardized procedures for collecting, handling, and shipping samples identify potential source(s) of error and help minimize them. Use 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.

Site screening methods might employ hazard categorization kits or "cookbook" procedures requiring interpretations based on chemical reactions which produce a color change. The degree of subjectivity inherent in interpretation, and the complexity of some of the procedures, introduce a significant source of potential error.

5.3.3 Sample Heterogeneity

Sample heterogeneity is a potential source of error in sediment sampling. Unlike water, sediment is rarely a homogeneous medium. Sediments exhibit variations with lateral distance and depth. This heterogeneity may also be present in the sample container unless the sample was homogenized in the field or in the laboratory. The laboratory uses only a small aliquot of the sample for analysis; poor reproducibility from heterogenous samples is a common error. If the sample is not properly homogenized, the analysis may not be truly representative of the sample and of the corresponding site. Thorough homogenization of samples limits the error associated with sample heterogeneity. (Note: Do not homogenize when analyzing for VOCs.)

5.3.4 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.

5.4 QA/QC SAMPLES

QA/QC samples are collected at the site or prepared for or by the laboratory. Analysis of 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, collocated, background, and rinsate, field, and trip blank samples. The most common laboratory QA/QC samples are performance evaluation (PE), matrix spike (MS), and matrix spike duplicate (MSD) 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.

The following sections briefly describe the types of QA/QC samples appropriate for surface water and sediment 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. (Splitting samples for surface water and sediments is discussed in Section 4.5.3.) Use replicate samples to assess error associated with sample heterogeneity, 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 Collocated Samples

Collocated samples are collected adjacent to the routine field sample to determine local variability of the sample location and contamination at the site. Typically, collocated samples for sediments are collected side by side, but no more than 3 feet away from the selected sample location. Collocated samples for surface water are collected from the same location and depth. Collocated samples are collected and analyzed as discrete samples; they are not composited. Analytical results from collocated samples can be used to assess site variation, but only in the immediate sampling area. Because of the non-homogeneous nature of sediment at sites, collocated samples should not be used to assess variability across a site and are not recommended for assessing error. Collecting many samples can demonstrate variation in sediments in a water body. Determine the applicability of collocated samples on a site-by-site basis.

5.4.3 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 samples are collected upstream of the area(s) of contamination (either on or off site) where there is little or no chance of migration of the contaminants of concern. Background samples determine the natural composition of the surface water and sediments and are considered "clean" samples. They provide a basis for comparison of contaminant concentration levels with samples collected on site. Collect at least one background surface water and one background sediment sample. Additional samples are often warranted by site-specific factors such as natural variability of local sediments, multiple sources, and discharges from off-site facilities. Tidal influences must be considered when selecting a background location. Background samples may also be collected to evaluate potential error associated with sampling design, sampling methodology, and analytical procedures.

5.4.4 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.

5.4.5 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) or sand, which are 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.

5.4.6 Trip Blank Samples

Trip blanks are samples prepared prior to going into the field. They consist of certified clean water (HPLC-grade) or sand 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. A trip blank should be included with each shipment or two-day sampling event. Trip blanks are used to evaluate error associated with shipping and handling, and analytical procedures.

5.4.7 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, analysis of PE samples is recommended in order to obtain definitive data.*

A blind PE sample may be included in a set of split samples provided to the 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 waste matrix interference, and thus can provide a clear measure of laboratory error.

5.4.8 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 of each matrix, 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 (i.e., triple volume).

5.4.9 Laboratory Duplicate Samples

A laboratory duplicate is a sample that undergoes preparation and analysis twice. The laboratory takes two aliquots of one sample and analyzes 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; selected 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 selected 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, sample methodology, and analytical procedures. Different analytical results from two or more replicate samples could indicate improper sample preparation (e.g., incomplete homogenization), 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% 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 direct, 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 off-site 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 2.13.5). 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 EPA standard methods and protocols.

5.7.3 Field QA/QC Samples

Field QA/QC samples were collected during surface water and sediment sampling at the ABC Plating site. One each of field duplicates were collected for surface water and sediment, respectively, plus duplicates for other media. Rinsate blanks were collected from ground-water and soil sampling equipment after decontamination by pouring deionized water through the respective piece of equipment and then into a sample container. The field duplicates 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 ten 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 objectives. The laboratory analyzed for metals using the methods of inductively coupled plasma (ICP) spectrometry and atomic absorption (AA). Two methods were conducted for hexavalent chromium: 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 or field screening 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" 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 the 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 contaminants 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 or marked sampling locations facilitating placement on a scaled map. Data posting is useful for depicting concentration values for both surface water and sediments.

6.3 CROSS-SECTION/FENCE DIAGRAMS

Cross-section diagrams (two-dimensional) and fence diagrams (three-dimensional) depict layers or phases of contaminants in the surface waters or sediments of rivers, lakes, and impoundments. Two-dimensional cross-sections may be used to illustrate vertical profiles of contaminants in surface water and sediment. Three-dimensional fence diagrams are often used to interpolate data between sampling locations, particularly where contaminants do not form horizontal layers. Both cross-sections and fence diagrams can provide useful visual interpretations of contaminant concentrations and migration.

6.4 CONTOUR MAPPING

Contour maps can depict contaminant concentration values in surface waters and sediments throughout the water body. This method may be useful for sediment, but is not typically used for surface water. Contour mapping requires an accurate, to-scale base map of the site. After data posting sample values on the base map, 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. Typical Superfund sites have low concentration/non-detect areas and "hot spots." If there is a big difference in concentration between the "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. Contour mapping is generally best used with non-flowing, static water bodies, or over large areas.

6.5 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 contaminant source prior to conducting more rigorous forms of statistical analysis. As with contour mapping, statistical data interpretation applications are typically used for sediment analysis.

6.6 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 showing extremely low data values (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 contour mapping. Data posting would be useful at such a site to illustrate hot spots and clean areas.

6.7 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.

All surface water and sediment samples were analyzed for total chromium and cyanide. Cyanide and chromium were not found above the 50 ppm detection limit in any of the surface water or sediment samples. Chromium was detected in soil and ground-water samples at the site.

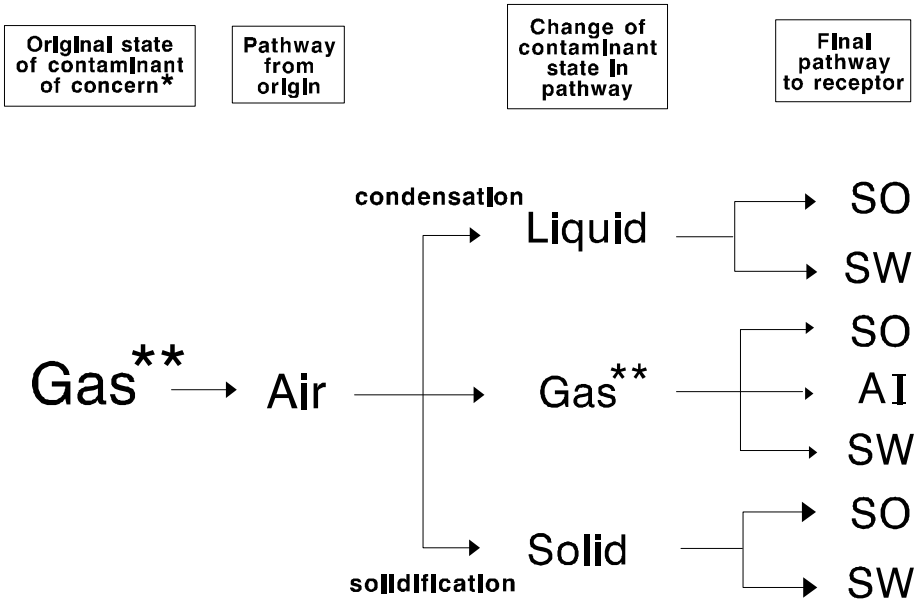
The rate of chromium contaminant migration in ground water and the potential long-term impact to nearby residential wells was estimated using a mathematical model which included worst case assumptions and evaluated attenuation of contaminants through soil and ground water. The OSC concluded that the potential for residential well contamination was minimal and therefore, the potential for contamination of surface water through the discharge of ground water was also considered 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
G,D	G,D	N/A
G,D	G,D	G,D
I,D	I,D	N/A
I,D	I,D	N/A
G,D	I,D	G,D
G,D	G,D	N/A
G,D	G,D	G,D

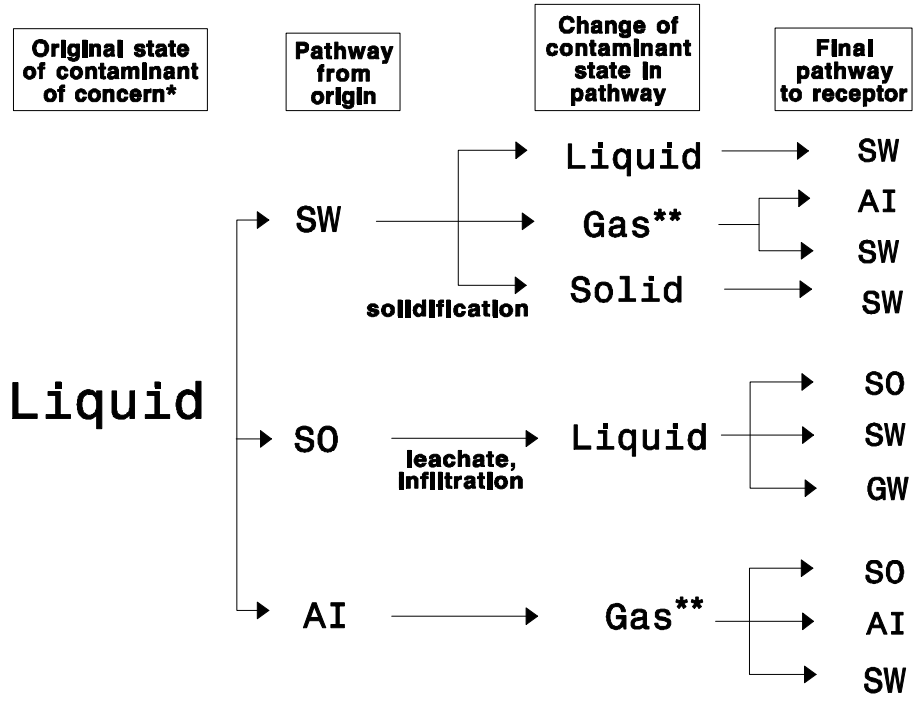
* May be a transformation product
** Includes vapors

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



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

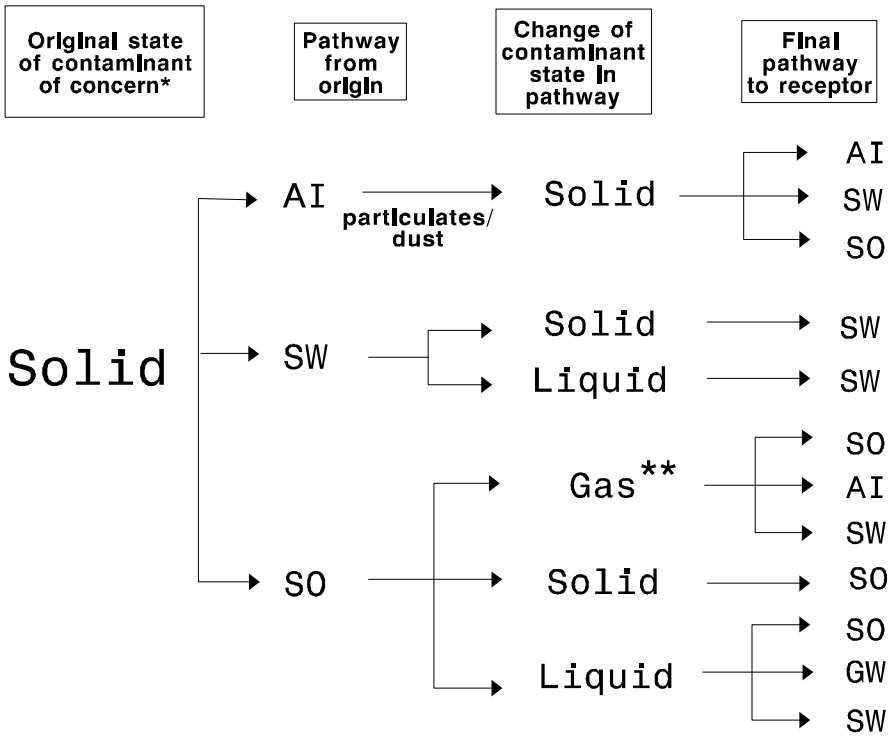
* May be a transformation product
** Includes vapors

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



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

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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.

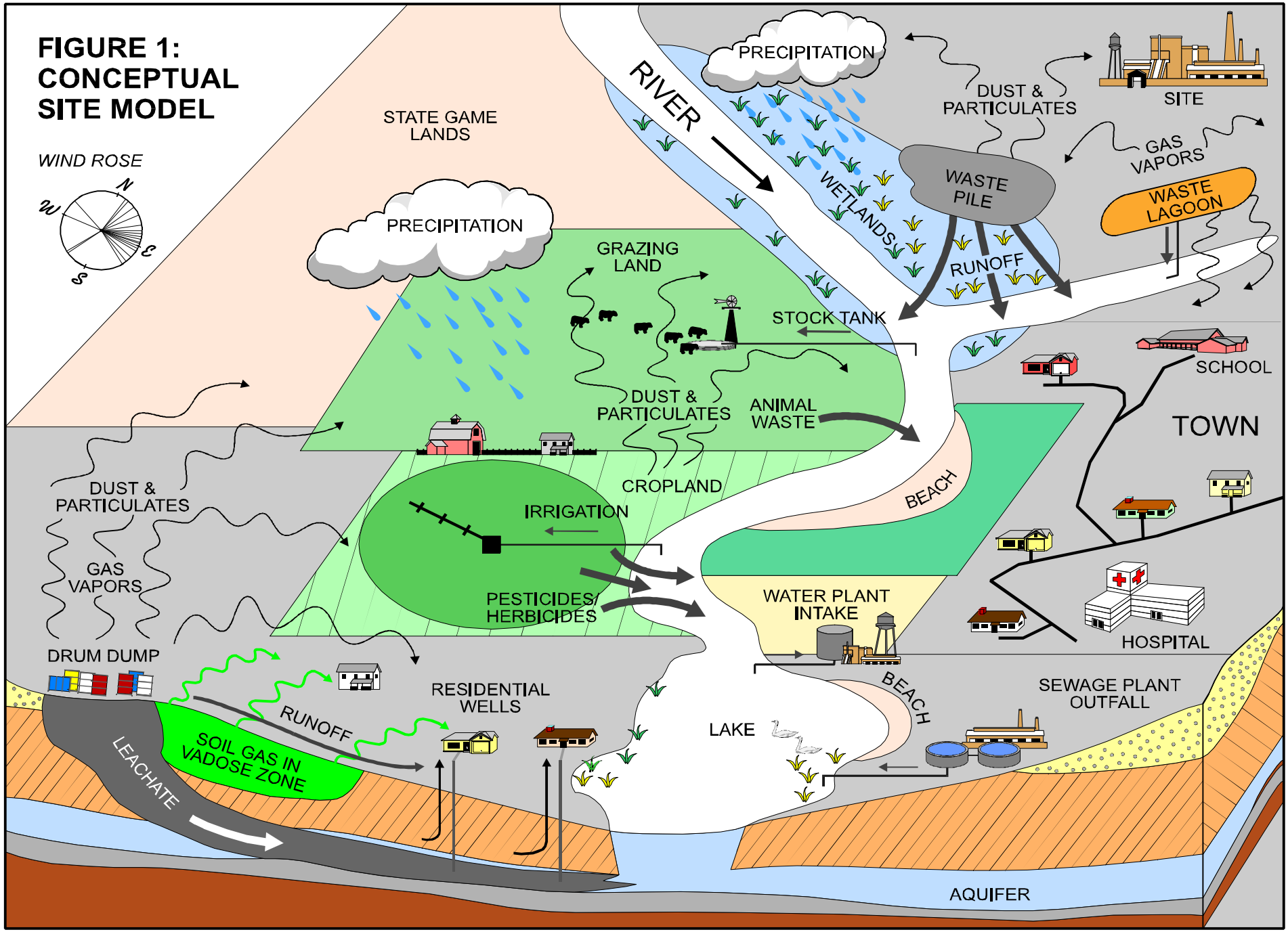


FIGURE 1:
CONCEPTUAL
SITE MODEL
WIND ROSE
N
W
E
S
STATE GAME
LANDS
RIVER
PRECIPITATION
DUST &
PARTICULATES
SITE
GAS
VAPORS
WETLANDS
WASTE
PILE
WASTE
LAGOON
RUNOFF
PRECIPITATION
GRAZING
LAND
STOCK TANK
SCHOOL
TOWN
DUST &
PARTICULATES
ANIMAL
WASTE
CROPLAND
BEACH
DUST &
PARTICULATES
IRRIGATION
GAS
VAPORS
PESTICIDES/
HERBICIDES
WATER PLANT
INTAKE
HOSPITAL
DRUM DUMP
RESIDENTIAL
WELLS
BEACH
SEWAGE PLANT
OUTFALL
RUNOFF
SOIL GAS IN
VADOSE ZONE
LEACHATE
LAKE
AQUIFER

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.)

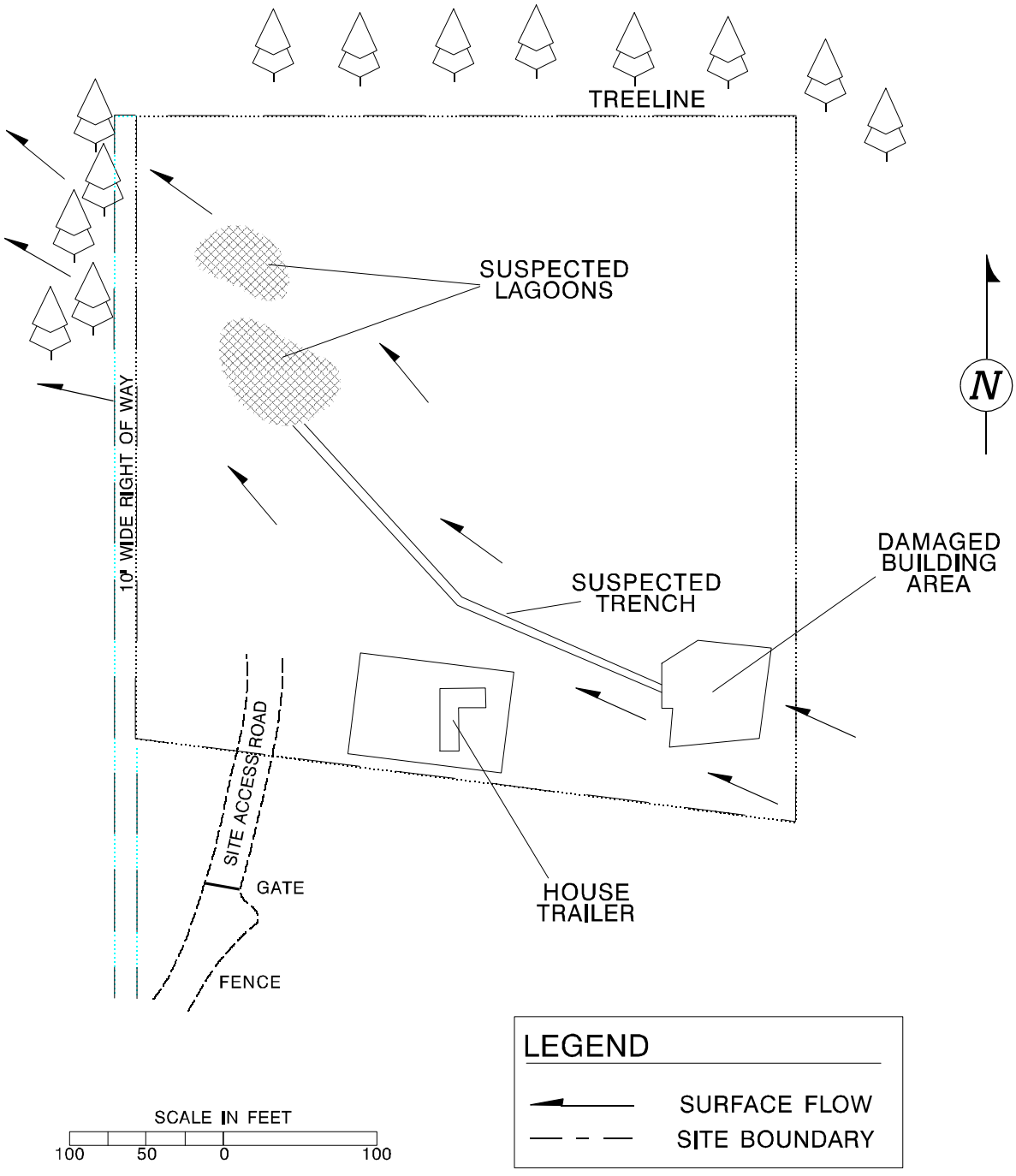
- Sample Order - Sampling order is from the least contaminated to the most contaminated wells or areas (if known).

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.

- Spontaneous Potential (SP) Logs - 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.

- Gamma Logs - 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).

- Gamma-Gamma Logs - 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.

- Neutron Logs - 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	
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	
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	
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	
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.

- Residential, Commercial, and Public Supply Wells - 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).

- Monitoring Wells - 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.:

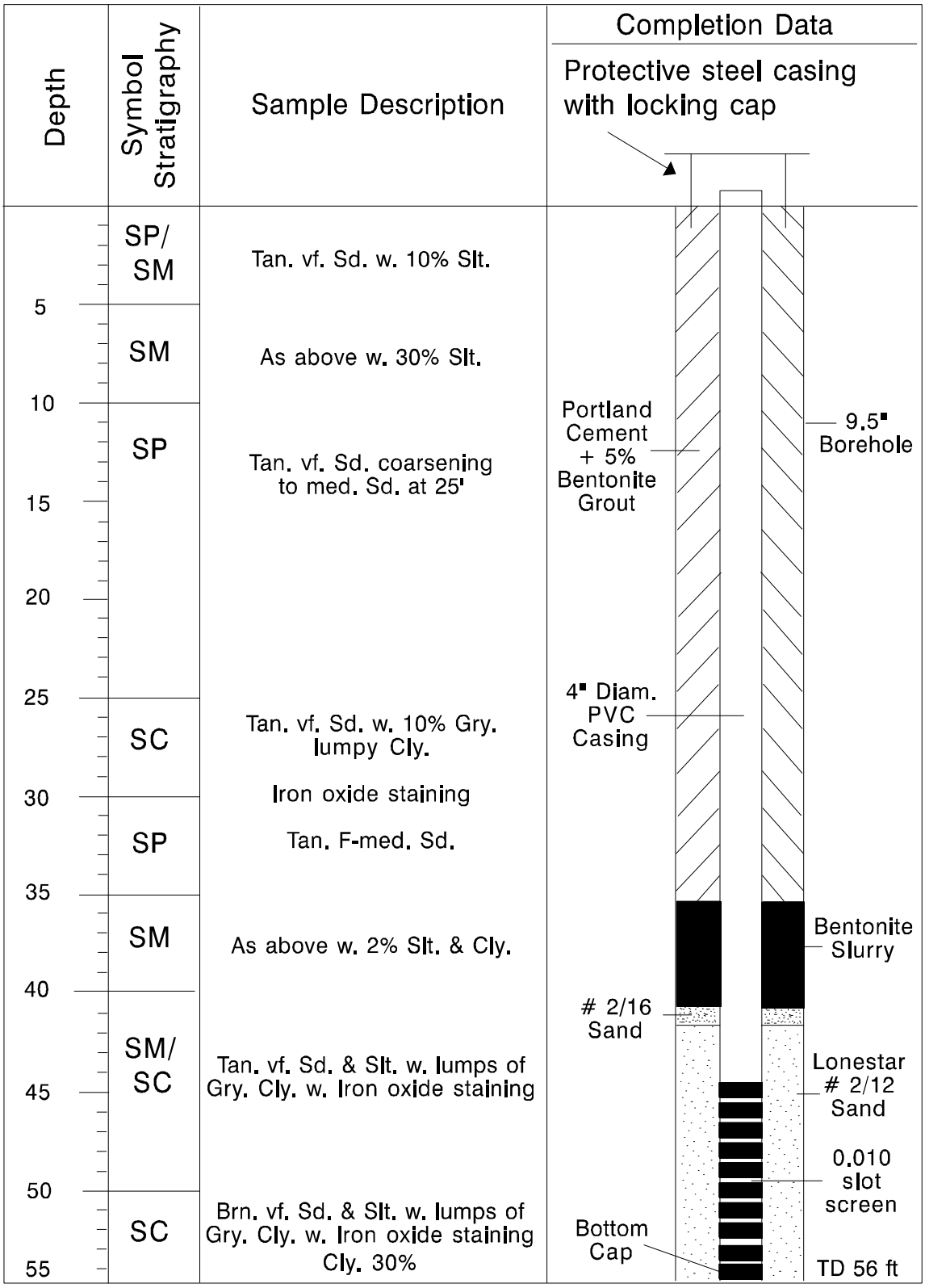
$$\text{Well volume} = \pi \times (\text{radius of well})^2 \times \text{height of water column} \times 7.48 \text{ gallon/ft}^3$$

(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.

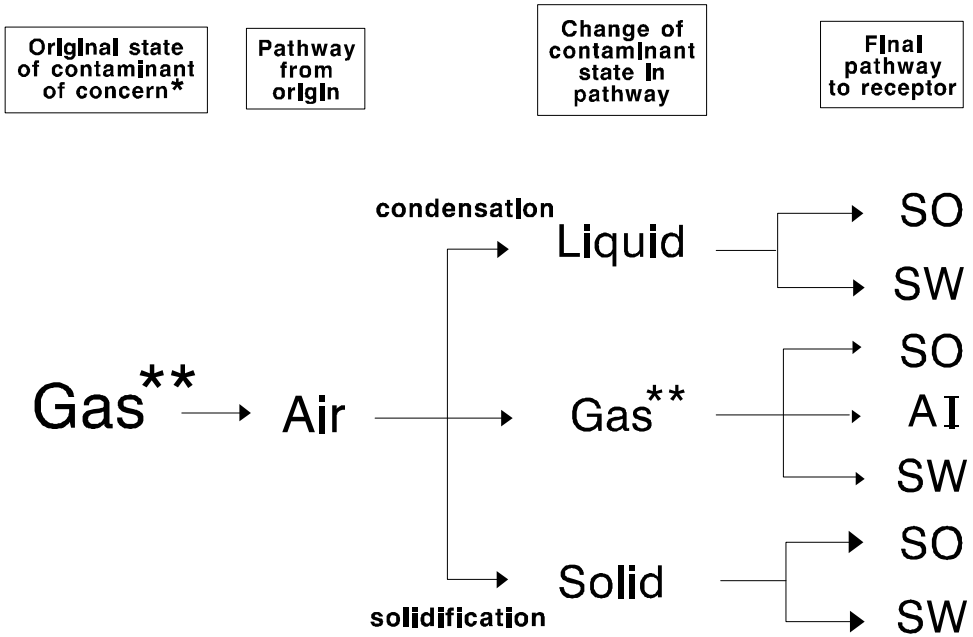
The rate of chromium contaminant migration in ground water and the potential long-term impact to nearby residential wells were estimated using a mathematical model which included worst case assumptions and evaluated attenuation of contaminants through soil and ground water. The OSC concluded that the 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
G,D	G,D	N/A
G,D	G,D	G,D
I,D	I,D	N/A
I,D	I,D	N/A
G,D	I,D	G,D
G,D	G,D	N/A
G,D	G,D	G,D

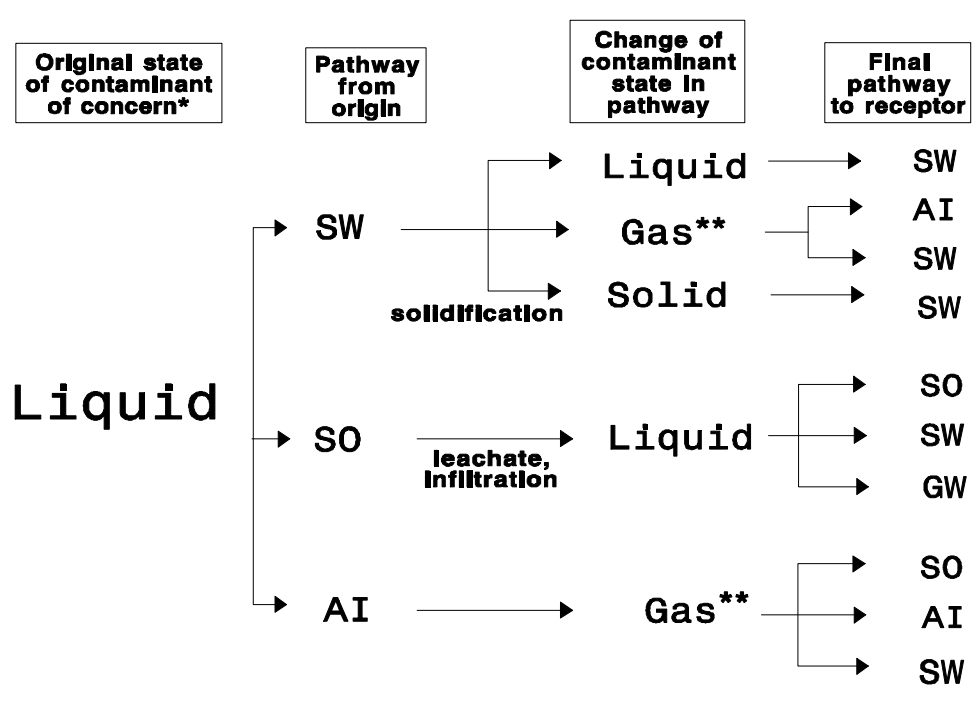
* May be a transformation product
** Includes vapors

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



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

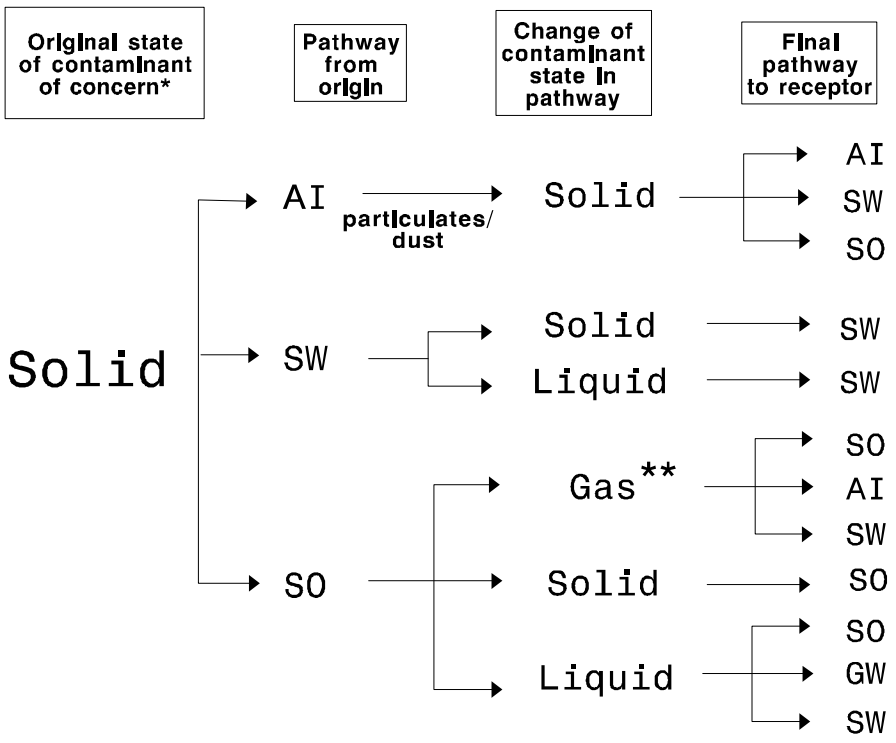
* May be a transformation product
** Includes vapors

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



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

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