DEPARTMENT OF TOXIC SUBSTANCES CONTROL
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

GUIDELINES FOR PLANNING AND IMPLEMENTING GROUNDWATER CHARACTERIZATION OF CONTAMINATED SITES

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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, RWQCBs work closely with DTSC in protecting the environment.

To aid in characterizing and remediating contaminated sites, DTSC has developed guidance documents and recommended procedures for use by its staff, local governmental agencies, responsible parties, and their contractors. The Office of Geology within DTSC provides geologic assistance, training, and guidance. This document has been prepared by Office of Geology staff to provide guidelines for the investigation, monitoring, and remediation of contaminated sites.

Please note that, within the document, the more commonly used terms, *hazardous waste site* and *toxic waste site*, are used synonymously with the term contaminated 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 two documents, released by Cal/EPA in July 1995:

> *Guidelines for Hydrogeologic Characterization of Hazardous Substances Release Sites, Volume 1: Field Investigation Manual*, and
> *Guidelines for Hydrogeologic Characterization of Hazardous Substances Release Sites, Volume 2: Project Management Manual.*

Mention of trade names or commercial products does not constitute Cal/EPA endorsement or recommendation.

Comments and suggestions for improvement of *Guidelines for Groundwater Characterization of Contaminated Sites* should be submitted to:

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This revised guidance relies heavily on the work of the authors of the original guidance documents. Their contributions continue to be appreciated.

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ABBREVIATIONS AND ACRONYMS

AQMD	Air Quality Management District
ARAR	applicable or relevant and appropriate requirement
ARCH	air rotary casing hammer
ASTM	ASTM International (formerly known as American Society of Testing and Materials)
bgs	below ground surface
Cal/EPA	California Environmental Protection Agency
CEG	certified engineering geologist
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHG	certified hydrogeologist
CMS	corrective measures study
CPT	cone penetrometer test
CSC	conventional site characterization
CSIA	compound specific isotope analysis
CSM	conceptual site model
DNAPL	dense non-aqueous phase liquid
DP	direct push
DQO	data quality objective
DTSC	Department of Toxic Substances Control
ERA	ecological risk assessment
FLUTe	flexible liner underground technologies
FSP	field sampling plan
GHG	greenhouse gas
GPR	ground penetrating radar
HASP	health and safety plan
HPT	hydraulic profiling tool
HSA	hollow stem auger
IRM	interim remedial measure
ITRC	Interstate Technology and Regulatory Council
LARWQCB	Los Angeles Regional Water Quality Control Board
LIF	laser-induced fluorescence
LNAPL	light non-aqueous phase liquid
MCL	maximum contaminant levels
MIP	membrane interface probe
MNA	monitored natural attenuation
NAPL	non-aqueous phase liquid
NTCRA	non time critical removal action
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene

ABBREVIATIONS AND ACRONYMS (cont.)

PDB	polyethylene diffusion bag
PE	professional engineer
PEA	preliminary endangerment assessment
PG	professional geologist
PHT	percussive hammer tool
PT&R	proven technologies and remedies
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RA	removal action
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
ROST™	Rapid Optical Screening Tool
RWQCB	Regional Water Quality Control Board
SAP	sampling and analysis plan
SCAPS	site characterization and analysis penetrometer
SCPT	seismic cone penetration testing
SFRWQCB	San Francisco Regional Water Quality Control Board
SLR	sea-level rise
SOP	standard operating procedures
SPMD	semi-permeable membrane device
SVOC	semi-volatile organic compound
TCE	trichloroethene
TCRA	time-critical removal action
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UVOST	ultra-violet optical screening tools
VOC	volatile organic compound
VSP	visual sample plan

1.0 INTRODUCTION

1.1 Purpose and Scope of this Document

The purpose of this guidance document is to present a recommended approach to planning and conducting groundwater investigations and is intended to be used by DTSC project managers and support staff, and by responsible parties and their environmental consultants, when planning and conducting site characterization activities. While this guidance was prepared by DTSC staff and has been written with the understanding that the approach presented will be used as a guide to performing investigations under DTSC oversight, it may be useful for performing investigations under the oversight of other state agencies or Certified Unified Program Agencies. This document is organized into the following sections:

- Section 2 discusses planning aspects including project scoping and work plan development.

- Section 3 discusses objectives and methods of groundwater characterization including nature and extent of contamination and groundwater flow.

- Section 4 discusses the selection and application of field methods for implementing the field work and obtaining the data.

The focus of this guidance is on groundwater characterization. However, groundwater investigations cannot be properly implemented without considering potential vadose zone contaminant sources, and results of groundwater investigation can indicate potential human health risks, such as indoor air intrusion of volatile organic compounds (VOCs). Consequently, the scope of this document has been expanded from previous guidance to include other media in addition to groundwater, and a multi-media approach to site characterization is recommended for most sites.

<u>A note about hyperlinks</u>: Because hyperlinks are temporary, hyperlinks to referenced documents are not provided in this document. Instead, readers are encouraged to use internet search engines to locate the references cited.

1.2 Other Guidance Documents

This document should be used in conjunction with 1) DTSC's *Preliminary Endangerment Assessment, Guidance Manual*, which provides a comprehensive overview of DTSC's investigation and cleanup process, 2) USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA 1988), and 3) USEPA's *Interim Final RCRA Facility Investigation Guidance* (USEPA 1989). DTSC has published several guidance documents (Cal/EPA 1994 and 1995 a through h) which include detailed discussions of techniques used in site characterization.

Other Cal/EPA and USEPA documents may be useful, as well as guidance documents developed by the Interstate Technology and Regulatory Council (ITRC), the standards developed by ASTM International (formerly, the American Society of Testing and Materials), and other parties. The State of Ohio's *Technical Guidance Manual for Hydrogeological Investigations and Ground Water Monitoring (TGM)* is a comprehensive online reference.

No guidance document can account for every possible variation that may exist at every contaminated site. The selection and application of any method or tool is the responsibility of those personnel overseeing and conducting the studies. Hence, adequate training and experience are required and independent judgment should be exercised where needed.

1.3 Overview of Cleanup Process

The intent of site characterization is to determine the nature and extent of contamination. The level of investigation must be sufficient to determine the risks to human health and the environment and to evaluate potential remedies.

Investigation and cleanup of contaminated sites may be governed by one of several federal or California laws, including:

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);
- Resource Conservation and Recovery Act (RCRA);
- Hazardous Waste Control Law;
- Hazardous Substances Account Act;
- California Environmental Quality Act (CEQA);
- Toxic Substances Control Act; and
- Porter-Cologne Water Quality Control Act.

The law applicable to a given site depends on such factors as the source, cause of the release, and cleanup process under which the site is being addressed. For example, school sites have additional requirements, and RCRA permitted sites may have specific regulations. Local codes may also apply. Site location may be critical, with respect to historical and cultural resources. However, although the terminology used may differ, procedural differences between cleanup authorities will not substantively affect the outcome of the investigation and cleanup, with respect to protection of public health and the environment.

While every site has a unique set of technical, logistical, and budgetary constraints that affect execution of the investigation, in the broadest sense, every site investigation follows similar processes for scoping and planning field investigations and for selecting a final remedy. DTSC's investigation and cleanup process generally involves the activities listed below. Projects at DTSC are usually administered under CERCLA or RCRA regulations, and the various project documents have specific designations under each set of regulations.

In the list below both CERCLA and RCRA document designations are presented.

- Evaluating initial site conditions
    - CERCLA Preliminary Endangerment Assessment (PEA)
    - RCRA Facility Assessment
- Characterizing the site
    - CERCLA Remedial Investigation (RI)
    - RCRA Facility Investigation (RFI)
- Assessing risk (CERCLA and RCRA)
    - Baseline Risk Assessment
    - Human Health and Ecological Risk assessment
- Evaluating and screening remedies
    - CERCLA Feasibility Study (FS)
    - RCRA Corrective Measures Study (CMS)
- Selecting a remedy
    - CERCLA Remedial Action Plan (RAP)
    - RCRA Corrective Action Plan
- Implementing the remedy
    - CERCLA Remedial Action Implementation Plan
    - RCRA Corrective Action Implementation Plan
- Operation and maintenance of the remedy
- Review after implementation
    - CERCLA 5-Year Review
    - 10-Year RCRA Permit Renewal

If action is necessary to protect public health and/or the environment, emergency or interim measures may be taken at any point in the process. Public participation is required at various stages during the process, as described in DTSC's *Public Participation Manual* (Cal/EPA 2001).

Site investigations should be conducted by professionals with a minimum of a bachelor's degree in engineering, geology, or related sciences, and several years of experience in the environmental field. For some activities, the signatures of licensed professional engineers and/or geologists (i.e., PEs and/or PGs) are required by the California Business and Professions Code.

Professionals with education and experience in chemistry, microbiology, toxicology, and other sciences, as well as other specialists, should be considered for inclusion on a project team as appropriate.

2.0 PROJECT PLANNING

2.1 Objectives of Site Characterization

The primary objectives in characterizing a site are to evaluate the nature and extent of contamination, identify the risk posed by contamination, and to collect data necessary to select a remedy, if one is needed. Additional site characterization data may be needed for the remedial design.

The information necessary to satisfy characterization objectives includes identifying:

- Contaminants,
- Affected environmental media,
- Nature and extent of contamination in the affected media, and
- Geologic factors that control the fate and transport of contaminants (e.g., rate and direction of contaminant migration, degradation, et cetera).

To perform a risk assessment, locations and exposures of human and ecological receptors (current and future) must be identified. The focus of this guidance is on hydrogeological (groundwater) investigations; however, in most cases, investigations of other media may be required.

A detailed description of site characterization is provided in USEPA's 1988 manual for site investigation, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*.

2.2 Objectives of Hydrogeological Investigations

The broad objectives of hydrogeologic characterizations are to determine:

- The nature and extent of contaminants in groundwater at the site (e.g., types of contaminants, concentrations, vertical and horizontal distributions, chemical properties, and breakdown products);

- The geology and hydrogeology beneath and surrounding the site (e.g., depth to groundwater, extent of aquifers, aquifer properties, nearby wells, potential contaminant transport pathways, groundwater-to surface water interactions); and,

- Fate and transport of contamination (e.g., contaminant migration and retardation).

Hydrogeological characterization is discussed in detail in section *3.0 Objectives and Methods*.

2.3 Characterization Strategy and Scope

In the next few sections, a recommended approach to planning a site investigation is presented, with an emphasis on work plan development.

The current practice in site investigation and remediation is patterned on a streamlined approach developed by USEPA, known as Triad.

Triad has three primary components:

- Systematic (or strategic) planning,
- Dynamic work strategies, and
- Real-time measurement systems.

Triad employs advanced or innovative investigative and analytical technologies—along with traditional field methodologies. Triad can accelerate project schedules, reduce overall project costs, and improve project outcomes. While not all sites will embrace the total Triad approach, most sites will benefit from utilizing Triad elements during site planning and investigation. A brief description of Triad components is provided in the next three sections. Detailed information is available at USEPA's *Triad Central* website, including a variety of case studies under *Triad Project Profiles*.

2.4 Systematic (or Strategic) Planning

Systematic planning occurs at the onset of a project (i.e., scoping meeting) and is revisited throughout the progress of a project. Systematic planning entails:

- Assembling a project team (e.g., scientists, engineers, geologists, toxicologists, attorneys, and public participation specialists);
- Identifying project objectives;
- Identifying key decisions that have to be made and the decision-makers;
- Developing a conceptual site model (CSM);
- Agreeing on data quality objectives (DQOs) for each phase of work;
- Designing sampling, data evaluation, and data management activities to achieve project objectives consistent with DQOs;
- Identifying stakeholders and other interested parties; and,
- Evaluating exit strategies (i.e., plans for taking the site through characterization to closure).

Systematic planning results in a project's logical development, efficient use of scarce resources, transparency of intent and direction, soundness of conclusions, and proper documentation. In site investigation, a crucial question is: "When do we stop studying?" With respect to each project, the question is answered (in advance) by the decision rules of the DQO process.

Elements that must be considered during strategic planning include: regulatory requirements, legal concerns, budgets and contracts, and stakeholder concerns. At planning meetings, decision uncertainty is evaluated and approaches for managing uncertainty are developed and agreed upon. For example, during the DQO process, the uncertainty inherent in analytical data is evaluated and an acceptable level of data uncertainty is identified.

A detailed checklist for systematic planning developed by the United States Army Corps of Engineers (USACE) is included as Appendix A.

The CSM is a critical component of systematic planning because the CSM is a scientifically defensible foundation for decision-making that evolves as the site investigation and remediation progresses. The CSM life-cycle is discussed in more detail in Section 2.11.

2.5 Dynamic Work Strategies

Dynamic work strategies provide flexibility in the field to change or adapt as information is collected using real-time measurement technologies. Dynamic work strategies are incorporated as decision-logic, usually expressed as "if … then" statements, within work plans. One example of a dynamic work strategy is to incorporate a decision rule for step-out sampling during groundwater investigations. A possible decision rule could be: "If the grab groundwater sample exceeds risk-based criteria, then the sampling tool should be pushed to the next sand or gravel zone and another grab groundwater sample collected." This type of decision rule requires real-time measurement systems, discussed in greater detail below.

During the DQO process, a decision framework is established and documented in the work plan. Different levels of decision-making can be specified whereby: 1) some decisions can be made by reference to "if…then" statements; 2) some decisions can be made by the field supervisor; and, 3) other decisions may require a call back to the office. Regulatory agency approval of the decision rules and decision framework begins with systematic planning and is obtained during review of the work plan. All decisions are recorded and included in the field report.

2.6 Real-Time Measurement Systems

Real-time measurement systems include any investigative or analytical technologies that support real-time decision-making. Real-time analytical technologies are distinguished by rapid turnaround times. Results are available quickly, allowing decisions about the progress of the investigation to be made in the field. Ideally, real-time measurement technologies streamline the investigative process by minimizing field mobilizations, as well as reporting and reviewing cycles.

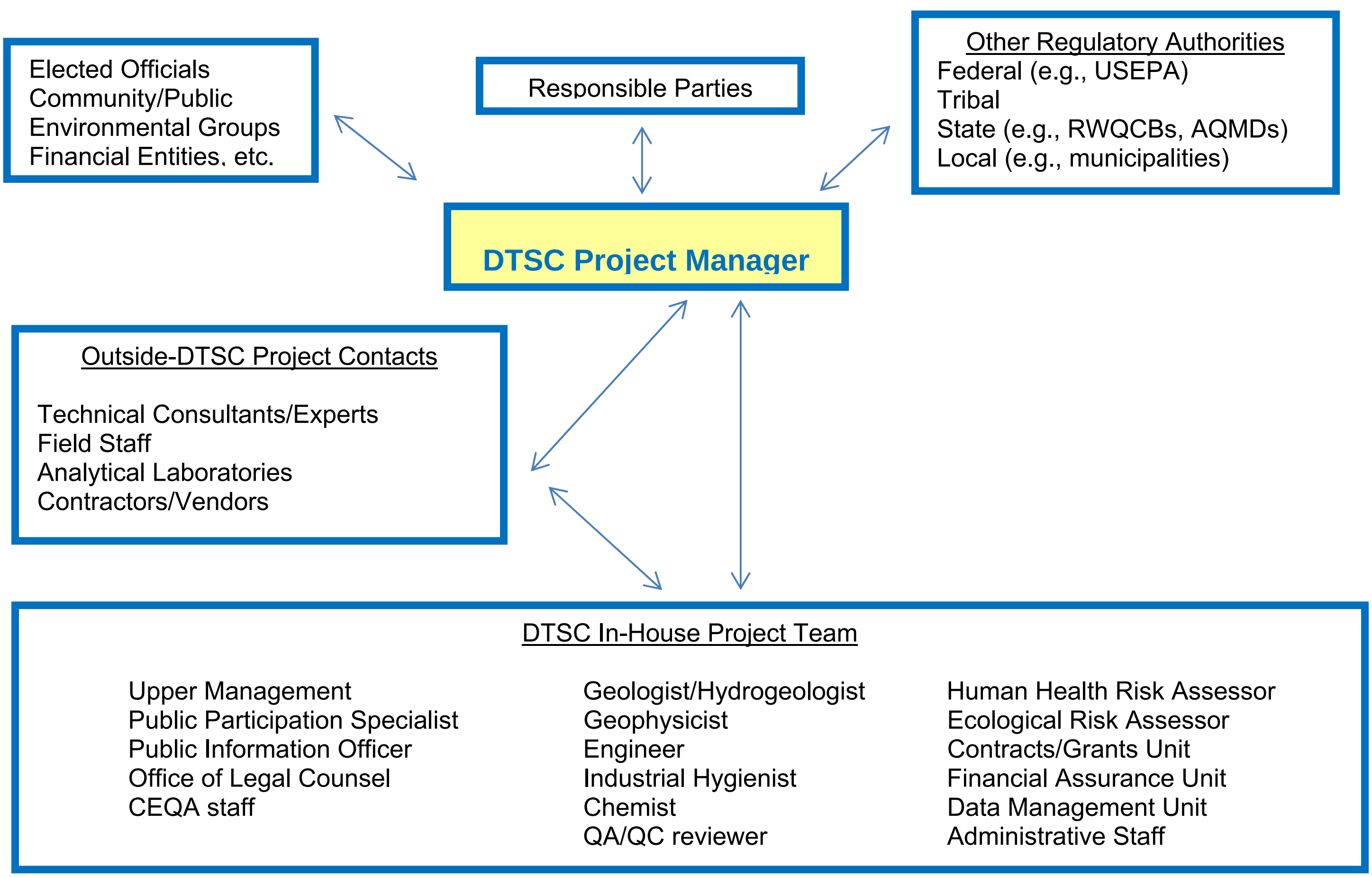
For example, using direct push tools, multiple sensors can be used simultaneously or consecutively and a robust CSM developed that incorporates several lines of evidence across various media. Sampling results from various media (including data generated using traditional methodologies) can be displayed in a cross-section format, along with lithologic and hydrogeologic properties. Data uncertainty is reduced by comparing information generated by various technologies or analytical methods (i.e., collaborative data sets). As data uncertainty is reduced, uncertainty related to decision-making is also reduced, and confidence in investigative and regulatory processes is advanced.

Real-time measurement technologies are described in greater detail in *4.0 Selection and Application of Field Methods*. Team members and technical staff should stay informed, as new tools are continually being developed and familiar tools are being upgraded and equipped with additional capabilities.

2.7 Assembling the Site Team

Assembling a site team is the first step in strategic planning and work plan development. Strategic planning involves the coordinated efforts of many individuals, including those that generate data and those that use data to make decisions. Because each site has different needs, and because different team configurations will be appropriate at different phases of site characterization, team structure may change as a project evolves and therefore, team membership should be re-evaluated frequently. A large group may be involved in the site team, whereas a smaller group may be selected for work plan development. Figure 2-1 shows possible team members and their relationships for a hypothetical DTSC site.

Figure 2-1 Project Relationships



DTSC project managers play the central role in all planning activities. Project managers identify key members of the site team for each phase of work, plan agendas for scoping meetings, initiate and track work requests and task orders, and serve as the communication hub for all team activities. Other responsibilities include: informing and securing approval of upper management, liaising with public participation, technical, and legal staff, setting and upholding schedules and budgets, and establishing lines of communication with responsible parties, contractors, and other stakeholders (e.g., tribal representatives).

At the scoping meeting for each work plan, the project manager should ensure that appropriate team members are present. For example, when developing a work plan for wetlands investigation, the ecological toxicologist assigned to the site should be present.

2.8 Work Plan Development

A work plan (also known as a sampling and analysis plan or SAP) has three components:

- Field Sampling Plan (FSP),
- Quality Assurance Project Plan (QAPP), and
- Health and Safety Plan (HASP).

These three components should be included in every work plan submitted to DTSC. The FSP, QAPP, and HASP are each designed as stand-alone documents. For example, the FSP should contain sufficient description and detail to enable the field crew to conduct field activities (i.e., step-by-step procedures and standard operating practices or SOPs).

Figure 2-2 illustrates the work plan development process. Table 2-1 lists recommended elements of the FSP, QAPP, and HASP. Table 2-1 lists are general—more (or less) elements may be needed, depending on the field activities proposed.

Figure 2-2 Work Plan Development Flow Chart

Assemble Project Team

↓

Conceptual Site Model (CSM)
- Pathway-Receptor Networks
- Geology/Hydrogeology
- Other CSM Elements

↓

Evaluate Nature and Extent of Contamination
and
Identify and Prioritize Data Gaps

↓

Data Quality Objectives (DQO) Process

↓

Sampling Design

↓

Work Plan
(aka Sampling and Analysis Plan or SAP)

↓

Field Sampling Plan (FSP) | **Quality Assurance Project Plan** (QAPP) | **Health and Safety Plan** (HASP)

This guidance has a specific emphasis on FSP development for hydrogeological investigations. Critical elements of the FSP are the CSM, DQOs, and sampling design. These elements are discussed below, along with risk assessment. Although the emphasis for this guidance is on hydrogeological (groundwater) investigations, the approach described also applies to work plans for other media, including multi-media work plans.

The QAPP is a critical element of each work plan. In particular, the QAPP is intended to ensure that data precision, accuracy (or bias), completeness, comparability, and representativeness meet DQOs and that the data are acceptable for decision-making. In documents submitted for DTSC's review, the QAPP relates to laboratory work and is usually limited to data validation and the usability of analytical samples (Table 2-1).

Box 2-1 Point of Clarification

In USEPA's guidance, the scope of the QAPP varies depending on project needs, but may expand to include project management, data acquisition and generation, and quality control of field activities (i.e., USEPA's Groups A, B, and C in Table 1). However, in work plans submitted to DTSC, project management, data acquisition and generation, and quality control of field activities are addressed in the FSP. USEPA's *Group D Data Validation and Usability* is the only topic usually addressed in QAPPs submitted to DTSC.

Table 2-1 Recommended Work Plan Content

Field Sampling Plan (FSP)

- Site History and Physical Setting
- Summary of Existing Data and Previous Response Actions
- Description of Field Activities
- Project Organization and Responsibilities
- Conceptual Site Model (CSM)
- Data Quality Objectives (DQOs)
- Sample Location and Frequency
- Sampling Equipment and Procedures
- Sample Designation
- Sample Handling and Analysis
- Field Instrument Quality Assurance/Quality Control (QA/QC)
- Utility Clearance
- Management of Investigation-Derived Waste (IDW)
- Reporting Requirements
- Schedule
- Standard Operating Procedures (SOPs)
- Field Forms

<u>Quality Assurance Project Plan</u> (QAPP)

- Site History and Physical Setting
- Description of Field Activities
- Project Organization and Responsibilities
- Quality Assurance Objectives
- Sampling Procedures
- Sample Custody
- Calibration Procedures
- Analytical Procedures
- Data Reduction, Validation, and Reporting
- Internal Quality Control
- Performance and Systems Audits
- Preventative Maintenance
- Data Assessment Procedures and Corrective Actions
- Quality Assurance Reports
- Laboratory Certification

<u>Health and Safety Plan</u> (HASP)

- Site History and Physical Setting
- Description of Field Activities
- Project Organization and Responsibilities
- Job Hazard Analysis
- Employee Training Assignments
- Medical Surveillance Program
- Personal Protective Equipment
- Exposure Monitoring Plan
- Site Control Measures
- Emergency Response Plan
- Confined Space Entry Procedures
- Spill Containment Program
- Potable Water and Sanitation Provisions
- Safe Drum/Container Handling Procedures
- Illumination Provisions

Detailed comprehensive discussions on quality assurance (as well as on sampling plans, data quality assessment, DQOs, et cetera) are provided in USEPA's *Agency-Wide Quality System Documents.* With respect to QAPPs, the primary reference is USEPA's *Guidance for Quality Assurance Project Plans EPA QA/G-5* (December 2002). See *Box 2-1 Point of Clarification*. QAPPs are not further discussed in this document.

A HASP should be provided for each work plan, and is required for state-funded projects. However, the HASP is not discussed in this document. For more information, see DTSC's 2011 guidance: *Site Specific Health and Safety Plan Guidance Document for Sites under DTSC Purview*.

2.9 Work Plan Scoping Meeting

At the work plan scoping meeting, decisions that have to be made are identified, as well as decision-makers and responsible parties. Meeting activities/outcomes include: evaluating site history and existing data, developing/updating the CSM, identifying data gaps, setting work plan objectives, establishing DQOs, agreeing on a sampling design that meets DQOs, generating a schedule, and determining reporting requirements.

Technical, legal, and public participation staff should be included in the FSP scoping meeting, as appropriate. For the project to be successfully designed and implemented, it is especially critical that technical staff who will be reviewing results of work plan activities participate in the scoping meeting. For example, geological, engineering, and risk assessment support staff should be included in the scoping meeting for a soil vapor intrusion study.

In addition to the specific work plan under development, an overall approach to site characterization and possible remedial actions should be discussed during the scoping meeting. For example, the team may discuss whether a presumptive remedy (or a proven technology) may apply to the site—or whether risks posed by the site are so significant that an expedited response action (or removal action) is warranted. At the meeting, potential obstacles or hurdles (to both the scope of the work plan and overall site characterization) should be appraised and a communication strategy agreed upon.

2.10 Risk Assessment

The primary goal of site characterization is to obtain the data necessary to evaluate potential current and future risks to human health and to the environment. A secondary goal of site characterization is collection of data needed for remedy selection.

During early stages of site characterization, a preliminary human and ecological risk evaluation is performed as described in DTSC's *Preliminary Endangerment Assessment Guidance Manual* (PEA Manual 2012). At this stage, the need for immediate action (e.g., fencing or evacuation) may be assessed.

Further along in the site characterization process—after sufficient data have been collected—a more detailed site-specific human health risk assessment (HHRA) and/or an ecological risk assessment (ERA) may be performed under oversight of the regulatory agency.

Work plans must be designed to collect the chemical and hydrogeological data needed for risk assessment, specifically:

- Nature and extent of contamination in all media;
- Current and potential (including future climate-related) pathways of exposure; and
- Current and potential receptors (including projected shifts in receptor habitats).

For long-term projects (e.g., when waste is left in place), consideration of future changes in pathways of exposure due to climate change may be warranted (e.g., shifts in receptor habitats due to sea level rise). Data quality sufficient for risk assessment is determined as part of the DQO process, discussed in Section 2.12, below.

2.11 Conceptual Site Model (CSM)

A CSM is a scientifically defensible foundation for decision-making that evolves as the site investigation and remediation progresses.

The CSM process is necessarily iterative. For example, at the start of a site investigation, the preliminary CSM is based on available information about the site setting and historical activities at the site. Suggestions for historical site data that should be evaluated are included in DTSC's PEA Manual and in ASTM standards for Phase I and Phase II Environmental Site Assessments. Information required for hydrogeological characterization is discussed in Section 3.

As data are collected, the CSM is continually updated and should be re-presented in subsequent work plans. When site characterization is complete, the CSM should be sufficiently detailed for remedy selection. Even after remedy selection, the CSM evolves: that is, during remedy implementation, predicted site responses are compared to actual site responses and the remedy is optimized, as needed. The evolution of the CSM through all phases of the project is described as the CSM life-cycle.

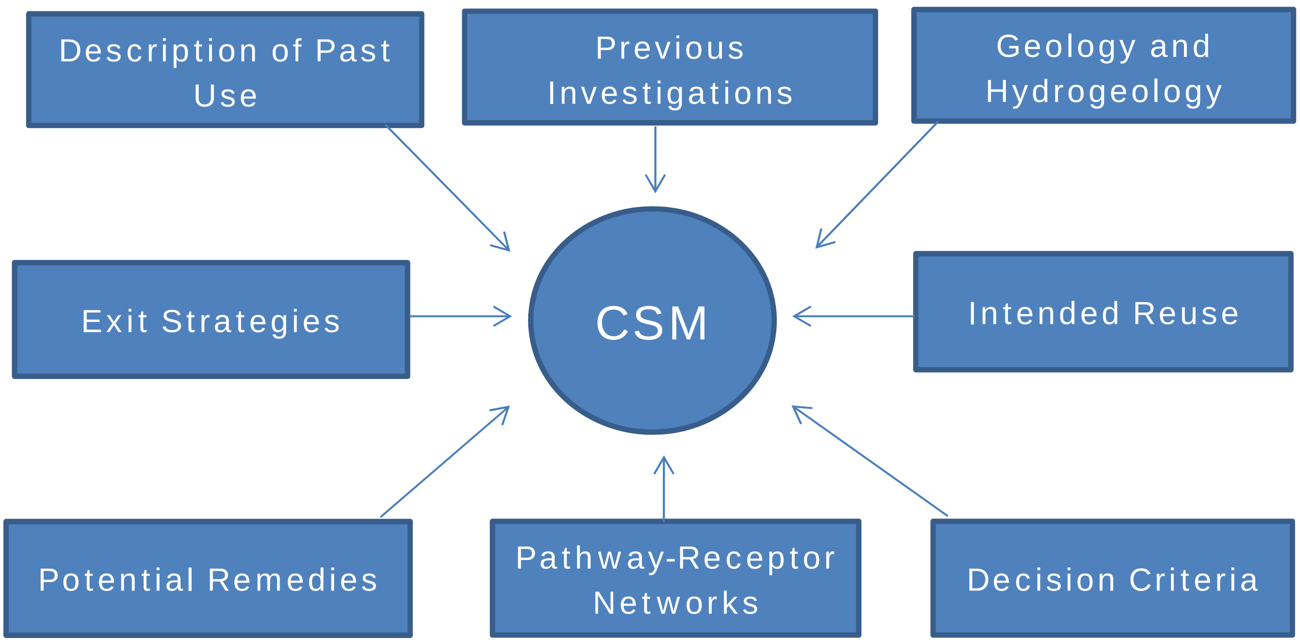
Traditionally, the CSM included only the elements needed for risk assessment (i.e., nature and extent of contamination in various media, pathways of exposure, and receptors). In the Triad approach, the CSM has expanded to include other elements. Traditional CSM elements are shown in *Figure 2-3 Anatomy of a CSM* as the box titled *Pathways-Receptor Networks*. New elements, or elements that have been expanded, are: *Past Use, Previous Investigations, Geology and Hydrogeology, Intended Reuse, Decision Criteria, Potential Remedies, and Exit Strategies*. Anticipated or projected future changes (e.g., related to climate change) might also be relevant to the CSM.

In the Triad approach, during work plan development, greater emphasis is placed both on evaluation of historical site data and on looking forward to potential remedies and site closure. A broader holistic viewpoint is maintained at all phases of site investigation, as opposed to a narrower focus on the tasks of a specific work plan.

The CSM should include a narrative and graphical description of the characteristics of a site that may affect the distribution and migration (fate and transport) of contaminants.

The CSM should be discussed in FSP scoping meetings and used as the basis for planning field work. That is, based on the CSM, data gaps are identified, prioritized, and addressed. Also, when describing the CSM, it is important to distinguish facts from theories and assumptions to ensure adequate transparency. Essential features of the site's hydrogeology, to be incorporated into the CSM, are discussed in detail in *3.0 Objectives and Methods*.

Figure 2-3 Anatomy of a CSM
(from USEPA's Triad Central website)



The CSM element which is the focus of this guidance is *Geology and Hydrogeology*. The degree of detail and accuracy of a hydrogeological CSM varies according to the site's contaminant properties and hydrogeology. For example, a homogeneous unconfined aquifer may require only simple cross-sections and water table maps to illustrate the hydrogeological elements of the CSM. In contrast, a more complicated setting with multiple aquifers, multiple confining layers, and multiple contaminants will demand a more detailed CSM. A complex CSM may include flownets, potentiometric surface or water table maps for each aquifer, geochemical diagrams, structural contour maps, and isopach maps (showing contours of equal thickness of a layer or strata). Sites with potentially greater risk may need CSMs of greater detail and accuracy.

Due to recent advances in data visualization software, animated versions of the CSM, with zooming and three-dimensional rotation, can be created. Data visualization tools are especially valuable for technical staff reviewing site data and for public meeting presentations. *Reporting Hydrogeologic Characterization Data from Hazardous*

Substance Release Sites (Cal/EPA 1995i, under revision) contains more detail on CSM graphical presentations.

2.12 Data Quality Objective (DQO) Process

The DQO process is a seven-step scientific and legally defensible data collection planning process that allows users to determine the type, quality, and quantity of data that will be sufficient for decision-making. The DQO process should be used at each stage of site characterization.

Outputs of the DQO process are statements that describe data quality and sampling design. Sampling design includes the spatial and temporal boundaries of the field activities, the overall sampling strategy, numbers and locations of samples, and sample collection and analysis methods.

The DQO process consists of seven iterative steps as shown in Figure 2-4. Steps 1 through 5 provide narrative descriptions and quantitative criteria, such as:

- A description of the environmental problem that initiated the study;
- A description of the CSM;
- The decisions that need to be made and inputs to the decision;
- The type, quality, and quantity of data needed;
- The decision rules, usually expressed as "if … then" statements; and
- An explanation of how the data will be used.

Step 6 establishes specific performance or acceptance criteria, known as data quality objectives or DQOs.

- For estimation problems (e.g., exposure point concentrations for an ecological contaminant or an average rate of groundwater flow), DQOs are expressed in terms of acceptable uncertainty at a desired level of statistical confidence.
- For decision problems (e.g., an exceedance of acceptable levels), DQOs are typically expressed as tolerable limits on the probability or chance (risk) of the data leading to an erroneous decision.
- In the case where the data are not sufficient for statistical analysis, this fact should be discussed. For example, if sampling locations are selected based on known areas of release (i.e., biased or judgmental sampling), as opposed to a statistical sampling approach, this information should be discussed in Step 6.

Figure 2-4 Data Quality Objective (DQO) Process

1 **State the Problem**
Summarize the Contamination Problem that will require new environmental data, and identify the resources available to resolve the problem.

2 **Identify the Decision**
Identify the decision that requires new environmental data to address the contamination problem.

3 **Identify Inputs to the Decision**
Identify the information needed to support the decision, and specify which inputs require new environmental measurements.

4 **Define the Study Boundaries**
Specify the spatial and temporal aspects of the environmental media that the data must represent to support the decision.

5 **Develop a Decision Rule**
Develop a logical "if... then..." statement that defines the conditions that would cause the decision-maker to choose among alternative actions.

6 **Specify Limits on Decision Errors**
Specify the decision-maker's acceptable limits on decision errors which are used to establish performance goals for limiting uncertainty in the data.

7 **Optimize the Design for Obtaining Data**
Identify the most resource-effective sampling and analysis design for generating data that are expected to satisfy the DQOs.

In Steps 1 through 6, narrative, quantitative, and qualitative criteria for the sampling design are identified. In Step 7, the sampling design is developed and optimized. If the work plan involves multi-media sampling or the use of various sensing technologies, each media and technology should be included in the DQO process.

Decision rules in the work plan should relate to the specific work to be performed and to specific media—not to overall decisions for the site. For example, it is not appropriate to state: "If sampling results are less than risk-based criteria, then no further action will be required at the site." Instead, the decision rule should state: "If groundwater sampling results at a location are less than risk-based criteria, then there will be no step-outs at that location." The regulatory decision on whether no further action is required at a site is a conclusion that should be reserved for a decision-document (e.g., the remedial action plan for the site).

The DQO process is described in detail in USEPA's *Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4,* February 2006.

2.13 Sampling Design

The project team evaluates the best overall investigation strategy for the work plan. For example, the team assesses whether the site should be subdivided into portions with different investigation objectives (i.e., source areas versus dissolved plumes). And, the team considers whether: 1) a dynamic work plan is appropriate; 2) the field work should be phased; or, 3) field work should be multi-tasked. In phased work, results from the first phase of work are reviewed prior to initiating the second phase of work (i.e., work proceeds sequentially from phase to phase, with a separate work plan for each phase). In multi-tasking, various phases or types of work occur simultaneously (e.g., grab groundwater sampling and well sampling, described in a single work plan).

The phased approach may be appropriate for some sites, where budget and resource constraints are relatively high and risk from contamination appears low. The time to completion may be prolonged if the phased approach is used. In contrast, dynamic work strategies and multi-tasking may shorten the overall time required for site cleanup, primarily by reducing the time required for the development of multiple work plans and the review of multiple field reports. A mix of strategies (i.e., dynamic work strategies, phased approaches, and multi-tasking) may also be selected.

The type, quantity, and quality of data to be collected will depend on the stage of site characterization (i.e., initial site assessment versus detailed studies for remedial implementation) and other factors (i.e., budget, availability of equipment, logistics). Collaborative, reconnaissance (or screening-level), or detailed investigations can be evaluated.

Collaborative

Collaborative designs relate to chemical analytical data. In collaborative designs, chemical analytical data of varying quality are collected, various chemical methods are used, and/or the data collected have differing DQOs or QA/QC. For example, low-quality grab groundwater samples analyzed in the field are compared to high-quality groundwater samples collected from monitoring wells and analyzed in a fixed laboratory with specified QA/QC. Another example: the soil sampling collaborative design includes 1) samples analyzed for metals by XRF (X-Ray Fluorescence) in the field and 2) duplicate samples submitted to a fixed laboratory for ICP (Inductively Coupled Plasma) analysis. A mix of low-quality with high-quality samples may decrease uncertainty while lowering cost.

Reconnaissance

Reconnaissance (or screening-level) investigations are often used where little or no site-specific information is available. The intent is to rapidly gather preliminary information with minimal cost and effort. Data collected from the screening-level investigations are used to focus the efforts of subsequent detailed studies. For example, screening-level grab-groundwater investigations can be conducted to determine the extent of groundwater contamination prior to installing permanent groundwater monitoring wells. Traditionally, screening-level investigations were considered to be qualitative rather than quantitative. However, data analysis using innovative screening-level technologies can sometimes be comparable to data analysis in a fixed laboratory (e.g., sufficient for risk assessment).

Detailed

Detailed investigations are more comprehensive and therefore, require more planning and justification. Hence, the cost and effort expended in data collection in detailed investigations may be greater than that for screening-level investigations. For example, pump tests to determine aquifer properties are more costly than slug tests and more costly than inferring aquifer properties from soil data. Traditional investigative technologies as well as innovative technologies can be employed in both screening-level and detailed investigations.

Practical constraints regarding access, seasonality, and physical location must also be identified when designing an investigation strategy.

Once the overall investigation strategy is decided upon, then, based on the CSM and the DQOs, details of the sampling design are determined—i.e., the type, quality, and quantity of data needed. Sampling design elements that should be documented in the FSP are:

- Number of samples;
- Sample type (i.e., media, composite versus discrete samples);
- Sample collection procedures;
- Physical sample (i.e., amount of material to be collected for each sample);
- Sampling locations (surface coordinates and depth) and rationales for selecting sampling locations;
- Sample handling (i.e., chain-of-custody, packaging, shipping);
- Analytical methods (or performance-based measurement standards); and
- Statistical sampling scheme (if applicable).

The FSP should contain sufficient detail for the field crew to execute the work, including step-by-step procedures for all sampling/investigation activities. Detailed descriptions of field activities are needed, so that regulatory staff can determine if the work proposed is consistent with guidance and standards of practice. Detailed descriptions are also needed so that regulatory staff overseeing field work can determine whether the work being executed is compliant with the work described in the DTSC-approved work plan. SOPs may be used in the FSP, provided that the SOPs are specific to the work that will be conducted. That is, generalized SOPs that contain descriptions of various tasks which are not part of the FSP scope are not acceptable—unless out-of-scope activities are redacted.

Figures and tables serve to organize and present data so that FSP objectives are transparent and review time is streamlined. Recommended figures and tables (and other elements) include:

- Signature page with stamp/seal (if required) of professional in responsible charge;
- Figure showing proposed sampling locations;
- Figures showing site vicinity, site features, and existing data (e.g., locations and concentrations);
- Table summarizing samples to be collected (e.g., sample identifications, duplicates, trip blanks, et cetera);
- Table itemizing analytical methods—and sampling and preservation requirements for each media (e.g., container, preservation, holding time, sample volume);
- Tables and figures summarizing existing data (e.g., chemical concentrations, water level measurements, well construction details);
- Table with geographic information for existing data (e.g., surface coordinates, depths);
- Project-specific SOPs;

- Chain-of-custody forms and shipping forms; and,
- Field forms for each FSP activity (e.g., groundwater sampling, well installation, well development, pump tests, soil gas sampling, et cetera).

Table 2-1 summarizes FSP contents and *4.0 Selection and Application of Field Methods* discusses various tools used for groundwater characterization. The worksheet format for work plans developed by federal agencies (USEPA, DOD, and DOE 2005) is acceptable, provided that the worksheets are complete and consistent with each other.

In addition, specific field activities are discussed in detail in DTSC's guidance manuals for groundwater investigations, which are currently being revised (Cal/EPA 1994 and 1995a through h). Individual manuals cover:

- Preliminary endangerment assessment,
- Groundwater sampling,
- Monitoring well design and construction,
- Aquifer testing,
- Groundwater modeling,
- Surface and borehole geophysics,
- Drilling, coring, sampling, and logging; and,
- Reporting for hydrogeological investigations.

USEPA's *Guidance for Choosing a Sampling Design for Environmental Data Collection EPA QA/G-5S* provides details on selecting a sampling and analysis design.

Visual Sample Plan (VSP) is a software tool for selecting the number and locations of samples that satisfy statistical requirements for decision-making. VSP is designed for the non-statistician and is available at no cost from the Pacific Northwest National Laboratory website.

2.14 Removal Actions

An outcome of the site investigation process is to identify whether expedited response actions (e.g., removal actions or RAs) are needed. In fact, RAs can be done any time during the characterization process when a need for expedited response action is identified.

RAs are short-term activities conducted when a release or threatened release poses an imminent or substantial risk to health or environment. RAs are classified as: emergency removals, time-critical removal actions (TCRAs), and non-time-critical removal actions (NTCRAs, aka interim remedial measures or IRMs). These RA classifications have different federal and state regulatory requirements. For emergency RAs and TCRAs, a streamlined regulatory process may be employed.

Often, activities involved in these RAs are similar. The key differences between emergency RAs, TCRAs, and IRMs are the type and severity of the potential threat to public health or the environment posed by a release and the immediacy of the response that is needed to minimize the threat. The project management team determines whether an expedited response is needed and whether the response should be classified as an emergency RA, a TCRA, or an IRM.

These principles should be kept in mind:

- The RA should reduce risk;
- The RA should not exacerbate the problem;
- Simple solutions are preferred; and
- The RA should be designed (if possible) for incorporation into the final remedy.

Because RAs can quickly reduce public health and environmental risk when effectively implemented, the RA approach is recommended wherever feasible. Using this approach, it is conceivable that small sites with limited contamination and simple geology could be characterized and remediated through a series of RAs. However, the applicability of any RA should be evaluated on a site-specific basis.

RAs can range from the simple to the complex. Examples of some activities that may be conducted as RAs, and the risks that the RAs minimize, are presented in Table 2-2.

Table 2-2 Examples of Removal Actions

Fencing/Posting Warning Signs: To minimize direct contact

Drainage Control: To minimize direct contact and contamination of surface water

Structural Stabilization: To maintain integrity of containment structures

Chemical Stabilization: To reduce spread of release or control dangerous chemical reactions

Soil or Waste Removal or Capping: To prevent direct contact and minimize spread of release

Alternative Water Supply: To prevent consumption of contaminated water by the affected population

Soil Gas/Free-Product/Groundwater Extraction: To minimize spread and severity of release

2.15 Presumptive Remedies

Presumptive remedies are preferred technologies for common categories of sites, based on historical patterns of remedy selection. If a presumptive remedy is appropriate for a site, data collection efforts can be reduced by focusing on specific data needs, and remedy selection streamlined, saving time and money. Therefore, presumptive remedies should be considered during work plan development.

USEPA's categories of sites for which presumptive remedies exist include: municipal landfills, contaminated groundwater sites, wood treatment sites, and sites with soils contaminated with VOCs. DTSC has developed Proven Technologies and Remedies (PT&R) guidance documents for: plating facilities, organochlorine pesticides in soil, chlorinated VOCs in vadose zone soil, vapor intrusion mitigation, and metals in soils. Additional categories of sites will be added as presumptive remedies are identified. Therefore, occasional checking of USEPA's website for presumptive remedies is recommended. Climate change impacts may need to be considered when assessing the appropriateness of presumptive remedies, especially when waste is left in place.

2.16 Investigation Endpoints

In site investigation, a crucial question is: "When do we stop studying?" With respect to each work plan, the question is answered (in advance) by the decision rules of the DQO process, as stated in the FSP.

With respect to the broader site characterization, and because each site is different, it is not possible to set explicit requirements that apply to all groundwater characterizations. Data uncertainties are reduced—as data gaps are filled, as the CSM evolves, and as site processes are better understood. Consequently, uncertainties related to decision-making are reduced. Confidence among team members increases as an investigation endpoint is approached. Therefore, the project manager should rely on the expertise and judgment of team members for determining that the endpoint has been reached and that: *Data are sufficient for risk assessment and remedy selection*.

2.17 Green Remediation and Sustainability

As part of the planning process, green and sustainable options should be considered during investigation, remediation, operation and maintenance, and remedial process optimization (e.g., five-year reviews).

Green Remediation

USEPA defines green remediation as the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions. For example, green options minimize energy and water consumption, as well as waste generation.

Sustainability

Sustainability involves a broader spectrum of considerations. In addition to minimizing energy, water, and waste, sustainability involves environmental, social, and economic aspects of decision-making.

Federal Executive Order 13514 (*Federal Leadership in Environmental, Energy, and Economic Performance,* Obama Administration, October 2009) defines sustainability as the ability "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations."

Sustainability is a visionary framework, which may be incorporated into a future, all-encompassing regulatory framework. *Sustainability and the U.S. EPA*, a 2011 study by the National Research Council, says: "…current approaches aimed at decreasing existing risks, however successful, are not capable of avoiding the complex problems in the United States and globally that threaten the planet's critical natural resources and put current and future human generations at risk, including population growth, the widening gaps between the rich and the poor, depletion of finite natural resources, biodiversity loss, climate change, and disruption of nutrient cycles."

USEPA's existing risk assessment/management paradigm is expected to be expanded to a sustainability paradigm. Project managers and technical consultants are advised to keep informed with respect to future regulatory requirements and to the various tools for sustainability assessments under development.

DTSC's *Interim Advisory on Green Remediation* (December 2009) introduces principles of sustainability (e.g., life-cycle assessment) and presents a simple tool, the green remediation evaluation matrix (GREM), which can be used to perform qualitative comparisons of treatment alternatives.

Other guidance documents

- USEPA 2008. *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites, Technology Primer.* EPA 542-R-08-002. Office of Solid Waste and Emergency Response (OSWER).
- USEPA 2009. *Green Remediation Best Management Practices: Site Investigation* EPA/542/F-09/004. OSWER and Office of Superfund Remediation and Technology Innovation (OSRTI).
- USEPA 2010. *Superfund Green Remediation Strategy*. OSWER and OSRTI.
- ITRC 2011. *Green and Sustainable Remediation: State of the Science and Practice*.
- ITRC 2011. *Green and Sustainable Remediation: A Practical Framework.*

2.18 Climate Change

Climate change, due to increasing greenhouse gases (GHG) in the atmosphere, will have long-standing impacts including changes in temperature, sea level, flooding, catastrophic fires, and extreme climatic events (e.g., increased intensity, duration, and frequency of storms). Some climate change concerns overlap with sustainability concerns (which are discussed in the previous section). Climate change effects may need to be considered during site investigation, remediation, and remedial optimization. For example, for sites where waste is left in place, future conditions or events that can alter the climate and hydrology in the vicinity of the site should be considered to prevent or minimize inundation, salt water intrusion, and damage to structural components of the remedy (e.g., caps, treatment walls, and pumps).

Mitigation

Mitigation refers to measures that directly reduce GHG emissions. In 2005, Governor Schwarzenegger issued Executive Order S-3-05, establishing statewide GHG emission targets. In 2006, the *Global Warming Solutions Act* (AB 32) was passed, requiring GHG emissions be reduced to 1990 levels by 2020. The California Air Resources Board's 2008 *Scoping Plan* identifies mitigation measures required to meet requirements of AB 32.

DTSC's CEQA projects require a GHG analysis. A project's GHG emissions must be quantified to the extent possible and compared with thresholds of significance specified in the air quality management plan (AQMP) for the air basin in which the site is located. AQMPs are developed and enforced by Air Quality Control Districts (AQMDs). Mitigation measures must be implemented if estimated emissions are deemed significant. County and municipal plans may also need to be considered.

DTSC project managers should consider GHG mitigation measures during project planning. For example, GHG emissions of trucks and other equipment should be assessed during investigation and remediation (e.g., when comparing excavation, in situ treatment, and containment). And, feasibility plans should include an assessment of GHG emissions, along with energy, water, and waste footprints, for proposed projects.

Adaptation

Adaptation refers to measures taken to manage climate change impacts.

Climate change scenarios (e.g., related to extreme precipitation, catastrophic fires, and sea level rise or SLR) provide information on possible future events at a site and forecast potential shifts in the timing and frequency of events in the site vicinity. For example, current estimates of flood frequency based on historical data may not be reliable indicators of future events (i.e., an historic 100-year flood may now actually be a 15-year flood)—and, the potential for catastrophic fires may impact remedy selection for sites near forested areas. Climate change scenarios should be evaluated during decision-making at a site, especially for long-term projects for which waste will be left in place. The *Cal-Adapt* website presents scenarios for various climate change impacts, including local impacts.

SLR is a climate change impact of special concern for coastal sites, the San Francisco Bay, and the Sacramento Delta. Governor Schwarzenegger's Executive Order S-13-08 directed State agencies to consider a range of SLR scenarios for the years 2050 and 2100—to assess project vulnerability, reduce expected risks, and increase resilience to SLR. In response, the Natural Resources Agency released *2009 California Climate Adaptation Strategy*. The purpose of this collaborative report from multiple state agencies was to begin a "statewide, ongoing, and committed process of adapting to a changing climate." Subsequently, the *Resolution of the California Ocean Protection Council* [OPC] *on Sea-Level Rise*, adopted on March 11, 2011, says that State agencies, as well as non-state entities implementing projects or programs funded by the state or on state property, should consider risks posed by SLR in all decisions regarding areas or programs potentially affected by SLR.

DTSC project managers have been advised to consider OPC's resolution during project planning. For example, SLR, the storm surge associated with SLR, and the potential for loss or gain of wetlands, should be considered during decision-making. The National Research Council's report on SLR (NRC 2012) provides additional information on SLR on the West Coast.

Project managers should keep informed with respect to future regulatory developments related to climate change impacts.

3.0 HYDROGEOLOGICAL OBJECTIVES AND METHODS

The previous section presented the following three broad objectives of developing the hydrogeologic CSM:

- Characterizing geology and hydrogeologic conditions,
- Characterizing aquifer parameters, and
- Delineating the nature and extent of contamination.

This section discusses these objectives in detail and also discusses groundwater and hydrogeological characterization methods that can be used to achieve these objectives. Issues related to field implementation of the characterization methods is presented in *Section 4 – Selection and Application of Field Methods*.

3.1 Geology and Hydrogeology

The compilation of data regarding the geologic and hydrogeologic characteristics of the site comprises a critical portion of the CSM. The CSM should present a description of the geology and hydrogeology beneath and surrounding the site in a detailed enough manner to delineate the full extent of groundwater contamination and identify contaminant transport pathways. Contaminant transport pathways from the original release, through the vadose zone (i.e., the unsaturated zone above the water table), and through the affected aquifers (aka water-bearing zones) should all be identified. This objective requires an understanding of the distribution, thickness, composition, and continuity of the lithologic (i.e., soil and rock) units that may influence groundwater flow and contaminant migration into and within any potentially affected water-bearing zones. Anthropogenic features that influence contaminant migration should be identified (e.g., wells, pumps, vaults, pipelines, and trenches).

Table 3-1 summarizes the information needed for an effective hydrogeologic characterization. Depths to the water table should be measured. Groundwater flow directions and gradients should be estimated for both the horizontal and vertical directions. Aquifers (i.e., water-bearing zones) and aquitards (zones which impede water flow) beneath the site should be delineated, along with any geologic features that may affect groundwater movement such as faults, folds, fractures, buried channel deposits, or solution features. Depths to the water table should be determined. The composition and properties of the soil and rock in the overlying vadose zone should also be evaluated. In addition to these factors, seasonal groundwater variations, transient effects (e.g., tides), recharge and discharge zones, and beneficial uses of aquifers should be identified.

Table 3-1 Summary of Hydrogeologic Characterization Information Needs

Geology and Hydrogeology		
Information Needed	Purpose	Collection Methods
Description of aquifers (e.g., depth, thickness, extent, conductivity, confined/unconfined)	Determine cross-contamination potential	Existing literature, lithologic sampling, water level measurements, chemical analytical data
Geologic features	Identify features such as faults, folds, fractures, buried channels, that may affect groundwater flow	Existing literature, lithologic sampling, water level measurements, geophysics
Description of aquitards (e.g., depth, thickness, extent, conductivity)	Determine cross-contamination potential, identify likely flow paths	Existing literature, lithologic sampling, water level measurements, chemical analytical data, geophysics
Depth to water table (seasonal and artificially imposed variations)	Assess potential for groundwater contamination. Assess potential for groundwater VOC impacts to pose a vapor intrusion risk.	Water level measurements, existing literature
Recharge and discharge areas	Locate potential receptors and locations for flow interception	Site inspection, field mapping, existing literature, water level measurements
Anthropogenic features	Evaluate potential for preferential pathways of groundwater flow or contaminant migration.	Records review, site inspection
Other	Tidal influences, seawater intrusion	Water level measurements, existing literature, chemical analytical data

3.2 Nature and Extent of Contamination

The nature and extent of groundwater contamination emanating from a site should be determined to the degree that is necessary for evaluating the risk to human and ecological receptors. Potential future risks should also be considered, as well as impacts to the groundwater resource.

Data needed to fulfill these objectives include: sources of contamination; contaminant properties, concentrations, and breakdown products; background concentrations; and, the horizontal and vertical extent of contamination in all media (Table 3-1).

With respect to groundwater, a common point of disagreement is the extent to which

Table 3-1 Summary of Hydrogeologic Characterization Information Needs (continued)

Aquifer Characteristics		
Information Needed	Purpose	Collection Methods
Porosity and types of porosity (e.g., granular, fractured)	Support groundwater modeling, assess characterization and treatment options	Lithologic sampling, existing literature
Groundwater flow rates	Estimate rate of migration	Water level measurements, existing literature, groundwater chemistry, in well instrumentation, groundwater models
Aquifer hydraulics (in particular, hydraulic conductivity)	Calculate groundwater velocity, support groundwater modeling	Aquifer tests, in situ testing, laboratory testing, existing literature
General groundwater quality (e.g., pH, salinity, dissolved solids)	Determine groundwater geochemistry, evaluate remedial options, identify discrete hydrogeologic units/hydraulic separation	Laboratory testing, field measurements, existing literature
Groundwater flow directions (horizontal and vertical)	Identify likely pathways for contaminant flow	Water level measurements, tracer tests, groundwater models

Nature and Extent of Contamination		
Information Needed	Purpose	Collection Methods
Contaminants of concern (e.g., concentrations, breakdown products, transformations)	Characterize nature of contamination, assess treatment options, assess fate and transport of contamination	Laboratory testing, in situ and field testing, existing literature
Background/Ambient Concentrations	Evaluate extent of contaminated groundwater, develop cleanup criteria, evaluate effect of up-gradient sources, or comingled plumes	Laboratory testing, in situ and field testing, existing literature
Extent of contamination in all media (groundwater, soil, soil gas, indoor air, surface water, bedrock)	Evaluate source areas and potential risk pathways	Laboratory testing, in situ and field testing, existing literature.
Contaminant concentrations	Lateral and vertical delineation of contamination, assess treatment options	Laboratory testing, rapid field evaluation methods
Mass flux estimates	Evaluate contaminant transport, assess treatment options	Laboratory testing, lithologic data, aquifer tests, in situ testing, groundwater modeling

contaminant concentrations in groundwater should be delineated. Essentially, for a plume to be properly characterized, to what low concentration should contaminants be delineated? There are several comparison criteria that can be used to evaluate if a plume has been adequately characterized. These criteria can include, but are not limited to; background (or ambient) concentrations, Maximum Contaminant Levels (MCLs) and the water quality objectives of the Regional Water Quality Control Board's Basin Plans.

The extent to which groundwater contamination is delineated will differ from project to project and should be based on a site-specific DQO process and decided during the planning stages of the investigation. A summary of the DQO process used for choosing the criteria for contaminant delineation should be included in the investigation work plan along with the assumptions used in developing the rationale. The criteria chosen for contaminant delineation should be lower than the eventual cleanup level. However, during the initial phase of site characterization, a cleanup level is often not available due to sparse characterization data. In this case, groundwater should be delineated to concentrations equivalent to the detection limits necessary for properly conducting a risk assessment. Using concentrations greater than the cleanup level as delineation criteria leads to incomplete characterization of groundwater contamination.

Seasonal variations and background/ambient concentrations of contaminants in groundwater (if any) should also be assessed.

The baseline risk assessment is a primary tool for selecting remedial options. USEPA 1988 (pages 3-20 through 3-23) provides an overview of the risk assessment process. The risk assessment provides a basis to establish cleanup levels for all contaminated media. Groundwater cleanup goals may be established above background values, provided the baseline risk assessment determines that increased risk to human health or the environment would not occur, and that such cleanup goals would not conflict with local or regional groundwater basin plans and policies. Comparing contamination from the site to background concentrations is an effective way of managing and evaluating risk. A disadvantage of not characterizing contamination to background concentrations is that viable risk management options may be prematurely eliminated based solely on a lack of data. For example, a contaminant source may be present upgradient of a site, and would not be discovered if background concentrations were not characterized.

3.2.1 Groundwater Quality

To determine the extent to which a site has impacted groundwater, and to provide data for risk assessment and remedial design, groundwater quality must be characterized. This includes identifying the contaminants present, their concentrations, their degradation products, and the vertical and lateral extent of contamination. Other groundwater data may be needed to assess field protocols and in situ processes—including field parameters (e.g., pH, conductivity, turbidity, temperature, dissolved oxygen or DO, and oxidation-reduction potential or ORP) and general water quality parameters (e.g., pH, salinity, total dissolved solids).

For naturally occurring compounds, or contaminants present at nearby sites, the background or ambient concentrations of compounds in groundwater must be characterized. Guidance for calculating background/ ambient background levels for metals (including arsenic) and polynuclear aromatic hydrocarbons (PAHs) are available as Notes from the Human and Ecological Office on the DTSC website.

In particularly complex hydrogeologic settings, stable isotopic analysis of oxygen and hydrogen can aid in determining water sources and in understanding processes such as recharge and groundwater 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 such as trivalent chromium (Cr^{+3}) and hexavalent chromium (Cr^{+6}). In the case of converging plumes, compound specific isotope analysis (CSIA) may distinguish between various sources of VOCs. CSIA may be used to evaluate monitored natural attenuation (MNA) progress. ITRC's CSIA Fact Sheets provide more information.

3.2.2 Contaminant Fate and Transport

Contaminant fate and transport refers to the manner in which contaminants move through the environment, and how they change as a result of interacting with the environment. Evaluating and describing how contaminants are moving through the environment, and understanding how contaminants may change as they move through the environment are essential to developing an accurate CSM. How contaminants change in the environment and how they move through the environment is termed contaminant fate and transport. The fate and transport of contamination from a source to a potential receptor can be divided into three stages:

- Contaminant released to ground or subsurface,
- Transport and transformation of contaminant in vadose zone, and
- Transport and transformation of contaminant in the saturated zone.

A receptor, either human or ecological, can be affected at any one of these stages. Groundwater is a resource that requires protection as if it were a receptor. Even if groundwater, or an aquifer, is not currently being used, it may be used in the future, and consequently needs to be protected. When planning a groundwater investigation, collecting data to evaluate how contamination has been released and how it is moving through the subsurface should be a primary objective.

How contamination moves in the environment and the degree to which it is transformed depends on several factors including:

- Type of release,

- Timing and mass of release,
- Contaminant concentrations,
- Chemical characteristics of the contaminants,
- Chemical interactions between contaminants,
- Physical and chemical characteristics of subsurface materials,
- Groundwater flow,
- Microbial populations in the subsurface,
- Potential routes of contaminant migration through various media, and
- Cross-media impacts (e.g., groundwater to soil gas to indoor air).

The project DQOs, or other planning tools used to develop the investigation strategy, need to take these factors into account to properly evaluate contaminant fate and transport and ensure that an accurate CSM is developed.

3.3 Aquifer Characteristics

Aquifers are soil or rock zones that transmit water easily. Aquifers are important in site investigation because groundwater contaminants will preferentially migrate through aquifers. These permeable zones are also described as “water-bearing” zones, because drinking water wells and production wells extract water from aquifers.

Aquifer parameters should be measured or estimated to a level of accuracy sufficient for the needs of the project, as determined during the DQO process. Aquifer parameters can be used to estimate the rate and direction of contaminant migration, predict the potential consequences of continuing migration, and design remedies to mitigate the effects of contamination. Depending on site requirements, aquifer parameters obtained from existing literature (in particular, reports from nearby sites) may be sufficient.

Hydraulic conductivity is one important parameter that should be understood to develop an accurate and detailed CSM. This parameter can be measured by conducting aquifer tests, such as pumping tests or slug tests, or by laboratory tests on samples of aquifer material. As part of the DQO process, the limitations of the testing methods as well as the accuracy and precision of the results should be evaluated and understood prior to performing aquifer tests or submitting samples for analysis. Other parameters that may be useful for designing groundwater remedies include transmissivity, storativity (confined aquifers), and specific yield (unconfined aquifers). This information is summarized in Table 3.1.

3.3.1 Hydraulic Conductivity

Hydraulic conductivity is a measure of the ability of a porous geologic material to transmit water. Spatial variations in hydraulic conductivity largely control migration of dissolved contaminants in groundwater but can be difficult to measure. Aquifer testing provides representative estimates of average hydraulic conductivity over a large scale, but does not provide a detailed profile of hydraulic conductivity that would be needed for mass flux estimates or design of in situ remedies. Slug tests provide estimates of hydraulic conductivity on a local scale, but well construction may influence the results.

A variety of direct-push hydraulic conductivity profiling tools is available to obtain detailed estimates of groundwater velocity and hydraulic conductivity in unconsolidated settings, and may be useful depending on the needs of the project. It may be possible to estimate hydraulic conductivity from soil types (e.g., direct observation of cores) or from indirect measurements (e.g., cone penetrometer tests or CPTs, pressure dissipation tests). However, in cases where hydraulic conductivity values will affect groundwater modeling, remediation system design, or other critical aspects of a project, representative estimates of large-scale average hydraulic conductivity should be determined using field methods such as aquifer testing. *Aquifer Testing for Hydrogeologic Characterization* (Cal/EPA 1995 f, under revision) contains guidance for conducting and analyzing aquifer tests.

It may be beneficial to use laboratory measurements of hydraulic conductivity to augment results of field testing as laboratory tests may provide valuable information about the vertical component of hydraulic conductivity of aquifer (and aquitard) materials. However, 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, which provide the most accurate representation of aquifer material, are difficult to collect. Therefore, field methods provide the best estimate of hydraulic conductivity in most cases.

3.4 Aquitard Characteristics

Aquitards are soil zones that limit the vertical movement of water. Aquitards are also described as “confining layers.”

Aquitards are generally comprised of silt and clay with low hydraulic conductivity (i.e., less than 10^{-6} centimeters per second or cm/sec) and can impede the vertical flow of water and contaminants. Aquitards can store groundwater and also transmit it slowly from one aquifer to another. As a result, aquitards can minimize the potential for groundwater contamination to move between aquifers. In particular, aquitards can protect aquifers from contamination. For these reasons, delineation and characterization of aquitards is an important aspect of site characterization for groundwater investigations.

Dissolved contaminants generally migrate more slowly through aquitards than aquifers due to retardation that occurs from adsorption onto organic matter and clay particles. Dissolved contaminants respond to vertical gradients (i.e., pressure differences between aquifers created by aquitards) as well as concentration gradients, discussed below. Some aquitards have poor integrity due to secondary permeability in the form of fractures, rootlets, or other features.

Dense non-aqueous phase liquids (DNAPLs) are denser than water and move downward in the water column under the influence of gravity. VOCs such as tetrachloroethene (PCE) and trichloroethene (TCE) are common DNAPLs. DNAPLs may form pools on the top of aquitards and may also penetrate aquitards through cracks, primary or secondary preferential pathways, and other features (including manmade features like wells). Fractures that are impervious to groundwater flow may be quite pervious to DNAPL. DNAPL penetration through substantial aquitards has been reported, contaminating drinking water aquifers with VOCs.

Dissolved phase contaminants and DNAPL also respond to concentration gradients. When concentrations in aquifers are elevated, contaminants move into adjacent aquitards under a chemical gradient until equilibrium is reached (a process called "matrix diffusion"). Over time, if the concentration in aquifers decreases (due to dilution, natural attenuation, or active remediation), contaminant migration reverses direction. Contaminants move from aquitards towards the lower concentrations in the aquifers (a process called "back-diffusion"). In this way, contaminated aquitards may serve as long-term continuing sources for groundwater contamination in aquifers.

Because of the existence of natural and manmade features that provide preferential pathways for contaminant migration—and because of the processes described above, no aquitard is completely impermeable. Moreover, hydraulic conductivity may vary considerably within an aquitard. Therefore, characterization of aquitards is a critical element of site investigations and an essential element of the CSM. For example, the depth, thickness, and extent of aquitards must be determined prior to locating monitoring and extraction wells, designing screened intervals, and planning in situ groundwater remediation.

In addition to limiting the vertical flow of water, aquitards may also limit or control the vertical movement of subsurface gasses. Aquitards may retard the upward migration of soil gas into overlying portions of the vadose zone, or redirect soil vapor contamination away from source areas. When performing vapor intrusion investigations it is important to assess the presence of potential aquitards and to consider how these low permeability units may affect vapor migration.

Prior to performing field investigation, existing regional and local data sources regarding aquitards and aquifers should be reviewed. For example, well logs in the site vicinity should be obtained and used to develop the initial CSM. Of particular interest are: historical wells (e.g., potential for cross contamination), drinking water wells (e.g., risk to populations and natural resources), and monitoring and extraction wells (e.g., design details). When reviewing well logs it should be kept in mind that they vary in detail and accuracy, and professional judgment is often needed in the interpretation of well logs.

Field investigative methods for delineating aquitards can include indirect methods (e.g., CPTs and geophysical surveys) and direct methods such as inspection of continuous cores and vertical hydraulic head profiling. Aquifer pump tests can be designed to determine the lateral continuity of aquitards and leakage properties. Perched zones, in which groundwater mounds over an aquitard that is limited in lateral extent, should be identified. Preferential pathways for contaminant migration through aquitards should be identified. Hydraulic conductivity can be measured in the laboratory from undisturbed soil samples, but is more often inferred from soil type or aquifer tests.

3.5 Groundwater Flow

The rate(s) and direction(s) of groundwater flow at a site, in both the horizontal and vertical dimensions, need to be estimated to evaluate dissolved contaminant plume distribution. Upward hydraulic gradients occur in ground-water discharge areas. Downward hydraulic gradients exist where ground-water recharge occurs, and can be exacerbated by pumping of nearby remediation and water-supply wells. Defining the vertical hydraulic head distribution at a contaminated site is an essential part of developing the CSM. Potentiometric information (from piezometers or monitoring wells with short well screens) and measurements of the hydraulic conductivity of aquifers are necessary to estimate the rate and direction of groundwater flow. These data are used in conjunction with an understanding of the site hydrostratigraphy, obtained from the geologic characterization described above.

Groundwater flow should be characterized in water-bearing units potentially affected by contaminants from the site. Subsurface structures that can affect groundwater flow should also be considered as they may serve as preferential pathways for contaminant migration. These subsurface structures can range from large naturally occurring structures such as faults, bedding planes, or buried steam channel deposits, to manmade structures such as historical wells, utility trenches, or sumps. Pumping wells or injection wells in the site vicinity may alter horizontal and vertical gradients and flow directions. During site investigations it is important to consider the effects that anthropogenic features may have on groundwater flow.

The investigator should 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 1995d, under revision) provides guidance on well design and installation.

3.5.1 Groundwater Level Measurements

Installing monitoring wells that will provide representative samples of background and downgradient water quality requires a general understanding of regional groundwater flow beneath a site.

To determine hydraulic gradients and groundwater flow directions, the investigator should develop and implement a water level monitoring program. The water level monitoring program must provide precise water level measurements at a sufficient frequency to gauge temporal variations in groundwater flow directions, including seasonal fluctuations in flow directions—or tidal fluctuations, if needed.

Accurate water level elevation measurements (generally $\pm$ 0.01 foot) are necessary to determine groundwater flow directions and groundwater flow rates. This requires that the location and elevation of each well be established by a California- licensed surveyor. A permanent reference point should be installed at each well to provide for an accurate survey. For the purpose of measuring hydraulic head, piezometers and wells should have as short a screened interval as feasible, generally ten feet or less. Well or piezometer screen placement should be based on the detailed boring log.

Whenever possible, wells should be located such that the geometry of the well network is conducive to evaluating groundwater flow directions and gradients. For example, wells for estimating vertical gradients should be close to each other (i.e., the horizontal spacing should be small relative to the vertical spacing being measured). For horizontal gradients, wells should be separated spatially, ideally in a triangular pattern. Wells installed along a line is will not provide useful groundwater gradient information because the water table (or the potentiometric surface) is planar. To estimate groundwater gradient and flow direction, at least three wells should be installed roughly in a triangular pattern. Locations potentially impacted by pumping wells and/or other anthropogenic features should be avoided, unless the purpose of the well is to evaluate the influence of such wells/features.

Hydrostratigraphic relationships should be determined by a trained professional when obtaining and evaluating water level data. To avoid the potential for cross contamination of aquifers, the well or piezometer screen should not penetrate multiple aquifers.

3.5.2 Water Table and Potentiometric Surface Maps

Water level data should be used to construct water table elevation contour maps for unconfined (i.e., shallow) aquifers, and potentiometric surface maps for confined (i.e., generally deeper) aquifers. The lines of equal elevation, or potential, are called equipotential lines. The data used to develop water table maps should be collected from piezometers or wells screened across the water table. Groundwater elevations used to develop a potentiometric surface map should be collected from piezometers or wells screened in the same aquifer. A separate map should be prepared for each aquifer. The direction of groundwater flow is determined by drawing flow lines perpendicular to equipotential lines. The magnitude of the horizontal hydraulic gradient can be determined from spacing of equipotential contour lines and the map scale.

Groundwater flow directions and hydraulic gradients should be established in both the horizontal and vertical directions and over time at regular intervals.

3.5.3 Vertical Groundwater Flow

To adequately determine groundwater flow directions, the vertical component of groundwater flow should 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. Vertical flow profiling can be conducted with a borehole flow meter or a short interval packer/pump located in the well bore to determine the depth of the primary inflow and outflow of groundwater from the open interval of a well.

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

3.5.4 Seasonal and Temporal Factors

Investigators should identify and evaluate natural and anthropogenic factors that result in short- or long-term variations in groundwater elevations and flow patterns. These factors may include variations in precipitation or recharge rates, presence of persistent facility water leaks, agricultural or landscape irrigation, onsite or offsite pumping or injection wells, tides, onsite or offsite construction, changing land use patterns (e.g., bare ground versus asphalt), onsite or offsite lagoons, ponds, and the presence of springs or streams.

Water levels should be measured at a sufficient frequency to detect and characterize temporal variations in groundwater 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, as in tidally influenced areas, continuous water level measurements may be needed. Onsite or offsite production or hydraulic control well pumping may affect both the rate and direction of groundwater flow, both laterally and vertically. Consequently, the potentially complex patterns of offsite pumping should be determined.

3.5.5 Determining Groundwater Flow Rate

The rate of groundwater flow should be determined for proper placement of monitoring wells and for evaluating the potential for contaminant migration. Where groundwater flows through a porous medium, such as unconsolidated sediments or highly fractured crystalline rocks, Darcy's Law is used to calculate the rate of groundwater flow.

The average linear velocity of groundwater flow ($\overline{v}$) is a function of hydraulic conductivity (K), hydraulic gradient (i), and effective porosity (n_e):

$$\overline{v} = K\, i \,/\, n_e$$

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

Chemical or isotopic tracer tests or other techniques can help determine groundwater flow direction and rates, and may be necessary to determine groundwater flow rates in certain geologic settings, such as some fractured crystalline rocks or karst.

3.6 Groundwater and Hydrogeological Characterization Methods

The methods and procedures to meet groundwater characterization objectives listed in Sections 3.1 through 3.4 can be assigned to the following classifications:

- Source characterization,
- Real-time measurements,
- Subsurface boring program,
- Analysis of soil and rock samples,
- Geophysical techniques,
- Monitoring wells,
- Transects,
- Groundwater sampling and analysis,
- Aquifer testing,
- Groundwater modeling, and
- Mass flux evaluation.

These methods are listed in their general (i.e., most common) order of use. However, application of any method is dependent on site-specific factors and some methods may not be used at all while others may be used more than once.

These methods and procedures are briefly described in the following sections. More detailed descriptions can be found in Cal/EPA's guidance documents (Cal/EPA 1994 and 1995 a through h), in *A Compendium of Superfund Field Operations Methods* (USEPA 1987), and in more recent publications by ITRC and others.

3.6.1 Source Characterization

Potential sources should be characterized to the extent that they may affect groundwater. This requires identifying the contaminants present, the affected media, and the concentrations of contaminants in various media. Based on historical records of operations, aerial photographs, site reconnaissance, and previous sampling, features and site activities that present potential sources of contamination should be identified during CSM development and project scoping. Potential sources that should be investigated include: tanks, drains, clarifiers, sumps, sewer lines, surface impoundments, degreasers, landfills, areas of stained ground or stressed vegetation, dry wells, other wells (e.g., dewatering wells, supply wells, abandoned drinking water wells), septic systems, container storage areas, pipelines, transformers, and other areas where hazardous materials or wastes were handled.

The nature of the source and the suspected rate of release of contaminants should also be identified. The potential for contamination of groundwater by the migration of contaminants through the unsaturated zone should be evaluated. *Preliminary Endangerment Assessment, Guidance Manual* (Cal/EPA 2012) contains a comprehensive description of the site history and site evaluation process.

Direct sampling of wastes and soils should be conducted, and samples should be analyzed for all contaminants suspected to occur at the site. The presence of degradation products of site contaminants should be investigated. In addition, indirect methods for source characterization may be used to optimize the locations for sampling and analysis, often resulting in lower costs. For example, active and passive soil vapor surveys can be conducted to identify the presence of VOCs. Various surface geophysical methods may be used to identify areas of waste disposal, buried drums, piping, and tanks. *Application of Surface Geophysics at Contaminated Sites* (Cal/EPA 2012) provides information on the applicability of methods.

3.6.2 Use of Real-Time Measurements

Real-time measurements are collected using field-based technologies which enable decision-making as data are collected. Typical field-based technologies include soil vapor sampling, CPTs, and membrane interface probes (MIPs). Guidance for utilizing these technologies is included in Section 4 of this document. When combined with a dynamic work plan, or other systematic planning tool, real-time measurements can increase the efficiency of field investigation activities. The efficiency is realized when data is gathered quickly enough so that the data generated can influence the progress of the field effort while it is still underway. For example, when using an MIP, the need for additional sampling points to delineate the lateral extent of contamination can be based on MIP logs recorded and produced in the field.

While the term real-time measurement is usually associated with field-based analytical technologies, standard analytical techniques can serve a similar purpose. If the project planning is such that analytical results are made available at the same time that decisions are required, then standard analytical techniques can serve the same purpose as field-based analytical technologies.

3.6.3 Subsurface Boring Program

Site characterization should always rely on direct methods of investigating site geology, through analysis of geologic materials collected from borings and trenches. Indirect methods, especially geophysical methods and CPTs, may provide valuable information that can be used with direct methods to interpolate geologic data between points where direct observations are made.

A site investigation entails characterization of the subsurface materials below the site. The characterization includes determining the lateral extent and thickness of all hydrostratigraphic units, identifying geologic features that may affect groundwater flow and contaminant migration (e.g., faults, fractures, and stream channel deposits), and collecting samples for lithologic description and laboratory analysis of mineralogy and engineering properties.

Hydrogeological site investigations generally require a subsurface boring program. The drilling methods selected should be capable of drilling in the geologic formations underlying 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 1995b, under revision) 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 trained professionals, supervised by a Professional Geologist or Professional Engineer licensed in California. Drilling should be conducted by a California-licensed C-57 contractor.

Using the CSM as a guide, the number of borings and their spacing should be based on geologic information, on the spatial distribution of actual or suspected releases, and on the data requirements for risk assessment. The project-specific DQOs should be used to verify that data generated from the borings will be used to fill data gaps in the CSM and be helpful for making decisions. Boreholes should be drilled to provide a detailed evaluation of site geology and to identify potential contaminant migration pathways. Continuous cores should be collected and logged to accurately identify stratigraphic relationships. Boreholes should be spaced closely enough so that accurate cross-sections can be constructed. The number of borings will depend on the complexity of site geology, the extent to which geologic units are 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.

Samples of geologic materials should be collected from borings at 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 should describe the nature of stratigraphic contacts. When practical or necessary, color photographs of representative samples should be taken and included in field reports. Whenever possible, core samples should be archived for later inspection, if needed.

Any boring that will not be completed as a monitoring well should be decommissioned so that it does not serve as a potential subsurface conduit for contaminant or fluid movement. This is usually done by filling the boring with a properly mixed grout emplaced with a tremie pipe. However, some instances require overdrilling the boring and then emplacing grout. The DTSC guidance document *Monitoring Well Design and Construction for Hydrogeologic Characterization* (Cal/EPA 1995d) can be consulted for methods used to properly decommission borings. Boring decommissioning should be performed in compliance with *California Department of Water Resources Water Well Standards, Bulletin 74-81* and *Bulletin 74-90*.

Direct push methods may require specialized grouting techniques based on site conditions. Information on direct push methods is available in:

- *Expedited Site Assessment Tools for Underground Storage Tank Sites, A Guide for Regulators*. EPA 510-B-97-001. USEPA . March 1997.
- *Use of Direct Push Technologies for Soil and Ground Water Sampling*. Chapter 15 in *Technical Guidance Manual for Ground Water Investigations*. State of Ohio Environmental Protection Agency. February 2005.
- *Techniques for sealing cone penetrometer holes.* Lutenegger, Alan J. and DeGroot, Don J. Can Geotech. J. 32: 880-891. 1995.

3.6.3.1 Sealing Confining Layers

In some situations, it may be necessary to drill through confining layers (i.e., aquitards). Investigators, in conjunction with the appropriate regulatory personnel (including geologists), should develop a method for drilling through the confining layer without creating a conduit for contaminant migration between hydraulically separated saturated zones.

The following 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 "conductor" casing, sealing the annular space in the cased portion of the borehole, and drilling a smaller diameter borehole through the confining layer.

- Direct push methods that may penetrate confining layers include single and dual-walled probes, direct push well installation (dual-walled only), real-time measurement tools, and sampling tools. Sonic drilling, using dual-walled methods, is similar in approach. In each case, proper grouting protocols and materials should be employed to minimize the potential for contaminant migration between water-bearing zones. Detailed information regarding sealing direct push boreholes is provided in the references cited in the previous section.

3.6.4 Analysis of Soil and Rock Samples

In addition to the field descriptions outlined above, the investigator conducts, 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, and
- Particle size analyses of unconsolidated or poorly consolidated samples.

Many parameters needed for evaluation of contaminant fate and transport and evaluation of remedial alternatives can be provided by submitting geologic samples for laboratory analysis. When selecting laboratory analytical methods and samples for analytical testing, DQOs should be taken into account so that the laboratory results serve a specific data need. The specific data needs and the necessary testing to fulfill these needs should be determined prior to collecting samples. This will help reduce investigation costs, and speed up decision-making.

3.6.5 Geophysical Techniques

Surface geophysical techniques may be used to plan the subsurface boring program by providing data to verify or modify the initial CSM prior to drilling boreholes. Based on the results of geophysical surveys, boreholes may be more 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 waste 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 Contaminated Sites* (Cal/EPA 2012) contains guidance on the use of surface geophysical techniques.

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. Due to the potential for large variations in subsurface conditions, oftentimes multiple interpretations from the same set of geophysical measurements are valid making the geophysical logs appear to be inconclusive. Consequently, information from geophysical surveys should be used in conjunction with direct observations from borehole samples to verify the interpretations of the geophysical logs. *Application of Borehole Geophysics at Contaminated Sites* (Cal/EPA 2012) contains guidance for the application of borehole geophysics and data interpretation.

3.6.6 Monitoring Wells and Well Placement

The CSM, which evolves as data are acquired, is the basis for installing monitoring wells. The CSM is based on site history and existing data, as well as site reconnaissance studies (e.g., surface/borehole geophysics, CPTs, existing wells, soil gas sampling, and grab groundwater sampling). This information is used to select appropriate well locations and screened intervals. For example, if the CSM indicates that DNAPL may be present, then it may be appropriate to construct wells with screened intervals at the bottom of aquifers to detect the DNAPL. Similarly, wells should be screened across the water table to detect light non-aqueous phase liquids, (LNAPLs), like various petroleum hydrocarbons.

Monitoring wells are installed to evaluate and document the contaminant types, their concentrations, and their lateral and vertical distribution. Each water-bearing zone that could potentially be affected by site contaminants should be characterized. This means, in most cases, that successively deeper water-bearing zones should be investigated when groundwater contamination is identified. Where groundwater is not contaminated but where the potential exists for future contamination (e.g., in an uncontaminated zone underlying a contaminated shallow zone), wells may be required for on-going monitoring. Monitoring should continue until the site is remediated and the risk to groundwater is removed.

The number and location of monitoring wells will depend on site-specific factors, including the variability of groundwater flow directions, the rate of groundwater flow, the complexity of hydrostratigraphy, and the number of water-bearing zones to be monitored. The number of contaminant sources on a site, the properties of contaminants, and the extent of groundwater contamination will also affect decisions regarding the number of wells needed and how the wells are spaced. Site-specific conditions such as drill rig access and permission to install and sample wells, along with facility operations, can also have an effect on where wells can be located and how many wells can be installed at a site.

For a simple case, such as a dissolved contaminant in a nearly homogeneous and isotropic aquifer, where there is little variation in groundwater flow, the following portions of the site and contaminant plume would require wells:

- Upgradient to provide background water quality,
- Within a plume to identify the distribution of contaminant concentrations,
- At either side of the plume to define the lateral extent of contamination,
- At the downgradient edge of the plume to monitor its migration,
- Clusters in a contaminated water-bearing zone to identify the vertical extent of contamination, and
- In underlying water-bearing zones to identify the presence or absence of contamination.

Guidance for the design and construction of monitoring wells is provided in *Monitoring Well Design and Construction for Hydrogeologic Characterization* (Cal/EPA 1995d, under revision). As the ground monitoring network is developed it is useful to perform a well usability assessment when new wells are constructed. Wells which have no use, or are detrimental to the environment, should be promptly destroyed.

Most hydrogeologic systems are highly heterogeneous and anisotropic. Detailed (aka high-resolution) characterization of the distribution of contaminants in groundwater, both laterally and vertically, may require many monitoring wells, or collection of numerous groundwater samples by other means as described in the next section. Detailed characterization may reduce remediation costs because such characterization identifies discrete contaminated zones. Discrete zones can be targeted for remediation, thereby, resulting in treatment of a smaller volume of groundwater with higher contaminant concentrations.

Detailed characterization of groundwater flow rates and directions, using piezometers designed for collection of water level data, may reduce the number of permanent monitoring wells needed. Reducing the number of monitoring wells, and, therefore, the number of groundwater samples and analyses reduces the cost of characterization.

Well placement and monitoring requirements during and after remedial design implementation depend on the type of remediation, the site conditions, the structural components of the remediation system, and the type of biological and/or chemical products injected or emplaced. Requirements will differ, for example, for bioremediation, chemical oxidation, pump and treat, treatment walls, slurry walls, caps, and monitored natural attenuation. This topic is outside the scope of this guidance, which is focused on characterization.

3.6.7 Transects

A transect is a line of multi-depth sampling points which provides detailed information regarding the distribution of groundwater contamination. Transects can be constructed perpendicular to and along the long axis of the plume. These sampling points are most often used to collect groundwater analytical data, but other data; such as hydraulic conductivity, geophysical measurements, MIP readings, CPT soundings, or lithologic samples, can also be collected using a transect strategy.

Using a transect strategy to characterize a groundwater contaminant plume requires numerous wells with short screen intervals installed at very specific depths (an approach known as high-resolution vertical profiling). Transects can be used in investigations where it is important to have a detailed characterization of aquifer material and contaminant distribution. The sampling points can consist of monitoring wells or piezometers with short screen intervals, or multi-depth sampling systems such as multi-channel tubing, Waterloo samplers, or similar systems. Installing a multi-depth transect across a groundwater plume can more clearly identify areas where the highest contamination and greatest mass flux occur. Mass flux evaluation is discussed in Section 3.6.12.

Installing transects across a groundwater plume may present some advantages over installing a typical groundwater monitoring network. The line or grid (if multiple lines are constructed) of sampling points in a transect typically increases the accuracy and precision of the plume definition and can identify high-concentration plume cores. This is advantageous when evaluating and designing treatment alternatives. For example, having a more precise definition of a groundwater contaminant plume will enable in-situ treatment to target optimum locations and depth intervals for removing as much contamination as possible.

Transects also allow for detailed evaluation of groundwater conditions over time. This can be useful for evaluating MNA and to assess whether concentrations in a groundwater plume are decreasing (or if the plume is merely shifting). When utilizing a typical broadly-spaced monitoring network, apparent trends in contaminant concentrations may be due to the plume shifting location rather than actual changes in contaminant concentrations. A more precise definition of the plume can provide better tracking of its location, and verify whether an apparent reduction in concentrations is due to contaminant degradation, or contaminant movement.

3.6.8 Characterization vs. Monitoring

The rationale for data collection and an explanation of how the data will be used need to be considered as part of the DQO planning process. Data collected for site characterization will have a different objective than data collected for monitoring site conditions. The sampling methods for each objective may be different. When characterizing a site, the CSM is being developed and the data collected are used to build an understanding of site conditions such as the extent and nature of contamination. In contrast, monitoring data confirm the CSM, which has already been well-developed. The monitoring data are used to evaluate whether conditions are static or changing. Because site characterization and groundwater monitoring have different data objectives, alternate groundwater sampling techniques and collecting grab groundwater samples may be more appropriate and cost effective than installing and sampling groundwater monitoring wells. In contrast, monitoring wells provide consistent sampling and temporal/geographic data which assures data comparability over time.

3.6.9 Groundwater Sampling and Analysis

Groundwater should be analyzed for contaminants that have been identified in waste or soil, or that may otherwise be present at a site. For site characterization, the focus should be on those contaminants that are highly mobile and most likely to reach groundwater, provide the best indicators of contaminant migration, pose the highest risk to receptors, and 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 groundwater sampling is provided in Representative Sampling of Groundwater for Hazardous Substances (Cal/EPA 2008). *Sampling and Preservation Requirements for Water Samples* is provided in Appendix B.

Several methods can provide rapid collection of groundwater samples either during drilling or during direct push investigations, including collecting samples from temporary well point installations. Inflatable packers may be used in some situations to allow purging of the borehole fluids prior to groundwater sampling. Temporary steel or PVC well points can be installed using a drill rig or direct push equipment to allow collection of potentiometric information and water samples. Collection of groundwater samples during drilling or direct push investigations may provide a rapid and cost effective initial characterization of groundwater contamination. This type of profiling may reduce the number of monitoring wells needed, thereby saving time and reducing cost. Various groundwater sampling methods are discussed in Section 4.0.

When feasible and practicable, to ensure higher quality grab samples, open boreholes and temporary well installations may be purged using small-diameter pumps to reduce turbidity and increase the likelihood that fresh formation water is sampled. This approach may be precluded at locations with high turbidity, due to siltation of pumps—for these locations, bailers may be used.

Collection of groundwater samples during borehole advancement, via direct push, or during well construction may require well permits in some California counties. The work may need to be conducted by a California-licensed drilling contractor.

Sampling techniques should be described in detail in a work plan submitted to DTSC technical staff prior to sample collection to ensure that the proposed sampling method is acceptable.

3.6.10 Aquifer Tests

Aquifer tests (such as slug tests and pumping tests) provide a means of determining hydraulic properties of water-bearing and confining zones in the subsurface. Aquifer properties are needed for the selection and design of groundwater cleanup remedies. Aquifer properties are also needed in mathematical calculations and in computer models which analyze groundwater flow and contaminant migration. Geologic conditions govern the hydrogeologic regime, so a CSM of geologic conditions, such as surface and subsurface geology along with the structure and thickness of water-bearing zones, needs to be developed before implementing aquifer testing. Results of the aquifer testing can then be used to confirm and refine the geologic CSM. Guidance for planning for and performing aquifer testing is provided in *Aquifer Testing for Hydrogeologic Characterization* (Cal/EPA 1995f, under revision).

3.6.11 Groundwater Modeling

Groundwater modeling refines the CSM by generating a mathematical approximation of groundwater conditions. In general, groundwater models produce an approximate representation of groundwater conditions based on information input by the modeler. By changing the model inputs, different aquifer conditions can be simulated. The computer code and mathematical procedures used in groundwater modeling are highly complex and need to be understood by the modeler to produce accurate simulations. It is essential that a geologist or a hydrogeologist takes part in the development and evaluation of groundwater models to ensure that the input parameters are representative of geologic conditions, the model is constructed in accordance with the project DQOs, and that the model simulations are reasonable.

As part of developing a groundwater model, a calibration procedure needs to be performed to ensure that the model predictions are in accordance with actual data. Groundwater models are most often used to better characterize groundwater flow, predict contaminant transport, locate areas of potential environmental risk, and to assess the effects of proposed remediation alternatives. Guidance is provided in *Ground Water Modeling for Hydrogeologic Characterization* (Cal/EPA 1995g, under revision).

3.6.12 Mass Flux Evaluation

Mass flux is a concept that combines contaminant concentrations with groundwater flow, and is defined as the mass of contamination crossing a specific cross section of an aquifer within a certain time. Therefore, mass flux is expressed in units of mass/time/area. Groundwater plumes are most often delineated and analyzed based on contaminant concentrations. Using mass flux, rather than only contaminant concentrations, we can improve our understanding of how groundwater plumes are moving—and evaluate the progress and efficacy of remediation.

Mass flux evaluations attempt to characterize both the contaminant concentration and groundwater flow within a contaminant plume. Some portions of a plume may have fairly high contaminant concentrations, but very little groundwater flow. This portion of the plume may pose less of a risk with regards to contaminant migration than an area with lower contaminant concentrations, but higher groundwater flow. Evaluating the relationship between contaminant concentrations and groundwater flow is the goal of mass flux evaluation.

Evaluating mass flux assists in assessing whether contaminant plumes are stable, expanding, or contracting, and whether a proposed remedial action will affect the future distribution and fate of contaminants. Through mass flux evaluations, remedial actions can be targeted to specific zones (e.g., during injection of hydrogen- or oxygen-releasing compounds for VOC degradation), resulting in more efficient and cost-effective cleanups.

Three basic methods are used to derive mass flux estimates: transect methods, well capture/pump test methods, and passive flux meters (ITRC 2010).

- *Transect methods* use high-resolution vertical profiling of contaminant concentrations and groundwater velocity by installing multiple individual monitoring points positioned perpendicular to the groundwater flow direction and contaminant plume axis. Contaminant concentration and flow data from the monitoring points are used to calculate the mass of contaminants moving across the transect within a specified time interval.

- *Well capture/pump tests* consist of pumping contaminated water from a well, and measuring the flow from the well along with contaminant concentrations.

- *Passive flux meters* are devices that estimate mass flux directly in a well.

Matrix Diffusion

Diffusion of contaminants from adjacent aquitards as well as diffusion of sorbed contaminants from aquifer materials or bedrock may occur. Estimates of matrix diffusion should be incorporated into mass flux evaluations.

4.0 FIELD METHOD SELECTION AND APPLICATION

The focus of this section is to provide project managers with a review of technologies applicable to groundwater characterization at contaminated sites. Selection and application of field methods for conducting a hydrogeologic investigation are widely varied and site-dependent. Methods may be broadly categorized as intrusive (e.g., drilling) or inferred (e.g., geophysical methods). Detailed descriptions of technologies discussed in this section are available from USEPA's CLU-IN website and Cal/EPA guidance documents. Mention of trade names or commercial products does not constitute Cal/EPA endorsement or recommendation.

4.1 Approaches to Site Characterization

Two approaches for hydrogeologic investigations are conventional (or traditional) site characterization and Triad site characterization. The Triad approach is described in Section 2.3, above. Elements of both approaches may be selected, based on site conditions and the DQOs for each investigation.

4.1.1 Conventional Site Characterization

The conventional site characterization (CSC) approach involves incremental data acquisition and interpretation, often over years with multiple cycles of reporting and regulatory review.

The CSC approach generally relies on traditional characterization methods (e.g., coring with drill rigs) to acquire soil gas, soil, and groundwater data.

4.1.2 Triad Site Characterization

The Triad approach substantially shortens the hydrogeologic investigation and promotes timely implementation of remedial measures. Essential components of Triad are:

- Systematic planning
- Dynamic work strategies
- Real-time measurement technologies.

Systematic planning and dynamic work strategies are described in Sections 2.4, 2.5, et seq. Real-time measurement technologies are described in the following sections.

Triad tools include direct push methods, surface and borehole geophysical techniques, onsite chemical analysis, and data visualization software. Where feasible, direct push methods are less intrusive and more cost-effective than drilling but are limited by depth. Direct push tools can convey geotechnical and geophysical data which are processed and interpreted using data visualization software. Multiple lines of evidence can be collected simultaneously and jointly displayed, facilitating efficient interpretation of data and reducing the uncertainties of decision-making.

4.2 Overview of Direct Push Tools

Direct push tools are used to characterize lithology, soil and aquifer properties, and contaminant distribution. Direct push tools originated with CPT methods, which have been used in geotechnical investigations over several decades. With direct push methods, in situ data can be acquired and immediately interpreted. The use of onsite mobile laboratories allows for real-time data analysis and interpretation, thereby making direct push methods particularly useful for Triad site characterization. Physical samples (e.g., soil gas, soil, and groundwater) can be also collected using direct push tools and sent to an offsite laboratory for analysis.

The three most important factors influencing selection of direct push tools are lithology, depth to groundwater, and site access. Direct push tool probes in unconsolidated sediments can often be advanced to 150 feet below ground surface (bgs). Below 150 feet bgs, direct push methods may not be feasible. Direct push methods are also unsuitable for coarse, consolidated, cemented, or lithified deposits—and for bedrock.

The direct push method deploys a hydraulically driven rod (solid or hollow dependent on function) which is pushed into the subsurface at rates specific to the type of tool. Sensors and sampling devices are attached to the rod. With certain tools, hydraulic tests can be conducted at specific intervals to determine hydraulic conductivity and to identify preferential flow pathways and barriers to flow.

Data quality objectives (DQOs) are developed for direct push methods. A framework for field decisions is established as “If…then” statements in the dynamic work plan. Depending on investigation objectives and the tools selected, data quality may range from qualitative screening-level data to quantitative data that can support a risk assessment. A close examination of direct push-supported technology is available in ITRC (2004). Also, the following technologies are presented on the USEPA Technology Innovation Field Services Division, Clean-Up Information (CLU-IN) website.

4.2.1 Direct Push Tools for Characterizing Soil Properties, Stratigraphy, and Aquifer Properties

Cone Penetrometer Test (CPT)

The CPT comprises a rod (hollow or solid as a function of the type of data needed) with a sensor-equipped cone. Sensors on the cone measure tip resistance and sleeve friction as the tool is pushed. The pressure and friction signals are conveyed to surface processors by electric wire, radio-wave, or direct pressure response. Upon acquisition, the combined pressure and friction data are processed to produce a stratigraphic and soil-properties log. Pore pressure dissipation tests can be used to estimate hydraulic conductivity.

Hydraulic Profiling Tool (HPT)

The hydraulic profiling tool (HPT) is used in both saturated and unsaturated soil and provides a vertical profile of soil hydraulic properties including hydraulic conductivity and electrical conductivity. The HPT identifies vadose zone and aquifer intervals suitable for sampling, well construction, slug/aquifer tests, or targeted remedial measures. The device can also be used to measure static water conditions across a site.

As the HPT is advanced, transducers measure soil and formation responses to controlled water injection. The process is analogous to a continuous slug test. Hydraulic conductivity is inferred from changes in transducer signals as water injection pressure changes in response to a soil's properties. For example, transducers sense the increase in injection water pressure as the tool transitions from sand to tight clay.

Soil electrical conductivity can be logged simultaneously with water injection pressures. Grab groundwater samples can be collected with added tools such as the BAT™ system.

Seismic Cone Penetration Testing Equipment

The Seismic Cone Penetration Testing (SCPT) tool identifies preferential contaminant pathways (e.g., sandy and coarser soils) and other lithologic properties and is used to locate zones containing DNAPL. The SCPT identifies important lithologic and aquifer properties by measuring shear wave velocity measurements in soil as the tool is pushed. It can also be fitted with a soil conductivity probe.

Percussive Hammer Tool (PHT)

The percussive hammer tool (PHT) uses a percussively-driven rod in lieu of a pushed rod. The PHT penetrates zones where a rod-driven tool encounters refusal (e.g., cobbles, indurated zones). The percussive forces on a PHT are generated with the rig static weight and a hammer attached to the top of the rods. PHT rigs are generally smaller than direct push rigs, affording them easier access to restricted areas.

4.2.2 Direct Push Tools for Groundwater Sampling

Sealed-Screen or Grab Groundwater Sampling

Sealed-screen or grab groundwater samplers typically consist of a short screen contained within a sealed, water-tight tube. The sampler is advanced with a direct push rig to a targeted interval. The protective outer rod is withdrawn exposing the screen to groundwater. Groundwater flows through the screen and into the drive rods or sample chamber. A bailer or pump is lowered through the hollow rod to collect groundwater in the screened chamber. The Hydropunch™ (a product of GeoInsight) is a common sealed-screen sampling device.

Exposed-Screen Groundwater Sampling

Exposed-screen samplers are pushed via direct push methods and are capable of collecting groundwater samples at multiple intervals as the sampling tool is advanced. The screen remains open to the formation while the tool is advanced. This allows vertical profiling of groundwater chemistry and contaminants. Exposed-screen samplers can be used to measure water levels at discrete intervals within moderate- to high-yield formations to roughly estimate vertical head distribution and gradient.

Proprietary names for exposed-screen sampling using direct push methods include BAT™ and the Waterloo Profiler™. The BAT™ system collects groundwater through a series of ports near the direct push rod-tip. The groundwater then enters a sampling tube fitted with a septum. The groundwater enters the tube when the septum is punctured by a needle as gravity increases. The sampling tube is then conveyed to the ground surface. The BAT™ device may also be left in the ground and used as a temporary well for monitoring purposes.

Direct Push (DP) Wells

DP wells are installed by being pushed or hammered into the target zone. A DP well is a permanent sampling point which is pushed to the selected depth. Due to a rapid installation rate, groundwater can be sampled and analyzed by an onsite mobile laboratory to provide data for in-field decision-making. DP wells may be installed with multiple ports to sample depth-discrete zones. When penetrating confining layers or source zones, dual tube direct push installations (analogous to conductor casing) may be prudent. “Pre-packed” well screens with sand packs facilitate well installation. The data quality from DP wells can rival the data quality obtained from conventional monitoring wells (ITRC 2006). These wells should be installed with adequate annular seals to comply with *California Department of Water Resources Water Well Standards, Bulletin 74-81* and *Bulletin 74-90*.

4.2.3 Active Soil Gas Investigations and Sampling Points

An active soil gas investigation is often necessary in hydrogeologic investigations to determine whether a contaminant source poses a threat to groundwater or whether groundwater contamination may partition to the vadose zone. In either event, direct push methods are the primary means of installing soil gas monitoring points in unconsolidated sediments including sand and silty sand. When combined with onsite analysis, active soil gas sampling can provide real-time data regarding VOC impacts. Extra precautions should be observed when using post-run tubing methods due to difficulties with installing adequate seals (DTSC, LARWQCB, and SFRWQCB 2012).

4.2.4 In-Situ Contaminant Distribution Measurement and Characterization

Membrane Interface Probes (MIPs)

MIPs are used to locate hydrocarbon and other VOC contamination, including LNAPL and DNAPL compounds, in the vadose and saturated zones. The tip of the MIP (from Geoprobe® Systems) is heated to 250˚F, volatilizing and mobilizing VOCs in soil gas, soil, and groundwater adjacent to the probe as it is advanced through the soil. Mobilized VOCs pass through the probe's membrane and into a carrier gas for transportation to the ground surface. Concentrations are analyzed by an onsite laboratory.

MIPs provide semi-quantitative (i.e., “relative”) data and are used to estimate contaminant mass for remedial measures such as in situ chemical oxidation (ISCO) injection points. MIPs also measure soil conductivity.

The MIP tool is adaptable to three sensors, which are usually employed simultaneously:

- Photoionization detector (PID) for aromatic hydrocarbons,
- Electron capture detector (ECD) for chlorinated contaminants, and
- Flame ionization detector (FID) for straight-chain hydrocarbons.

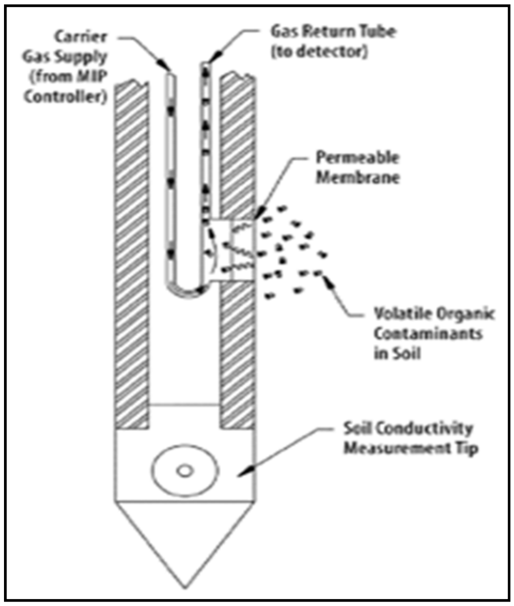
The MIP is generally limited to depths of approximately 60 to 100 feet under ideal conditions. MIP penetrations cannot be grouted as the tool is withdrawn; therefore, special care should be taken to avoid cross contaminating aquifers. In some cases, grouting of boreholes after withdrawal may be acceptable—for example, when the site stratigraphy and contaminant distribution are well known. Figure 4-1 depicts a MIP tool.

Laser Induced Fluorescence (LIF) and Ultra-Violet Optical Screening Tools (UVOST)

Both Laser-Induced Fluorescence (LIF) and the Ultra-Violet Optical Screening Tool (UVOST) are direct push tools that provide screening-level qualitative and quantitative information without directly sampling LNAPL and heavier hydrocarbons including petroleum, oil, and lubricant contamination. With the appropriate tool, LIF can detect aromatic hydrocarbons. LIF and UVOST are appropriate for preliminary assessments, source delineation, and contaminant distribution investigations.

The LIF is deployed at discrete depths where a laser beam is directed (through a window in the tool) into the soil. A fluorescent response indicates relative presence of LNAPL or petroleum-based compounds.

Figure 4-1 Diagram of MIP Tool (Source: USEPA, CLU-IN)



LIF is not suitable for locating chlorinated hydrocarbons or DNAPLs such as PCE. Geotechnical sensors are normally integrated with the LIF tool to simultaneously obtain geotechnical and stratigraphic soil data.

LIF technology is deployed in two types of systems: Site Characterization and Analysis Penetrometer System (SCAPS) and Rapid Optical Screening Tool (ROST™) systems. SCAPS is available through the United States Department of the Navy and Army Corps of Engineers. The ROST™ system is available commercially through Fugro, Inc.

The UVOST projects a beam of ultraviolet light through a window in the tool into the soil at targeted depths. UVOST detects gasoline diesel, jet fuel (kerosene), motor oils, cutting fluids, hydraulic fluid, crude oils, and fuel oils. UVOST is less reliable for detecting weathered fuel, heavy oil, chlorinated VOCs, and PCBs. False positives can occur when the probe passes through a zone with calcareous sands, sea shells, or peat.

Direct push tools have been coupled with software-driven visualization technologies to depict two-and-three-dimensional interpretations (e.g., cross-sections or fence diagrams) of contaminant distribution, as described in Section 4.2.6.

4.2.5 Ribbon NAPL Devices

Ribbon NAPL devices provide a yes or no answer to the question of whether NAPL-phase contaminants are present in the vadose zone. The ribbon NAPL device is inserted in a hollow rod and filled with potable water. After the rods are pushed to the targeted depths, the rods are withdrawn and the device is pressed against the borehole wall by the hydrostatic pressure of the water. The ribbon is coated with a hydrophobic absorbent compound. NAPL is attracted to the compound and wicks onto the ribbon. On the ribbon, the NAPL reacts with a dye (e.g., Sudan IV), causing a color change. When the ribbon is withdrawn from the borehole, the depths of NAPL are determined by visual inspection of the dye along the ribbon. The Flexible Liner Underground Technologies, Ltd. (FLUTe) is a commercially available ribbon NAPL device.

The water-filled ribbons can accept geophysical tools. Borehole geophysical logging may be performed in borings which would be difficult to keep open, using conventional drilling methods.

4.2.6 Ultra Violet Light (UV) Core Photography

UV photographs of soil cores are color-corrected to allow a clear distinction between hydrocarbon zones and clay laminations. This photographic method enables correlation between ROST or LIF images with UV core images. This method is effectively the same as the UVOST, except that the UV core imagery is performed at the surface.

4.2.7 Data Visualization Technology

Data visualization technology relies on software to generate figures and visualizations of the subsurface.

Visualization software consists of commercial and USGS-derived numerical computer codes which produce a range of visual depictions ranging from stratigraphic columns to fence diagrams, maps, logs, cross-sections, and other three-dimensional depictions of contaminant distributions and soil properties. Aquifer properties and parameters may be interpreted by products based on USGS ModFlow and Surfer codes developed in the 1980s and 1990s which have been consistently updated.

Relational data bases can be assembled which permit development of geographic information system (GIS) and other map-based software. Visualization software is well developed—with niche-marketing for specific subsurface investigations. This technology is well adapted for any in situ measuring technology where data is acquired by wire or radio frequency for instantaneous processing (e.g., CPT, SCAPS, and MIPs). In an ideal dynamic work plan context, visualization technology may evolve in an hour-by-hour progression as data is acquired and processed. With the evolving depiction and understanding of contaminant distribution, field decisions, described in the dynamic work plan, can be made.

4.3 Drilling Methods: Hydrogeologic Characterization Tools Appropriate to All Investigations

Drilling is used for well construction, obtaining continuous soil cores, soil gas well or probe installation (where direct push methods fail), and grab groundwater sampling using devices described in previous sections.

Drilling methods commonly used in hydrogeologic investigations can be divided into five major categories: hollow-stem auger, mud rotary, air rotary, percussion, and rotosonic. For detailed information regarding these methods, please consult the *Drilling, Coring, Sampling and Logging at Hazardous Substance Release Sites Guidance Manual for Groundwater Investigations* (Cal/EPA 1995b, under revision).

Various drilling methods, including hollow-stem auger, mud and air rotary, are compatible with grab groundwater sampling using driven-ahead, sealed screen or open devices (Section 4.2.2.2). For example, Hydropunch™ and BAT™ systems are commonly used for acquiring depth-discrete groundwater samples as boreholes are advanced.

Criteria for the selection of drilling methods are presented in Tables 4-1 and 4-2, below. Table 4-1 presents inherent advantages and disadvantages of each method whereas Table 4-2 presents criteria for selecting drilling methods based on targeted lithology and depth. In general, depth to target, cross-contamination potential, presence of aquitards, the need for chemical sampling, and well construction all influence the selection of a drilling method.

The potential for cross contaminating aquifers requires sealing off individual aquifers while drilling. CSC methods include the installation of telescoped conductor casing or the use of methods that drive casing while drilling. Triad approaches include using dual-wall DP wells.

4.4 Soil and Rock Sampling

Soil and rock sampling may be divided into two categories: disturbed and undisturbed samples.

Disturbed samples consist of disaggregated material that is not representative of its initial condition. Examples of disturbed samples are drill cuttings and surface scrapings

Undisturbed samples are more representative of their initial condition. The term "undisturbed" is a misnomer, because every sample is unavoidably disturbed to some degree during collection. Undisturbed samples have been collected in a manner that minimizes disturbance and allows them to retain much of their original structure. These samples can be considered reasonably representative of the material from which the sample was collected. Examples of undisturbed samples include rock and soil cores collected from sampling tubes or core-barrels.

Table 4-1 Summary of Drilling Methods (after USEPA 1991)[1]

	Drilling Methods						
	Air Rotary	Mud Rotary	Hollow Stem Auger	Percussion	Dual-Wall Reverse Circulation	Rotosonic	Direct Push
Description	Rotating drill stem, uses air to remove cuttings.	Rotating drill stem, uses mud to keep borehole open and remove cuttings, mud is pumped into the borehole though the drill stem.	Rotating hollow stem with continuous auger helix.	Casing or hammer chips and crushes rock to advance borehole.	Rotating drill stem using mud to keep borehole open and remove cuttings, mud with cuttings is pumped up through the drill stem.	High frequency vibrations allows drill stem vibrate into subsurface.	Drill rods are hydraulically pushed into subsurface on a truck mounted drill rig.
Advantages	Keeps liquids from borehole.	Allows for deep drilling, lessens cross contamination potential, allows for geophysical logging.	Soil samples easily collected, obviates need for well centralizers, easy mobilization	Allows immediate location of water bearing zones, able to penetrate consolidated sediments, coarse zones, or rock.	Beneficial where borehole stability and lost circulation are problematic, prevents cross contamination, allows for geophysical logging.	Rapid advancement, allows complete core recovery, drills through most materials.	Minimal to no cuttings or fluids to manage, allows rapid groundwater sampling, less expensive than other methods, supports Triad and dynamic work plans, easy mobilization.
Disadvantages	Precludes VOC sampling until well is developed, imprecise lithologic logging.	Generates considerable drilling waste, requires tripping drill stem to surface to collect soil samples, adds liquids to the subsurface, extensive well development often required, inaccurate locating of water bearing zones.	Depth limitation, potential of smearing borehole wall, requires keeping augers in place to keep borehole open. Larger rigs are available which may attain greater depth.	Imprecise lithologic logging, precludes collecting continuous cores, delays in VOC sampling.	Requires tripping drill stem to surface to collect soil samples, adds liquids to the subsurface, extensive well development often required, inaccurate locating of water bearing zones.	Heat generated by vibration precludes soil matrix VOC sampling.	Limited by depth and lithology.

[1] Tables 1 and 2. For more information on see: Neilson, D.M., ed., 2006. *Practical Handbook of Environmental Site Characterization and Groundwater Monitoring, Second Edition. CRC Press Taylor and Francis Group, Boca Raton, FL.*

Table 4-2 Drilling Methods for Various Geologic Settings (after USEPA 1991)

Geologic Setting	Drilling Methods						
	Air Rotary[1,2]	Mud Rotary[1]	Hollow Stem Auger[3]	Percussion[4]	Dual-Wall Reverse Circulation	Rotosonic	Direct Push
Unconsolidated, poorly consolidated materials less than 125 feet deep	Good (casing required)	Good (mud invasion in vadose zone possible)	Good (cobbles may limit penetration)	Good (cable tool inefficient)	Excellent	Excellent	Good
Unconsolidated, poorly consolidated materials more than 125 feet deep	Good (casing required)	Excellent	Marginal (limited availability)	Good (cable tool inefficient)	Excellent	Good	Marginal
Consolidated material less than 500 feet deep	Excellent	Excellent	Not Available	Excellent	Excellent	Good	Not Available
Consolidated material more than 500 feet deep	Good (limited by compressor capacity)	Excellent	Not Available	Excellent	Excellent	Not Available	Not Available

Notes:
[1] Includes conventional and wireline core drilling
[2] Air filtration required for monitoring well installation
[3] Not recommended for monitoring well installation in interbedded sand/clay/silt
[4] Includes cable tool & dual tube methods.

4.4.1 Soil Sampling

Soil samples are collected using both CSC methods and direct push methods. Soil sampling (i.e., of the vadose and saturated zones) may be required to:

- Determine the areal and vertical extent of contamination in soil, especially within source locations;
- Assess the potential for partitioning between media (e.g., soil to groundwater);
- Estimate contaminant mass;
- Estimate mass flux; and,
- Evaluate indoor air risks when tight lithologic conditions preclude active soil gas sampling.

For VOC soil sampling, the DTSC recommends that USEPA Method 5035 be used (Cal/EPA 2004).

Soil sample collection devices which are commonly available are split-spoon samplers, thin-wall samplers, core barrels, and direct push core liners including acetate sleeves. Sample collectors may be driven by successive percussion impacts (disturbed and relatively undisturbed samples) or pushed by pneumatic ram, or other direct push methods (for undisturbed samples). Brass or plastic liners, placed inside the sampler barrel, are often used for ease of retrieval and sample preservation.

Sample compaction is usually acceptable for cores collected for visual identification or chemical testing. In this case, split-spoon samplers or core barrels can yield satisfactory results. Samples for VOC soil matrix analysis should be collected in accordance with EPA Method 5035. EPA Method 5035 describes several methods for preserving samples in the field, including using preservatives such as methanol and sodium bisulfate, and sub-sampling devices which preserve the sample or seal the sample from the atmosphere (e.g., Encore™).

Cores intended for physical testing should be collected with minimal disturbance. In this case, thin-wall push samplers (e.g., Shelby tubes) or core barrels (for rock) should be used. The sampler should be able to sample at least several inches ahead of the drill bit, to minimize disturbance from drilling action or drilling fluid circulation. Cal/EPA 1995b provides more information on soil and rock sampling.

4.4.2 Continuously Cored Samples with Standard Penetration Test Blow Counts

DTSC recommends that continuously-cored samples be logged where appropriate or feasible. Physical and budgetary constraints may not allow continuous-cored sample from every borehole. Continuous cores, coupled with standard penetration test (SPT) blow counts, provide high-quality lithologic and, where applicable, contaminant distribution data which reduce uncertainty in hydrogeologic characterization. When continuous sampling of every borehole is not feasible, selected boreholes should be continuously sampled; their number and locations should be chosen to provide representative coverage of site geology and areas of interest to the investigation.

Continuous cores may not be feasible for non-cohesive soils such as sand (e.g., flowing sand) or gravel, if site conditions indicate that soil loss from the core barrel is likely. In this case, alternate sampling methods may be needed to get a complete record of the lithology.

4.4.3 Logging of Drill Cuttings

Drill cuttings may provide lithologic identification for borehole logging if the drilling method precludes core-barrel sampling such as percussion drilling (e.g., ARCH). Drill cuttings provide imprecise depth intervals resulting in uncertainty of sample depth or origin, mixing from varying depths, and the washing-out of fines. HSA drilling methods yield cuttings which are significantly mixed; hence auger-flight cuttings are not suitable for logging purposes. If mud rotary drilling is used, and cuttings are obtained to supplement cores and geophysical logs, proper mud maintenance should be followed to insure the collection of representative cuttings samples. For a detailed presentation of logging, consult Cal/EPA 1995b.

4.5 Wells and Piezometers

This section briefly discusses the primary attributes of monitoring, extraction, and observation wells—and piezometers. The details of their use and construction are presented in *Monitoring Well Design and Construction for Hydrogeologic Characterization* (Cal/EPA 1995d). Also, USEPA 1991 presents a useful overview of well construction.

Wells should be designed by a California Professional Geologist or Professional Engineer – Civil, in compliance with the *Geologists and Geophysicists Act* as implemented by the Department of Consumer Affairs Board for Professional Engineers, Land Surveyors and Geologists.

4.5.1 Monitoring Wells

Monitoring wells are used to assess groundwater quality, evaluate aquifer characteristics and determine groundwater flow direction and gradient. Monitoring wells may be either single-screen or multi-port designs.

- *Single screen wells* are screened in only one zone.
- *Multi-port wells* are screened in several discrete zones, and are designed and constructed to eliminate hydraulic connection between screened zones.

Figure 4-2 illustrates the difference between these two types of wells. Single-screen wells are the predominant type used for hydrogeologic characterization. Direct push methods may be used to install pre-pack and small-diameter wells.

Well screen lengths are generally 10 feet or less; however, site conditions may warrant longer screens. For example, longer screen lengths may be needed for wells screened across a fluctuating water table, including remediation extraction wells in LNAPL zones. Multiple zones may be monitored by drilling successively deeper boreholes close together and installing a single-screened well in each hole. This type of installation is known as a monitoring well cluster. Nested wells, which contain multiple wells in a single borehole, are generally not recommended because of difficulties involved with installing reliable seals between zones and evaluating potential seal leakage. Installing well clusters rather than nested wells is the preferable method of monitoring multiple groundwater zones.

Multi-port wells provide an alternative to cluster wells when monitoring of a series of intervals in a single water-bearing zone is required. Multi-port should not be installed across aquitards or confining layers.

Well destruction may be difficult in small diameter wells (and piezometers): tremie pipes used for grouting may encounter resistance due to inclination or occlusion of portions of small-diameter wells.

Additional details regarding well construction are in *Monitoring Well Design and Construction for Hydrogeologic Characterization (*Cal/EPA 1995d, under revision).

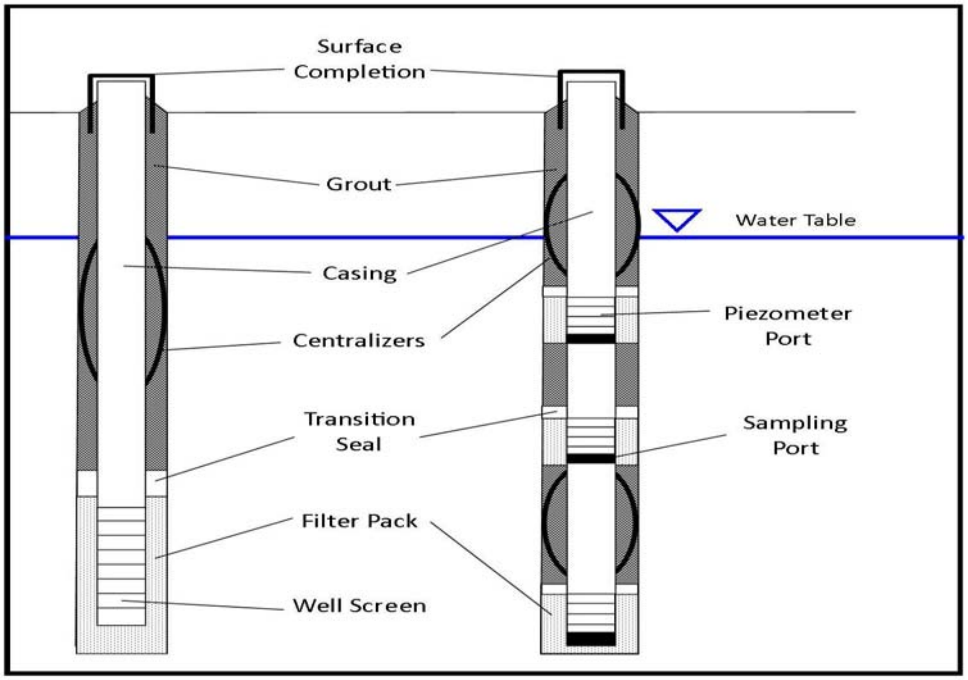
4.5.2 Extraction and Observation Wells

Extraction and observation wells are commonly paired so that observation wells provide drawdown or water pressure ("head") data relative to pumping in the extraction well.

Extraction Wells

Extraction wells withdraw large quantities of groundwater at rates suitable for aquifer tests, hydraulic control of contaminated groundwater, and extraction of contaminated groundwater for treatment (i.e., pump and treat). Extraction wells generally have larger diameter boreholes and casing and longer screened intervals (in the case of hydraulic controls or fully-penetrating aquifer tests) than monitoring wells. Extraction wells are constructed using methods similar to monitoring wells, although materials may be more robust. The primary concerns for extraction well design are screen interval location and filter pack composition to optimize production in targeted zones. Extraction and treatment well screen length should not be substantially longer than contaminant plume thickness. Screen length should never span more than one discrete water-bearing zone within an aquifer if contamination is present.

Figure 4-2 Diagram of Single Screen and Multi-Port Wells for Single Water-Bearing Zones



Observation Wells

Observation wells are often constructed near extraction wells, to measure water level drawdown or fluctuations during aquifer tests or during long-term hydraulic control or groundwater extraction and treatment. Observation wells, which measure drawdown in response to extraction well pumping, may have screen lengths greater than 10 feet. The screen length in observation wells should not exceed the screen length of the extraction well. The construction of observation wells is similar to monitoring wells, and they may sometimes be designed to serve as monitoring wells depending on site-specific needs.

4.5.3 Piezometers

Piezometers are short-screened wells which measure discrete-zone water levels or potentiometric (i.e., water pressure) head within an aquifer. They are usually cost-effective where only head data is needed and chemical samples are not required.

Two types of piezometers are in common use: open tube piezometers and electronic piezometers.

Open tube piezometers consist of a short screen, an open bottom (or porous tip), and casing or tubing extending to the ground surface. Open tube piezometers are constructed in a manner similar to monitoring wells, but may have smaller diameter casing (usually between 0.75 and 2 inches) and shorter screens. Grab groundwater samples may be collected from open tube piezometers with small-diameter bailers or pumps (bladder or peristaltic, depending on site conditions).

Electronic piezometers use pressure transducers placed inside a well within the screened interval. The transducer responds to pressure variations as water levels rise and fall and sends an electrical signal to surface or remote (if the system is equipped) data loggers. Electronic piezometers are useful where frequent measurements are required, such as during aquifer tests, in tidal zones, or near streams.

Piezometric data from transducers may be transmitted via telemetry to a distant location. Wireless telemetry devices use analogue or digital data transmission via radio-wave frequencies or cell phone technology to a central processor or a data may be intercepted via drive-by downloading. Piezometric data sent via telemetry reduces expenses by eliminating the need to send personnel into the field, in possibly remote areas, to download data. Telemetry technology is rapidly advancing and is available from a wide array of commercial vendors who specialize in applications ranging from remote pipe pressure sensing to burglar alarm systems.

4.6 Groundwater Sampling

Groundwater contaminant data is a critical element for hydrogeologic characterization. Groundwater sample collection methods include: bailing, pumping, low-flow purging, conventional purging, and passive ("no purge") sampling. Regardless of the sample collection method, sample preservation and storage guidelines should be strictly followed to ensure reliability and defensibility of sample results. See Appendix B for a tabulation of sampling and preservation methods. The applicability of groundwater preservation methods varies based on the sample collection technique. The analytical laboratory that will be analyzing the samples should be consulted regarding sample preservation and appropriate sample containers prior to sample collection.

Groundwater sampling typically involves removing a volume of groundwater from a monitoring well or borehole, using one of the methods briefly described below. More detailed information is provided in *Representative Sampling of Groundwater for Hazardous Substances, Guidance Manual for Groundwater Investigations* (Cal/EPA 2008).

Bailers

Bailers are narrow containers with one or more check valves, designed to be lowered into a well and filled. The filled bailer is then brought to the surface and the water decanted into appropriate sample containers. Bailers may introduce low-bias in VOC analytical results by allowing sample aeration (Cal/EPA 2008). Bailers are used in some direct push methods for grab groundwater sampling (e.g., Hydropunch™).

Conventional Submersible Pumps

Conventional submersible pumps are designed to bring groundwater to the surface as either dedicated pumps or portable pumps. Dedicated pumps are typically installed in the well, when the well is constructed and are not removed. Portable submersible pumps are used in multiple wells and are decontaminated after each use.

Low-Flow or Minimal Drawdown Submersible Pumps

Low-flow or minimal drawdown submersible pumps are designed to extract groundwater at a low flow, ranging from 100 to 500 milliliters per minute (ml/min). The most common low-flow pump is the bladder-pump which is activated by nitrogen or compressed air conveyed via hose to the pump. The low-flow pump is used with the sampling protocol described by Puls and Barcelona 1996. The intent of low-flow purging is to withdraw water at the rate at which water is naturally flowing through the screened interval; therefore, drawdown should be minimized. The low-flow sampling method minimizes the amount of water required for parameter stabilization using conventional sampling methods. Like conventional submersible pumps, low-flow pumps (including bladder pumps) may be dedicated or portable. Samples for VOC analysis should be collected at 100 mL/min to prevent off-gassing of VOCs and low-biased results.

4.7 Passive (No Purge) Samplers

Passive (“No Purge”) samplers are described by USEPA’s CLU-IN as any method based on the free flow of contaminant molecules from the sampled media to a receiving phase in a sampling device. Depending upon the sampler, the receiving phase can be a solvent (e.g., water), chemical reagent, or porous adsorbent (e.g., activated carbon). While there are many different designs for passive samplers, most have a barrier between the sampled medium and the receiving phase. The barrier determines the sampling rate that contaminants are collected at a given concentration and can be used to selectively permit or restrict various classes of chemicals from entering the receiving phase. For additional, detailed information, *Protocol for Use of Five Passive Sampler to Sample for a Variety of Contaminants in Groundwater* (ITRC 2007) should be consulted.

Passive samplers can be deployed in series for evaluating vertical distribution (or stratification) of contaminants (e.g., in historical wells or wells with long screens). However, ambient (natural) or induced vertical flow within the well bore may confound results. Ongoing research suggests that natural ambient flow, temperature inversions, and density effects can induce mixing within wells, resulting in a flow-weighted averaging effect.

To evaluate temporal variability, multiple samplers can be installed simultaneously and individually retrieved at different times, (e.g., in a demonstration of method applicability for specific combinations of contaminants). The sampling log should include sampler depth, sampler installation date, and retrieval dates.

Results for passive samplers that are decanted at the surface (like bailers) may be low-biased for VOCs, due to off-gassing during retrieval and decanting. There are three types of passive samplers, based on CLU-IN descriptions: thief, diffusion, and integrative.

4.7.1 Thief Sampling Devices

Thief samplers are designed to obtain a grab groundwater sample at the depth to which they are lowered. They are activated either by pulling up or by using an up and down motion to force water into the sampler (HydraSleeve™ by GeoInsight™) or by a triggering device at the well head (e.g., Snap samplers by ProHydro, Inc. and Kemmerer samplers by Wildco®).

HydraSleeve™

The HydraSleeve™ sampler is a flexible, collapsible sample tube or sleeve (usually made of 4-mil polyethylene tubing), typically 30 inches long with a 1.5-inch fill diameter (650 ml). The sleeve is closed at the bottom. At the top, there is a self-sealing reed valve. A weight is attached to the bottom of the sampler or tether line to carry the sampler below the water surface to the intended depth (ITRC 2006). The sleeve is lowered on the tether to a selected depth and then retracted for sample collection. The sample is collected by pulling the sleeve upward at a rate of one foot per second or greater, which will fill the sleeve. The sampler is then withdrawn to the surface for decanting to appropriate sample containers.

Kemmerer Sampler

The Kemmerer sampler is a flow-through point source device. It consists of a sample container with stoppers on each end. The sampler is attached to a line and lowered through the water column in an open configuration. This allows water to flow through the sampler. At the desired depth, a messenger is sent down the line, causing the two stoppers to close and capture the water that has entered the sample container at that depth. The stainless steel, polyurethane, or PVC filling tube comes in various sizes and the stoppers are constructed from polyurethane, silicone, or Teflon®. This sampler is suitable for most contaminants as the sample is decanted to appropriate containers at the ground surface.

Snap Samplers

Snap samplers literally snap closed (like a clam shell) to collect groundwater samples. Like other passive samplers, the Snap sampler collects groundwater samples in situ without purging. Snap samplers (singly or in series) are suspended in the well; the double-ended bottles are closed while submerged in the well; and, a special device is used to retrieve the samples. When Snap samplers bottles are brought to the surface, the end caps still have the retainer pin tab. This portion of the cap must be clipped off to allow placement of the septa cap. The vial can then be used directly in common laboratory auto sampler equipment. Samples are not exposed to ambient air during retrieval, field preparation, or analysis at the lab--unless manual dilutions or re-analyses are required. Various sizes are available, as different sampling volumes are required for analysis of physical and chemical water quality parameters, including VOCs and metals.

4.7.2 Diffusion Sampling Devices

Polyethylene Diffusion Bag (PDB) Samplers

The PDB sampler consists of a 1- to 2-foot long low density polyethylene (LDPE) tube closed at both ends and containing laboratory grade organic-free deionized water. They may capture upwards of 350 ml of sample for multiple VOA samples and duplicates (ITRC 2006). The samplers are buoyant, so they must be weighted for deployment. They can be lowered into a well using polyester rope, stainless steel, or Teflon coated stainless steel wire. Typical PDB samplers are shown in Figure 4-3.

Like other passive samplers, PDBs are set at specific depths and can thereby characterize depth-specific contaminants. PDBs collect the sample over time, hence the sampling results are time-weighted. In boreholes with considerable vertical flow, the depth-specific PDB time-weighted average concentration may contrast with samples acquired by bailing, pumping, or thieving.

PDBs may be hung in series to collect multiple depth-discrete concentrations. The bags must remain in the well for at least 14 days, although deployment times exceeding 6 months have been documented. PDBs are generally only used for nonpolar VOCs including chlorinated solvents. The samplers are not appropriate for hydrophilic polar molecules, such as inorganic ions. A summary of compounds suitable for sampling with PDB samplers is presented in Table 4-3. Acetone, methyl tertiary butyl ether (MTBE), and styrene did not show good laboratory correlation (Vroblesky 2001).

4.7.3 Integrative Sampling Device

By sequestering (concentrating) chemicals over time, integrative samplers can provide evidence of episodic changes in concentrations that grab samples may miss. Also, because they sample a relatively large quantity of water and sequester the chemicals of concern, they have ultra-low detection limits.

For typical groundwater sampling, the GORE® Module is tied to a weighted string and lowered to the desired sampling depth. The module is exposed for 15 minutes to four hours, then retrieved, and analyzed at GORE’s offsite laboratory (ITRC 2007). For vertical stratification sampling, the module can be deployed in a stacked configuration.

The adsorbents are thermally desorbed and analyzed by a modified EPA SW846/8260 method (gas chromatography and mass selective detection). Target analytes are VOCs and semi-volatile organic compounds (SVOCs) and may include water-soluble compounds (e.g., tertiary butyl alcohol and 1,4-dioxane), and polycyclic aromatic hydrocarbons(PAHs) (ITRC 2007). Results are reported in units of mass. GORE will estimate concentration, provided exposure time, percent water saturation, and soil porosity are provided.

Figure 4-3 Typical Diffusion Bag Samplers
(Source: USEPA, CLU-IN)

Semi-Permeable Membrane Device

The Semi-Permeable Membrane Device (SPMD) consists of a neutral, high molecular weight lipid (such as triolein) which is encased in a thin-walled (50 to100 μm) lay-flat polyethylene membrane tube. The nonporous membrane allows nonpolar chemicals to pass through to the lipid where the chemicals are concentrated. A standard SPMD is 2.5 cm wide by 91.4 cm long and contains 1 milliliter (mL) of triolein.

SPMD deployments typically are for one month, however, depending on the study design, deployment times can range from days to months. Table 4-4 lists the compounds which the SPMD captures.

Table 4-3
Tested Compounds Showing Good Correlation between PDB Samplers and Laboratory Tests

Benzene Bromodichloromethane Bromoform Chlorobenzene Carbon tetrachloride Chloroethane Chloroform Chloromethane	2 Chlorovinyl ether Dibromochloromethane Dibromomethane 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene Dichlorodifluoromethane 1,2-Dichloroethane 1,1-Dichloroethene	cis-1,2-Dichloroethene trans-1,2-Dichloroethene 1,2-Dichloropropane cis-Dichloropropene 1,2-Dibromoethane trans-1,3-Dichloropropene Ethylbenzene Naphthalene Toluene	1,1,1-Trichloroethane 1,1,2-Trichloroethane Trichloroethene Trichlorofluoromethane 1,2,3-Trichloropropane 1,1,2,2-Tetrachloroethane Tetrachloroethene Vinyl chloride Total xylenes
Source: Vroblesky 2001a			

Table 4-4
Classes or Specific Chemicals Known to Concentrate in SPMDs

Priority pollutant PAHs and alkylated PAHs Many heterocyclic aromatics, cyclic hydrocarbons (e.g., decalin and alkylated decalins) and aliphatics Organochlorine pesticides Other pesticides (e.g., diazinon, endosulfans, pyrethroids, toxaphene, and trifluralin PCB congeners Chlorinated naphthalenes Chlorinated dibenzofurans (e.g., 2,3,7,8-TCDF)	Chlorinated dibenzodioxins (e.g., 2,3,7,8-TCDD) Polybrominated diphenyl ethers Chlorinated benzenes Chlorinated anisoles and veratroles Alkyl phenols (nonyl phenol) Triclosan Tributyl tin Sulfur Essentially, any compound with log Kow ≥ 3.0
Source: CLU-IN, from Huckins et al. 2006	

4.8 Soil Gas Sampling

Soil gas samples are collected to measure vapor-phase contaminants in the vadose zone. Vadose zone vapor phase concentrations may impact groundwater. Hence, characterizing the distribution of soil gas is an important component in a hydrogeologic investigation.

Soil gas sampling techniques may be either active or passive. Passive methods employ a sorbent sampling device (e.g., GORE® Module) which can be placed in the subsurface for a specified time interval (conventionally two weeks), then retrieved for sample extraction and analysis. Passive soil gas methods can also be used for vertical profiling--by hanging a string of sampling devices in a single borehole. However, similar to passive sampling for groundwater, ambient (natural) or induced vertical flow within the well bore may confound results.

Soil gas probes may be constructed as either temporary or permanent sampling probes. Temporary probes are for one-time sampling and are decommissioned after the sampling event. Permanent soil gas probes are intended to provide time-series data for monitoring ongoing changes in soil gas concentrations stemming from migration or chemical transformation in the plume and remedial measures.

For a detailed description and discussion of soil gas sampling and strategies, please consult:

- *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance)* (DTSC 2011), and
- *Advisory—Active Soil Gas Advisory* (DTSC, LARWQCB, and SFRWQCB 2012).

4.9 Geophysical Investigative Methods

There are two major categories of geophysical investigative methods applicable to hydrogeological characterization: surface geophysics and borehole geophysics.

Surface geophysics comprises a suite of remote sensing techniques made at the ground surface whereas borehole geophysical methods are deployed down an open (i.e., uncased) borehole. These methods are thoroughly described in *Application of Surface Geophysics at Contaminated Sites* (Cal/EPA 2012) and *Application of Borehole Geophysics at Contaminated Sites* (Cal/EPA 2012).

Each geophysical method measures a different physical property; therefore, the choice of methods is dependent upon data needs and site-specific geology. No single method provides conclusive information; hence, a blend of methods may be needed. Selection of appropriate geophysical methods and data interpretation must be performed by a California Professional Geophysicist or a qualified California Professional Geologist, pursuant to the *Geologists and Geophysicists Act*.

Surface geophysics use indirect measurements of geologic properties, to define geologic and hydrogeologic features that cannot be directly observed. Surface geophysical techniques are appropriate for CSC or Triad investigations. Borehole geophysics are direct measurements of electrical and other properties of the subsurface as measured in a boring advanced by drilling methods or direct push methods.

Geophysical results can be integrated into visualization technologies to depict either contaminant distribution or other subsurface features.

4.9.1 Surface Geophysics

Surface geophysical surveys utilize the following techniques for geological and hydrogeological interpretations.

- *Resistivity*—measures electrical resistivity by passing electrical currents directly into the earth.

- *Electromagnetic* (similar to resistivity)—measures induced electromagnetic fields rather than direct measurement of electrical currents.

- *Seismic* (including reflection and refraction)--measures the passage of acoustic waves through the earth. Seismic methods are chiefly used in unconsolidated sediments to locate subsurface contrasts reflective of bedrock, faults, or confining layers. Seismic reflection methods provide greater resolution, however, at greater cost than seismic refraction methods.

- *Radar* (also known as ground penetrating radar or GPR)—uses electromagnetic signals directed to the subsurface to estimate bedrock depths, depth to water, soil and sediment strata depths, and the depths of subsurface bedrock fractures. GPR is also widely used to locate the presence and depths of subsurface hazards or infrastructure including pipes, drums, tanks, cables, and contaminants. Generally, GPR is applicable to depths downward of 10 meters.

- *Magnetometry* (with uses similar to radar)—measures changes in the ambient magnetic field caused by the presence or absence of magnetic materials. Used for locating underground tanks and other buried ferrous objects.

- *Gravimetry*—measures minute changes in the Earth's gravitational field caused by differences in the distribution of mass; used mainly for regional geologic studies.

The results of surface geophysical surveys are interpretive and should be confirmed by direct observation (e.g., soil or rock cores). Although not definitive, these surveys are a cost-effective method of gathering substantial amounts of information to focus subsequent studies.

4.9.2 Borehole Geophysics

Borehole geophysical measurements are made by passing measurement probes through a borehole. The record of measurements is called a log. Most borehole geophysical logging methods require an open (i.e., uncased), fluid-filled hole for proper operation; however, some measurements can be made through casing or in a dry hole. Methods commonly used are described below.

- *Electrical* (includes spontaneous potential, resistivity, and other electrical or electromagnetic energy)—measures the electrical properties of soil and rock. Used for lithologic correlation and identification. Under ideal circumstances, used for estimating water quality and formation porosity.

- *Nuclear* (including gamma logs)—measures natural radioactivity or uses radioactive sources to measure absorption or scattering of nuclear energy in surrounding materials. Used for lithologic correlation and identification. Some nuclear logs can also be used to estimate moisture content, porosity, and density.

- *Sonic*—measures velocity of acoustic waves in rock and soil. Used primarily to estimate porosity, but can also be used to assess the adequacy of well construction.

- *Caliper*—uses flexible feelers to measure borehole diameter. Used to correct other logs and to assess borehole quality. Used for indirect, qualitative measurements of soil and rock strength.

- *CPTs*—measure point resistance and side friction of soils. From these properties, lithology and hydraulic conductivity are inferred.

- *Downhole Video Logging*—A video camera which records the visual condition of a well or borehole.

- *Downhole Flow Meters*—Devices which measure and record flow velocities in a well or borehole.

Factors Influencing Geophysical Method Selection

In general, all quantitative survey methods work best in areas of minimal human development. Buildings, vibrations, and stray electromagnetic fields can limit the effectiveness of quantitative surveys.

Complex geologic conditions can also limit interpretation accuracy. Qualitative interpretations may be the sole interpretations obtainable in areas of heavy development or complex geology. In any case, knowledge of site-specific field conditions is a prerequisite for planning any geophysical survey.

Technique selection should be based on: site conditions, decision-making needs, areas/targets of interest, borehole conditions, and data requirements. Please consult Cal/EPA 1995c and e for a thorough discussion of tool selection and drilling methods for geophysical logging.

5.0 PRESENTATION OF SITE CHARACTERIZATION DATA

5.1 Technical Memoranda

Technical memoranda are essentially informal site characterization progress reports. Their purpose is to provide timely information on current site investigation activities and present preliminary information for review by the regulatory agencies. Regular reporting through technical memoranda can help identify problems and data gaps early, thereby enabling a consensus to be developed between responsible parties and regulatory agencies prior to delivery of the formal site characterization reports. When utilizing the Triad site characterization strategy, issuing technical memoranda can be an effective method of documenting project decisions and the data that were used to reach those decisions. Technical memoranda should be developed as needed to keep stakeholders informed of site characterization activities.

Information to be presented in technical memoranda includes the following (where applicable):

- Site history,
- Physical setting and site features,
- Summaries of historic groundwater quality data and other environmental data,
- Description of the field work conducted,
- Investigation results:
    - Chemical analytical data,
    - Boring and well location maps,
    - Lithologic, geophysical, and CPT logs, and other logs acquired using direct push methods,
    - Monitoring well construction logs,
    - Geologic maps,
    - Geologic cross sections,
    - Aquifer test data, and
    - Groundwater modeling results,
- CSM update,
- An evaluation of the sufficiency of investigation with respect to meeting DQOs,
- Field and laboratory QA/QC summary and analytical laboratory reports,
- Field forms (e.g., chain of custody and groundwater sampling forms),
- Description of the handling, storage, management, and disposal of investigation-derived waste (and manifests, etc.), and
- Deviations from the work plan and corrective actions taken (if any).

Data presented in technical memoranda need not always be cumulative. However, even if historical data is not included, interpretations presented in earlier reports and memoranda should always be updated as warranted by new information. That is, the

CSM should be revised as needed. *Reporting Hydrogeologic Characterization Data from Hazardous Substance Release Sites* (Cal/EPA 1995i) provides more information on technical memoranda reporting.

5.2 Groundwater Quality Reports

Groundwater quality reports are summaries of groundwater monitoring data only. Since groundwater sampling often occurs according to a more frequent schedule than other site characterization activities, submittal of groundwater quality reports should follow a schedule appropriate for the site-specific circumstances and should contain the following:

- Site history,
- Physical setting and site features,
- Description of the field work conducted,
- Cumulative monitoring data,
- Cumulative water elevations,
- Well location figures,
- Well screen elevations and other well construction details,
- Trend analysis,
- Plume maps,
- Field and laboratory QA/QC summary and analytical laboratory reports,
- An evaluation of the sufficiency of investigation with respect to meeting DQOs,
- Field forms (e.g., chain of custody and groundwater sampling forms),
- Description of the handling, storage, management, and disposal of investigation-derived waste (and manifests, etc.), and
- Deviations from the work plan and corrective actions taken (if any).

Annual groundwater quality reports summarize groundwater sampling efforts for the preceding year. Contents of the annual reports are similar to the groundwater quality reports (above), with the following additions:

- Seasonal plume maps for the preceding year,
- Seasonal groundwater elevation maps for the preceding year,
- Cumulative hydrographs for all monitoring wells,
- Summary of well conditions, corrective actions taken, and recommendations for future maintenance, and
- A review of data needs for groundwater sampling and proposed amendments (additions or deletions) to the monitoring program.

Unlike the technical memoranda, groundwater quality reports are *cumulative* (i.e., all previous sampling results are included in each report). This enables easier identification of trends in contaminant migration or possible errors in the data. Cal/EPA 1995i provides additional discussion of groundwater quality reporting contents.

5.3 Site Characterization Reports

Site characterization reports, such as Remedial Investigation (RI) and RCRA Facility Investigation (RFI) reports, provide the formal documentation of field investigation activities. The purpose of these site characterization reports is to provide the final results of the field investigations and the results of the baseline risk assessment.

Site characterization reports should contain (in addition to the human health and ecological risk assessments):

- Site history,
- Physical setting and site features,
- Elements of the CSM, including:
  - Extent of contamination in all affected media, (i.e., groundwater, soil, soil gas, indoor air, surface water, bedrock),
  - Contaminant fate and transport,
  - Points of exposure and receptors (human and ecological),
  - A description of site geology and hydrogeology,
  - Cumulative monitoring data,
  - Cumulative water elevations,
  - Well screen elevations and other well construction details, and,
  - Current and future uses, including beneficial uses of groundwater,
- Description of the field work conducted,
- Investigation results (itemized in Section 5.1),
- An evaluation of the sufficiency of investigation with respect to meeting DQOs,
- Summary of field and laboratory QA/QC and analytical laboratory reports,
- Description of the handling, storage, management, and disposal of investigation-derived waste (and manifests),
- Deviations from the work plan and corrective actions taken (if any),
- Field forms, and
- Conclusions and recommendations (including an assessment of data gaps).

Conciseness should be a goal for all site characterization reports. With regular reporting (including documentation) through technical memoranda, a site characterization report may simply summarize previously reported information. Text should be minimized wherever possible by the use of tables, graphs, and illustrations. Additional information on the use of illustrations for data reporting is provided in *Reporting Hydrogeologic Characterization Data from Hazardous Substances Release Sites* (Cal/EPA 1995i).

Suggested content for site characterization reports is presented in Table 5-1. Additional discussion of site characterization reports is provided in USEPA 1988, DTSC's PEA Manual, and Cal/EPA 1995i. However, be aware that tables and recommendations of earlier publications, although useful as checklists, may not fully capture the current approach to the CSM life-cycle and the DQO process.

Table 5-1 Suggested Content for Site Characterization Reports

Data presented in site characterization reports should be sufficient for developing and screening remedial alternatives. The information below is adapted from USEPA (1988) and DTSC (1993)

1. Study Area Investigation

   Discuss field activities associated with site characterization. These activities may include assessment or monitoring of some but not necessarily all, of the following:

Surface features	Contaminant source
Meteorology	Surface water and sediment
Soil and vadose zone	Geology and seismic setting
Groundwater	Human population
Ecological setting	Historical land use

2. Physical Characteristics of Study Area

   Provide results of field activities; the following areas may be covered:

Surface features	Meteorology
Soils	Surface water conditions
Geology	Groundwater quality
Geologic structures	Groundwater flow
Ecological data	Demography and land use

3. Nature and Extent of Contamination

   Present data on contaminant composition and vertical as well as horizontal extent for all affected media. Include descriptions of any spatial or temporal trends in contamination.

Source areas	Soil
Groundwater	Soil vapor/gas
Air	Surface water
Indoor air	Sediments

4. Contaminant Fate and Transport

   Describe potential routes of migration and estimated persistence of contaminants in the study area. Include physical, chemical and biological factors of importance for media of interest. Discuss factors affecting contaminant for each affected media. Present modeling methods and results if applicable.

5. Summary and Conclusions

   Summarize results presented in previous section, describe data limitations and any recommendations for additional work. Present recommended remedial action objectives.

Appendices

Appendices may include, but are not limited to, technical memoranda, analytical data, QA/QC evaluations , and risk assessment methodology as appropriate.

6.0 DATA REQUIREMENTS FOR REMEDY SELECTION

As presented in USEPA 1988, reports that document remedy selection, such as a feasibility study or CMS, require that cleanup alternatives be developed and screened concurrent with the site characterization investigation. Screening involves the evaluation of alternatives based several criteria, including effectiveness, implementability, and cost. Remedy selection, design, and implementation are based on these evaluations. Therefore, information collected during the site characterization investigation should be sufficient to support these evaluations.

Data needs and reporting requirements for various remedies will differ; therefore, data and reporting requirements for remedy selection can only be discussed in a very general sense in these guidelines. Data needs and report contents, including necessary documentation, should be developed by the project team for each site.

For example, the following data needs are critical to screen remedies involving the extraction and treatment of groundwater:

- Remedial action objectives,
- CSM (e.g., contaminant properties, concentrations, and extent in all media, and other CSM elements shown on Figure 2-3),
- Extraction and injection well locations,
- Extraction and injection rates,
- Aquifer characteristics (e.g., depth, thickness, extent, hydraulic conductivity, porosity, et cetera),
- Aquitard characteristics, and,
- Calculation or modeling of zones of influence for contaminant extraction.

A practice occurring with increasing frequency is deferral of selected data needs to the remedial design phase. Occasionally, these deferrals are detrimental to the evaluation of the selected remedy. Collecting data needed for adequate remedy screening should not be deferred to the remedial design. All data critical to remedy screening should be collected during the site characterization phase so they can be used during the remedy screening and remedy selection portions of the project.

7.0 CONCLUSION

This guidance document was developed to provide a framework that can be applied statewide, for conducting hydrogeologic characterizations of contaminated sites under the authority of the DTSC. This document provides a process model for hydrogeologic investigations, summarizes commonly used methods and general guidelines for their application, and presents general objectives for completing the hydrogeologic portion of any site characterization. Additionally, minimum content and reporting requirements are outlined to substantiate achievement of these objectives.

The investigation methodology presented in this document is closely related to the site characterization and remedy selection processes presented in USEPA 1988. This process, in general, is similar for every site characterization project. In detail, however, technical, logistical and budgetary constraints that exist at every site result in acceptable minor deviations from this process. No guidance document can account for these site-specific variations. Therefore, guidance is no substitute for experience and professional judgment. Exceptions to these guidelines should be anticipated, and independent judgment, based on experience, should be exercised where needed. Despite these limitations, the guidelines presented in this document provide an acceptable starting point for all hydrogeologic investigations, and can assist in acceptable data collection, appropriate analysis, and adequate presentation of findings, in a consistent fashion, for all contaminated sites throughout California.

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Appendix A

United States Army Corps of Engineers
Checklist for Systematic Planning

IMPLEMENTING SYSTEMATIC PROJECT PLANNING

What is systematic project planning?

Systematic planning is the process for defining an adaptive strategy and approach that can be used on projects to achieve site closure and reuse as quickly as possible. It focuses on determining where a project is going, how it is going to get there, and how will it be determined when the objective is met. The environmental community has long recognized the value of systematic project planning as reflected in the EPA's data quality objective (DQO) process, the U.S. Army Corps of Engineers' (USACE) *Technical Project Planning (TPP) Guidance* (USACE 1998), the U.S. Air Force's *Performance-Based Management Master Guidance* (November 2005) and others. In many cases, there can be misunderstandings about what type of planning is being conducted on a project because of the differences in nomenclature used by different federal agencies and departments.

In this document the Systematic Planning Process (SPP) is defined as the planning process that is based on the scientific method and includes planning management of the many non-scientific issues that impact site cleanup, such as uncertainty about budgets and contracts, stakeholder interests and fears, legal concerns, and regulatory interpretation. To be effective SPP must address all uncertainties that affect how a project's end goals are framed, shaping the decisions that must be made to bring the site to closure and reuse (Remediation 2005).

What are the fundamental requirements of SPP?

SPP encompasses activities that extend beyond data collection to determine compliance with some action level or cleanup goal. During SPP, the site conceptual model (CSM) is used to help evaluate site reuse options, guide remedial design, and develop long-term monitoring strategies. Effective SPP consists of several activities, including:

- Stakeholder involvement - building "social capital", a cohesive team of project stakeholders (such as site owners, regulators, community members, and technical specialists) suited to address site-specific problems
- Identification of project objectives/goals - development of clear objectives for site closure based on property re-use scenarios or known end uses and likely site remedies (i.e. site exit strategy). The project objectives drive the decisions that need to be made along with uncertainties that affect them. These objectives are identified based on the information in a CSM.
- Design of sampling and data management activities to achieve project objectives - stakeholders identify data needs based on the CSM, and develop strategies to collect and evaluate data needed to manage the principal sources of uncertainty that affect decision-making within the constraints of the project.
- Design of site closeout, remediation approach, performance objectives, and metrics – stakeholders identify likely site closure scenarios and remedial options based on the CSM. From this, strategies to implement, monitor performance, optimize, and shut down can then be developed.

While there is no checklist for performing SPP, the process should address the following key considerations:

- Building social capital among project stakeholders
- Clearly identifying project objectives and site exit strategy
- Identifying constraints such as budgets, timelines, and logistics
- Developing a CSM and defining potential exposure scenarios
- Addressing data and resource needs
- Identifying project boundaries and decision criteria
- Developing acceptable levels of uncertainty
- Understanding technical limitations of proposed sampling and remedial technologies
- Agreeing on applicable or relevant and appropriate requirements (ARARs) and time frame for achieving them
- Developing approaches for managing programmatic and project non-scientific and scientific uncertainties
- Translating project needs into sampling, analysis, and decision-making requirements

SPP can be applied to individual sites or to entire installations. For federal facilities, the individual site systematic planning process must comply with the master installation-wide strategic plan and federal facilities agreements (if in place).

What does an SPP session look like?

An SPP session can take many forms based on team preferences, schedule, site complexity, and location. Typically, a session will be in the form of a meeting of the whole team that takes 1-3 days. Although there is a benefit to having the whole team present throughout the session, support team members could attend parts of the meeting or be available for questions at certain times depending on their schedule. Key team members should be present for the entire session. Rather than engaging in consecutive days of planning, teams can also elect to break up the sessions into smaller meetings or teleconferences.

Regardless of the format, SPP sessions include the following:

- Introduce and clearly define participant roles/responsibilities and decision-making authority
- Identify meeting and project objectives
- Establish expectations and ground rules of group
- Identify existing sources of information
- Articulate the CSM
- Identify and gain consensus on key project uncertainties and contingencies
- Define acceptable levels of uncertainty and discuss technical limitations of strategies
- Translate into existing information review, sampling, analysis, and decision-making requirements

- Provide mechanism for decision-making when consensus is not achievable
- Identify and track action items
- Establish tentative project schedule

The following items are essential points to cover in SPP discussions:

<u>Regulations and Guidance</u>

- What is the regulatory framework within which action(s) are being taken?
- What pertinent guidance exists (e.g., if RCRA, what current RCRA guidance exists that will be relevant to any action taken. For groundwater actions see http://www.epa.gov/superfund/resources/gwdocs/)?
- What documentation is required for the regulatory framework?
- What types of review (i.e., regulatory, in-house legal, etc.) will be required throughout the process?
- What are the site ARARs?
- Will any ARAR waivers be required?
- Where are the points of compliance?

<u>Stakeholders</u> (if they hold a veto, legal or otherwise, they are a stakeholder)

- Who is funding the effort?
- Who has overall responsibility for the project?
- Who has day-to-day responsibility for the project?
- Who are the regulators?
- Who is providing technical support and/or technical review?
- Who are the public stakeholders?

<u>Conceptual Site Model</u>

- What information is currently available pertinent to the contamination status of the site?
- What are the project boundaries? Are there individual sites that all contribute to a larger site?
- Are there off site sources or other factors that can affect contaminant fate and transport or remedies on site?
- What are the contaminants of concern or potential concern?
- What are the potential receptors under current and reasonably expected future exposure pathways?
- What is the site geology and hydrogeology?
- What are the contaminant fate and environmental transport mechanisms? Geochemical conditions? Biological conditions?
- Has a risk assessment been performed, and if not, is one required?
- Are there residual sources contributing to a groundwater plume? How are source areas being defined? Does the site have an LNAPL or DNAPL source?
- What is the groundwater use designation?
- What are the contaminant levels that require action, what is their technical basis, and how are they defined? If they are default target levels will additional information be used to refine these levels?

- What past remedial actions and locations of remedial components and monitoring points?
- What are all historical, current, and expected future land uses?
- What are the decisions that will need to be made?
- Where are the sources of uncertainty within the CSM that prevent decisions from being made based on existing information?
- Which of those uncertainty sources can be addressed by data collection?
- Can data be collected using a dynamic work strategy? If so, how will this be done?
- What decision uncertainty cannot be addressed by data collection? What contingencies are required to address this uncertainty?

Exit Strategy

- What is the exit strategy for the overall project (note components may vary based on the stage of CSM development)?
  - What are the environmental conditions that pose an unacceptable risk that requires remediation?
  - What are the remedial action objectives that must be met to mitigate the risk?
  - What is the means selected to achieve the objectives?
  - What are the metrics to be used to demonstrate success?
  - What are the required post closure actions?
- What are the agreed to land use and risk management strategies?
- How does the site exit strategy translate into project decision logic?
  - What is the program level decision logic and how does it link to project level decision logic?
  - What is the project level decision logic?
  - How do goals for individual sites impact each other?
  - Are there logical interim actions to take?
  - What is the field level decision logic?
  - Who needs to be involved at various decision points?
- How will decision logic be documented?

Remedy

- What is the proposed future land use for the project?
- What precedents exist for problems of this sort either on-site or at similar sites?
- Is there a presumed remedy that will most likely be implemented, if remediation is necessary?
- What are the information requirements necessary for documenting closure?
- What is the probability of the remedy failure and what is the consequence of failure?
- Would the RA benefit from a phased combined technology approach?

Project Planning and Management

- Who constitutes the core planning team for the project (i.e., who will actively participate in planning and decision-making)?
- What are the team's expectations for the systematic planning process?
- Does this project have linkages with other planned, on-going, or completed projects on site? If so, what are those linkages?

- What is the overall project strategy?
- What constraints are known that might affect project strategy (e.g. budgetary, programmatic, real-estate access, procurement, schedule, past precedent, litigation potential, etc.)?
- How can a dynamic work strategy be implemented using real-time techniques to address data gaps?
- What is the logical sequence of activities to address data gaps in an efficient manner?
- Is there a way to compress activities required to achieve exit strategy?
- What are the analytical and/or measurement options for addressing data gaps?
- What contract mechanisms are available to execute the work and are they the most suitable for the project?
- What will the documentation process look like to support the strategy (e.g., types of documents, purpose, review requirements, etc.)?
- What is the project communication strategy? What decisions do individual stakeholders need to weigh in on? Will decision support tools be utilized?
- If there are transitions in team membership, what steps will be taken to continue the systematic planning process?

When is SPP performed?

SPP is practiced throughout a project, and not just in the beginning phases. SPP is also an iterative process that continues as the site CSM evolves. The concepts of building social capital, defining exit strategies, developing a CSM, and defining potential exposure scenarios are applicable to any type of environmental remedial project. These range from those for site assessment and investigation, to cleanup design and implementation, and to long-term operations and monitoring. For example, for a site that is looking to achieve closure, SPP can be used to bring together the key stakeholders needed to agree on the steps to reaching closure, even when those steps do not include performing additional field activities.

How does SPP build social capital among project stakeholders?

The "human factor" on projects is as integral to successful SPP as technological and scientific ones. To address this, SPP is performed using teams. By jointly developing consensus on overall strategy, identifying issues that could reasonably impede successful site development, proposing likely solutions for impediments and contingencies, the team ensures that needs and expectations are identified up-front and that rework to meet these expectations later is minimized. The teams should communicate the practical limitations of modern analytical and remedial technologies to develop strategies that can lead to achievable project successes.

The core team includes representatives of the responsible party, regulatory agencies, local groups or organizations, and technical expertise resources. Planning for environmental projects includes a wide variety of individuals and institutions, including project management and technical personnel, legal support, customers, suppliers, contractors, scientific experts, and other stakeholders, who together will determine if the project is successful. All members of projects that can support consensus-based decision-making should be included. For the team to be successful, participants must be committed to work through technical issues in a non-adversarial manner. Successful teams are also ones where there is membership continuity over the life-cycle of a project, since the team will embody a collective understanding of the technical and political basis for work done to date, and work proposed for the future. The end result of the team-approached planning is that the team identifies the decisions to be made, along with known and missing information and determines what information must be collected to support quality decision making activities.

One example of a team might include Federal Facility personnel (e.g., base personnel, contract managers, contractors) which meet in a scoping meeting with their counterparts in regulatory agencies to develop the plan for environmental data collection. Other members including technical experts in human health and ecological risk assessment, hydrogeology, chemistry, and quality assurance, contracting, legal support, and remedial design, may participate in the process, either in team meetings or in consultations behind the scenes. Other members might include individuals from the community. Community stakeholders participate in the process through routine briefings and public meetings on the proposed team approach. The best way to incorporate community input in the systematic planning should be determined at the beginning of the project.

Project managers should facilitate stakeholder involvement and commitment throughout the project, particularly during field activities so that concerns can be managed and addressed in real-time. Stakeholder involvement early in the process and continuing as the project is ongoing is crucial to avoiding disputes or last minute surprises associated with stakeholder concerns. These agreements on approach are especially critical if dynamic strategies are being used in the field that require real-time decision making. Increased involvement of the project manager and senior project staff at critical times or delegating greater decision-making power to the field technical team is also necessary to ensure quality field investigations are conducted with optimum efficiency.

What should the project objectives/goals discussions include?

It is critically important that project stakeholders agree on the project objectives/goals as early as possible in the process. Ideally, project objectives/goals are established before development of a project plan. If a project is in process, project objectives/goals can be set for future phases of work. Without a clear project objective, the path to site closure and how uncertainties are managed with respect to the project objectives cannot be developed. The following are examples of the types of questions that often are considered during development of project objectives:

- What are the potential sources and other environmental issues at the site?
- What are the potentially-impacted media and receptors?
- What is the planned reuse?
- Who is responsible for cleanup of the site?
- What are the appropriate cleanup levels for the site?
- Is there sufficient data to support closure?
- What data are needed to support implementation of potential remedies?
- Do viable treatment or containment technologies or other alternatives exist?
- What is the preferred remedial alternative?

- What is the estimated cost for redevelopment of the site?
- What is the economic viability of cleanup?
- What data are needed to evaluate remedy effectiveness, once implemented?
- How can closure be documented?
- How can system performance be optimized and operating costs be reduced?
- What contingencies need to be established to ensure objectives are being met?

What does managing uncertainty mean in systematic planning?

Effective SPP requires the management of decision uncertainty beginning with all parties agreeing on what the project decisions should actually be. Once the project objective are defined, decision uncertainty can then be developed with respect to these objectives in the context of achieving site closeout. Uncertainties on projects have many forms, including:

- Contaminant and media heterogeneity
- Whether risk pathways are complete
- Investigation and remedial techniques
- Schedule and budget
- Future land uses
- Attitudes and positions of the public

SPP works to describe the uncertainty in terms that allow it to be resolved and prioritized such that meaningful answers can be obtained, decision makers can define levels of tolerable uncertainty to the decisions, and judgments can be made concerning the adequacy of the answer. Management of uncertainty is probably the single most important team activity that can reduce the level of stress and potential conflict around decision-making.

What are the Benefits to Using Systematic Planning Process?

There are certain benefits that result from using a Systematic Planning Process. The benefits include:

- Encouraging comprehensive, careful planning by soliciting input from concerned customers and stakeholders;
- Addressing costs and schedule in the design phase, the critical time to address total project constraints;
- Communicating and documenting proposed activities and decisions to be made so that *everyone* has a common understanding of requirements when considering the data collection or work design, strategies, and the end use of products;
- Addressing the concerns of customers, suppliers, and relevant technical experts for products, services, and activities, thus minimizing the possibility of repeating work because of inappropriate or inadequate project implementation; and
- Facilitating the application of promising innovative technology by reconciling technology capabilities with site-specific considerations.
- Identifying contractual mechanisms that facilitate the use of dynamic work and performance based strategies
- Identifying and planning contingencies for innovative technologies and approaches

What comes out of the Systematic Planning Process?

The primary products of SPP sessions are a written identification of the strategy to execute the regulatory process through closure, and a framework that uses dynamic decision logic to resolve outstanding uncertainties that can be addressed through information/data collection. There are several ways to document the progress of the Systematic Planning Process depending on how the sessions are run, i.e., correspondence, after action reports, progress reports, and meeting or planning minutes.

Once the SPP sessions are completed, project-specific products of the SPP can be developed including living Conceptual Site Models, Dynamic Work Strategies, Demonstrations of Methods Applicability as necessary, and Standard Project Planning documents (Quality Assurance Project Plans, Field Sampling Plans, and Environmental Health & Safety documentation, Standard Operating Procedures, etc.).

SPP should continue throughout the life of the project. For small projects, SPP follow-up sessions may be held at key project milestones. For larger projects, SPP sessions can occur before each new major phase of work, for example, site characterization, feasibility study, etc. Each new SPP session will build off the work of the prior sessions, with work plans and reports summarizing the revised CSM, project decisions, etc.

Appendix B

Sampling and Preservation Requirements for Water Samples

Appendix B Sampling and preservation requirements for water samples

Parameter	Container[a]	Preservation	Holding Time	No. of Samples x Min. Volume (ml)
Acidity	P,G	Cool, 4°C	14 days	1 x 100
Alkalinity	P,G	Cool, 4°C	14 days	1 x 100
Ammonia	P,G	Cool, 4°C; H2SO4 to pH<2	28 days	1 x 1000
Asbestos	P	Cool, 4°C	48 hours	1 x 1000
pH	P,G	None	Measure in field ASAP	1 x 50
Radioactivity	P,G	HNO_3 to pH<2	6 months	1 x 1 gallon
Total Organic Halides (TOX)	Amber G-V	Cool, 4°C; HNO_3 to pH<2 [If chlorinated 1ml 0.1M Na_2SO_3]	14 days	3 x 100
Total Organic Carbon (TOC)	Amber-G	Cool, 4°C; H_3PO_4 or H_2SO_4 to pH<2	28 days	1 x 100
Chloride	P, G	None	28 days	1 x 100
Cyanide (total)	P, G	Cool, 4°C; 10N NaOH to pH>12; 0.6g Ascorbic acid if Cl is present	14 days; 24 hours if sulfide is present	1 x 1000
Flouride	P	None	28 days	1 x 500
Nitrate	P,G	Cool, 4°C	48 hours	1 x 500
Sulfate	P,G	Cool, 4°C	28 days	1 x 200
Sulfide	P,G	Cool, 4°C; 4 drops of 2N Zn Acetate per 100 ml of sample, 6N NaOH to pH>9	7 days	1 x 1000
Chromium VI	P,G	Cool, 4°C	24 hours	1 x 500

[a]P = Polyethlyene container with polypropylene closure.

G = Glass container with Teflon-lined closure.

G-V = Glass VOA (volatile organic analyte) vial or bottle with Teflon-lined cloure (no headspace).

Appendix B (continued) Sampling and preservation requirements for water samples

Parameter	Container[a]	Preservation	Holding Time	No. of Samples x Min. Volume (ml)
Dissolved Metals (except Cr VI)	P,G	Filter On-Site; HNO_3 to pH<2	6 Months (except Hg, 28 days; 13 days in plastic container)	1 x 1000
Total Metals	P,G	HNO_3 to pH<2	6 Months (except Hg, 28 days; 13 days in plastic container)	1 x 1000
Extractable (semi-volatile) Organics	G	Cool, 4°C	7 days to extraction, analysis 40 days after extract	1 x 1000*
Purgeable (volatile) Organics	G-V	Cool, 4°C	14 days	2 x 40*
Purgeable Aromatics	G-V	Cool, 4°C; HCl to pH<2	14 days	2 X 40*
Acrolein & Acrylonitrile	G-V	Cool, 4°C	14 days	2 X 40*
Gasoline	G-V	Cool, 4°C	14 days	2 x 40*
Pesticides & PCBs	G	Cool, 4°C	7 days to extraction; analysis 40 days after extract	1 x 1000*
Phenols	G	Cool, 4°C; H_2SO_4 to pH<2	7 days to extraction; analysis 40 days after extract	1 x 1000*
Oil & Grease	G	Cool, 4°C; H_2SO_4 to pH<2	28 days	1 x 1000*

[a]P = Polyethlyene container with polypropylene closure.

G = Glass container with Teflon-lined closure.

G-V = Glass VOA (volatile organic analyte) vial or bottle with Teflon-lined cloure (no headspace).

Need to submit additional containers of samples for QA/QC with each batch. Check with lab for number of containers needed.