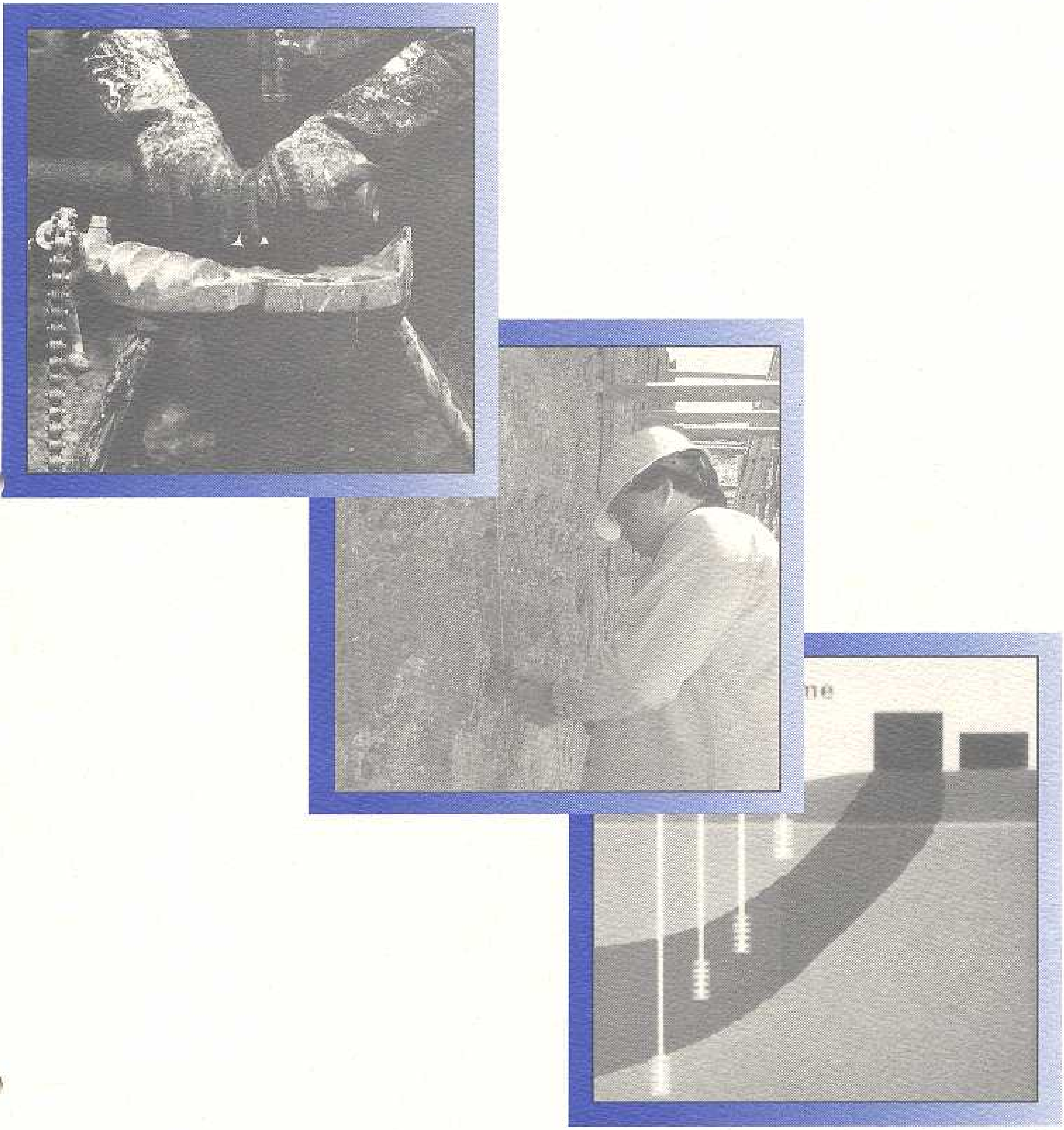
Guidelines for Hydrogeologic Characterization of Hazardous Substance Release Sites

Volume 1: Field Investigation Manual



State of California
Environmental Protection Agency

GUIDELINES FOR HYDROGEOLOGIC CHARACTERIZATION AT HAZARDOUS SUBSTANCES RELEASE SITES

Volume 1: Field Investigation Manual

July 1995

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FOREWORD

The California Environmental Protection Agency (Cal/EPA) is charged with the responsibility of protecting the state's environment. Within Cal/EPA, the Department of Toxic Substances Control (DTSC) has the responsibility of managing the state's hazardous waste program to protect public health and the environment. The State Water Resources Control Board and the nine Regional Water Quality Control Boards (RWQCBs), also part of Cal/EPA, have the responsibility for coordination and control of water quality, including the protection of the beneficial uses of the waters of the state. Therefore, the RWQCBs work closely with DTSC in protecting the environment.

To aid in characterizing and remediating hazardous substance release sites, DTSC had established a technical guidance work group to oversee the development of guidance documents and recommended procedures for use by its staff, local governmental agencies, responsible parties and their contractors. The Geological Support Unit (GSU) within DTSC provides geologic assistance, training and guidance. This document was prepared by GSU staff in cooperation with the technical guidance work group and the RWQCBs. This document has been prepared to provide guidelines for the investigation, monitoring and remediation of hazardous substance release sites. It should be used in conjunction with the companion reference for hydrogeologic characterization activities:

Guidelines for Hydrogeologic Characterization of Hazardous Substances Release Sites
Volume 2: Project Management Manual

Please note that, within the document, the more commonly used terms, *hazardous waste site* and *toxic waste site*, are used synonymously with the term hazardous substance release site. However, it should be noted that any unauthorized release of a substance, hazardous or not, that degrades or threatens to degrade water quality may require corrective action to protect its beneficial use.

This document supersedes the 1990 draft of the DTSC Scientific and Technical Standards for Hazardous Waste Sites, Volume 1, Chapters 1 and 4, and is one in a series of Cal/EPA guidance documents pertaining to hazardous substance release site remediation.

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Steve Belluomini	Supervising Hazardous Substances Engineering Geologist I,
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1 INTRODUCTION

1.1 Regulatory Authority

The Department of Toxic Substances Control (DTSC), within the California Environmental Protection Agency, has the responsibility for managing the State's hazardous waste programs to protect public health and the environment. DTSC's authority to manage the hazardous substance cleanup program is contained in Chapter 6.8 of the California Health and Safety Code. DTSC conducts site remediation oversight activities authorized by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), amendments to CERCLA, and state and federal regulations promulgated to implement those acts.

1.2 The RI/RS Process

The remedial investigation and feasibility study (RIDS) are two critical components of site remediation under CERCLA and state laws. The RIFS is the process through which a site is characterized, the risk to receptors is quantified, and remedial alternatives are evaluated. Site characterization is the portion of the *RIFS* process in which the nature and extent of contamination at a site are determined, and the processes that move contaminants through the environment are assessed. The data fiom site characterization are used to assess the risk to public health and the environment, and to select a remedial action.

1.3 Scope of Guidance

This document addresses the hydrogeology portion of site characterization, which includes all aspects of a site that relate to actual or potential contamination of ground water. Characterization of wastes and soils is addressed only to the extent that transport of contaminants fiom these media may impact ground water. Although characterization of air and surface water are not addressed, there may be instances in which surface water contamination may impact ground water.

This document is a brief description of the Cal/EPA's recommended approach to hydrogeologic site characterization, and a *summary* of data requirements. References are provided to eight Cal/EPA documents (Cal/EPA, 1995a-h) on various aspects of hydrogeologic investigations, which include detailed discussions of techniques used in site characterization. This guidance document should be used with *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (US*. EPA, 1988), which fully describes the RI/FS process. Other guidance documents are referenced as appropriate.

The guidance is intended to be used by responsible parties (RPs) and their environmental consultants when conducting site characterization activities. The document should be used by, and hydrogeologic investigations conducted by, professionals with a minimum of a bachelor's degree in engineering, geology or related sciences, and several years experience in the environmental field. Professionals with education and experience in chemistry, microbiology, toxicology, and other sciences should be included on a project team when appropriate.

The guidelines in this document should be followed when ground water contamination has occurred, or a risk of ground water contamination has been identified. Such a determination may come through conducting a preliminary endangerment assessment (PEA) or other initial study. The Department's Preliminary Endangerment Assessment Manual (DTSC, 1994) describes the requirements for conducting a PEA.

This guidance is expected to improve the quality of site characterization activities, while reducing the cost and time for completion and regulatory approval of hydrogeologic characterization. Early interaction with the Department, during the scoping phases of the site characterization, is important in reaching these goals.

For a broader discussion of the management of hydrogeologic characterization projects, the Department is producing the document *Guidelines for Hydrogeologic Characterization at Hazardous Substance Release Sites, Volume 2: Project Management Manual* (Cal/EPA 1995a), which includes case studies of ground water investigations.

2 SITE CHARACTERIZATION PLANNING

2.1 Characterization Objectives

The primary objectives in characterizing a site are to obtain information to identify the risk posed by actual or potential contamination, and to collect data necessary to select a remedial alternative and design a remediation system if one is needed. Site specific objectives should be developed early in the planning process.

The information necessary to satisfy these objectives for ground water includes an understanding of the contaminants present and their properties, as well as their three-dimensional extent and concentrations in the subsurface, and an understanding of the geologic and hydrologic factors that control the migration of these contaminants. The locations and exposures of actual or potential receptors must be identified to perform a risk assessment.

2.2 Review of Available Information

The scoping phase of site characterization includes all activities conducted to plan and facilitate field work and analysis of data. Scoping should include compilation and review of all available information. Information review serves two purposes: (1) to provide data for formulation of a conceptual model of hydrogeology and contaminant transport, and (2) to establish a basis for designing field investigations.

Information that should be reviewed, and possible sources to be consulted are detailed in Table 1. Guidelines for Hydrogeological Characterization at Hazardous Substance Release Sites, Volume 2: Project Management Manual (Cal/EPA, 1995a) includes an appendix containing detailed information on data sources.

Table 1. Summary of information needs and possible sources.

Type of Information	Facility	Literature Search	Government Agency'
Description of facility and operations	X		
Description of nearby facilities			X
Inventory of hazardous materials managed or disposed on site	X		
Locations of hazardous substance handling, storage, treatment and disposal areas	X		
Documented releases of hazardous substances	X		X
Chemical composition and properties of suspected contaminants		X	
Regional and site-specific geologic and hydrologic studies		X	X
Locations of water supply and other wells (active and inactive), and pumping records			X
Previous investigations on or near site	X		X
Climatic data		X	X
Maps (including topography, soil, geology and insurance)		X	X
Aerial photographs		X	X

'Includes U.S. EPA, DTSC, SWRCB, RWQCB, U.S. Geological Survey, California Division of Mines and Geology, California Dept. of Water Resources, county health departments, water districts, and local planning commissions

2.3 The Conceptual Site Model

Site characterization begins by constructing a conceptual hydrogeologic model of the site based on review of available data. A conceptual model is a narrative and graphical description of the characteristics of a site that may affect the distribution and migration of contaminants. The conceptual model should be used as the basis for planning field work, and must be presented in the R1work plan. In the initial conceptual model, the known data and any assumptions made should be clearly differentiated. Data gaps in the conceptual model will be filled through collection and interpretation of field data. The final conceptual model, following site characterization field activities, should be detailed enough to meet the characterization objectives, and provide enough information to allow regulatory decisions to be made.

The conceptual model should incorporate all essential features of the hydrogeologic system and site under study. The degree of detail and accuracy of a conceptual model varies according to the hydrogeologic setting and waste type. For example, a homogeneous unconfined aquifer may require only simple cross-sections and water table maps to illustrate the conceptual model. In contrast, a more complicated setting with multiple aquifers, multiple confining layers, and complex waste types will demand a more detailed conceptual model. Such a model may include flow-nets, potentiometric surface or water table maps for each aquifer, geochemical diagrams, and a series of structure contour and isopach maps. *Reporting Hydrogeologic Characterization Data From Hazardous Substance Release Sites* (Cal/EPA, 1995h) contains more detail on the types of graphics that are needed to illustrate the conceptual model.

2.4 Work Plan Development

Review of available data and development of a conceptual model serve two major functions in planning subsequent field investigations. First, data gaps in the conceptual site model define the scope of the investigation. For example, lack of site specific information on the direction of ground water flow will require the installation of piezometers or monitoring wells for measurement of water levels. Second, available information will help to identify the investigation methods to be applied. For example, knowledge of the geologic materials that may be encountered, and available data on the depth to ground water, will aid the selection of drilling methods.

The work plan should be designed to guide the collection of information that will verify and refine the conceptual model. Field activities described in the work plan may be classified into four broad categories: source characterization, geologic characterization, characterization of ground water flow, and characterization of ground water quality. The hydrogeologic characterization work plan will often be developed as a part of a comprehensive remedial investigation work plan.

2.4.1 Site Map(s)

A site topographic map is needed for work plan development. The site map(s) should be presented at a scale of 1 inch = 200 feet or larger, with an appropriate contour interval to accurately depict site topography. The site map should identify all potential sources of contamination, above ground and underground utilities, roads and site access, site drainage, and any other information needed for the planning of field work.

2.4.2 Field Methods

All field methodologies for drilling, soil and ground water sampling, well and piezometer construction, geophysical surveys, trenching, and other activities should be identified. Field procedures should be described in detail in the work plan or in an accompanying field sampling plan.

2.4.3 Chemical Analyses

Chemical analysis methods should be identified for each environmental medium, whether soil, soil vapor, waste or ground water. The suite of chemical analyses must be adequate to identify the full range of contaminants that may occur at the site. Records of chemical use or disposal should be evaluated to identify constituents of concern. If site records are incomplete, constituents of concern should be based on the operations that took place at the site. Analysis for all contaminants potentially occurring at the site should be performed. However, site characterization activities should be focused on those compounds that pose the highest risk, and those that provide the best indication of waste migration. In addition to constituents derived from the site, naturally occurring constituents and stable isotopic.compositions in ground water should be investigated so that the geochemistry of ground water can be fully understood.

2.4.4 Sample Locations and Number

The locations, type, and number of samples should be identified in the work plan, and shown on a site map and cross sections. The number of samples and suite of chemical and isotopic analyses will depend on site characteristics, but must be sufficient to identify the nature of contaminant sources, to define the distribution of contaminants in the subsurface, and to provide data for risk assessment, remedy selection and remedial design. In addition, samples should be collected to evaluate the physical properties of soils and aquifer materials.

Contingencies for collection of additional samples, dependent on the results of initial sampling, should be proposed in the work plan. In this way, two or more phases of site characterization field activities may be conducted without developing additional work plans, thereby saving time and reducing casts.

Rationale should be provided for each sample location, sampling technique, and analytical method. All proposed samples should be presented in tabular form, to include the sample medium, location, depth, sampling method, analyses, and rationale for the sample. Table 2 is an example format for presentation of proposed samples.

2.4.5 Presumptive Remedies

To the extent possible, presumptive remedies should be considered during development of the work plan. In this way, much of the data needed for selection and design of remedial alternatives may be collected during site characterization. Time and money can be saved if additional phases of field activities are not needed to evaluate remedial alternatives. Proven remedial technologies and their applicability were compiled by the California Base Closure Environmental Committee (CBCEC, 1993).

Table **2.** Example summary format for work plan sampling proposals.

Sample Number	Medium[1]	Location	Depth	Sampling Method[2]	Analyses[3]	Rationale

[1]Examples include waste, soil vapor, soil, ground water
[2]Examples include split-spoon sampler, bailer, grab sample
[3]EPA or other method designations (e.g., 624,8010,ASTM 0422)

2.4.6 Field Schedule and Work Plan Modifications

A proposed schedule for all field activities should be provided in the work plan. The schedule should include adequate time for regulatory review. Review time can be reduced through early involvement of regulatory agency staff in work plan development.

While hydrogeologic characterization is generally an iterative process, the time needed to characterize a site can be reduced through good planning. Multiple tasks can be scheduled during the same period of field work, with contingencies outlined for subsequent field activities. Based on results of initial sampling, decisions can be made, with regulatory approval, to guide additional work while in the field. A protocol should be provided for making changes to the work plan.

3 FIELD ACTIVITIES

Hydrogeologic investigations are conducted to obtain information in four broadly defined categories. Sources of actual or potential contamination must be defined, with respect to their location, chemical composition, and rate of release. Site geology must be characterized, including the distribution of geologic materials, stratigraphic and structural relationships, and other features that affect the subsurface migration of contaminants. The rate and direction of ground water flow must be determined for all potentially impacted aquifers. Finally, ground water quality must be characterized, including the contaminants present, their concentrations, and their vertical and lateral extent. For naturally occurring compounds, or contaminants present at nearby sites, the background concentrations of compounds in ground water must be characterized. Stable isotopic studies should be considered in cases where the hydrogeology is particularly complex, or when isotopic compositions can help to identify or verify the source(s) of a ground water contaminant.

3.1 Preparations for Field Work

An initial site reconnaissance should have been made before work plan development, and additional activities should be conducted during development of the work plan to ensure accessibility and safety of sampling locations. This will include surveys for overhead and underground utilities, planning of routes for movement of heavy equipment on- and off-site, coordinating with persons affected by field operations, and acquisition of permits.

Personnel responsible for implementing the field program should ensure that all contractors and field personnel have read the work plan and understand the scope of work as well as the specific field procedures to be followed.

Regulatory agency staff should be notified, and provided with a detailed schedule of field activities, at least two weeks before the start of field work. Regulatory oversight during field work will reduce the time needed for approval of modifications to the work plan, and for review of final reports.

3.2 Source Characterization

Based on historical records of operations, aerial photographs, site reconnaissance, previous sampling, and potential sources of contamination should be identified during scoping. Potential sources that should be investigated include tanks, drains, sumps, surface impoundments, landfills, areas of stained ground or stressed vegetation, dry wells, septic systems, container storage areas, pipelines, transformers, and other areas where hazardous materials or wastes were handled. All potential sources should be characterized to the extent that they may affect ground water. This requires identifying the contaminants present, their specific forms, and their concentrations. The presence of degradation products of site contaminants should be investigated. The nature of the source and the suspected rate of release of contaminants must also be identified. The potential for contamination of ground water by the migration of contaminants through the unsaturated zone must be evaluated.

Direct sampling of wastes and soils should be conducted, and samples should be analyzed for all contaminants suspected to occur at the site. In addition, indirect methods for source characterization may be used to optimize the locations for sampling and analysis, often resulting in lower costs. Soil vapor surveys can be conducted, in addition to soil sampling, to identify the presence of volatile organic compounds. Various surface geophysical methods may be used to identify areas of waste disposal. *Application of Surface Geophysics at Hazardous Substance Release Sites* (Cal EPA, 1995b) provides information on the applicability of methods.

3.3 Geologic Characterization

Site investigation must always include direct methods of investigating site geology, through analysis of geologic materials collected from borings and trenches. Indirect methods, especially geophysical methods and cone penetrometer testing (CPT), may provide valuable information that can be used with direct techniques to interpolate geologic data between points where direct observations are made.

A site investigation must include characterization of the subsurface materials below the site, which includes determining the lateral extent and thickness of all hydrostratigraphic units, identifying geologic features that may affect ground water flow and contaminant migration, such as faults, fractures, and stream channel deposits, and collecting samples for lithologic description and laboratory analysis of mineralogy and engineering properties.

3.3.1 Subsurface Boring Program

All hydrogeological site investigations must include a subsurface boring program. Drilling methods must be selected that are capable of drilling in the geologic formations present at the site to the expected depths of investigation. The drilling methods should provide for sample collection and well installation if it is planned. *Drilling, Coring, Sampling and Logging at Hazardous Substance Release Sites (Cal EPA,* 1995c) provides guidance on the selection of methods for drilling and sampling, and the types of information to be collected from boreholes.

Geologic field work should be conducted under the direction of a trained geologist. The field program must be supervised by a geologist registered in California, who must take responsibility for the work of field personnel. Drilling must be conducted by a California licensed C-57 contractor.

The number of borings and their spacing should be based on geologic information obtained during scoping and on the spatial distribution of actual or suspected releases. Boreholes should be drilled to provide for detailed evaluation of site geology and to identify potential contaminant migration pathways. Boreholes should be spaced closely enough so that accurate cross-sections can be constructed. Subsurface borings, from which continuous core samples of geologic materials have been collected, must be completed to accurately identify stratigraphic relationships. The number of borings will depend on the complexity of site geology, the extent to which geologic unitare laterally continuous across the site, the presence of fractures, channel deposits or other preferential pathways for contaminant migration, and the extent to which indirect methods for geologic characterization have been used.

Core samples of geologic materials should be collected from borings at all suspected changes in lithology. For boreholes that will be used for installation of a monitoring well, at least one sample should be collected from the monitoring well screened interval to facilitate well intake design. The investigator should ensure that samples of every geologic formation are collected and described, and must describe the nature of stratigraphic contacts. Core samples should be archived whenever possible, and color photographs taken of representative samples from the boring.

In some situations, it may be necessary to drill through confining layers. Investigators, in conjunction with the appropriate regulatory personnel, must develop a method for drilling through the confining layer. Care must be taken when drilling into confining units so that the borehole does not create a conduit for migration of contaminants between hydraulically separated saturated zones.

The following two approaches for drilling through confining layers should be considered.

- Drill initial boreholes on the perimeter of the site (in less contaminated or uncontaminated areas). These borings could penetrate the confining zone to provide for characterization of deeper units. At a minimum, boreholes upgradient of the source could be drilled through the possible confining layer to characterize site geology. The appropriateness of this approach must be evaluated on a site-specific basis.

- Drill boreholes using techniques that minimize the danger of cross-contamination between water-bearing zones. Such techniques typically involve drilling a borehole partially into the possible confining layer, installing an exterior casing, sealing the annular space in the cased portion of the borehole, and drilling a smaller diameter borehole through the confining layer.

Any boring that will not be completed as a monitoring well must be decommissioned by filling with a properly mixed grout emplaced with a tremie pipe.

3.3.2 Analvsis of Soil and Rock Samples

In addition to the field descriptions outlined above, the investigator should conduct, where necessary, laboratory analyses of each geologic unit to obtain the following information: mineralogy and chemistry of the aquifer and confining units, moisture content, bulk density and other engineering properties of each geologic unit, organic carbon content of geologic materials, hydraulic conductivity of each geologic unit, particle size analyses of unconsolidated or poorly consolidated samples. Many parameters needed for evaluation of contaminant fate and transport and evaluation of remedial alternatives may be provided by laboratory analysis.

3.3.3 Cone Penetrometer Testing (CPT)

Depending on site geology, a CPT survey can be used as a reconnaissance tool to provide preliminary site data for planning, or the surveys can be integrated into a broader investigation program to provide supplemental data between widely spaced drill holes or other data measurements. CPT surveys can also provide potentiometric measurements and estimates of hydraulic conductivity of materials.

CPT involves pushing an electronic measurement device into the subsurface to determine the tip resistance and side friction created by subsurface materials. This information is correlated to engineering soil classifications using a computer. In all cases, lithologic data obtained from CPT surveys must be correlated with lithologic information obtained from nearby boreholes to verify the CPT results.

Exploratory holes from CPT surveys must be properly abandoned, using a bentonite slurry or cement bentonite grout emplaced through a tremie pipe.

3.3.4 Geophysical Techniques

3.3.4.1 Surface Geophysics

Surface geophysical techniques may be used to plan the subsurface boring program by providing data to verify or modify the initial conceptual model prior to drilling boreholes. Based on the results of geophysical surveys, boreholes can be effectively located to obtain necessary geologic information. Surface geophysical techniques may also be useful to correlate geologic data between widely spaced boreholes, and to identify wate disposal areas. The applicability of a particular method or tool to a site depends on the purpose of the survey, the site geology, and the scope of the site investigation. *Application of Surface Geophysics at Hazardous Substance Release Sites* (Cal EPA, 1995b) contains guidance on the use of surface geophysical techniques.

3.3.4.2 Borehole Geophysics

Borehole geophysical techniques are applied as a suite of measurements that, when used in combination, allow the interpreter to determine physical properties of a geologic formation. Borehole geophysical methods maximize the amount of data collected from a boring. The potential for multiple interpretations of geophysical data results from the large number of potential combinations of subsurface conditions that can occur to produce the measured response. Therefore, information from geophysical surveys must be used in conjunction with direct observations from borehole samples to verify the interpretations of the geophysical logs. *Application of Borehole Geophysics at Hazardous Substance Release Sites* (CalEPA, 1995d) contains guidance for the application of borehole geophysics and data interpretation.

3.4 Characterizing Ground Water Flow

The rate(s) and direction(s) of ground water flow at a site, in both the horizontal and vertical dimensions, must be determined. Potentiometric information, obtained from piezometers or monitoring wells with short screens, and measurements of the hydraulic conductivity of geologic materials are necessary to estimate the rate and direction of ground water flow. These data must be used in conjunction with an understanding of the site hydrostratigraphy, obtained from the geologic characterization described above. Ground water flow must be characterized for all water-bearing units potentially affected by contaminants from the site.

The investigator must install wells from which accurate potentiometric information can be obtained to characterize the site hydrologic regime. Depending on their design, these installations may also serve as monitoring wells for evaluating water quality, *Monitoring Well Design and Construction for Hydrogeologic Characterization* (Cal/EPA, 1995e) provides guidance on well design and installation.

3.4.1 Ground-Water Level Measurements

Installing monitoring wells that will provide representative samples of background and downgradient water quality requires a thorough understanding of ground water flow beneath a site. To determine hydraulic gradients and ground water flow directions, the investigator should develop and implement a water level monitoring program. The water level monitoring program must provide precise water level measurements, in a sufficient number of piezometers or wells, at a sufficient frequency to gauge both seasonal average flow directions and temporal variations in ground water flow directions. To determine ground water flow directions and ground water flow rates, accurate water level elevation measurements (generally $\pm$0.01 foot) must be obtained. For the purpose of measuring hydraulic head, piezometers and wells must have as short a screened interval as feasible, generally ten feet or less.

Hydrostratigraphic relationships should be determined by a qualified ground water scientist when obtaining and evaluating water level data. Unqualified individuals may confuse a potentiometric surface with the water table in areas where both confined and unconfined aquifers exist. In all cases, well or piezometer screen placement must be based on the detailed boring log, and the well or piezometer screen must not intercept hydraulically separated zones of saturation.

3.4.2 Potentiometric Maps

Water level data should be used to construct water table maps and potentiometric surface maps for other water bearing zones. The data used to develop water table maps should be from piezometers or wells screened across the water table. The data used to develop potentiometric surface maps should be from piezometers or wells screened in the same hydrostratigraphic zone. The direction of ground water flow may be determined by drawing flow lines on the potentiometric surface or water table map. The magnitude of the horizontal hydraulic gradient can be determined from spacing of equipotential contour lines and the map scale.

A potentiometric surface or water table map will show approximate horizontal ground water flow directions. To determine monitoring well locations and screened intervals, however, ground water flow directions and hydraulic gradients must be established in both the horizontal and vertical directions and over time at regular intervals.

3.4.3 Characterizing Vertical Flow of Ground Water

To adequately determine ground water flow directions, the vertical component of ground water flow must be evaluated. This requires the installation of well or piezometer clusters. A cluster is a closely spaced group of wells screened at different depths. Wells or piezometers should generally be placed in separate boreholes rather than in a single borehole. In some situations, a multi-point well may be installed, in which discrete measurements can be taken at different levels.

The vertical component of hydraulic gradient should be calculated, and the direction(s) of ground water flow determined for a vertical profile at a site. This profile should be aligned roughly parallel to the horizontal direction of ground-water flow as indicated by the potentiometric surface or water table map.

3.4.4 Seasonal and Temporal Factors

Investigators must identify and evaluate factors that result in short- or long-term variations in ground water elevations and flow patterns. These factors may include variations in precipitation or recharge rates, presence of persistent facility water leaks, on- or off-site pumping or injection wells, tides, on- or off-site construction, changing land use patterns, and on- or off-site lagoons, ponds, the presence of springs, or streams.

Water levels must be measured frequently enough to detect and characterize temporal variations in ground water flow. Initially, weekly or monthly water level measurements may be needed to characterize seasonal fluctuations, followed by quarterly monitoring after the water level variations have been described. In some cases, such as in tidally influenced areas, more frequent, or even continuous, water level measurements may be needed. On- or off-site well pumping may affect both the rate and direction of ground water flow, and the potentially complex patterns of off-site pumping must be determined.

3.4.5 Determining Hydraulic Conductivity

Hydraulic conductivity is a measure of the ability of a geologic material to transmit water. Aquifer testing must be performed to provide representative estimates of hydraulic conductivity. Acceptable field methods include slug tests or pumping tests. *Aquijer Testing for HydrogeoZogic Characterization* (Cal/EPA, 1995f) contains guidance for conducting and analyzing aquifer tests.

It may be beneficial to use laboratory measurements of hydraulic conductivity to augment results of field tests, however, field methods provide the best estimate of hydraulic conductivity in most cases. Because of the limited sample size, laboratory tests commonly miss secondary permeability features such as fractures and joints, and can greatly underestimate hydraulic conductivity. In addition, truly undisturbed samples are difficult to collect. Laboratory tests may provide valuable information about the vertical component of hydraulic conductivity of aquifer and aquitard materials.

3.4.6 Determining Ground Water Flow Rate

The rate of ground water flow must be determined for a site to allow proper placement of monitoring wells. In most areas, where ground water flows through a porous medium, such as unconsolidated sediments or highly fractured crystalline rocks, Darcy's Law can be used to calculate the rate of ground water flow. The average linear velocity of ground water flow ($\bar{v}$) is a function of hydraulic conductivity **(K),** hydraulic gradient (i), and effective porosity (n_e):

$$\bar{v} = K i / n_e$$

Effective porosity, the percentage of a soil, sediment or rock that consists of interconnected pores through which water can flow, must be estimated from laboratory tests or from values cited in the literature. Effective porosity is generally comparable in value to specific yield.

Chemical or isotopic tracer tests or other techniques may be necessary to determine ground water flow rates in certain geologic settings, such as some fractured crystalline rocks or karst.

3.5 Characterization Ground Water Quality

To determine the extent to which a site has impacted ground water, and to provide data for risk assessment and remedial design, ground water quality must be characterized. This includes identifying the contaminants present, their concentrations, and their vertical and lateral extent. For naturally occurring compounds, or contaminants present at nearby sites, the background concentrations of compounds in ground water must be characterized. In particularly complex hydrogeologic settings, stable isotopic analysis of the oxygen and hydrogen can aid in determining water sources and in understanding processes such as recharge and ground water mixing. In addition, stable isotopic analysis can be useful in determining contaminant source (e.g., $^{15}N/^{14}N$ in nitrate) or discriminating between background and contamination (e.g., $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ and $^{15}N/^{14}N$ in nitrate).

3.5.1 Monitoring Wells

When the rate and direction of horizontal and vertical ground water flow have been determined, monitoring wells should be installed. Guidance for the design and construction of monitoring wells is provided in *Monitoring Well Design and Construction for Hydrogeologic Characterization* (CalEPA, 1995e).

Monitoring wells must be installed to characterize the types of contaminants that have affected ground water, the concentrations of contaminants, and their lateral and vertical extent in ground water. Each water-bearing zone that could potentially be affected by site contaminants must be characterized. This means, in most cases, that successively deeper water-bearing zones must be investigated when ground water contamination is identified. If ground water contamination is not identified, ongoing monitoring may be necessary to monitor potential ground water contamination until a site is remediated and the risk to ground water is removed.

The number and location of monitoring wells will depend on site specific factors, including the variability of ground water flow directions, the rate of ground water flow, the complexity of hydrostratigraphy and the number of water-bearing zones to be monitored, the number of sources on a site, the properties of contaminants, and the extent of ground water contamination.
For a simple case, such as a dissolved contaminant in a homogeneous and isotropic aquifer, in which ground water flow does not vary over time, the following wells would be needed:

- an up-gradient monitoring well to provide background water quality,
- one or more wells within a plume to identify the distribution of contaminant concentrations,
- wells at either side of the plume to define the lateral extent of contamination,
- one or more wells at the down-gradient edge of the plume to monitor its migration,

- one or more well clusters in a contaminated water-bearing zone to identify the vertical extent of contamination, and

- one or more wells in underlying water bearing zones to identify the presence or absence of contamination.

Most hydrogeologic systems are highly heterogeneous. Detailed characterization of the distribution of contaminants in ground water, both laterally and vertically, may require many monitoring wells, or collection of numerous ground water samples by other means as described in the next section. The costs of remediation may be reduced, however, if discrete contaminated zones can be targeted for cleanup, resulting in remediation of a smaller volume of ground water with higher contaminant concentrations.

Detailed characterization of ground water flow rates and directions, using piezometers designed only for collection of water level data, may reduce the number of monitoring wells needed. Reducing the number of monitoring wells, and, therefore, the number of ground water samples and analyses, can provide a savings in the cost of characterization.

3.5.2 Alternate Ground Water Monitoring Methods

Several methods are available to provide rapid collection of ground water samples either during drilling or CPT surveys, or from temporary well point installations. HydroPunch™ and BAT™ samplers can be used with either a drill rig or CPT rig to provide grab samples of ground water. Ground water samples can be taken from within the borehole with many drilling methods. Inflatable packers may be used in some situations to allow purging of the borehole fluids prior to ground water sampling. Temporary steel or PVC well points can be installed using a drill rig or CPT equipment to allow collection of potentiometric information and water samples. Use of methods for collection of ground water samples during drilling or CPT surveys may provide a rapid and cost effective initial characterization of ground water contamination. This may reduce the number of monitoring wells needed, thereby saving time and reducing cost.

Collection of ground water samples by these methods may require well permits in some California counties, and that the work be conducted by a California licensed drilling contractor.

3.5.3 Ground Water Sampling and Analysis

Ground water should be analyzed for all contaminants that have been identified in waste or soil, or that may otherwise be present at a site. The site characterization should focus, however, on those contaminants that are highly mobile and most likely to reach ground water, that provide the best indicators of contaminant migration, that pose the highest risk to receptors, and that affect remedy selection.

Methods for purging and sampling monitoring wells should be selected to provide representative samples for the chemical constituents of interest. Guidance for ground water sampling is provided in *Representative Sampling of Ground Water for Hazardous Substances* (CalEPA, 1995f).

3.6 Data Analysis

Thorough analysis of the data collected during field activities should be conducted by an experienced geologist. Site characterization data should be used to refine the conceptual site model. Following site characterization field activities and data analysis, the investigator should be able to:

- correlate stratigraphic units between borings, identify the thickness and lateral extent of zones of potentially high hydraulic conductivity, identify the thickness and lateral extent of confining formationsAayers, and establish the presence or absence of geologic features such as fault zones, fracture traces, and buried stream deposits that may affect migration of contaminants,

- identify the potential impact on ground water from waste sources and contaminated soils,

- accurately estimate the rate(s) and direction(s) of ground water flow in all water bearing zones of interest, and define the nature and causes of temporal variations in ground water flow, and

- identify the source and the lateral and vertical extent of contamination in each impacted water-bearing zone, define the distribution of concentrations of each contaminant of concern, and characterize ground water quality from the zone underlying the zone of contamination

Mathematical ground water models can be used as a method of managing large quantities of site data, or to provide answers to specific questions. *Ground Water Modeling for Hydrogeologic Characterization* (CalEPA, 1995i) provides guidance for conducting and reporting ground water modeling studies.

Additional data gaps should be identified and further field work conducted if necessary. The completed site characterization and conceptual hydrogeologic model provide the basis for risk assessment, and remedy selection. Additional investigation will often be needed to support remedial design.

4 PRESENTATION OF SITE CHARACTERIZATION DATA

A report of the hydrogeologic characterization, which may be contained within a broader report of a complete remedial investigation, should be prepared for regulatory review. The final conceptual site model should be included. The report of hydrogeologic characterization should be prepared in accordance with the guidance in *Reporting Hydrogeologic Characterization Data from Hazardous Substance Release Sites* (CalEPA, 1995h). The report, or appropriate sections containing geologic observations and conclusions, must be signed by a geologist registered to practice in California.

The hydrogeologic characterization should contain a discussion of the level of uncertainty of conclusions, outline data gaps remaining in the conceptual model, and provide recommendations for additional work needed to meet characterization objectives.

Characterization data, and preliminary interpretations and conclusions, may be presented as they become available, rather than waiting until a final report is prepared. Such ongoing reporting should facilitate a consensus being reached between responsible parties and regulatory personnel, and may result in an overall reduction of the time necessary for regulatory approval.

one or more wells at the down-gradient edge of the plume to monitor its migration,

5 REFERENCES

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CalEPA, 1995a, Guidelines for hydrogeologic characterization at hazardous substance release sites, Volume 2: Project management manual, California Environmental Protection Agency, Department of Toxic Substances Control.

CalEPA, 1995b, Application of surface geophysics at hazardous substance release sites, California Environmental Protection Agency, Department of Toxic Substances Control, 19 p.

CalEPA, 1995c, Drilling, coring, sampling and logging at hazardous substance release sites, California Environmental Protection Agency, Department of Toxic Substances Control, 27 p.

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CalEPA, 1995f, Representative sampling of ground water for hazardous substances, California Environmental Protection Agency, Department of Toxic Substances Control, 34 p.

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DTSC, 1994, Preliminary endangerment assessment guidance manual, California Environmental Protection Agency, Department of Toxic Substances Control.

U.S. Environmental Protection Agency, 1988, Guidance for conducting remedial investigations and feasibility studies under CERCLA, United States Environmental Protection Agency, Office of Emergency and Remedial Response, EPA/540/G-89/004 (OSWER Directive 9355.3-01).

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Name: Address:

Name and address are optional, but including them will help us follow-up and address your comments.

Title: Guidelines for Hydrogeologic Characterization of Hazardous Substance Release Sites
Volume 1: Field Investigation Manual

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