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Section 5 Site Investigation Techniques

I. INTRODUCTION

Consistent and appropriate site investigation techniques must be used to ensure that accurate, reliable, and representative data are collected during the site assessment process. The following guidance is provided to establish standardized methods and procedures for the investigation, testing, and interpretation of geology, hydrogeology, and contaminant mobility. This section is not intended to duplicate well-established methods and procedures, but to establish minimum standards for proper investigation techniques at a contaminated site.

The investigation techniques include soil and rock sampling, soil vapor sampling, direct measurement of vapor flux, groundwater sampling, laboratory analysis, and stockpile sampling. Additional guidance on standard field and laboratory methods can also be found in many textbooks, government agency documents, and professional society publications.

II. BORING AND WELL PERMITS

Permits are required for all groundwater, vadose wells, cathodic protection wells, and for many exploratory borings (San Diego County Code, Title 6, Division 4). Standards for well construction, destruction, reconstruction, or repair are as stated in California Department of Water Resources Bulletins 74-81 and 74-90. More specific boring and well construction standards are presented in Appendix B.IV. An explanation of permit requirements is provided below. Completed permit applications must be submitted to the San Diego County Department of Environmental Health (DEH), Monitoring Well Program (MWP) and approval must be received before drilling can begin.

In San Diego County, wells include:

- Community supply wells,
- Individual domestic wells,
- Commercial supply wells,
- Industrial supply wells,
- Agricultural supply wells,
- Cathodic protection wells,
- Groundwater monitoring wells (observation wells and piezometers),
- Groundwater remediation wells,
- Vadose monitoring wells, (vapor wells, gas monitoring wells, vapor probes),
- Vapor extraction/inlet wells, and

- Borings (test holes, auger holes, driven test holes, cone penetrometer test holes, Site Characterization and Analysis Penetrometer System [SCAPS] test holes, geotechnical borings, etc.).
- Geothermal Heat Exchange Wells
- Enhanced Leak Detection (ELD) Probes

A. Permit Requirements

1. Groundwater, Vadose, and Cathodic Protection Wells

Well permits are required for any groundwater, vadose, or cathodic protection well installation regardless of how the well is installed. Dewatering wells require a permit if they will be used beyond the initial construction phase. Information on the construction and destruction methods and specific permitting requirements for cathodic protection wells can be found on the San Diego County website at the MWP webpage:

http://www.sdcountry.ca.gov/deh/water/sam_monitoring_well_page.html

2. Enhanced Leak Detection (ELD) Probes

ELD is used to monitor new and existing underground and above ground storage tanks and associated pipelines for vapor and liquid leaks. All vertical vapor probes installed after underground and above ground tanks and pipelines are in operation require a permit. For details about permitting and construction requirements, refer to Appendix B.

3. Exploratory or Test Borings and Geotechnical Borings

Well permits are required on all sites for:

- Any boring in which a casing will be installed
- Any boring that has a monitoring device installed
- Any soil boring greater than 20 feet in depth
- Any soil boring, 20 feet or less in depth, where the groundwater table is anticipated to be encountered

A permit for geotechnical borings may be waived after review of information on the location of the borings by the MWP. Waivers are considered only for areas where hazardous waste or hazardous materials have not been stored, are not now stored, are not proposed to be stored or areas where soil and groundwater contamination is not known or suspected. Submit a waiver request (available at the above referenced webpage) along with a detailed site map and a description of the proposed work to assist the MWP in the evaluation.

4. Well Destruction

Well permits are required for the destruction of any groundwater, vadose, or cathodic protection well unless the well is destroyed within the life of the permit.

5. Well Reconstruction

Well permits are required for reconstruction of any groundwater, vadose, or cathodic protection well. A reconstruction is defined as an alteration to a well beyond minor modifications to the surface completion above the bentonite layer. Minor modifications may be completed without a permit but must be approved by the MWP before work begins.

B. Permit Application

Submit one original complete “Permit Application for Groundwater and Vadose Monitoring Wells and Exploratory or Test Borings” (well/boring application), detailed site plan, additional supporting documents (if required), and the appropriate fees to the Monitoring Well Permit Desk. A copy of the well/boring application is available in Appendix B.II and on the above webpage. The MWP will not process the application until all fees are submitted. The application must have original signatures of both the driller and the Professional Geologist (PG), Registered Civil Engineer (RCE), Certified Engineering Geologist (CEG), or Certified Hydrogeologist (CHG) in responsible charge of the work. Please allow seven to ten (7 to 10) working days after a complete application package is received for processing and review.

If an incomplete application is submitted, the permit application may be returned. The approved permit will be emailed to the contact person indicated in the application and the driller.

1. Application for Groundwater Monitoring Well Construction, Destruction, and Borings

Complete the “Permit Application for Groundwater and Vadose Monitoring Wells and Exploratory or Test Borings.” The following information must be included on the application.

- a. Assessor’s parcel number (APN)
- b. Current property owner
- c. C57 driller's information (all work must be done by a properly California licensed driller with a bond to work in San Diego County.)
- d. Licensed Geologist or Civil Engineer on project
- e. Number of wells (or borings) to be constructed or destroyed
- f. Well type
- g. Drilling method
- h. Proposed materials to be used
- i. Proposed well construction or for well destructions, a copy of the well “as built” diagram or well construction permit number(s)
- j. Driller’s signature (must have original signature)
- k. Original signature of Professional Geologist (PG), Registered Civil Engineer (RCE), Certified Engineering Geologist (CEG), or Certified Hydrogeologist (CHG) for wells and borings. The driller’s signature must be provided for well destructions.
- l. Evidence of a \$7,500 bond, posted with the County of San Diego, Department of Environmental Health
- m. Detailed site plan (drawn to scale) showing the location of the proposed well(s) and/or boring(s) and the location of existing wells. The plan must show the location of existing improvements, such as structures, underground storage tanks (USTs), and underground utilities. An adequate vicinity map is also required to show the site location in relation to the surrounding area.

n. Supporting documents:

- Applications for traffic control permits, and encroachment/excavation permits for work in the public right-of-way
- A Property Owner Consent (POC) form is required on applications for all work except: onsite, open LOP site assessment cases (SAM is lead agency), Caltrans property and Military property.

2. Application for Cathodic Protection Wells and ELD Probes

All of the above information is required with the exception that only a driller's signature is required.

3. Fees

To be accepted by the MWP, a well/boring application must be submitted with the appropriate fees. The current permit fees are detailed on page three of the application that is provided on the monitoring well webpage.

4. Refund of Permit Fees

If you did not complete the original scope of work for the permit issued, submit a written request to the Monitoring Well Permit Desk for a refund of the appropriate portion of the unused fees. Your request must be received within 30 days after the expiration date of the permit. A fee will be deducted from the refund to cover the processing and the technical review of the permit.

2. Permit Extensions

A permit is valid for 120 days. It may be extended for an additional 120 days for the purpose of completing the original scope of work. Two extensions may be requested for 120 days each for the purpose of completing the original scope of work.

Submit a written request for an extension to the Monitoring Well Permit Desk before the expiration date, along with an extension fee. Contact the Monitoring Well Desk for the amount of the fee as it is based on the Environmental Health Technician hourly rate. The maximum term of a permit cannot exceed 360 days.

3. Permit Modifications

Permit modifications will be granted if the Monitoring Well Permit Desk is notified at the time of initial drilling activities that further work is needed. We will require a written request for a modification, including the additional fees and a revised site map to be submitted to our office within five (5) business days. If it is determined after the initial drilling that additional work is necessary, a new application must be submitted.

C. Inspections

1. Drilling Inspections

The Monitoring Well Permit Desk must be given 48 hours notice prior to commencement of drilling activity. MWP staff conduct random on-site drilling inspections. These inspections are to observe field activities and to ensure that all work is being completed in compliance with the current local and state requirements.

2. Well Completion Inspections

- a. MWP staff will perform inspections of all sites that have groundwater, vadose, or cathodic protection wells, or where these wells have been destroyed, to determine if the wells were completed or destroyed in accordance with current local and state standards and to observe the long-term maintenance of the well(s).
- b. Inspection reports will be issued when it is observed that monitoring wells or cathodic protection wells are not being maintained and/or they present a potential public health hazard or environmental hazard.

3. Re-inspections

While inspecting drilling sites, DEH staff may discover that the scheduled drilling operations were cancelled. If the DEH Monitoring Well Permit Desk has not been properly notified of a drilling cancellation, and staff travels to a site to conduct an inspection, a re-inspection fee may be required. Contact the Monitoring Well Permit Desk at (619) 338-2339 for any drilling activity, including cancellations.

No additional fees are charged for the initial inspection. A re-inspection fee will be required for each subsequent re-inspection unless satisfactory proof of compliance, such as photos, has been provided to MWP staff. Subsequent non-compliance will result in an Official Notice to attend an office conference and further enforcement action.

D. Drilling Bond

Prior to obtaining a permit to drill, the licensed driller must have a \$7,500 bond posted with DEH. This bond can either be a cash bond or an insurance performance bond. For details concerning drilling bonds, call (858) 565-5173.

E. Permit Conditions

1. Workplans

An approved drilling permit application does not constitute an approved workplan as defined in CCR Title 23, Article 11, Section 2722.

2. DEH Notification

The consultant/driller must notify the Monitoring Well Permit Desk 48 hours before the date of drilling. Additionally, the consultant/driller must also notify the Monitoring Well Permit Desk of any cancellation or rescheduling of drilling. Call (619) 338-2339 for all scheduled drilling, cancellations, or rescheduling.

3. 60-Day Drilling Report Submission

Within 60 days after construction or destruction of wells, or drilling of borings, a drilling report with the following information must be submitted to the MWP. The drilling report must be sent directly to the County of San Diego, Department of Environmental Health, Site Assessment and Mitigation Program, Monitoring Well Permit Desk, P. O. Box 129261, San Diego, CA 92112-9261.

a. For wells and borings, provide:

(1) Location and identification of property by:

- Site name and address
- Assessor's parcel number
- Establishment number (H#), if any
- Well permit number

(2) A detailed plot plan drawn to scale showing location of site and nearest cross streets, property boundary lines, existing improvements such as USTs, piping, and/or utilities, and the location of all wells and borings, both existing and proposed.

(3) A detailed log for each well/boring describing the density, moisture content, color, grain size distribution, and character of all lithologic units penetrated. The log must include:

- Depth of first groundwater
- Static water level in the completed well(s)
- Date of measurement
- Field vapor readings
- Dates of drilling initiation and completion

(4) A detailed "as-built" well construction diagram with well/boring diameter, type of casing, screened interval, screen slot size, type of filter pack, location and type of seals, surveyed well elevations and locations, and volumes of materials used (cubic feet) for each well/boring or a statement that they were sealed in accordance with State and Local guidelines. Surveying must be performed by an appropriately licensed professional and meet the accuracy requirements of CCR Title 12, Section 2729-2729.1.

(5) A grain-size analysis of the lithologic unit or units that represent soils adjacent to the perforated portion of the well, if performed.

- (6) All laboratory analysis data and chain of custody if there is no current DEH, RWQCB or DTSC site assessment case.
 - (7) All well construction and boring reports must have the original signature of the registered professional and/or their seal as required by the Business and Professions Code. The PG, CEG, RCE, or CHG, who signed the permit application, is responsible for the accuracy and completeness of the logs and accompanying data
 - (8) The name of the drilling company who completed the work
- b. For Well Destruction
- (1) Provide a detailed site plan, as outlined in Section 5.II.E.4.a. (2), drawn to scale, and giving accurate locations of all wells and borings with well identification numbers.
 - (2) Include the location of the site by:
 - Site name and address
 - Assessor's parcel number
 - Well permit number and/or establishment number
 - (3) Documentation of well destruction includes:
 - Description of the method of destruction including auger size
 - Description of the type of sealing materials and volume of materials used (cubic feet)
 - Date the work was started and the date the work was completed
 - The name of the drilling company who completed the work.

4. Storage of Drill Cuttings and Groundwater

a. Drum Labeling

Temporary drum storage of contaminated drill cuttings (soil) or groundwater requires proper labeling.

- (1) If the drill cuttings or groundwater is a hazardous waste, a hazardous waste label must be properly completed and affixed to drums. All hazardous waste must be managed, stored, and disposed in accordance with all applicable hazardous waste laws and regulations.
- (2) If the drill cuttings (soil) or the groundwater is not suspected of being contaminated (e.g., awaiting laboratory results), the drums must be clearly marked with the following information.
 - Description of contents (e.g., soil, water)
 - Boring identification
 - Date of boring
 - Consulting company name
 - 24-Hour contact phone number

b. Drum Storage

All drums must be labeled and stored within a secure area. Drums containing hazardous waste must be removed within 90 days. Minimum stormwater requirements must be met according to Appendix N.

F. Well and Boring Standards

Please refer to Appendix B.II for local standards on well construction, well reconstruction, and well and boring destruction. Additionally, San Diego County requires all work to comply with the Department of Water Resources Bulletins 74-81 and 74-90.

III. SOIL AND ROCK SAMPLING

A. Geologic Observations and Interpretations

Understanding the geology at a site is critical in designing and implementing site assessment and remediation programs. Observations of soil and rock types encountered during site investigations should be integrated with all site findings and correlated with the local geologic environment.

Consider the following items to improve your understanding of the site.

- Review of existing geologic information from all available sources such as:
 - Published geologic maps and reports,
 - Personal or company experience in the site vicinity,
 - Reference material at local university libraries,
 - Site investigation and assessment reports prepared by environmental consultants on file with governmental agencies such as DEH, RWQCB, building departments, GeoTracker or others.
- Review of aerial photographs
- Review of topographic maps
- Observation of road cuts, excavations, and other exposures in the site vicinity
- Drilling one or more soil boring(s) using continuous coring methods

It is important to understand the local geologic environment to interpret the significance of changes in soil and rock types encountered in excavations and boreholes at the site.

Field observations, chemical analytical data, presence of groundwater, and presence of free product should be detailed in boring logs and trench logs. The depth and thickness of perched water or zones with non-aqueous phase liquid (NAPL) above the water table should be logged, sampled, and reported on the boring logs. Drilling generates cuttings that can be logged and interpreted to describe the underlying rock type and geologic structure. An interpretation should be made between fill and native soil, and should include an identification of the fill and native soil contact. Furthermore, all soil and fill materials should be described by using a soil

classification system. Rocks and geologic formations should be described by using an appropriate rock classification system, such as ASTM.

A list of the observations that should be made and noted on field logs is presented in Table 5-1. Note that additional field descriptions for soils may be made depending on grain size. A key must be submitted with all boring logs. A list of field description guides is available in Appendix I.II, under *Technical References*.

An PG, CEG, RCE, or CHG who is registered with, or certified by, the State of California must log all soil and rock materials. A trained and experienced technician working under the direct supervision and review of one of these registered professionals shall be deemed qualified, provided this professional assumes responsibility for the accuracy and completeness of the logs. In addition, all work and reports that require geologic or engineering evaluations and/or judgments must be performed under the direction of an appropriately registered or certified professional. The registered professional must sign all reports containing such information.

TABLE 5-1: FIELD DESCRIPTIONS FOR SOIL AND ROCK

DESCRIPTIONS	(1) SOIL	(2) SEDIMENTARY
Classification System	USCS	List system used
Classification	ML, SW, CL, etc. Specify fill or native soil.	Sandstone, siltstone, conglomerate
Distribution/Abundance of Grain Size	Relative (include maximum Particle size)	Relative (include maximum particle size)
Minerals	Optional	List most abundant to least abundant
Color	Munsell Color Chart	Munsell Color Chart
Moisture Content/Saturation	Relative	Relative
Odor	Optional	Optional
OVA Readings	Optional	Optional
Contaminant Discoloration	As present	As present
Natural Organics	As present	As present
Plasticity	Degree of	Degree of
Visible Porosity	As applicable	As applicable
Blow Counts	As applicable	As applicable
Density (field)	Relative	Relative
Induration	Optional	Relative
Cementation	As present (type and degree)	As present (type and degree)
Weathering	Not applicable	Degree of
Fossil Assemblages or Trace Fossils	As present	As present
Texture/Structure	Grain shape(s) layers/laminations	Bed thickness, laminations, sorting, packing, grain shape(s), fracturing or folding, etc.
Other Observations	As present	As present

TABLE 5-1 (cont.): FIELD DESCRIPTIONS FOR SOIL AND ROCK

DESCRIPTIONS	(3) IGNEOUS	(4) METAMORPHIC
Classification System	List system used	List system used
Classification	Diorite, monzonite, gabbro, dacite, basalt, etc.	Schist, gneiss, quartzite, mylonite, etc.
Minerals	List most abundant to least abundant	List most abundant to least abundant
Particle/Grain Size Distribution	Relative (include maximum particle size)	Relative (include maximum particle size)
Color	Munsell Color Chart	Munsell Color Chart
Moisture Content/Saturation	Relative	Relative
Odor	Optional	Optional
OVA Readings	Optional	Optional
Contaminant Discoloration	As present	As present
Natural Organics	Not applicable, unless in fractures	Not applicable, unless in fractures
Visible Porosity	As applicable	As applicable
Blow Counts	As applicable	As applicable
Density (field)	Relative	Relative
Induration	Relative	Relative
Weathering	Degree of	Degree of
Fossil Assemblages or Trace Fossils	Not applicable	As present (remnant)
Texture	Euhedral to anhedral, equigranular to porphyritic, vesicular to scoriaceous, crystalline or glassy, etc.	Lineations, foliation, cleavage, cataclastic to mylonitic, etc.
Structure	Size and density of fractures, faulting, folding, cleavage, etc.	Size and density of fractures, faulting, folding, cleavage, etc.
Other Observations	As present	As present

Site geology controls the migration of contaminants. An understanding of soil and rock types within their geologic framework allows for better determination of the location of additional soil borings and monitoring wells, should further assessment or monitoring of subsurface contamination be necessary. Graphical presentations such as geologic cross sections are essential to illustrate interpreted changes in soil and rock types (refer to Appendix F.I for examples of site maps and geologic cross sections). Site-specific geologic information is necessary to evaluate and design remediation programs and to perform fate and transport studies.

B. Sample Collection

The goal of the site assessment is to determine the nature and extent of contamination. The quality and integrity of samples, sample locations, and other field observations will strongly influence interpretation of site conditions. Sample collection, management, and analysis must be done in accordance with the procedures specified in:

- CCR Title 22, Division 4.5, Chapter 11, Article 3, Section 66261.20(c), and
- U.S. Environmental Protection Agency document, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Sixth Edition (2007).

Many container types are available for contaminant sampling and/or storage. The contaminant class determines the type of container that is selected. Follow the protocols outlined in EPA SW-846 for selecting the appropriate containers and for determining proper handling and storage requirements. Sleeves or liners are generally used when volatile compounds are present or suspected. Their use, however, may be limited by certain geologic conditions in San Diego County. Non-clear sleeves and liners also limit observations of lithology and the presence or absence of contamination. For these reasons, glass jars with Teflon-lined lids are commonly used. When glass jars are used they should be filled completely to minimize headspace.

C. Sampling to Delineate Contamination

Subsurface sample locations should be guided by the underlying geology, contaminant characteristics, and field conditions to determine the extent and magnitude of contamination. Discrete samples are required to demonstrate delineation of contamination; composite samples will not be accepted. Delineation is generally complete when successive nondetectable levels of contaminants are observed.

Samples have historically been collected at intervals of 5 feet. However, since thin distinct layers of contaminated soil may exist, or changes in lithology that affect contaminant distribution may occur within a 5-foot interval, soil and rock samples should be collected at significant changes in lithology and other locations as necessary, based on field observations of contamination.

Within the capillary fringe and the saturated zone, samples should generally be collected at 1- to 2-foot intervals in order to delineate the "smear zone." For the purpose of this manual, the "smear zone" is defined as soil or rock in the vicinity of the capillary fringe, and below the water table, which contains contaminants in a sorbed or free product phase (light non-aqueous phase liquid or LNAPL). The smear zone develops when the water table fluctuates or is depressed by NAPL. The smear zone will provide a continuing source of groundwater contamination and must be delineated for an effective remediation program to be designed.

Site-specific sampling protocol and sampling strategy must be presented in a workplan (Section 4.III), and should be discussed with DEH staff. Sampling plans often need to be modified during field operations; therefore, details of the sampling and analyses actually performed must be described in the site assessment report.

D. Drilling Techniques for Sample Collection

A number of sample collection techniques are used in subsurface investigations. Determining a suitable approach to sampling will depend upon the site accessibility, underlying lithology, and contaminant type. Driven sampling methods that utilize split-spoon samplers, probe/push-sampling techniques, and continuous coring techniques are preferred because these methods allow collection of samples at precise depths. Samples should be collected at least 6 to 18 inches in advance of the drill bit or auger to ensure that undisturbed native material is obtained.

Because the original borehole depth of grab samples collected from auger flights is uncertain, this sampling technique should only be used when driven-sampler and continuous-coring methods are not feasible. When grab samples are being collected, they should be obtained from the lowest flight of the auger and close to the auger stem. Caving or sloughing of the sides of the borehole in softer sediments may further complicate identification of grab sample depths and should be noted on field logs.

Drilling methods that add water, drilling fluids, or other substances into the boring during drilling may contaminate samples, spread contamination, and interfere with analysis for target compounds. A Material Safety Data Sheet (MSDS) must be obtained from the manufacturer for each drilling fluid or additive used at the site. For percussion drilling and other down-hole devices that require lubrication, a pure vegetable oil or other petroleum-free hydrocarbon lubricant must be used. Any substance introduced into the boring or drilling environment should be sampled for comparison analysis of target compounds if cross-contamination is suspected.

The most common drilling and auguring methods are presented in Table 5-2. Actual site conditions may affect the suitability of these methods. Alternative approaches must be discussed with DEH staff.

TABLE 5-2: SAMPLING TECHNIQUES

METHOD	BEST RESULTS IN	NOT GOOD FOR	OTHER REMARKS
Hollow Stem Auger	Fill, soil, most sediments	Larger cobbles, boulders, hard rock	Good for discrete, in situ samples
Solid Stem Auger (18-24 inch diameter)	Fill, soil, cobbles, consolidated sediments	Cohesionless or saturated soil, boulders, hard rock	Large quantities of spoils; difficult sampling below water table; poor sample integrity
Bucket Auger	Cobble-rich strata, consolidated sediments	Cohesionless or saturated soil, boulders, hard rock	Large quantities of spoils; difficult sampling below water table; poor sample integrity
Probe/Push Samplers (CPT, Strataprobe, Geoprobe or like samplers)	Fill, soil, most sediments, weathered decomposed granite	Gravelly soil, cobbles, boulders, hard rock	Limited sample volume for analysis; limited depth. Doesn't penetrate consolidated soils.
Air Rotary	Any soil or rock	----	Air may volatilize contaminants; air stream must be dual filtered
Air Percussion	Cemented strata, conglomerate, boulders, cobbles, hard rock	Unconsolidated soils and sediments	Air may volatilize contaminants; air stream must be dual filtered
Mud Rotary	Any soil or rock	----	Use only appropriate drilling fluids
Rock or Diamond Coring	Hard rock	Gravels, cobbles, unconsolidated soils	Use face-discharging drill bit designed for environmental purposes
Casing Hammer	Soil, unconsolidated river wash, gravel, cobbles, conglomerate	Hard rock	----
Vibracores	Soft mud and other saturated, unconsolidated or benthic sediments	Consolidated sediments, hard rock	----
Hand Auger	Fill, soil, most sediments	Cobbles, boulders, hard rock	Limited depth
Sonic	Fill, soil, sediments, cobbles, consolidated or cemented strata	Cobbles, boulders, hard rock, or cobbles	Heat generated from drilling may volatilize contaminants

IV. SOIL VAPOR SAMPLING

The following guidelines are for conducting soil vapor sampling in San Diego County. The references used to develop these guidelines are presented in Appendix I.II.E. Other vapor survey standards (e.g. DTSC) may be applicable for a particular application. For cases under DEH jurisdiction, a work plan must be submitted and approved prior to initiation of fieldwork in accordance with Section 6 of this document.

A. Field Data Collection

This section does not provide guidance on indoor air sampling. For such guidance, the reader is referred to the DTSC vapor intrusion guidance, and the ITRC vapor intrusion guidance (www.itrcweb.org).

1. Introduction

Soil vapor surveys can be used for a number of purposes, including the following:

- **Initial Site Screening**, where the objective is to assess if volatile organic chemicals (VOCs) are present;
- **Site Assessment/Characterization**, where the objective is to assess the source, extent, and magnitude of impacted soil, groundwater and/or vapor;
- **Risk Assessments**, where the objective is to assess the risk to public health; safety and the environment;
- **Remediation and Post-Remediation Monitoring**, where the objective is to assess remediation progress or completion; and
- **Ongoing Monitoring** for risk assessment, remediation monitoring, landfill gas monitoring and background methane monitoring.

These guidelines provide information on the following:

- Acceptable methods of sample collection;
- Analysis methods
- Transient and other environmental factors that could affect the outcome of a vapor survey;
- Vapor survey design for a variety of sites including petroleum-related sites, dry cleaners and industrial facility sites, methane testing sites; and
- Documentation, including work plans, field notes and reporting.

2. Overview of Soil Vapor Survey Methods

Three principle methods exist for collecting soil vapor data:

- Active
- Passive
- Flux Chambers

Each method offers advantages and disadvantages that are briefly described below. The design and protocols of a soil vapor survey program are dependent upon the objectives of the

program, the types of contaminants anticipated to be present, and the site conditions. There are a variety of sampling methods and equipment designs for collecting soil vapor samples that can potentially yield different values.

Active: The active approach consists of the withdrawal of an aliquot of soil vapor from the subsurface, typically with a sampling probe, followed by analysis of the withdrawn vapor. Analysis is often performed on-site using a variety of analytical instruments. Alternatively, soil vapor samples can be stored in gas-tight containers and analyzed at an off-site laboratory. The active method is quantitative and values are reported in gas concentration units (e.g., parts per million by volume [ppmv], micrograms per liter [$\mu\text{g/L}$] -vapor). This approach is the most common soil vapor collection method for a number of reasons, including ease of sample collection, opportunity for real-time data to direct further sampling, and the ability to acquire quantitative measurements.

Passive: There are two basic kinds of passive sampling: qualitative and quantitative. Both rely on passive adsorption of VOC vapors from soil over time, which is latter quantified by a laboratory and the mass adsorbed is proportional to the level of contamination. If the uptake rate has been experimentally measured and reported in a scientific publication, the mass adsorbed can be used to calculate a concentration (i.e., quantitative passive sampling); otherwise, the data are either qualitative or semi-quantitative, which can still be useful for delineation, but will generally require verification prior to use in estimating exposure point concentration for a risk assessment.

Flux Chambers: Flux chambers consist of an enclosed chamber that is placed on the surface for a specific period of time. Vapor concentrations are measured in the chamber after a period of time. This method is also quantitative and yields both concentration data in the chamber and flux data (mass/area-time). Flux chambers are the least common soil vapor survey method, and are typically used only for risk-based applications when direct vapor fluxes out of the subsurface are desired.

3. Procedures Which Influence Reported Soil Vapor Data

Soil gases can travel long distances from the contamination source and can potentially be representative of the “general area of contamination.” However, soil gas surveys should be used cautiously. Due to chemical specific characteristics, geologic conditions, and atmospheric influences, soil gas surveys can provide misleading results. Reported soil vapor data can depend greatly upon the collection protocols that are used to generate the data. For this reason, it is important to understand the factors that may influence the reported data. This section presents a description of a number of various factors that influence the reported data for different sampling methods.

a. Active Soil Vapor Surveys

Active Soil Gas Collection Methods

1.1 Probe Installation

Prior to installing soil gas probes care must be taken to locate potential subsurface structures of features such as buried pipes, tanks and electrical lines.

Two techniques are most commonly used to install soil gas probes:

- (1) Insertion of a hard rod (probe) to a target depth, collection of soil gas through the rod while it is in the ground and subsequent removal of the rod (Figure 1). This method is commonly referred to as the probe-rod method or sometimes as the temporary probe method (since the probe rods are temporarily in the ground).
- (2) Burial of an inert pipe or tube (typically 1/8" to 1/4" OD) to a target depth with subsequent sampling of the soil gas. Tubing can be buried in holes created with hand driven rods, direct-push systems, hand-augers, or drill rigs (Figure 2). This method is referred to by several names such as soil vapor monitoring wells, soil gas implants, semi-permanent method (if the tubes are removed after a short period of time) or permanent probe method (if the tubing is left in the ground for a longer period of time).

Both methods have been shown to give reliable, reproducible data (DiGiulio et. al., 2006). The choice of which method to use should depend upon the site, access, and the project goals. Typically, sampling through the probe rod is faster and less likely to disturb the in-situ soil gas, especially for small diameter rods (<0.5" OD). For limited-access areas, a hand-driven probe may be all that is applicable. For deeper depths, probes inserted by direct-push methods are more convenient. If the probe-rod methods are used, samples should be collected through small-diameter inert tubing that runs down the probe rod so the sample does not contact the inside of the probe rod.

For repeated sampling or in low permeability soils, burial of soil gas implants offers advantages (Figure 2). Multiple tubes can be buried in the same hole and are commonly referred to as nested, multi-depth vapor wells (Figure 3). Please note, the shallow probes (3 feet or shallower) should be placed in a separate adjacent hole from the deeper probes. Section 5.3.2 contains an SOP for constructing nested vapor wells.

For both methods, a competent surface seal should be installed to prevent ambient air from infiltrating into the soil gas sample through the insertion hole, especially at shallow sampling depths (<3 feet bgs or below foundation). Detailed protocols for both methods can be found in the standard operating procedures listed in §5.3, in CA-USEPA (2003), API (2005), DiGiulio et al. 2006, and USEPA (2007).

Sample Tubing Type: Three studies have been done to evaluate different types of tubing. Air Toxics (Hayes et. al, 2006) conducted tests of three tubing types (Teflon®, nylon, PEEK) that showed little difference in the tubing type. Low-level blanks were detected in nylon, but the values were far below required soil-gas risk-based screening levels. An earlier study presented at a conference in 2004 (Ouellette, 2004) compared the adsorption of a hydrocarbon standard by five tubing types (Teflon®, nylon, polyethylene, vinyl and flexible tygon). Nylon and Teflon® showed insignificant losses (<10%), but the others showed higher losses, especially the flexible tubing, where losses were up to 80 percent. The EPA (2008) tested 5

types of tubing (Teflon®, nylon, PEEK, polyethylene, & stainless steel). All gave similar results except for polyethylene which was consistently lower.

Polyethylene and flexible tubing (e.g., tygon) should be avoided. For rigid-wall tubing, in practice, the type of tubing is not nearly as important as where the tubing is stored and how it is handled. Any type of tubing can become contaminated and contribute to false positives if it is stored in the back of a truck unsealed or near the truck exhaust.

Sample Spacing: The selection of sampling locations is strongly dependent upon the objectives of the program and the need for adequate coverage. Predetermined and widely spaced grid patterns are most commonly used for reconnaissance work, while closely spaced, irregularly situated locations are commonly used for covering specific source areas. Guidelines on sample spacing for various applications are summarized in Section 5.IV.A.5. of this guidance.

Collection Depth: Collection depths should be chosen to maximize the chances of detecting contamination, yet minimize the effects due to vapor movement, changes in barometric pressure, and surface temperature, or breakthrough of atmospheric air from the surface (refer to Section 5.IV.A.4 for further discussion of these factors). In general, the effects due to these processes are considered to be minimized at depths 3 to 5 feet below the ground surface (bgs) or building foundation. However, some processes such as bioattenuation, oxygen replenishment, and sub-structure flushing will occur primarily in the upper few feet of the vadose zone, so sampling in this zone should not necessarily be precluded. If soil gas data from depths less than 3 feet bgs or below the foundation are collected, additional sampling events may be appropriate to ensure representative values, especially if the measured values yield risks that are near acceptable levels. In such cases, burial of permanent vapor tubes is advised. Guidelines on collection depth for various applications are summarized in Section 5.IV.A.5.

Purge Volume: The sample collection equipment used for active soil vapor surveys has an internal volume that is filled with air or some other inert gas prior to insertion into the ground. This internal volume, often called the dead volume, must be completely purged and filled with soil vapor to ensure that a representative soil vapor sample is collected.

If soil gas implants are installed and probes are sampled the same day as installation, the air volume of the sand pack should also be included in the total system volume.

Different opinions exist on the optimum amount of vapor to be purged. Several published studies are now out that compare soil-gas concentrations collected with purge volumes ranging from 0.5 L to 100 L (DiGiulio et. al, 2006; McAlary & Creamer, 2006, USEPA 2007). The results of these studies, done in relatively coarse-grained soils, show no significant difference in concentrations. However, in finer-grained soils, large volumes are often not possible or difficult to collect. If larger sample volumes are attempted, the potential for leaks around fittings increases and the samples can be less representative.

Since soil vapor data are often interpreted in a relative fashion, it is important that the purge volume be consistent for all samples collected from the same site.

While it is important to collect enough vapor to purge the system, collecting too much vapor can also have drawbacks. The larger the quantity of soil vapor withdrawn, the greater the uncertainty in the location of the collected sample, and in turn, the greater the potential that atmospheric air might have been drawn down the outside of the probe body.

In addition, large purge volumes can create vacuum conditions that cause contaminant partitioning from the soil into the gas phase, which is not representative of in situ soil vapor conditions. Thus, sampling equipment with small internal dead volumes offers advantages over systems with larger dead volumes because the former systems require significantly less vapor to be withdrawn when purging the system.

At a minimum, enough vapor should be withdrawn prior to sample collection to purge the probe and collection system of all ambient air or purge gas (1 purge volume). One to three total system purge volumes are recommended as a minimum default value.

Sample Flow Rate & Applied Vacuum: Many US agencies and DTSC have put a limit on sample flow rate (typically <200 ml/min) because they are concerned that excessive flow might create turbulent flow at the probe tip and influence the soil-gas concentrations. The USEPA (USEPA 2007) actually measured soil-gas concentrations over different flow rates ranging from 100 ml/min to 5000 ml/min in soil gas probes. There was no significant difference in measured soil gas concentration. This suggests that for relatively coarse-grained soils, flow rate does not appear to be an important variable on soil-gas concentrations.

Higher vacuums increase the potential for leaks in the sampling system and for potential desorption of COCs off the soil. Most US agencies & DTSC are requiring applied vacuums at the probe to be less than 10 inches of Hg. A qualitative method to quickly estimate if there is little permeability and too much vacuum is likely to be applied is to hook up a 20cc to 50cc gas-tight, plastic syringe to the probe and pull on the plunger. If the plunger is hard to pull (compare to pulling outside air) or if the plunger is pulled back towards the probe after released, then there is likely too little permeability to get an uncompromised sample.

Equilibration Time: When probes are installed, the in-situ soil gas can be displaced and a period of time is required for the soil gas to re-equilibrate. A recent USEPA study (need reference) showed the following equilibration times were required:

- Sampling through probe rod installed by hand: 30 minutes
- Sampling through probe rod installed with direct push methods: 1 hour
- For probes where tubes are buried in a sandpack in the ground: 8 hours

If rotary drilling or percussion methods are used to emplace the tubes, or if air knives are used to clear the sample locations, longer periods of time are required for the sand pack to equilibrate with the soil gas. To determine the equilibration time, a test of concentration vs. time can be used to determine when values stabilize. Another method is to purge the soil gas and monitor the soil gas concentration with a portable meter. When the concentrations stabilize, equilibrium is assumed and a sample can be collected for analysis.

Probe Seals: For collection systems with large purge volumes or designed to collect large sample volumes, it is often necessary to seal the probe at the surface. Seals may also be necessary for small volume systems if the soils are extremely porous and the sampling depth close to the surface (less than 3 feet). Most common sealing techniques are to pack the upper contact of the probe and the soil with grout or to use an inflatable seal.

Testing for Leaks : To ensure that valid soil gas samples are collected with no breakthrough of air down the probe rod or through leaks in the sampling train, a tracer compound can be applied at the base of the probe rod or at the top of the buried probe tubing where it contacts the surface and near all connections in the sampling train. Seal integrity is then confirmed by analyzing collected soil gas samples for the applied tracer

compound. . Common tracer compounds are gases (e.g., helium, carbon dioxide, SF₆, butane) or liquids (freons, isopropanol, hexane). With both methods, an enclosure/shroud is placed over the probe at the surface, the compound is introduced into the shroud, the concentration in the shroud is measured, and the concentration in the collected soil gas sample is measured. If the tracer compound concentration in the soil gas sample is less than 15% of the concentration of the tracer compound measured in the shroud, the sample is considered leak-free.

The concentration in the shroud and soil gas sample can be measured with portable meters (He, CO₂, etc.), or with an on-site lab, or with an off-site lab. Measuring the tracer compound on-site is recommended since it gives the ability to recognize a compromised sample in real-time and re-collected the sample, rather than finding out the sample was compromised after you leave the field.

An alternative method to the shroud method is to apply liquid tracers using paper towels or clean rags. The tracers are easily and quickly supplied at multiple locations (probe, sampling rod, and sampling train) simultaneously.. This method is particularly more suited for sampling through the probe rod since it can be easily applied at the base and top of the rod. However, since the starting concentration under the towel or rag is typically not known, an arbitrary maximum value of 10 ug/L of the tracer compound in the collected soil gas sample is considered as the leak-free threshold (assuming the tracer compound was at its vapor pressure below the towel, this value would represent <0.1 % of a leak). Values this low can not be easily measured with portable meters so analysis is either done with a mobile laboratory or by an off-site lab. Another disadvantage of this approach is that small leaks (as low as 10 µg/L) can cause a lab to raise their detection levels depending on the tracer compound used, especially if the toxic organic (TO) methods are being used.

Leak Testing the Sampling Train. The sampling train should be tested for leaks by applying a vacuum on to the system from the top of the probe to the location of the *sampling container*. ***The applied vacuum should hold steady for at least 60 seconds. Alternatively, the sampling train can be put under the sample shroud containing tracer leak compound during sample collection as described previously.***

Probe Decontamination: All external parts should be wiped clean and washed as necessary to remove any soil or contaminant films. The internal vapor pathway should be purged with a minimum of five volumes of air or an inert gas, or replaced, or washed if contamination or water is present in the probe. Probes fitted with internal tubing offer advantages because the internal tubing can simply be replaced.

Systems with Vacuum Pumps: Soil vapor samples from collection systems employing vacuum pumps should be collected on the intake side of the pump to prevent potential contamination from the pump. Further, because the pressure on the intake side of the pump is below atmospheric, soil vapor samples must be collected with appropriate collection devices, such as gas-tight syringes and valves, to ensure that the samples are not diluted by outside air.

Sample Containers & Storage of Samples: While on-site analysis is advantageous to ensure sample integrity, soil vapor samples can be collected and analyzed off-site. To minimize potential effects on the sample integrity, it is recommended that:

- Do not chill samples during storage as is common with soil and water samples. The temperature should not be lower than 40° unless ambient temperature fall below 40°.
- Samples and sample storage should not be left in the direct sunlight.
- For petroleum-hydrocarbons (aliphatics and aromatics) and biogenic gases (methane, carbon dioxide and oxygen), allowable containers include tedlar bags, gas tight vials (glass or stainless steel), polished or passivated steel canisters (Summa), and adsorbant tubes. Recommended maximum storage time in tedlar bags is approximately 2 to 3 days. Storage time in canisters is 14 to 30 days depending upon the COC. If samples are going to be shipped, do not fill a tedlar bag more than 2/3 full.
- For halogenated compounds (e.g., TCE, TCA, PCE), allowable containers include tedlar bags, gas tight vials (glass or stainless steel), polished or passivated steel canisters (Summa), and adsorbant tubes. Storage time in tedlar bags is compound specific but is typically 3 or more days for most of the common halogenated compounds (TCE, TCA, PCE). Recommended maximum storage time in canisters is 14 to 30 days depending upon the COC.
- For samples collected on adsorbants, storage times may be up to 15 days after sample collection depending upon the adsorbant used and COC.

Collection of Soil Vapor Samples with Summa Canisters: Because Summa Canisters generally are large volume containers (1 to 6 liters) under high vacuum, extra care should be exercised during sample collection to ensure that air from the surface is not being inadvertently sampled or that desorption of contaminants from the soil does not take place. To minimize the potential of surface breakthrough, seals around the probe rod at the surface should exist. To minimize the potential desorption of contaminants from the soil, Summa Canisters should be between 500 to 1000 ml in size and should be filled at a rate less than 0.2 liters (200 cc) per minute.

b. Passive Soil Vapor Surveys

Sample Spacing: The selection of sampling locations for passive sampling is based upon the same considerations as active soil vapor methods: program objectives and the need for adequate coverage. Predetermined and widely spaced grid patterns are most commonly used for reconnaissance work, while closely spaced, irregularly situated locations are commonly used for covering specific source areas. Guidelines on sample spacing for various applications are summarized in Section 5.IV.A.5.

Collection Depth: Passive surveys are nearly always conducted by burying the collector close to the surface (6 inches to 3 feet). This protocol was developed not for technical reasons, but for convenience in deploying and retrieving the collector. Ideally, similar to active surveys, collectors should be deployed as close to the suspected contamination source as practically possible to minimize the effects of vapor movement. In addition, collectors buried within a couple feet of the surface will be very susceptible to air infiltration due to changes in barometric pressure and surface temperature. If the outside air is contaminated, for example at an active gasoline station or inside of an active dry-

cleaning operation, the passive collectors could conceivably adsorb more contamination from infiltration of the surface air than from subsurface contamination. In this situation, it is advisable to bury the collector to deeper depths (greater than 3 feet).

Exposure Period: As with collection depth, the exposure period for passive collectors is generally selected more for convenience factors than for technical reasons. The key assumption that is made when interpreting passive soil vapor data is that each collector is exposed to the same quantity of soil vapor. Thus, passive collectors are typically deployed for the same period of time on a site or the data is normalized based upon the exposure time. Typical exposure times are a few days to two weeks.

In practice, the exposure period for a passive collector should depend upon the concentration of the contaminant of interest and desired detection levels. In areas of suspected high concentration, collectors can be left in the ground for shorter periods (1 to 5 days). In areas of suspected low concentrations, collectors are often left in the ground for two or more weeks. For areas of unknown concentration, the optimum approach is to determine the deployment time by burying a number of collectors in the same location and measuring them over a period of time.

Method Blanks: Since the passive soil vapor method does not enable real-time data, analysis of blanks is extremely important to verify that detected contamination was not from another source, such as the passive collector itself or handling and storage during transport from the site to the laboratory. The only way to evaluate this possibility is to include a method blank and trip blank as part of the sample batch. A method blank consists of an unused collector picked at random from the collector batch. A trip blank is an unused collector that is kept sealed, and accompanies the other collectors to and from the site and to the laboratory for analysis.

c. Surface Flux Chamber Surveys

Sample Spacing: The primary motive of flux chamber surveys is to measure the upward flux of vapor out of the ground or into a room for risk-based purposes. A minimum of three chambers should be deployed in the room or on the ground surface to provide representation of the area of interest and to demonstrate reproducibility. Chambers should preferably be located in areas where surface features suggest possible conduits to the subsurface (e.g., cracks, drains, electrical conduits, etc.). At least one chamber should be deployed in the area of anticipated maximum subsurface contaminant concentration, if identified, from a previous subsurface investigation.

Insertion Depth or Seals: Valid measurements require that the bottom of the chamber be sealed from exchange with atmospheric air. On soil surfaces, chambers are either inserted into the ground to a depth of one or more inches or the chamber flange covered with native soil or sealant. On finished surfaces such as floors, an airtight seal must be made between the chamber bottom and the surface, typically using a gasket or sealant.

Covers: Reflective coverings are sometimes necessary in outside locations to protect against temperature extremes that could create advective flow. Opaque coverings are required to minimize the potential of photo destruction of compounds.

Exposure Period: Chambers should be deployed for a minimum of eight (8) hours, with the exposure period during normal occupancy conditions. Longer exposure times, on the

order of 24 hours, are preferred since they give a time-integrated result that is more representative of the actual flux into a surface enclosure.

Number of Samples per Exposure Period: Collection and analysis of multiple samples from a chamber at regular intervals over the deployment period (e.g., every 4 hours) is advised since it allows estimates of precision, allows identification of spurious measurements, and allows any variability in the measured fluxes to be detected.

Sample Containers & Storage of Samples: Refer to Section 5.IV.A.3.a for a description of applicable containers and storage considerations.

4. Temporal Variations and Other Environmental Effects

There have been a number of recent studies on the temporal variation of soil gas concentrations due to common meteorological parameters (Luo et. al., 2006; USEPA 2007;). The results of these studies show that variations in soil gas concentrations at depths 2 feet bgs or deeper due to temperature changes, barometric pressure, and wind speed are typically less than a factor of 2). Seasonal variations in cold climates are generally less than a factor of 5. Concentration variations will be greater the closer the samples are to the surface. For shallower sampling depths (< 2 feet), larger variations can be expected in areas of greater temperature variation and during heavy periods of precipitation.

a. Temperature

Effects on soil gas concentrations due to actual changes in the vadose zone temperature are minimal (USEPA 2007). For sub-foundation soil gas samples, the concentrations may be affected by changes in an overlying building's heating system in cold winters and/or Heating, Ventilation and Air-Conditioning (HVAC) system during the hot summers creating advective flow beneath the foundations.

Seasonal temperature variations are also minimal in southern California, and except for special environments such as the desert and the mountains, are unlikely to create a significant effect on soil vapor concentrations in the vadose zone.

b. Barometric Pressure

Changes in barometric pressure can lead to a pressure gradient between the soil vapor and atmosphere creating a flow of soil vapors out of the vadose zone during barometric lows and into the vadose zone during barometric highs. The potential effects decrease with increasing sampling depth. Recent published studies have shown that variations in soil gas concentrations due to barometric pressure are insignificant (USEPA EPA/600/R-07/141, December 2007)

d. Precipitation (Rainfall)

Infiltration from rainfall can potentially impact soil vapor concentrations by displacing soil vapor, dissolving volatile organic compounds, and by creating a "cap" above the soil vapor. In practice, infiltration from large storms only penetrates into the soil on the order of inches. Hence soil vapor samples collected at depths greater than 3 feet bgs are unlikely to be significantly affected. Soil vapor samples collected closer to the surface (less than 3 feet) without surface cover may be affected. If the wetting front has penetrated to the

sampling zone, it typically can be recognized by difficulty in collecting soil gas samples. If high vacuum readings are encountered when collecting a sample, or drops of moisture are evident in the sampling system or sample a soil gas sample should not be collected. Measurement of % moisture of the soil may also be useful if shallow sampling is performed during or shortly after significant rainfall (e.g., greater than 1 inch).

Soil gas concentrations have been shown to change drastically during periods of extreme precipitation creating a rise in the water table with contaminated water or by creating a clean water lens that prohibits oxygen transport from the atmosphere into the vadose zone. In general, soil vapor sampling should be completed greater than one week following any significant rainfall event.

5. Soil Vapor Survey Design For Specific Types of Sites

This section gives specific guidelines for designing soil vapor surveys for common types of sites.

a. Petroleum Related Sites, Including Underground Storage Tanks

(1) Chemical Specific/Analytical Considerations

Because petroleum products, such as gasoline and diesel, are complex mixtures containing a wide variety of different hydrocarbons, the appropriate analytical measurements depend upon the product type as follows:

- Aromatics (BTEX) and naphthalene: Method 8260, TO-15, or TO-17.
- MTBE and Oxygenates: Method 8260, TO-15, or TO-17
- Methane: The use of gas chromatography method with a flame detector, such as 8015 modified.
- Carbon Dioxide, Oxygen and Nitrogen: The use of gas chromatography (GC) method with a thermal conductivity detector, such as ASTM Method 1945-96. Portable GC meters, if calibrated correctly on day of use, are also allowed for these compounds.
- PAHs: Due to low vapor pressures, these compounds cannot be detected by active soil gas methods (except for naphthalene) and only the lightest ones can be detected by passive soil gas methods.

(2) Site Assessment/Characterization Applications

Certain components of an UST system are more likely to fail than others. For example, the tops of USTs where bungholes or man ways are present, seams in the UST, seams in asphalt or concrete surfaces, and elbows in the piping runs, and dispensers are typical sources of leaks. In addition, the base of the tank pit and associated piping can often be source zones due to the pooling of leaked substances. The sampling program should cover the most likely sources.

Soil Vapor Method: The active soil vapor method is most typically employed. The passive soil vapor method can also be used, especially in locations with limited access and at sites where relatively low concentrations of VOCs are expected.

Sample Location & Spacing: The sampling grid spacing should be sufficiently small to encounter areas of former USTs, piping, dispensers, etc. and any areas of gross contamination. When historical data regarding the layout of a UST system are unavailable, a useful strategy is to collect samples in a grid pattern. For a typical service station, a grid spacing of ~50 feet may be reasonable. For more detailed site assessment/characterization, a sample spacing of 10 to 20 feet is reasonable in the source area.

Collection Depth: Soil vapor samples are typically collected from 5 to 15 feet bgs to assess surface and UST releases. The chosen depth will be dependent upon the suspected source and what is being assessed: soil and/or groundwater. To assess the vertical extent of contamination, collect samples every 5 feet to 10 feet depending upon the depth to groundwater at the location of highest concentration. Typically sample depths shallower than 5 feet will be evaluated on a case-by-case basis.

(3) Health Risk Assessment Program Design

Soil Vapor Method: The active method is most commonly used. Passive soil vapor methods are not applicable since they are non-quantitative. Permanent probes/implants offer the advantage of assessing transient effects that could affect contaminant vapor flux rates. Surface flux chambers may also be used.

Sample Location & Spacing: Enough samples should be collected to allow a representative estimate of the average flux to the base of the existing or future structure. At a minimum, samples should be collected at the location of highest vadose zone contamination near or under the structure and at each corner of the structure (inside if possible, immediately outside if not).

Collection Depth: For active soil vapor programs, samples should initially be collected from 5 feet bgs unless there is reason to suspect shallower contamination. If the calculated risk exceeds allowable levels, a vertical profile of the soil vapor at shallower depths may be appropriate. Samples from shallower depths are more subject to infiltration of surface air and variability due to transient effects. If soil vapor data from depths less than 3 feet bgs are collected, additional sampling events may be appropriate to ensure representative values.

Sample Frequency: Typically, one to two sampling events following installation of the probes are sufficient to assess the risk pathway. In some situations additional sampling events may be appropriate (e.g., for shallow sampling depths).

Use of Tracers and Measurement of the Tracer, Oxygen and Carbon Dioxide in Soil Gas: All samples collected from a depth of 5 feet or shallower should have a tracer applied at the surface to verify that there is a good annular seal. In addition, both oxygen and carbon dioxide should be measured to provide an indication of aerobic/anaerobic conditions.

(4) Post-Remediation Assessment & Contaminant Monitoring

Sample spacing and collection depth will be dependent upon the objective of the monitoring and upon the size of the remediation area. For risk assessment and remediation monitoring, use the respective protocols described previously, but using

semi-permanent probes/implants that are sampled multiple times over the course of the project.

(5) Special Considerations for Fuel Sites

Vapor Leaks: Subsurface vapor leaks are possible from USTs and piping associated with them (vent pipes, pipe joints, vapor recovery lines, and tank bungs). Such leaks can create situations with no corresponding detectable soil contamination. Soil vapor located near or at the leak may contain concentrations of these compounds. Soil vapor further from the source may contain only some of these compounds due to differences in their physical properties.

Potential Impact of Vapor Contamination on Groundwater: Leaking gasoline vapors from a UST are a likely contaminant pathway to groundwater for both MTBE and ethanol due to their high concentrations in the tank vapor and extremely low Henry's Law constants. In contrast, leaking gasoline vapors are an unlikely contaminant pathway to groundwater for the aromatics due to their lower concentrations in the tank vapor and moderate Henry's Law constants. The potential importance of this contaminant pathway increases with decreasing groundwater depth and is particularly acute in locations where the water table is near or above the UST and where the vadose zone is dry. Sampling programs assessing this contaminant pathway should focus on the collection of soil vapor samples vertically through the vadose zone at regular intervals down to groundwater. The concentration profile down to groundwater and concentration at the groundwater interface may enable an estimate of the importance of this pathway.

b. Dry Cleaners & Industrial Facilities with Non-Petroleum VOCs

At industrial facilities, a variety of contaminants, conditions, and potential sources can exist. Many industrial sites contain above ground solvent sources, such as degreasers, clarifiers, storage tanks, ink presses, spray booths, which can leak into the vadose zone. Subsurface sources can include leakage from drains, sumps, pipelines and manufacturing lines. Consequently, a soil vapor survey at an industrial facility should be performed only after a comprehensive historical site review and a thorough site reconnaissance have been performed to establish the potential sources and types of contamination. At dry cleaners sites, soil vapor contamination commonly exists under the washer unit; and soil contamination with corresponding soil vapor contamination commonly exists near liquid release sources such as sumps, drains, storage areas, and other disposal areas.

Vapor Clouds: Due to their high vapor pressures and high vapor densities, vapors may emanate from containers or pipes holding gaseous or liquid chlorinated compounds, collect on the floor, penetrate through the slab, and create a zone of contaminated vapor in the vadose zone. Such leaks can create soil vapor contamination with no corresponding detectable soil contamination. Such vapor clouds are commonly found under the washer unit at dry cleaners, under vapor degreasers, and in other above ground confined spaces containing solvents.

Potential Impact of Vapor Contamination on Groundwater: Due to their relatively low Henry's Law constants, the potential for vapors leaking from the surface to significantly impact groundwater is low, except in cases of very high soil vapor concentrations (typically greater than 100 µg/L-vapor at the groundwater interface)

or in the presence of contaminated soil. Sampling programs assessing this contaminant pathway should focus on the collection of soil vapor samples vertically through the vadose zone down to groundwater. The concentration profile down to groundwater and concentration at the groundwater interface will enable an estimate of the importance of this contaminant pathway.

(1) Chemical-Specific/Analytical Considerations

Chemicals associated with industrial facilities vary depending upon the type of facility, but typically include chlorinated solvents and degreasers, such as methylene chloride, TCA, TCE, PCE, acetone, and methyl ethyl ketone. Not all compounds at a facility may be detectable by soil vapor methods depending upon their vapor pressures. At dry cleaners sites, the primary compound is PCE and its breakdown products/adulterants: vinyl chloride, dichloroethylene (cis & trans 1,2 DCE), and TCE. For quantitative programs, the appropriate analytical methods are 8021, 8260, TO-15, or TO-17. The detection limits, calibration procedures, and other QA/QC criteria should meet the requirements presented in Section 5.IV.B.

(2) Site Assessment/Characterization Applications

Soil Vapor Method: The active soil vapor method is most typically employed. The passive soil vapor method can also be used for site characterization of large areas to isolate smaller areas for active soil vapor sampling.

Sample Location, Spacing, & Depth: A soil vapor survey performed as part of a site assessment and characterization would ideally be performed in a phased approach, starting with a wide spacing between sampling points (50 feet to 100 feet) to obtain an overall assessment of the site (and off-site if necessary) then focusing the sampling in areas of higher contamination to better define its limits (10 feet to 25 feet). Vapor samples should be collected from all potential source areas. Initial sampling depths should be determined by the type of release anticipated:

- Surface and near surface releases: 3 to 5 feet bgs
- Deep releases (e.g., tanks, pipelines): at bottom of tank or pipeline.
- To assess the vertical extent of contamination, collect samples every 5 feet to 10 feet depending upon the depth to groundwater at the location of highest concentration.

(3) Health Risk Assessment

The collection method, sample location, sample spacing, and collection depth criteria are the same as described for fuel sites, with the following exception. For health risk assessments at adjoining rooms/businesses to a dry cleaners active soil gas samples should also be collected either within 1 foot of the base of the slab or subslab to test for the presence of higher soil vapor concentrations caused by preferential transport at the bottom of the slab. Procedures used to collect samples at this shallow depth should ensure that no ambient air is collected.

Sample Frequency: Typically, two to three sampling events following installation of the probes are sufficient to assess the risk pathway. In some situations additional sampling events may be appropriate (e.g., for shallow sampling depths).

Use of Tracers and Measurement of the Tracer, Oxygen and Carbon Dioxide in Soil Gas: All samples collected from a depth of 5 feet or shallower should have a tracer applied at the surface to verify that there is a good annular seal. In addition, both oxygen and carbon dioxide should be measured to provide an indication of aerobic/anaerobic conditions.

(4) Post-Remediation Assessment & Contaminant Monitoring

Sample spacing and collection depth will be dependent upon the objective of the monitoring and upon the size of the remediation area. For risk assessment and remediation monitoring, use the respective protocols described previously, but using semi-permanent probes/implants that are sampled multiple times over the course of the project.

c. Methane Testing

(1) Chemical Specific/Analytical Considerations

Methane is a colorless, odorless gas existing naturally in atmospheric air at a concentration of approximately 2 to 3 ppmv. It is commonly formed in the subsurface from the anaerobic breakdown of organic matter and can reach concentrations in the soil gas exceeding 50% in areas with abundant sources of organic carbon. Sources for methane generation include landfills, swamps and bogs, petroleum reservoirs (oil & gas), farmlands, and areas contaminated by organic matter sources (sewage, petroleum spills, etc.). Methane may also originate from non-biogenic, thermal origins, such as from volcanic sources. Because petroleum reservoirs are unknown in San Diego County, the most likely sources of high methane on a site will be from the degradation of organic matter or from a leak from an existing methane or natural gas line. In areas of known volcanic rocks or thermal activity (e.g., Jacumba), thermogenic sources of methane may contribute. If natural gas lines exist on a site, the local gas company (SDGE) will send personnel to test for leaks.

Analysis Methods: Methane is most commonly measured with either a flame ionization detector (FID) or thermal conductivity detector (TCD). FIDs are approximately 10,000 times more sensitive than a TCD and can detect methane in the low parts per million range. TCDs typically measure methane at concentrations exceeding 1 part per thousand (greater than 1,000 ppmv). Both portable and laboratory-grade instruments exist with these detectors. For applications where quantitative results are desired, the analytical methodology employed is typically gas chromatography (GC). A variety of gas chromatographic methods using the FID & TCD have been developed by the petroleum industry and may be used. EPA Method 8015 modified for methane may also be used. Regardless of the actual analytical method used, the detection limits, calibration procedures, and other QA/QC criteria should meet the requirements presented in Section 5.IV.B.

Soil Vapor Method: Active soil vapor surveys and flux chamber surveys are applicable to methane investigations. Passive soil vapor surveys are not used for methane investigations since methane is not quantitatively absorbed on the passive collector.

(2) Site Assessment/Characterization

Sample spacing: The selection of sampling points is strongly dependent upon the need for adequate coverage and budget. General grid patterns with 50 feet to 100 feet centers are typical for reconnaissance work, while closer spaced, irregularly situated locations (10 feet to 50 feet) are commonly used for covering potential source areas.

Collection depth: A nominal collection depth of five (5) feet bgs is generally considered to maximize the chances of detecting contamination yet minimizing the effects due to changes in barometric pressure, temperature, or breakthrough from the surface. Methane is generated under anaerobic conditions, which typically exist at deeper depths in the vadose zone. For source determination, samples should be collected at various depths at the same location to determine the depth of the methane source.

(3) Health Risk Assessment (Upward Vapor Migration)

Potential Risk: The principal health and safety risk posed by methane is the risk of explosion due to concentration build-up in confined spaces such as underground public utility structures (sewage lines, utility trenches & vaults) or above ground structures. The lower explosive limit (LEL) for methane is 5% (50,000 ppmv). The County of San Diego is concerned if concentrations exceeding 10% of the LEL (5,000 ppmv) are detected in the shallow soil gas near existing or proposed aboveground structures.

Sample Location & Spacing: Enough samples should be collected to allow a representative estimate of the average flux into the existing or future structure. For commercial sites, a minimum of 4 locations, one on each corner of the footprint, should be initially collected. For larger proposed residential developments, one location per lot is sufficient initially. Additional locations on the footprint or lot are advised if elevated levels (greater than 1,000 ppmv) are found. .

Collection depth: For active soil vapor programs, samples should initially be collected from 5 feet bgs. If significant levels (greater than 1,000 ppmv) are found at this depth, collection of a sample closer to the surface (1 foot to 2 feet) at the same location is advised to document if elevated levels approach the surface. It is also advisable to do vertical profile sampling at deeper depths if significant levels are detected to determine if there is a potential methane source zone below the proposed structure.

(4) Post-Development Assessment and Contaminant Monitoring

For contaminated sites, monitoring of the methane levels immediately below existing or proposed aboveground structures is advised. Refer to the existing County ordinance for specific requirements.

6. Documentation

a. Workplan

A comprehensive workplan should be prepared and submitted for review and approval to the lead agency prior to implementation. Revisions to the work plan may be requested prior to approval. If the work is completed without a workplan or prior to agency involvement, additional investigation may be required to render regulatory decisions related to adequacy of any health risk evaluation or regulatory closure.

The workplan should provide sufficient details, description of site conditions, and identify project objectives so that the lead agency can fully evaluate the proposed work. The work plan should reference the applicable section(s) of the SAM Manual or other guidance documents, rather than restating existing technical guidelines. The work plan should contain the main sections, and address specific issues, pertaining to:

- Health and safety
- Purpose and scope of work planned
- Background information (site history, existing analytical data, etc.)
- Current site conditions, depicting surface features and known buried structures
- Site conceptual model
- Description of proposed work (e.g., sampling strategy and protocol, including sampling technique and analytical methodology, purge rate, sampling frequency)
- Description of the methods to be used to evaluate the integrity of the vapor samples including biogenic gas monitoring, and tracer testing.
- Schedule of proposed work

The type of equipment to be used and/or the contractor planned for the work should be identified. The needed information in the work plan should be presented in a succinct and accurate manner to facilitate the review process, using existing tabular data and clear illustrations as deemed necessary. Existing analytical data should also be presented in tabular form and/or graphically on maps.

b. Field Data

Data acquisition and good field notes are important to document site-specific conditions observed and encountered during the actual vapor sampling and related field work. Such information can/should be used to prepare the written report and other work products (e.g., data tables, maps, etc. as described in Section 5c. below). Accurate and clear field notes, maintained on special forms and work sheets, could be used to further assess site conditions and the findings of the vapor survey. The site-specific types of information that should be acquired in the field and documented include, but should not be limited to:

- Sampling locations (detailed map at an appropriate scale to illustrate the data points)
- Sampling methods and devices, including QA/QC procedures
- Field equipment calibration, detection limits, quantification, and unusual conditions
- Sample identification/designation
- Date and time of sample collection
- Identification of sampling personnel
- Sampling depth (including obstructions encountered), or sampling height
- Known or encountered stratigraphic/lithologic conditions, as applicable
- Apparent soil moisture conditions encountered, as applicable
- Weather conditions
- Sample purge volumes
- Volume of vapor sample extracted
- Analytical method(s)
- Chain of custody records
- Tracers and biogenic gas monitoring

It is recognized that some of the information may be documented/maintained by the contractor (field technician) actually conducting the vapor sampling, if an outside company is used. The field work should be supervised by an appropriately trained and experienced professional.

c. Report Preparation

The components of the summary report should include the items listed in Section 4.VI of this Manual. Some of the items may not be applicable to the particular (site-specific) vapor survey to be performed. For example, information may not be available or understood regarding the lithologic/stratigraphic conditions beneath the concrete slab while conducting a building ventilation survey to assess potential volatile compounds within the enclosed space.

B. Laboratory Analysis of Soil Gas Samples

This guideline is intended for use whenever soil gas samples are collected for the purpose of conducting a health risk assessment for submittal to Site Assessment and Mitigation (SAM). SAM will not accept a health risk assessment if the associated soil gas samples have not been analyzed and reported in accordance with this guideline.

Volatile organic compounds (VOCs) within the unsaturated zone partition into the adsorbed, dissolved, free liquid, and vapor phases. Measurement of VOCs through an active soil gas investigation is an accepted site assessment practice. In San Diego County, soil gas concentrations of contaminants, such as benzene, are accepted as input into the SAM Vapor Risk 2000 assessment model for evaluation of potential increased risk to human health from vapor migration into buildings. The SAM Vapor Risk 2000 assessment model is described in the SAM Manual in Section 6 and in the SAM webpage at:

http://www.sdcounty.ca.gov/deh/water/sam_vapor_risk_assessment_2000.html

Since significant decisions are made based on the soil gas data collected at contaminated sites, it is imperative that the soil gas data reported to this agency are consistently of high quality. The following guideline will assist in producing results of high quality.

1. Laboratory Analysis of Soil Gas Samples

a. Primary Target Compounds

Group A - Fuels Target Compounds	
Benzene	Tert-amyl methyl ether (TAME)
Toluene	Ethyl tertiary butyl ether (ETBE)
Xylenes	Tertiary butyl alcohol (TBA)
Ethylbenzene	Tetrachloroethene added as indicator compound
Methyl tertiary butyl ether (MTBE)	Trichloroethene added as indicator compound
Di-isopropyl ether (DIPE)	
Group B - Volatile Halogenated Hydrocarbon Target Compounds	
Chloroform	1,1,1-Trichloroethane
1,1-Dichloroethane	1,1,2-Trichloroethane
1,2-Dichloroethane	Trichloroethene (TCE)
1,1-Dichloroethene	Vinyl chloride
Cis-1,2-Dichloroethene	Trichlorofluoromethane (Freon 11)
Trans-1,2-Dichloroethene	Dichlorodifluoromethane (Freon 12)
Dichloromethane (methylene chloride)	1,1,2-Trichloro-trifluoroethane (Freon 113)
Tetrachloroethene (PCE)	Naphthalene
Group C - Combined Group Target Compounds	
All compounds in Groups A & B	
Methane	

Deviation from these Target Compound Groups may be allowed with prior consultation and approval of the SAM project manager.

b. Other Target Compounds

Analyze for other VOCs based upon site history and conditions.

c. Reporting Limit (RL)

If the SAM vapor risk model is used, the following DLs are appropriate for the target compounds listed.

Compound	Detection Limit
Benzene	0.1 µg/l-vapor
Toluene, Ethylbenzene, and Xylenes	1 µg/l-vapor
MTBE, TAME, DIPE, and ETBE	1 µg/l-vapor
TBA	10 µg/l-vapor
VOCs (except vinyl chloride)	1 µg/l-vapor
Vinyl chloride	0.05 µg/l-vapor
Methane	10 ppmv

Note: these DLs are based on a sample collected at a depth of 1 foot below the interior floor slab of a structure. Determination of site-specific detection levels is allowed but it must be documented how they were determined. Higher DLs may be applicable when samples are collected at greater depths. Lower DLs may be necessary for a risk

assessment if another model is used or if sub-slab soil gas samples are collected. In all cases, the DLs must clearly be below the concentration at which the risk is at, or below the one in one million health risk level. DLs in excess of this threshold may require additional testing.

d. Analytical Methods

Allowable methods are EPA Method 8021, 8260, TO-15, T0-17 and for SVOCs, any of the applicable NIOSH or Toxic-Organic (TO) sorbent methods for the compounds of interest. Refer to Table 5-12.

e. Identification of Calibration Standards and Laboratory Control Sample (LCS)

- (1) Properly and clearly identify all calibration standards and the LCS.
- (2) Prepare the LCS from a standard that is totally independent from the standards used for the initial calibration. A totally independent source means a different supplier (whenever possible) or a different lot from the same supplier. Note: an LCS is also required for method TO-15.

f. Gas Chromatography (GC) and Mass Spectrometry (MS)

- (1) Use a type of column that can separate all the target compounds. Coelution of the target compounds is not acceptable unless the compounds are distinguished and quantified by two different types of detectors in use at that time. For MS detection, resolution of all compounds is not required.
- (2) Analyze the initial calibration and daily mid-point calibration check standards, LCS, blank, and samples using the same GC conditions (or e.g., detector, temperature program, etc.).
- (3) Use a GC run time that is long enough to identify and quantify all the target compounds.

g. Initial Calibration

The initial calibration must be recorded in Table 5-3.

(1) Perform an initial calibration:

- for all compounds listed in Group A, or B, or C in Section 5.IV.B.1.a;
- when the GC column type is changed;
- when the GC operating conditions have changed; and
- when the daily mid-point calibration check cannot meet the requirement in Section 5.IV.B.1.h.(3).

- (2) Include at least five different concentrations of the standard in the initial calibration, with the lowest one not exceeding five times the RL for each compound.

For MS detection, make certain that the mass spectrometer is tuned in accordance with the laboratory's standard protocol prior to the analysis of standards or samples (e.g., a 50-ng injection of 1,4-bromofluorobenzene meets the requirements listed in EPA Method 8260B).

- (3) Calculate the response factor (RF) for each compound and the calibration concentration prior to analyzing any site samples. Calculate the average RF for each compound. The percent relative standard deviation (%RSD) for each target compound should not exceed 20% except for the following compounds, which should not exceed 30%:

Trichlorofluoromethane (Freon 11)
Dichlorodifluoromethane (Freon 12)
Trichlorotrifluoromethane (Freon 113)
Chloroethane
Vinyl chloride
Tertiary butyl alcohol (TBA)

All target compounds that exceed these requirements must be flagged. Note: for methods TO-15 & TO-17, the %RSD for all target compounds can be up to 30% with two analytes up to 40% RSD.

- (4) Verify the true concentration of the standard solutions used with the LCS after each initial calibration. Conduct the verification using an LCS with a mid-point concentration within the initial calibration range. The LCS must include all the target compounds. The RF of each compound should be within $\pm 20\%$ of the initial calibration, except for Freon 11, 12, and 113; chloroethane; vinyl chloride; and TBA; which should all be within $\pm 30\%$ of the initial calibration. Note: for methods TO-15 & TO-17, the %RSD for all target compounds can be up to 35%. All target compounds that exceed these requirements must be flagged. Any compound that exceeds these requirements may be considered invalid for use in health risk evaluations.

h. Daily Mid-point Calibration Check

The daily mid-point calibration check is required before analyses start in the morning. The daily calibration check results should be included in the lab report sent to the client.

- (1) Check the calibration using the calibration standard solution with a mid-point concentration within the linear range of the initial calibration before any sample is analyzed.
- (2) Include the following compounds and **every** compound expected or detected at the site in the daily mid-point calibration check standard:

Group A	Group B	Group C
Benzene	1,1-Dichloroethane	All of Group A and B & methane
Toluene	1,2-Dichloroethane	
Xylenes	1,1-Dichloroethene	
Methyl tertiary butyl ether (MTBE)	Cis-1,2-Dichloroethene	
Tetrachloroethene	Trans-1,2-Dichloroethene	
	Tetrachloroethene	
	1,1,1-Trichloroethane	
	1,1,2-Trichloroethane	
	Trichloroethene	

- (3) Ensure that the RF of each compound (except for Freon 11, 12, and 113, chloroethane, vinyl chloride, and TBA) is within $\pm 20\%$ of the initial calibration's average RF. If detected, the RF for Freon 11, 12, 113, chloroethane, vinyl chloride, and TBA should be within $\pm 30\%$. Note: for methods TO-15 & TO-17, the (RF) for all target compounds can be 30%.

i. Blank

- (1) Analyze field blank(s) to detect any possible interference from ambient air.
- (2) Investigate and determine the source(s) and resolve any laboratory contamination problem prior to analyzing any samples if the blank shows a measurable amount of the target compound(s).

j. Sample Analysis

- (1) Ensure that the requirements for the initial calibration, the daily mid-point check, the blank, and the LCS are met before any site samples are analyzed. If they are not, all reported values must be flagged with a footnote describing the deviance. Depending upon the project goals, the sample result may be considered inadequate and need to be resampled.
- (2) Analyze samples within 30 minutes after collection to minimize VOC loss. Longer holding time may be allowed if the laboratory uses special sampling equipment (e.g., sorbent trap, glass bulb) and demonstrates that the holding time can exceed 30 minutes with no decrease in results.

- (3) If the concentrations of constituent(s) in a sample exceed 10% of the highest concentration in the calibration range, either reanalyze the sample using a smaller volume and dilution, or flag the result and provide a narrative justifying the validity of the result. Be advised that depending upon the explanation and project goals, the sample result may be considered inadequate and need to be resampled.
 - (4) Attain a DL as indicated in Section 5.IV.B.1.c If lesser sample volumes or dilutions are used to offset possible high concentrations of constituents in the initial run, use the initial run to calculate the results for constituents that are not affected by the high concentration so that a DL referenced in Section 5.IV.B.1.c can be achieved.
 - (5) Quantify sample results using the average RF from the most recent initial calibration.
 - (6) Add surrogate compounds to all samples. Ensure that the surrogate compound concentration is within the initial calibration range. Two to three different surrogate compounds [one aromatic hydrocarbon and two chlorinated compounds (early and middle eluting, except gases)] should be used to cover the different temperature programming range for each GC run. Note: this requirement also applies to methods TO-15 & TO-17.
 - (7) Calculate the surrogate recovery for each GC run. Surrogate recovery should not exceed $\pm 25\%$ of the true concentration of the surrogate. If recoveries fall outside these limits, all reported values must be flagged with a footnote describing the deviance. **Depending on the preponderance of data, samples with data outside the limits may be required to be resampled and analyzed. For EPA TO-15 and TO-17, the acceptance ranges for surrogate recoveries are to be statistically determined by the laboratory.**
 - (8) Analyze duplicate samples at a minimum of 1 every 20 samples (5%).
- k. Compound Confirmation
- (1) Conduct compound confirmation by GC/MS whenever possible. Use second column confirmation with surrogate(s) for compound confirmation if GC/MS is not used.
 - (2) Add surrogate compounds to standards and site samples for second column confirmation to monitor the relative retention time (RRT) shift between GC runs. This is required for better compound identification when ELCD, PID and FID are used for analysis.
 - (3) Usually one sample is adequate and quantitation is not required for second column confirmation. Second column confirmation can be done with a different GC. The representative sample can be collected in a Tedlar™ bag and confirmation can be done off-site. The maximum holding time for samples in a Tedlar™ bag taken to an off-site laboratory is compound specific. For benzene, the maximum holding time is 4 hours. Please refer to the time frames outlined by the National Institute of Occupational Safety and Health (NIOSH) for other compounds. For further information on the NIOSH Manual of Analytical Methods (NMAM), 4th ed. DHHS

(NIOSH) Publication 94-113 (August 1994), refer to the web site @ www.cdc.gov/niosh/nmam/order.html.

- (4) Second column confirmation is not necessary if the compounds present have been confirmed from previous soil gas investigations.

l. Samples with High Concentration

- (1) The DL may be raised above 1 µg/L for compounds with high results (i.e., the limit as specified in Section 5.IV.B.j.(3) and those closely eluting compounds for which quantitation may be interfered with by the high concentrations.
- (2) Quantify sample results according to Section 5.IV.B.j.(4) for analytes that are not affected by the high concentration compounds.
- (3) If high VOC concentrations in an area are known from previous soil gas analysis, Sections 5.IV.B.1.1.(1) and 5.IV.B.1.1.(2) are not necessary when analyzing samples from the area in question.
- (4) When dilution with ambient air is used for samples with high results, dilute and analyze in duplicate each day at least one sample to verify the dilution procedure.

m. Shortened Analysis Time

- (1) Shorten the GC run time only under the following conditions:
 - (a) The exact number and identification of compounds are known from previous soil and soil gas investigations; and
 - (b) The consultant has been given permission by an approved work plan by the lead agency to analyze only for specific compounds.
- (2) The following requirements must be met when shortening GC run-time:
 - (a) Based on the previous site assessment work on-site, the compounds present are fully known.
 - (b) The compounds must not coelute;
 - (c) Perform the initial calibration and daily mid-point calibration check and analyze the LCS and samples under the same conditions as the shorter GC run time;
 - (d) Quantitate using the average RF from the initial calibration utilizing the shorter run time; and
 - (e) Perform a normal run time analysis whenever peaks are detected within retention time windows where coelution, as indicated by the calibration chromatograms, is likely.

n. Last GC Test Run Per Day of Analysis

The closing calibration analysis must be included in the lab report to the client.

- (1) A closing calibration or LCS is required at the end of the day to verify that the calibration is still within limits. Include the same compounds used in the daily mid-point calibration check analysis, as listed in Section 5.IV.B.1.h.(2). Attain an RF for

each compound within $\pm 20\%$ difference from the initial calibration's average RF, except for Freon 11, 12, 113, chloroethane, vinyl chloride, and TBA, which should be within $\pm 30\%$. All target compounds that exceed these requirements must be flagged. Any results that exceed these requirements may be considered invalid for use in health risk evaluations. Note: for methods TO-15 & TO-17 a closing CCV is not required.

- (2) Analyze the closing calibration standard at the detection limit concentration instead of the mid-point concentration if all samples from the same day of analysis show non-detect (ND) results. The recovery for each compound must be at least 50%. If less than 50%, all the ND results of the samples may be considered questionable.
- o. Site Inspection
- (1) Unannounced, on-site inspection by the lead agency may occur. The inspector or case manager may request hard copies of the complete laboratory data, including raw data for the initial calibration, daily mid-point check, LCS, and blank results. Failure to provide this information may result in the data being considered inadequate and may require samples to be reanalyzed.
 - (2) The soil gas consultant must be able to answer reasonable inquiries on the use of the instruments, analytical procedures, and QA/QC procedures.
- p. Record Keeping in the Mobile Laboratory

Maintain the following records in the mobile laboratory:

- (1) A hard copy record of calibration standards and LCS with the following information:
 - (a) Date of receipt
 - (b) Name of supplier
 - (c) Lot number
 - (d) Date of preparation for intermediate standards (dilution from the stock or concentrated solution from supplier)
 - (e) ID number or other identification data
 - (f) Name of person who performed the dilution
 - (g) Volume of concentrated solution taken for dilution
 - (h) Final volume after dilution
 - (i) Calculated concentration after dilution
- (2) A hard copy of each initial calibration for each instrument used for the past few months
- (3) The laboratory standard operating procedures

2. Reporting of Soil Gas Sample Results and QA/QC Data

- a. Reports for all sample test results should be presented in the preferred reporting formats outlined in Table 5-4. The QA/QC data should be presented in the preferred reporting

formats that are provided in Table 5-3. Compounds may be listed by retention time or in alphabetical order. Include in the table of sample results all compounds in the analyte list. Report unidentified or tentatively identified peaks. Submit all data requested upon request. Identify the source(s) of the contaminants detected in the investigation, as indicated by the data.

b. Report the following for all calibration standards, LCS, and environmental samples:

- (1) Site name / Project name
- (2) Address
- (3) Sample Date
 - (2) Laboratory name
 - (3) Date of analysis
 - (4) Sample result
 - (5) QA/AC - Soil & Water

Method Blank

LCS/LCSD

MS/MSD

Soil Vapor

Method

LCS/second and/or LCSD

3. Acknowledgement

This guideline, although based on the State of California, California Regional Water Quality Control Board-Los Angeles Region *Interim Guidance for Active Soil Gas Investigation* (February 25, 1997), has been modified to meet SAM requirements. At present, EPA SW846 does not address soil gas as a matrix for the analytical methods SAM typically uses. Also, there is no California accreditation process to review the methodology or require specific QA/QC when soil gas is the matrix.

SAM accepts soil gas data for input into the SAM Soil Gas Vapor Risk 2000 assessment model for evaluation of potential increased risk to human health from vapor migration into buildings. Because of this, a higher level of accuracy and precision of the data is required than that necessary for soil gas surveys for other purposes.

TABLE 5-4: SOIL GAS SAMPLE RESULTS

SITE NAME: _____ LAB NAME: _____ DATE: _____

ANALYST: _____ COLLECTOR: _____ INSTRUMENT ID: _____

NORMAL INJECTION VOLUME: _____

Sample ID	Sample 1	Sample 2	Sample 3							
Sampling Depth										
Purge Volume										
Vacuum										
Sampling Time										
Injection Time										
Injection Volume										
Dilution Factor										
COMPOUND	DETECTOR	RT	AREA	CONC	RT	AREA	CONC	RT	AREA	CONC

Compound 1
Compound 2
Compound 3
.
.
.
.

Surrogate 1
Surrogate 2

Total Number of Peaks
by Detector 1 (specify)
by Detector 2 (specify)
Unidentified peaks and/or other analytical remarks

Note: Data for retention time and soil vapor results can be placed in separate tables.

V. DIRECT MEASUREMENT OF VAPOR FLUX

Due to site conditions it is sometimes necessary to directly measure the vapor flux through the floor of a structure. A flux chamber is used for this type of measurement. A flux chamber consists of an enclosed chamber that is placed on the surface to directly measure emissions. Flux chambers can be used to take either active or passive samples. Passive flux chambers have not been adequately tested under field conditions, and are therefore not recommended at this time and will not be discussed further. Active flux chambers measure vapor concentrations through time. This method is quantitative and yields both concentration data and flux data (mass/area-time). In general, numerous locations are tested to evaluate the varying conditions of the floor slab.

A. Active Flux Chamber

Equipment: The sampling equipment consists of an air-tight container open on the bottom, placed at least 2 centimeters (cm) into the soil with optional sample ports for temperature and pressure probes, an air distribution system for sweep gas, and an outlet gas line. To the outlet gas line, various sample trains can be attached to collect samples for later analysis, or instruments can be attached to analyze samples on-site.

Purge Volume: Before samples are taken, the chamber should be purged with at least 3 volumes of clean air (bottled "zero" air or ambient air that has been passed through a carbon filter).

Chamber Pressure and Temperature: Pressure and temperature should be kept as close to ambient as possible to minimize the possibility of losses to the atmosphere or addition of ambient air.

Sweep Air Flow Rate: The incorporation and selection of the sweep gas flow rate depend on the anticipated concentrations, the purpose of the sample program, and modeling considerations. If the purpose of the sampling program is to estimate health risk when the soil is open to the atmosphere, it may be desirable to model ambient wind conditions.

Sample System Pumps: Sample pumps should be upstream of inlet carbon filters or after all grab sample ports to minimize the possibility that lubricants in the pump could contaminate the sample, or use pumps specifically designed for air sampling. The design of the sampling system should ensure that samples are not contaminated by ambient air.

Sampling Techniques: Samples from the chamber can be taken either as discrete samples or by adsorbing the chamber vapors onto an adsorbent medium.

Discrete Sample Containers: Discrete samples can be taken in either Summa™ canisters or Tedlar™ bags. Summa™ canisters should be pre-evacuated. The vacuum should be measured before and after sampling.

Sorbed Samples: The laboratory that will analyze the sample should prepare the sorbent media.

Sampling Interval: Flux chambers should be sampled over a minimum of 3 time intervals.

B. Analysis of Samples

Refer to the previous section (Section 5.IV.B) for the discussion of methods.

VI. WELL DEVELOPMENT

The goal of well development is to improve hydraulic communication between the geologic formation and the well. Hydraulic communication is degraded when clay and silt in the formation (or in fractures), and/or drilling muds, are smeared on the borehole wall during the drilling process. Well development improves hydraulic communication by eliminating or reducing this smear. Development also improves the filtering action of filter pack that surrounds the well casing.

Most monitoring wells need to be developed after construction. The intensity of development depends on the purpose of the well and the nature of the water-bearing materials. There is no “cook book” formula for monitoring well development. Determining what constitutes acceptable development is a professional judgment that is left to the registered professional. SAM will consider the quality of development when evaluating data obtained from the well and when establishing the length of monitoring programs.

A. Important Terms

Non-aqueous phase liquid (NAPL): Immiscible liquids that are found on the surface of the water table, at the base of the well and in the formation’s interstitial pore space in both the saturated and unsaturated zones. When NAPL is observed in a well, it is commonly referred to as phase-separated product, free product, floating product, liquid phase hydrocarbon, light non-aqueous phase liquid (LNAPL) or dense non-aqueous phase liquid (DNAPL).

Water-bearing materials: Term that is generally equivalent to aquifer. In San Diego County many water-bearing formations do not meet the textbook definition of an aquifer; nevertheless, these formations are subject to investigation and remediation.

Well development: The process by which hydraulic communication between the well and the surrounding material is improved.

Filter pack: Also known as sand pack or gravel pack. The filter pack consists of non-reactive granular material matched to the slot size of the well screen to prevent the movement of fines into the well.

B. Selection of Well Development Method

The quickest and possibly the only effective way to remove clay smear is to generate a strong back-and-forth flow of water between the well bore and the formation. Several development methods generate a back-and-forth flow. Method selection is influenced by the type of formation material, drilling method, well recovery rate, well depth, depth to water, contaminants, purpose of the well, and other factors that only an experienced professional can determine. The advantages and disadvantages of various well development methods are discussed in the National Water Well Association’s document entitled *Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells* (Aller et al., 1989, p. 228-245).

In general, block surging and airlifting are acceptable development methods. Over-pumping is commonly used for development but is not as effective as those methods mentioned above. The use of vacuum trucks has similar results as over-pumping and is discouraged. Other methods may be suitable but should be discussed with the regulatory agencies before implementation.

C. Considerations

The following items should be considered when using monitoring wells to obtain water quality data:

1. A well that has never been properly developed may be a questionable source of data. Documentation of well development is necessary for a well to be considered reliable.
2. A well should be redeveloped when its use changes, when the data become suspect, or when the well becomes “silted-in,” bio-fouled, encrusted, or sits idle for an extended period.
3. NAPL sometimes appears in a well weeks to many months after construction. While this may indicate actual spreading of the product, it can also reflect insufficient initial well development or a formational material with low hydraulic conductivity. Unexplainable variation in groundwater sample results over a period of time may be the result of “delayed development” caused by repeated purging of the well.
4. The County of San Diego considers that reliable observation of static water level and NAPL thickness frequently cannot be made until at least 72 hours after well development. Therefore, samples should not be obtained until at least 72 hours after proper well development, or possibly longer if NAPL is expected.
5. Stability of field-measured turbidity has been used to indicate effectiveness of well development.
6. No specific values exist for duration of development activity, or the volume of water to be removed as part of the development process. The purpose of the well, type of contaminant, and geologic conditions must be considered when deciding on the appropriate level of development.
7. If water has been added during drilling, at a minimum, that volume of water must be removed in addition to the development water.
8. Well development will cause a filter pack to settle. It is recommended that partial development take place before any sealing material is placed above the filter pack. This will increase the long-term reliability of the annular seal and minimize bridging of well material. Complete the development process after seal installation.

D. Reporting

It is essential that the development process be clearly documented in the reports submitted to SAM. The following information must be reported:

- Description of development method used,
- Date and duration of development,
- Quantity of water removed,
- Type and quantity of anything (including water) added during drilling and development, and
- Qualitative description of well water throughout the development process (clear, cloudy, etc.).

VII. WELL PURGING AND SAMPLING

This guideline has been developed to provide consistent and representative sampling of groundwater monitoring wells. The well or wells to be sampled are assumed to be properly constructed and developed. This section focuses on sampling of groundwater for dissolved organic chemicals but can also be applied to sampling of inorganic compounds.

There has been considerable research and evaluation of the requirements for purging of wells and sampling methodologies. Sampling approaches can vary depending on the goal of the sampling program. In general there are four methods that have been accepted. These are high-flow purging and sampling, low-flow purging and sampling, no-purge discrete sampling, and non-purge grab sampling. It should be noted that consistency over time is very important. The same methods should be used each time the wells are purged and sampled unless a different purging method would improve sample quality and data precision.

A. Important Terms

Borehole volume: Volume of water that is contained in the well casing plus volume of water contained in the pore spaces of the filter pack.

Recovery: The measure of groundwater's return to its static level after purging.

Fast recovering well: A well is considered to be fast recovering if recovery to 80 percent or more of its static condition occurs within 2 hours when using the high-flow purging method.

Slow recovering well: A well is considered to be slow recovering if recovery to 80 percent of its static water level takes longer than 2 hours when using the high-flow purging method.

Purging: The act of evacuating (removing) water from a well. This includes water in the blank casing, screened casing, and filter pack.

Sample: A subset of a whole, which is representative of the whole.

Depth Discrete Sample: Distinguished from a grab sample by having a specific location in the well (i.e., depth).

Flow Sample: A sample collected from a pump.

Grab Sample: A sample obtained in a single aliquot or mass using a device specifically designed for the purpose. Grab samplers may include a bailer or other similar device(s).

Stability: Refers to the consistency of field water quality indicator parameters over a specified time interval. The most sensitive field parameters are dissolved oxygen, specific conductance, and temperature.

Purging and Sampling Methods: The following methods are currently approved by SAM.

High-flow Purging and Sampling: Purging using a pumping rate greater than 1 liter per minute (lpm) or 0.26 gallon per minute (gpm) (Barcelona and Puls, 1996). Traditionally, the high-flow purging method has been widely used. This method typically involves the removal of up to 3 borehole volumes prior to sampling. Samples are most often collected with a bailer or other device after completion of purging. This methodology provides a composite of the contaminant concentration within the well and will likely not be suitable for low yield wells.

Low-flow (Low Stress or Low Impact) Purging and Sampling: Purging using a pumping mechanism that produces low-flow rates (less than 1 lpm or less than 0.26 gpm), which causes minimal drawdown of the static water table and usually employs a flow cell in which geochemical parameters are continuously monitored. These parameters may include dissolved oxygen content, oxidation-reduction potential (redox), conductivity, turbidity, and/or pH. Samples are obtained when all chemical parameters have stabilized thus demonstrating qualitatively that the groundwater being purged is in equilibrium (refer to Table 5-7). Samples are collected directly from the pumping mechanism with minimum disturbance to the aquifer groundwater. The low-flow purging method (purging to parameter stability) tends to isolate the interval being sampled, provides more accurate water quality measurements, and reduces the volume of purge water generated. This method has an advantage in that it can limit vertical mixing and volatilization of volatile organic compounds in solution within the well casing or borehole as compared to high-flow purging and sampling.

No-purge Grab Sampling: The non-purge grab sampling method refers to the Western State Petroleum Association's (WSPA) sampling methodology that was proposed in 1996 for fuel releases and approved by the State Water Resources Control Board in 1997. This sampling methodology involves the collection of a grab sample taken from a well without purging. The sample is acquired using a grab-type-sampling device and is generally acquired at or near the air-water interface of a well. These samples may not be representative of the aquifer water quality. To date the studies on this method are limited and inconclusive. This method is allowed on a limited basis and generally a comparative testing plan is required prior to approval.

No-purge Discrete Sampling: This method includes discrete point-interval sampling (DPIS) devices and other devices that allow sampling from a discrete interval within a well without compromising the vertical stratification of water quality conditions in the well bore. A discrete sample is acquired without splitting and must be taken from a well that has been demonstrated to have a net flow, or a measured flow through the well.

Such sampling is useful for characterizing specific zones or intervals within a saturated well screen or borehole.

B. Purging and Sampling Methodology

This section outlines procedures for high-flow, low-flow, no-purge grab, and no-purge discrete interval sampling. For consistency and to help evaluate results over time, the use of one method of purging and sampling over time is highly recommended.

There has been significant discussion in the literature regarding shifting from the high-flow purge methodology to the low-flow purge methodology. The low-flow methodology has been demonstrated to minimize or overcome many of the limitations created by the high-flow purging method. These limitations include sample turbidity, alteration of sample chemistry, altered ambient flow conditions, and the need to purge excessive volumes of water to achieve stability.

In the high-flow purging method, low-yield wells have often been evacuated to dryness and allowed to recover prior to sampling. In many cases, wells that are considered to be “low yield” could readily be pumped continuously at sustained rates less than 1 lpm or 0.26 gpm. In these situations, the low-flow method is recommended provided that it is implemented in accordance with guidelines.

The evacuation of the well to dryness poses several problems:

- Cascading water as the well recovers results in changes to water chemistry due to aeration and volatilization,
- Draining water from the filter pack may result in air being trapped in the pore spaces, with lingering effects on water chemistry,
- Increased sample turbidity may result from the stress on the formation and stirring up of settled solids in the bottom of the well, and
- The excessive time required for sufficient recovery of the well may affect sample chemistry through prolonged exposure to the atmosphere.

Depending on the purging method to be used there are specific equipment limitations. Table 5-5 provides a description of the various methodologies and their applicability.

Method	Low-flow (< 1 lpm)	High-flow (> 1 lpm)
Peristaltic Pump	1	2
Centrifugal Pump	3	3
Submersible Impeller Pump	1	3
Bailer	X	2
Bladder Pump	3	3
Vacuum Truck	X	X

SECTION 5: SITE INVESTIGATION TECHNIQUES

- 1 - Not recommended, better methods exist
- 2 - Useful with limitations
- 3 - Recommended method
- X - Unacceptable

Proper selection of sampling devices or pumps is critical to the quality and representativeness of the sampling results. Table 5-6 provides a summary of the acceptable sampling methods for the various chemicals of concern.

Method	Analytical Sampling					
	VOCs	Semi VOCs	Metals and Inorganics	Petroleum Hydrocarbons		General Chemistry
				C3-C16	C16+	
Peristaltic Pump	X	1	3	X	1	2
Centrifugal Pump	2	3	3	2	2	3
Submersible Impeller Pump	2 3 if low-flow	3	3	2	3	3
Bailer	2	2	2	2	2	2
Bladder Pump	3	3	3	3	3	3
Vacuum Truck	X	X	X	X	X	X
DPIS	3	3	2	2	2	2
Diffusion Sampler	2	2	X	2	2	X
Grab Sampler	2	2	2	2	2	2

- 1 - Not recommended, better methods exist
- 2 - Useful with limitations
- 3 - Recommended method
- X - Unacceptable

Notes: Centrifugal pump—assumed at a low-flow rate (no greater than 1 lpm)

1. High-flow Purging and Sampling Method

This method is widely used and involves the removal of water from the well at a rate in excess of 1 lpm (0.26 gpm) by a variety of methods, including pumps, bailers, etc. The following steps are necessary to collect representative samples. Well purging to “dryness” should be avoided for the reasons cited in Section 5.VII.B. Consideration should be given to the use of low-flow or passive purging methods in the future.

a. Measure for NAPL

LNAPL and DNAPL may be present in groundwater monitoring wells. If NAPL exists, the well sampling procedure described in this section will typically not apply. Special considerations may be necessary and should be discussed with the SAM project manager on a case-by-case basis.

b. Measure Water Level

The groundwater level in the monitoring well should be measured to an accuracy of 0.01 foot prior to purging and sampling activities.

c. Placement of Pump

The pump should be placed in the lower one-third of the well screen.

d. Calculation of Borehole Volume

The following equation can be used to calculate the borehole volume.

$$BV = \frac{7.48 \pi}{4} [CD^2 + P (BD^2 - CD^2)] (WD - GW)$$

Where:

BV	=	the borehole volume (gal)
CD	=	the casing diameter (ft)
P	=	the porosity of the filter pack (e.g., if porosity is 25% use 0.25 in the formula)
BD	=	the borehole diameter (ft)
WD	=	the well depth (ft)
GW	=	the depth to groundwater (ft)

Note: The above equation, as written, applies to wells constructed straddling the water table. The equation may be modified for circumstances where the static water table is above the top of the filter pack.

e. Calculation of Percent Recovery

The following equation may be used to calculate the percent recovery after purging.

$$PR = \left(1 - \frac{RD}{MD} \right) \times 100$$

Where:

PR	=	the percent recovery (%)
RD	=	the residual drawdown (ft) - the difference between the water level prior to purging and the measured water level at any time after purging
MD	=	the maximum drawdown (ft) - the difference between the static water level prior to purging and the measured water level immediately after purging

f. Parameter Stability

It is assumed that parameter stability is achieved when the difference between successive measurements is less than 10 percent. Generally, measurements are made after one borehole volume is removed and then at one-half borehole volume intervals. Commonly, the measurement of temperature, specific conductance, and pH are used exclusively, but it has been found these parameters are less sensitive to field conditions. It is recommended that dissolved oxygen, turbidity, specific conductance, and temperature be monitored.

g. Purge Well

The well must be purged with a device that does not compromise the sample by cross-contamination, aeration, or other negative effects. Refer to Table 5-5 for the acceptable purging devices for this method.

(1) Fast Recovering Wells

DEH considers the following two options acceptable methods for properly purging fast recovering wells:

(a) Option I

- i. Remove 3 borehole volumes of water.
- ii. Allow the well to recover to 80% of its static condition prior to collecting the sample.

(b) Option II

- i. Remove 1 borehole volume of water.
- ii. Conduct field water-quality measurements (dissolved oxygen, turbidity, specific conductance, and temperature).
- iii. Remove an additional ½ borehole volume of water. Conduct field water quality measurements again. If the first and second measurements vary by less than 10%, purging is considered adequate. Proceed to step (v.) below.
- iv. Repeat step (iii) until the measurements vary by less than 10% or until 3 borehole volumes of water have been removed.
- v. Allow the well to recover to 80% of its static condition before collecting the sample.

(2) Slow Recovering Wells

- (a) Remove 1 borehole volume of water.
- (b) The well should be allowed to recover for 2 hours after purging has stopped. Then the well should be sampled as soon after 2 hours as possible. Note that if the well recovers to greater than 80% in less than 2 hours, it is a fast recovering well and the steps in Option I or II above must be implemented.
- (c) Consider using the low-flow method for future sampling events (refer to Section 5.VII.B.2, below).

h. Collect Samples

After the monitoring well has been properly purged, the guidelines below for groundwater sample collection should be followed.

- (1) In the case of a fast recovering well, samples should be collected when the well has recovered to 80%. In the case of a slow recovering well, samples should be collected as soon as possible after 2 hours have elapsed.
- (2) Collect groundwater samples from wells with sampling equipment in accordance with Table 5-6.

- (3) Sampling equipment must be compatible with the contaminant being analyzed.
- (4) Sampling equipment should be decontaminated before use.
- (5) Samples requiring organic analyses should not be filtered.
- (6) Samples should be transferred from the sampling device to a container in a manner that minimizes aeration.
- (7) Samples should be collected in approved sample containers appropriate for the type of analysis to be performed.
- (8) Samples should not be transferred from one sample container to another.
- (9) Headspace in sample containers should be avoided.
- (10) EPA SW-846 sample preservation and holding times for specific analyses should be followed.
- (11) Appropriate sample chain-of-custody procedures must be followed (refer to Section 5.X).
- (12) Appropriate QA/QC procedures must be followed (refer to Section 5.X).

2. Low-flow Purging and Sampling Method

The low-flow purging and sampling method has been described in the literature since the mid-1980s with a defined methodology being accepted by the U.S. EPA in 1995. An overview of this methodology is presented in a U.S. EPA Ground Water Issue paper titled *“Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures”* by Robert Puls and Michael J. Barcelona dated April 1996.

Low-flow purging and sampling is appropriate for collection of groundwater samples for all groundwater contaminants, including inorganic compounds, metals, pesticides, polychlorinated biphenyls (PCBs), volatile and semi-volatile organic compounds (VOCs and SVOCs), other organic compounds, and radiochemical and microbiological constituents. This method is not applicable to the collection of LNAPL or DNAPL.

Low-flow refers to the velocity of the water entering the pump intake. Low-flow purging also results in limited drawdown. This method can be applied to wells that meet the following criteria:

- The well can be pumped at a constant low-flow rate of 0.1 to 1.0 lpm, with an overall **goal** of less than 0.10 meter or 0.33 foot of drawdown in the well during purging. This goal may be difficult to achieve under some circumstances due to geologic heterogeneities and may require adjustment based upon site-specific conditions. The goal is to minimize drawdown and achieve a stabilized pumping water level as soon as possible.
- The maximum well screen or open borehole intake length should be 20 feet when sampling from a single point within the intake.

- Where the screen or open zone is longer than 20 feet and a target zone cannot be identified based on either of the boring logs, it may be necessary to sample multi-levels to identify the target zone.
- a. Pump Placement

Proper pump placement requires detailed knowledge of the site's lithology, the hydrogeologic properties, contaminant depths, and the well construction details, along with the specific goals and objectives of the monitoring program. The following is general guidance on pump placement. Following placement of the pump, the well needs to sit for a minimum of 2 hours prior to purging.

(1) Homogeneous Geologic Conditions

For a well screened or open across a single homogeneous geologic unit and where the saturated interval is not more than 20 feet long, the pump intake should be positioned adjacent to known soil impacts. Where the compounds of interest are known to concentrate near the top or the bottom of the screen zone, it may be desirable to locate the pump intake in the upper one-third or lower one-third of the interval, respectively.

(2) Heterogeneous Geologic Conditions

For a well screened or open across heterogeneous geologic conditions and where the saturated interval has layers of contrasting permeability, it may be necessary to locate the pump intake adjacent to any anticipated preferential flow pathways, zones of concern, or areas of known contamination.

b. Flow Rate

The flow rate used during purging must be low enough to avoid increasing the water turbidity. The following measures should be taken to determine the appropriate flow rate:

- The flow rate should be determined for each well, based on the hydraulic performance of the well.
- The optimum flow rate for each well should be established during well development or redevelopment, or, if possible, in advance of the actual sampling event.
- The flow must be adjusted to obtain stabilization of the water level in the well as quickly as possible.
- The maximum flow rate used should not exceed 1 lpm (0.26 gpm).
- Once established, this rate should be reproduced with each subsequent sampling event.
- If a significant change in initial water level occurs between events, it may be necessary to reestablish the optimum flow rate at each sampling event.

c. Measurement of Water Level and Drawdown

Measurement of the water level in the well during purging is important when establishing the optimum flow rate for purging. The goal is to achieve a stabilized pumping water level as quickly as possible with minimal drawdown, to avoid stressing the formation and mobilizing solids and to obtain stabilized indicator parameters in the shortest time possible.

d. Measurement of Indicator Parameters and Turbidity

Continuous monitoring of water quality indicator parameters is used to determine when purging is completed and sampling should begin. Stabilized values, based on selected criteria listed in Table 5-7, should be met prior to sampling. The use of an in-line flow cell (closed) system is recommended for measuring indicator parameters, except for turbidity. Indicator parameter collection is more important when low-flow purging is used and additional parameters are needed as compared to the high-flow purging method.

Generally, measurements are taken every 3 to 5 minutes and water chemistry parameters are considered to be stable when they are within the following ranges for three consecutive readings.

Constituent	Criteria
Dissolved Oxygen Content (DO)	± 0.2 mg/l
Oxidation-Reduction Potential (redox)	± 20 mv
Turbidity	± 10 %
Specific Conductance	± 3-5% of reading
Temperature	± 3% of reading (min. of ± 0.2°C)
pH	± 0.2 units

e. Equipment Requirements

Because the methodology requires that disturbance to the water column in the well be minimized, the same pumping device used for purging should be used for sampling (i.e., the pump should be left in place after purging). Refer to Table 5-5 and Table 5-6 for the proper pumping equipment for the low-flow method.

(1) Dedicated and Portable Systems

Studies have shown that installation of any device into a well disturbs the stratification typically exhibited in a well due to laminar flow of groundwater in the well. Insertion also potentially mobilizes suspended solids in the water column due to disturbance of settled and adhered solids in the casing and agitation of water in the filter pack. Therefore, low-flow purging and sampling techniques are more accurate when dedicated systems are used. Dedicated systems result in lower initial turbidity values and lower purge volumes to achieve stabilized indicator parameter readings and should be considered when a well will be sampled multiple times.

If portable systems are used, they must be placed carefully into the well and lowered into the screen zone as slowly as possible. Placement of the portable pump can disturb the groundwater flow conditions resulting in non-equilibrium conditions. Therefore, longer purge times and greater purge volumes may be necessary to achieve indicator parameter stabilization. After installation, the portable pump should remain in place at least 2 hours to allow settling of solids and re-establishment of horizontal flow through the screen zone. If initial turbidity readings are excessive (>50 nephelometric turbidity units [NTU]), pumping should cease and the well should rest for another 1 to 2 hours before re-initiating pumping. In wells set in very fine-grained formations, longer waiting periods may be required. If the well consistently produces high turbidity water (>50 NTU), even at low pumping rates, redevelopment of the well should be considered before further sampling.

(2) Water-Level Measurement Equipment

Continuous water-level measurement devices are preferred, such as down-hole pressure transducers, but electronic water-level tapes can be used. The devices used must be capable of measuring to 0.01-foot accuracy.

(3) Indicator Parameter Equipment

Measurement of indicator parameters (dissolved oxygen content, redox potential, specific conductance, temperature, and pH) is required. This is most easily performed using an in-line flow cell (closed) system attached directly to the pump discharge tubing. For turbidity measurement, a separate field nephelometer should be used.

f. Collect Samples

After the monitoring well has been properly purged using the low-flow method, use the guidelines outlined in Section 5.VII.B.1.h (where appropriate) for groundwater sample collection. However, when using this method it is of utmost importance to collect the groundwater samples using the same pump or device used for low-flow purging without moving it or causing disturbance to the well.

g. Well Specific Sampling Procedures

Due to the complexity of this sampling method, preparation of well specific sampling procedures is recommended for consistency and reproducibility. SAM may require either a workplan for low-flow sampling, submittal of well specific parameters or both. At the least, the registered professional's understanding of site specific conditions must be evident in reports or other submittals which provide low-flow sampling results.

3. Non-Purge Method

The San Diego RWQCB has concluded that use of the non-purge sampling method (as outlined in the California Groundwater Purging Study for Petroleum Hydrocarbons prepared for the Western States Petroleum Association (WSPA) in October 1996) can be considered for wells that meet the following minimum conditions:

- The only contaminants of concern are gasoline petroleum hydrocarbons,

- No NAPL exists in the well,
- The well construction details are known and documented,
- The well is screened across the water table, and
- The well is properly developed.

Prior to implementation of this method, SAM may request multiple monitoring events using the standard purging and sampling method in conjunction with the non-purge method to determine repeatability and variance of the methods.

A formal request must be submitted with a California registered professional (PG, PE, CEG, CHG) certifying the items listed above, and a statement that the non-purge method will provide representative water quality results for the compounds of concern.

4. Discrete Point-Interval Sampling (DPIS)

The purpose of DPIS is to collect groundwater samples from monitoring wells that represent groundwater conditions vertically in the well. This is accomplished by obtaining the samples at pre-determined depths within the screened interval of the well. The use of DPIS is effective for collecting zone-specific and vertical profile samples from a well. Vertical profiling can be used to identify zones of concern for future long-term sampling programs.

The DPIS has three primary benefits:

- Minimizes disturbance of sediment in the bottom of the well, thereby producing a sample with low turbidity,
- Eliminates aeration of groundwater during sample collection, and
- Eliminates the need to purge well (in wells that have demonstrated net flow or measured flow through the well).

This procedure addresses the collection of water samples and NAPL (if present).

a. Review Available Site Historical Data

If available, review the borehole logs and well construction diagrams to determine the geologic and hydrologic conditions associated with the well.

b. Measure Water Level

Measure the groundwater level in the monitoring well to an accuracy of 0.01 foot prior to sampling activities.

c. Prepare DPIS Sampling Device

Select an appropriate DPIS sampling instrument and prepare for sampling in accordance with the manufacturer's specifications. Make certain that the equipment has been properly decontaminated prior to use. All sampling equipment must be compatible with the contaminant being analyzed.

d. Well Purging

Well purging is not required for DPIS sampling instruments when used in accordance with the manufacturer's specifications.

e. Sample Collection

(1) After the monitoring well has been properly gauged and surveyed for NAPL, and the depth of the top of the screened interval has been determined, the following procedures should be followed for sample collection.

(2) Deliver the sampling instrument to a pre-determined depth that is a minimum of 6 inches below the top of the screened interval of the well:

(a) Discrete Interval Sampling

(i) Sample from the top of the well down to limit disturbance in the well.

(b) Routine Monitoring

(i) After proper vertical profiling of the well, routine sampling shall be taken from the zone of highest concentrations.

(ii) For closure (final phase) sampling, vertically profile the well in accordance with the original procedures used in the initial vertical profiling.

(iii) Where applicable, follow the sample handling guidelines outlined in Section 5.VII.B.1.h.

C. Groundwater Sampling from Excavations and Boreholes

DEH recognizes that groundwater samples collected from open excavations and boreholes can be useful as screening tools or for water disposal characterization; however, the consultant should confer with DEH before doing such sampling. In areas where groundwater has beneficial uses and where stringent cleanup standards apply, water samples from open excavations or boreholes are discouraged and DEH or the RWQCB may not accept the results. Groundwater samples collected from open excavations and boreholes may not be representative of groundwater present within adjacent formations for some of the following reasons:

- Open excavations may have a large water-surface area exposed to the atmosphere that allows the rapid loss of VOCs dissolved in the groundwater.
- The sloughing of contaminated soils from the sidewalls can contaminate groundwater within an open excavation.
- Open excavations may also collect surface water runoff, which would dilute any contaminants present in the groundwater and/or add other contaminants.
- Groundwater samples from open boreholes have similar limitations, as well as potential turbidity problems.

D. Groundwater Sampling from Wells Installed in Excavations

On some sites, well casings have been placed into former UST excavations and the excavation has been backfilled with sand or gravel. Most of these excavation wells have been intended for

potential recovery of free product or contaminated groundwater, not water quality sampling. The use of UST excavation wells for groundwater elevations and groundwater quality may not be representative of conditions within the adjacent geologic formation. The consultant should confer with DEH prior to sampling from such wells.

If excavation wells are to be used to obtain groundwater samples, protocols for groundwater sampling from traditional monitoring wells should be followed in principle. Collection of groundwater samples from excavation wells should occur only after a sufficient volume of water has been removed in order to purge the well casing and the sand or gravel backfill in the former UST excavation. Purge volume includes water in the well casing plus the water within the pores of the sand or gravel filling the entire excavation.

An approved well/boring permit application from DEH is required prior to constructing or destroying a UST excavation well. These wells must be constructed in compliance with State and County well construction standards.

E. Groundwater Sampling Using Alternative Sampling Devices

Recent studies suggest that sampling devices other than the traditional monitoring well can be used to obtain representative groundwater samples for initial characterization to aid in the placement of permanent groundwater monitoring wells. Proposals to use alternative sampling devices (e.g., well points, direct push or BAT® samplers) will be considered on a case-by-case basis and will be reviewed within the context of the goals of the site assessment.

Unlike traditional monitoring wells, which are usually screened over several feet of the water-bearing formation, alternative sampling devices are typically more depth discrete. For petroleum hydrocarbon cases in which contaminants tend to be found near the water table, care must be taken to ensure that these sampling devices are positioned to collect a sample from this zone. It is also important to follow the manufacturer's instructions to ensure that valid samples are collected.

Correlation of groundwater sample results with those from adjacent monitoring wells, or collection of groundwater samples from multiple depths at each sampling point to determine the vertical distribution of contamination may be required. Some of these alternative sampling devices provide a one-time opportunity to obtain a sample; this could be a disadvantage if additional sampling and monitoring is necessary.

Groundwater elevation data can be obtained from some alternative sampling devices. Because of the slow recovery rate of some geologic formations, these data are generally not considered reliable for determining groundwater gradient or static water conditions.

F. Groundwater Monitoring and Reporting Checklist

The following guidelines provide a consistent format for a groundwater monitoring program. A groundwater monitoring program includes:

- Measurement of groundwater elevation,
- Measurement of NAPL thickness (if present),
- Analysis of dissolved chemical concentrations,
- Interpretation of results, and

- Reporting.

This information is incorporated into a monitoring report that is submitted to DEH. **The report must include interpretations of the data and be signed by an appropriately registered professional.** The monitoring frequency will be established by the lead agency (either DEH or the RWQCB). Monitoring frequency will vary depending on site-specific conditions.

The following checklist provides a general format to achieve consistent reporting of groundwater monitoring programs.

1. Monitoring Activities

- Accurately survey all wells horizontally and vertically relative to a fixed point in accordance with State GeoTracker guidelines. The vertical measurement should be to an accuracy of 0.01 foot.
- Measure depth to groundwater and NAPL (if present) in all wells to within 0.01 foot from a permanent reference mark on the well casing.
- Follow the SAM Manual guidelines for well development, purging, and groundwater sampling.
- Collect groundwater samples from designated wells. Generally, these wells will not contain NAPL.
- Submit all samples to a State Department of Health Services-certified laboratory for the analyses requested.
- Analyze water samples for the chemical constituents as described in this section or in accordance with the monitoring program established for the site by the lead agency. For contaminants not listed, contact the lead agency.

2. Reporting

- Graphic Presentation

Include site maps (plot plans) that are drawn to a scale that remains constant from reporting period to reporting period. These maps must include the following information.

- Potential contaminant sources
- Well locations
- Groundwater elevation contours
- Groundwater flow direction(s)
- Extent of NAPL
- Extent of dissolved chemical constituents of concern
- Analytical results as appropriate

Line or bar graphs are helpful when illustrating variations in groundwater elevations, NAPL thickness, and dissolved chemical concentrations with time. Cross sections are recommended if the previous interpretation of subsurface conditions has changed.

- Tabular Presentation

Present all of the following data in tables to show a chronological history and allow quick and easy reference of the most recent data.

- (1) Well designations
- (2) Well construction (including well casing elevation, total casing and screen length, and depth to top of screen)
- (3) Groundwater depths
- (4) Groundwater elevations
- (5) NAPL elevations
- (6) NAPL thickness
- (7) Analytical results (current as well as historical)
- (8) Measurement dates

c. Discussion

Provide a discussion of the field and laboratory results, which includes the following information:

- (1) Conclusions
- (2) Data anomalies
- (3) Variations from protocols
- (4) Conditions of wells, including vaults and seals
- (5) Management of drill cuttings and purge water
- (6) Trend analysis
- (7) Data interpretation
- (8) Recommendations

d. Appendices

Include the following information in appendices:

- (1) Complete analytical laboratory reports
- (2) Well purging and sampling documentation (including equipment used, date and time, and infield water quality measurement), which must include all information on the attached example purge log.
- (3) Decontamination procedures
- (4) Field QA/QC methods
- (5) Sample preservation
- (6) Documentation of quantities of product, well development and purge water, and drill cuttings recovered or generated during field activities, and documentation of their proper disposal or recycling (include copies of hazardous waste manifests and bills of lading)

VIII. Non-Aqueous Phase Liquids

Soil and groundwater impacts may include the presence of NAPL. Depending on the physical properties of the contaminant, the NAPL may be lighter or denser than water. In general, contaminants such as fuels (e.g., TPH) have densities that are lower than water and are commonly referred to as LNAPL. Chlorinated hydrocarbons (CHCs) have densities that are higher than water and are commonly referred to as DNAPL.

NAPL can occur in the subsurface, partially or completely saturating pore or fracture spaces. Because of the low solubility of these chemicals, the presence of NAPL can be an ongoing source of groundwater contamination. To properly evaluate the long-term impacts of a release to groundwater, and the environmental risk, it is important to determine if NAPL is present. The presence or absence of NAPL in the subsurface will influence how the site is managed with respect to the selection of site characterization methods, consideration of appropriate remedial technologies, and development of a viable risk assessment. The San Diego RWQCB has provided some guidance on the data collection requirements for the evaluation of NAPL (Appendix E.V).

A. Evaluation and Determination of Residual Saturation

Initial site characterization data used to evaluate the presence of DNAPL include:

- Visual identification of chemical product in soil
- Visual identification of chemical product in wells or excavations
- Comparison of measured chemical concentrations in groundwater to equilibrium partitioning concentrations
- Comparison of measured chemical concentrations in soil to equilibrium partitioning concentrations
- Anomalous concentrations of chemicals in groundwater, soil, or soil vapor

NAPL characterization needs to include some or all of the following elements:

- Detailed characterization of site stratigraphy
- Determination of capillary properties of key lithologies
- Determination of NAPL chemical composition and fluid properties
- Estimation of NAPL mobility
- Estimation of residual NAPL distribution (horizontally and vertically)
- Estimation of NAPL volumes

The presence of NAPL is of significant concern because it has the potential to cause explosions and vapor problems, and/or be a continuous source of groundwater contamination. Additionally, these compounds can move through geologic materials as a NAPL, as dissolved components in water, or as vapors in soil pores.

As a general practice, the presence of NAPL in the subsurface has been investigated by using wells screened through the capillary fringe and the water table. The presence or lack of NAPL in wells or excavations is due to a number of site-specific conditions that may change with time. Typical conditions can include, but may not be limited to, a fluctuating water table, residual NAPL saturation, and soil type. Due to these conditions, the use of wells to define the presence of NAPL has resulted in inconsistent and unreliable results.

The following guidance is provided to aid in determining if NAPL is present at the site in the unsaturated and saturated zones.

A percentage of a fluid that is introduced into a soil will be permanently captured within the porous structure of the soil and/or rock materials. This is due to surface tension characteristics and capillary forces. The maximum percentage by volume of the liquid retained after gravity drainage is the specific retention of that liquid for that specific soil. For liquids other than water, this is commonly called the **residual saturation**. Besides reporting residual saturation as a percentage or fraction of the pore space, it is also commonly reported by laboratories as mass of the hydrocarbon per unit mass of soil (e.g., mg/kg, micrograms per liter [ug/kg], parts per million [ppm], parts per billion [ppb]).

Work by Hoag and Marley (1986), Huntley et al. (1994a,b), Melrose and Brander (1974), Mercer and Cohen (1990), Rathmell et al. (1973), and Tyler and Finley (1991) evaluated residual saturation for various NAPLs and soil/rock types. These researchers demonstrated that a significant fraction of NAPL would remain in soil after gravity drainage. Parker (1991) provides a modification of the Brooks-Corey relative permeability function (Equation 5-3, below) to estimate residual NAPL as a function of soil hydraulic conductivity and NAPL type. The equation assumes that below some critical threshold (q_c), NAPL loses pore continuity and becomes trapped by soil capillary forces, and movement is considered insignificant:

$$S_{ro} = (1 - S_{rw}) * [q_c \mu_{ro} / (\gamma_{ro} K_{swz})]^{0.25} \quad \text{Equation 5-3}$$

Where:

- S_{ro} = the residual NAPL saturation (dimensionless)
- S_{rw} = the residual water (dimensionless)
- q_c = the critical flow rate (centimeters per second [cm/sec])
- μ_{ro} = the relative NAPL viscosity to water (dimensionless)
- γ_{ro} = the relative NAPL specific gravity to water (dimensionless)
- K_{swz} = the vertical hydraulic conductivity of the soil (cm/sec)

A more accurate method of determining the residual saturation for a specific soil on a site is a laboratory test method that uses the Dean Stark Method (API RP40) described in Section 5.VIII.D.

Since Equation 5-3 provides residual saturation as a percentage or fraction of the pore space, it needs to be converted to units of mass of the hydrocarbon per unit mass of soil (e.g., mg/kg and ug/kg). This conversion makes it possible to compare the estimated residual saturation to laboratory data for the site. Equation 5-4 should be used to complete this conversion.

$$C_s = \frac{S_{ro} \theta \rho_o}{((\rho_w \theta_w) + \rho_b) (1 \times 10^{-6} \text{ kg/mg})} \quad \text{Equation 5-4}$$

Where:

- C_s = the concentration of compound in soil (mg/kg)
- S_{ro} = the residual NAPL saturation (dimensionless)
- ρ_o = the density of NAPL (gm/cm^3)
- ρ_w = the density of water (gm/cm^3)
- ρ_b = the dry bulk density of soil (gm/cm^3)
- θ = the total soil porosity (dimensionless)
- θ_w = the water filled porosity (dimensionless)

Equations 5-3

and 5-4 and conservative assumptions on soil type and petroleum-specific residual NAPL saturation were used to generate Table 5-3. DEH selected conservative saturated soil hydraulic conductivities, soil properties, and petroleum properties to provide the lowest expected residual saturation for a particular fuel and soil type. Other parameters such as the relative viscosity (μ_{ro}) and the specific gravity (γ_{ro}) are presented in Table 6-2(b) in Section 6. The water filled porosity (θ) is considered equal to the values for residual water (S_{rw}) presented in Table 5-8.

Soil Type ASTM- D2487	Approx. Particle Size (mm)	K_{swz} (cm/sec)	θ (dim)	S_{rw} (dim)	ρ_b (gm/cm ³)	TPH Concentration (mg/kg)			
						Gasoline/ Naphtha (mg/kg)	Kerosene / JP-4 (mg/kg)	Diesel #2 (mg/kg)	Fuel Oil (mg/kg)
Gravel	76.2-4.75	100	0.30	0.001	2.00	560	780	1000	1400
Sandy Gravel	Based on % fines	5.0	0.36	0.005	1.86	1,500	2,100	2,800	3,800
M- Coarse Sand	4.75-0.425	1.0	0.37	0.007	1.83	2,300	3,200	4,400	5,900
Fine Sand	0.425- 0.074	0.5	0.38	0.009	1.81	2,900	4,000	5,400	7,300
Silty Sand	Based on % fines	0.05	0.41	0.018	1.76	5,600	7,800	10,000	14,000
Silt	0.074- 0.005	0.0005	0.48	0.10	1.65	19,000	27,000	36,000	49,000
Clay	<0.005	0.000005	0.56	0.39	1.56	44,000	61,000	82,000	110,000

1. The critical flow rate (q_c) used to calculate the above values was 1×10^{-7} cm/sec.
This table does not apply in fractured crystalline rock environments
2. The TPH concentration values were determined by using Equations 5-3 and 5-4.

NAPL characterization requires an approach that is distinctly different from dissolved-phase characterization because immiscible flow is controlled by parameters not addressed in a dissolved-phase assessment. These parameters include the fluid properties of the NAPL and the capillary properties of the porous media.

There are many ways to determine the presence of NAPL. A more detailed discussion of the following techniques can be found in Cohen (1993) and Pankow (1996).

B. Visual Evidence

It is possible to identify NAPL visually in soil core samples. This is best accomplished when large quantities of NAPL have been detected or when there is dark colored NAPL such as creosote. More often than not, identifying NAPL visually is difficult because the NAPL may be clear or present near the soil's residual saturation.

C. Field Testing

Field testing methods can greatly increase the probability of determining NAPL presence. Laboratory tests have indicated that NAPL could be identified 80 percent of the time by using UV fluorescence or the soil-water-dye shake test (Cohen, 1993). The following describes the different types of field test methods:

- **Ultraviolet Light (UV) Fluorescence:** UV examination of soil cores can identify some contaminants such as trichloroethene (TCE) and perchloroethene (PCE). Uncontaminated soil should also be examined as a control since some soil minerals also fluoresce.
- **Soil-water Shake Tests:** If NAPL is suspected in a portion of a soil core, a soil-water shake test can be performed by mixing a small volume of soil with an equal volume of water in a clear vial. The presence of DNAPL can be determined by examining the sides and bottom of the tube. To enhance the test, a small amount of hydrophobic dye such as Red Sudan IV or Oil Red O can be placed in the vial. The dye, which is soluble in NAPL compounds but insoluble in water, will cause the NAPL to change color.
- **Vapor Analysis:** If volatile organic compound (VOC) readings from a head-space analysis are on the order of 1,000 to 2,000 ppm, NAPL may be present.
- **Drilling Fluids:** The presence of NAPL in drilling fluids can be determined by visual examination of the fluid for sheen.
- **Soil Analytical Data:** If the soil sample results are at or above the chemical's residual saturation, NAPL may be present.
- **Groundwater Analytical Data:** The presence of NAPL can also be determined by evaluation of water quality analytical results. If a particular compound is present at concentrations on the order of 1 to 10 % of the chemical solubility, NAPL may be present.
- **Observation of NAPL in Well or Excavation:** LNAPL will be observed floating on top of the groundwater in the well, whereas DNAPL will be observed at the bottom of the well or excavation. Please refer to Cohen (1993) or Pankow (1996) for a more detailed discussion of this topic.

D. Laboratory Testing

Currently, neither the EPA nor the ASTM has specified laboratory methods for determining the mobility of NAPL. Since there are no prescribed methods outlined, the following methodology can be used to evaluate product mobility in soil for sites located within San Diego County. The data derived from this laboratory test can be used to assess the potential mobility of NAPL under in situ conditions.

The following are the recommended procedures for this method:

1. Conduct product mobility testing on soil samples that represent in situ conditions in terms of soil compaction, soil structure, and contaminant concentrations.
2. Visually examine the geologic formations and/or soil structure in road cuts or trenches on or near the site to verify in situ conditions.
3. Evaluate subsurface soils for the potential of “finger flow” movement of contaminants. “Finger flow” is present to a degree in most cases. In those cases where fine-grained soils overlay uniform clean sands and/or coarse-grained sands, “finger flow” may pose a significant problem, and a groundwater monitoring well may be required to evaluate potential impacts to groundwater.
4. For those soils that need to be re-compacted (e.g., because of cobbles), make every effort to replicate the sample to in situ conditions.
5. Determine the residual saturation by using the following testing method: (Prior to collecting samples for this method contact your laboratory to determine sample size and preparation needed to complete the testing.)

The soil sample is placed in a temperature-controlled centrifuge and subjected to increasing rotational speeds from 50-5000 revolutions per minute (rpm). Each rotational speed is maintained up to 24 hours or until fluid production stabilizes before the speed is increased to the next step. Volumes of water and hydrocarbons produced are determined by using calibrated collection tubes. Values are recorded at each step. Following the final step, the sample is removed from the centrifuge and residual fluids are extracted (Dean-Stark Method; API RP40). At the completion of the test the following items should be reported:

- Initial hydrocarbon saturation (% and mg/kg)
 - Residual hydrocarbon saturation (% and mg/kg)
 - Fluid production vs. capillary pressure relationship
 - Sample petrophysical properties: effective porosity (%), grain and bulk density (gm/cc)
6. Compare the measured residual saturation values to the highest TPH concentration from the site. If the site value is less than the laboratory residual saturation value, the contaminant is considered to be below residual saturation. This will indicate that the contaminant is not mobile as a NAPL. If the site value is greater than the laboratory value, the contaminant is above the residual saturation and may be mobile. This indicates further investigation and/or remediation is necessary.

7. Review subsequent guidance sections regarding evaluation of soil leachability and potential impacts to groundwater.

IX. SOIL LEACHABILITY

To estimate the leaching potential of impacted soil, one of the following laboratory testing methods for leachability of a particular soil can be used:

- **EPA Method 1312**, Synthetic Precipitation Leaching Procedure (SPLP)
- **ASTM Method D4874-95**, Leaching Solid Material in a Column Apparatus

These tests are intended to aid in determining the maximum concentration of a contaminant that may remain in soil without potentially leaching to groundwater. A leachability study is not appropriate in materials where transport is primarily through fractures or if fractures are suspected.

A. Soil Sampling

For the majority of situations, obtain a minimum of three samples from each predominantly impacted soil type or geologic unit. These samples should encompass the full range of contaminant concentrations. One of the samples must represent the highest concentration of soil contamination; this is commonly located in or near the source. If the soil type or geologic unit varies in texture and composition, additional samples will need to be taken and analyzed to evaluate the leachability of the contaminant.

B. Analysis of Soil and Leachate

The following table is provided for guidance on the analyses to be performed. The soil analysis must be completed prior to running the SPLP analysis. The SPLP method should not be used to analyze soil samples with non-detect concentrations.

<u>Substance</u>	<u>Soil</u>	<u>SPLP Leachate</u>
Gasoline	EPA-8260	EPA-8260
Diesel	EPA-8260 and/or 8270	EPA-8260 and/or 8270
JP-4	EPA-8260 and/or 8270	EPA-8260 and/or 8270
Kerosene	EPA-8270	EPA-8270
MTBE	EPA-8260B	EPA-8260B
Waste Oil**	Case-by-case	Case-by-case
Solvents**	Case-by-case	Case-by-case

** The specific analysis will be determined on a case-by-case basis. Selection of target compounds should be based on knowledge of the waste.

C. Leachate Testing Procedures

1. SPLP Testing (EPA Method 1312)

This method is a standard laboratory procedure designed to determine the leaching potential of organic and inorganic compounds present in soils and wastes. It provides a leachate for analysis from a disaggregated soil or waste sample. This method uses pH-adjusted deionized water for metals analysis, and deionized water for cyanide and organic compounds.

2. Leaching Solid Material in a Column Apparatus (ASTM Method D4874-95)

This method is a standard laboratory procedure for generating aqueous leachate from soil using a column apparatus. It provides a leachate suitable for organic and inorganic analyses from samples that are undisturbed. This method is less aggressive than the SPLP procedures outlined above and is considered to be more representative of field conditions.

Since method detection limits (MDLs) for the target analyses will vary between analytical laboratories, it is important to acquire a sufficient volume of pore water to achieve detection limits down to the required action level.

To provide results that are more representative of in situ field conditions, this method should be modified as follows:

- a. Test only undisturbed samples to represent optimum field conditions of porosity, density, or moisture. Do not disaggregate and repack columns.
- b. Use a flexible sleeve column loaded to in situ confining pressures to prevent channeling. The laboratory should be notified of the depth of the sample so that the proper confining pressure can be maintained. The flexible sleeve should be of Teflon or other relatively inert material to prevent contamination of the leachate.

D. Data Interpretation

The sample results should be plotted on log-log graph paper. The soil results are plotted on the x-coordinate and the leachate results are plotted on the y-coordinate. Separate graphs should be made for each soil type or geologic unit.

The following example is provided to demonstrate the interpretation of benzene SPLP data.

EXAMPLE:

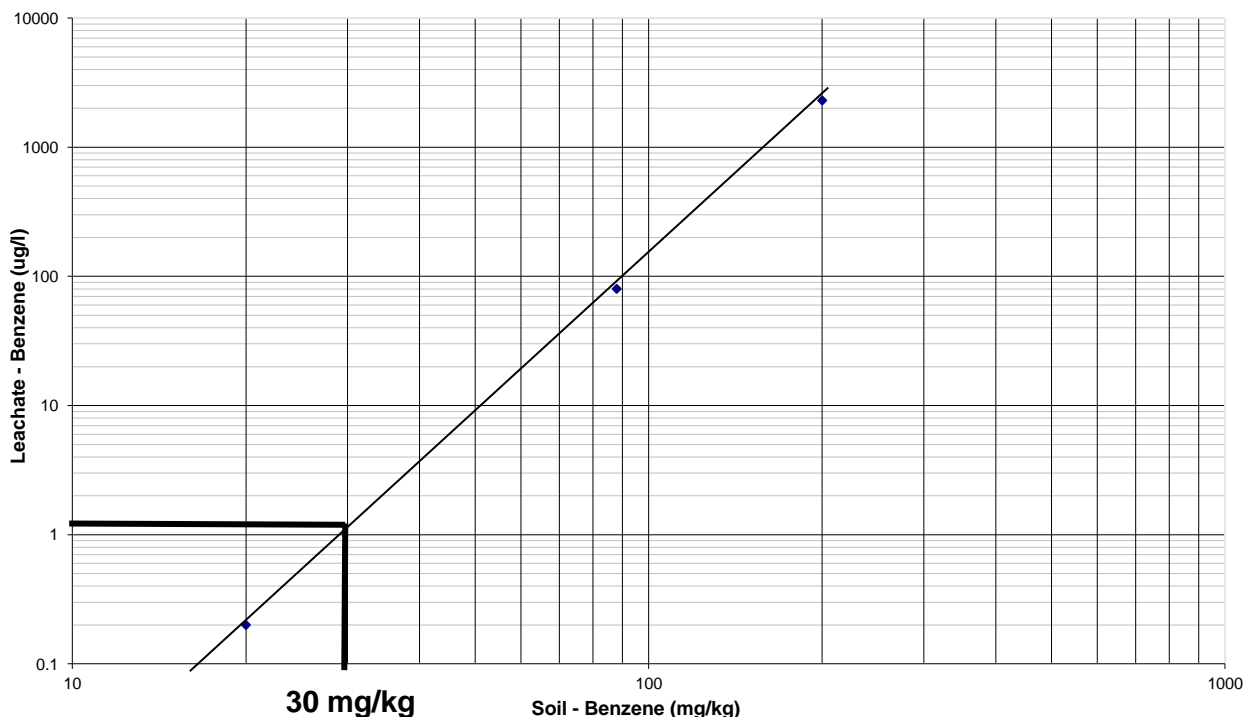
Three samples were obtained from a site in an area where groundwater was designated as having municipal and domestic uses. Torrey Sandstone, which was observed to be a light-brown, medium-grained, subangular, and moderately indurated arkosic sandstone, underlies the site. The following are the soil and SPLP results for benzene:

	<u>Soil</u>	<u>Leachate</u>
Sample 1	200 mg/kg	2,300 ug/l
Sample 2	82 mg/kg	80 ug/l
Sample 3	20 mg/kg	0.20 ug/l

Figure 5-1 is a graph of the data above. At the point on the plotted line where benzene is 1 ug/l in the leachate (the MCL for benzene), the corresponding benzene concentration in the soil sample is 30 mg/kg. Assuming no attenuation in the unsaturated zone, all soils greater than 30 mg/kg may impact groundwater in excess of the water quality goals for the area.

Figure 5-1

Soil Concentration vs. Leachate Concentration



X. LABORATORY ANALYSIS

Analytical reports and QA/QC data packages prepared for submittal to DEH must be in accordance with the sampling and analysis plan for a specific program, either UST Removal or Initial Site Assessment for contamination characterization. The analyses shall be performed by an Environmental Laboratory Accreditation Program (ELAP) certified laboratory granted by California Department of Health Services (DHS). All analyses shall be performed in accordance with laboratory certification criteria and the CCR, Title 22. A copy of all relevant laboratory data must be submitted to DEH.

A. Required Analytical Methods

For UST removals, the analyses in Table 5-9 must be performed. For site assessment purposes, the analyses in Table 5-10 must be performed. Additional analyses may be required for treatment, remediation, transport, or disposal purposes. EPAMethod 8015B or DHS-TPH analysis preparation methods for various fuels are provided in Table 5-11.

Regardless of which analytical method is used, EPA8015B or DHS-LUFT, or detector FID or GCMS, it is imperative that consistent results be obtained so that analytical data can be compared effectively from different laboratories. To accomplish this, gasoline and diesel must be evaluated using the same carbon ranges and quantitated in the same manner. The gasoline carbon range is to be determined from C6- C10 and the diesel range is to be determined from C10- C28. The retention time for C6 is to start after the elution of 2-methyl-pentane and the retention time for

C10 is to start after the elution of 1,2,4-trimethylpenatane. The response factors for gasoline and diesel are to be determined using a calibration curve from gasoline and diesel standards, respectively. Gasoline is to be integrated baseline to baseline, summing the total area responses across the specified carbon range. Diesel is to be integrated using a dropline integration whereby a horizontal baseline is drawn to obtain total area under the diesel “Hump”. If heavy oil components alter the baseline near the C28 end, the dropline integration baseline should remain consistent to the method blank. The calibration factor (CF) is calculated as follows:

$$CF = \frac{\text{Total area within Carbon range}}{\text{Mass injected (nanograms)}}$$

Samples are to be prepared, analyzed and integrated in the same manner as the standards. If samples contain a significant concentration of chlorinated or other non-petroleum type analytes, the laboratory should remove their area responses from the total area determined. If this subtraction is not performed, at a minimum, the data should be flagged to indicate this.

Note: For samples collected at the time of UST removal, copies of chromatograms may be submitted with the laboratory report for all TPH analyses by the EPA Method 8015B and/or DHS-TPH Method. These chromatograms will be qualitatively evaluated to help determine if further site assessment is needed.

TABLE 5-9: REQUIRED ANALYSES FOR UST REMOVALS¹

SUBSTANCE	COMPONENT	METHOD
GASOLINE/DIESEL	Total Petroleum Hydrocarbons (TPH C ₆ -C ₂₈) ²	EPA 8015B or DHS-LUFT
	BTEX and VOCs ³	EPA 8260B
	MTBE, TBA, and related oxygenates ³	EPA 8260B
WASTE OIL	Total Recoverable Petroleum Hydrocarbons (TRPH)	EPA 418.1
	BTEX and VOCs ³	EPA 8260B
	MTBE, TBA, and related oxygenates ³	EPA 8260B
	TPH extended	EPA 8015M
DRY CLEANING SUBSTANCE	Stoddard Solvent	EPA 8015B
	PCE	EPA 8021 or 8260B
OTHER	Submit a written plan to DEH with UST removal application	Various

¹ Analyses are most commonly performed on soil samples. Water samples in areas of shallow groundwater may be requested.

² Upon request, copies of chromatograms should be submitted on 8.5 x 11 format. These chromatograms will be used qualitatively to help determine if further site assessment is needed.

³ The highest TPH or TRPH sample from each UST excavation should be analyzed for BTEX, VOCs, MTBE, TBA and related oxygenates. In the event that there are diesel and gasoline USTs in the same excavation, the highest TPH sample from each UST type should be analyzed for BTEX, VOCs, MTBE, TBA and related oxygenates. In addition, for piping and dispensers, the highest TPH sample per piping run should be analyzed for BTEX, VOCs, MTBE, TBA and related oxygenates.

TABLE 5-10: LABORATORY ANALYSES FOR INITIAL CONTAMINANT CHARACTERIZATION

SUSPECTED SUBSTANCE	A. COMPONENT	B. METHOD
GASOLINE DIESEL JET A FUEL	Total Petroleum Hydrocarbons (TPH) ^{1,4}	EPA 8015B or DHS-LUFT
	Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) ^{2,4}	EPA 8260
	Volatile Organic Compounds ³	EPA 8260
	Total Lead ^{2,3,4,7}	EPA 6010
	Organic Lead (Soil Only) ^{3,5}	DHS organic lead or EPA 3050 or 6010
	MTBE ^{2,4}	EPA 8260B
	Other Oxygenates	EPA 8260
	Polynuclear aromatics (PNAs) (Diesel Fuel) ^{2,4}	EPA 8310 or 8270 ⁷
WASTE OIL	Total Recoverable Petroleum Hydrocarbons (TRPH)	EPA 418.1
	Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) ²	EPA 8260B
	MTBE	EPA 8260B
	Chlorinated Hydrocarbons ²	EPA 8021 , 8260 or 8010
	PCBs ³	EPA 8082
	Title 22 Metals ^{2,3}	EPA 7000 or 6010
	Total Lead ^{2,3,4,7}	EPA 6010 or 6020
	Organic Lead (Soil Only) ^{2,3}	EPA 3050/6010
KEROSENE, HEATING FUEL, BUNKER FUEL	Total Petroleum Hydrocarbons (TPH) ^{1,4}	EPA 8015B
	PNAs ^{2,4}	EPA 8310 or 8270 ⁶
OTHER (e.g., plating facilities, agricultural sites)	Submit written plan to DEH	Various, per approved Workplan
DRY CLEANING SUBSTANCES	Stoddard Solvent	EPA 8015B
	Perchloroethylene (PCE)	EPA 8021 or 8260
	Carbon Tetrachloride ³	EPA 8260
	Volatile Organic Compounds ³	EPA 8260

The above analyses are for initial site characterization. Preliminary screening should be based on historical use, operational process, and nature of substance used at the site. Further analyses and monitoring of site activities will depend on the results of the characterization.

¹ The samples must be analyzed with an appropriate standard (Gas, Diesel, Jet Fuel, etc.) and the amount of **petroleum** hydrocarbons must be quantified between C₆ and C₃₀. Report all carbon ranges discovered.

² The number of samples to be analyzed must be based on specific site conditions. At a minimum, analysis of the sample with the highest TPH or TRPH concentration will be required.

³ A written justification for omitting this analysis may be submitted for consideration.

⁴ Analyze for every water sample collected.

⁵ Analyze on the highest TPH gasoline sample only.

⁶ Use Method 8310 PNA list of compounds only.

⁷ If the Total Threshold Limit Value for lead is greater than 50 mg/kg, run the Soluble Threshold Limited Concentration test and screen for organic lead.

TABLE 5-11: PREPARATION METHODS

SUSPECTED SUBSTANCE	TPH METHOD
Gasoline, Diesel, Jet A Fuel, Kerosene	EPA 8015B or DHS-LUFT using a solvent extraction and EPA 5030 purge
Gasoline only	EPA 5030 using purge and trap followed by GC/MS
Diesel only	EPA 8015B using a solvent extraction
Lead	EPA 3050/6010
Stoddard Solvent	EPA 8015B using a solvent extraction

The following information should be discussed with an analytical laboratory for analyses criteria not listed in this manual. Identify the substances or chemicals of concern, the breakdown products or components to be analyzed, and the recommended analysis methods. DEH will consider alternative analysis methods on a site-specific basis only. Alternative methodology should provide results that are as good and/or more representative than standard method results. Such alternative plans must be included in the scope of a corrective action workplan and submitted to DEH for review and approval. Written approval of such plans is required if the results will be submitted to DEH.

Analytical reporting limits are presented in Table 5-12. It is recognized that high levels of contamination, dilution factors, or matrix interferences may result in higher detection limits. A written explanation should be provided to DEH upon request when the recommended minimum detection limits are exceeded. Use of these minimum detection limits is highly recommended. Analytical results will be evaluated in accordance with current technical information. For optimum representative results, consideration must be given to the method and extraction solvent selected.

TABLE 5-12: REPORTING LIMITS

Contaminant & Method	Matrix	Recommended Reporting Limit
Gasoline, Diesel, Jet A Fuel (EPA 8015B)	Soil	Gasoline & Jet A -10.0 mg/kg, Diesel 500 mg/kg
	Water	Gasoline & Jet A - 10 ug/l, Diesel 500 ug/l
	Vapor	NA
Benzene (EPA 8260)	Soil	0.05 mg/kg
	Water	0.5 ug/l
	Vapor	0.1 ug/l-vapor
Toluene (EPA 8260)	Soil	0.05 mg/kg
	Water	0.5 ug/l
	Vapor	1 ug/l-vapor
Xylene (EPA 8260)	Soil	0.05 mg/kg per isomer
		0.15 mg/kg isomer total
	Water	0.5 ug/l per isomer
		1.5 ug/l isomer total
Ethylbenzene (EPA 8260)	Soil	0.05 mg/kg
	Water	0.5 ug/l
	Vapor	1 ug/l-vapor
Volatile Organic Compounds (EPA 8021 or 8260)	Soil	0.005 mg/kg to 0.5 mg/kg depending on compound
	Water	0.5 ug/l to 100 ug/l depending on compound
	Vapor	1 ug/l-vapor
Organic Lead (EPA 6010 or 3050)	Soil	0.5 mg/kg
Total Lead (EPA 6010 or 6020)	Water	5 ug/l (primary MCL for drinking water)
Total Recoverable Petroleum Hydrocarbons (EPA 418.1)	Soil	10.0 mg/kg
	Water	500 ug/l
MTBE, TAME, DIPE and ETBE (EPA 8260B)	Soil	0.1 mg/kg
	Water	1 ug/l
	Vapor	1 ug/l-vapor
TBA (EPA 8260B)	Soil	1 mg/kg
	Water	10 ug/l
	Vapor	10 ug/l-vapor
PNA/Naphthalene (EPA 8270 or 8260) and PNA (EPA 8270 or 8310)	Soil	200-400 ug/kg
	Water	10 ug/l
	Vapor	Site specific. Check with DEH representative.
PCBs/Pesticides (EPA 8082 or 8270)	Soil	SW-846 requirements/estimated quantitation limits
	Water	
Vinyl chloride	Soil	0.005 mg/kg
	Water	0.5 ug/l
	Vapor	0.05 ug/l-vapor.

TABLE 5-12: REPORTING LIMITS (Continued)		
Contaminant & Method	Matrix	Recommended Reporting Limit
Methane (EPA 8015 Mod)	Vapor	10 ppmv (0.001%)
Carbon Dioxide (CO ₂) – Field Method	Water	Check with DEH representative.
	Vapor	1000 ppmv
Oxygen (O ₂)	Water	Check with DEH representative.
	Vapor	1000 ppmv
Nitrogen (N)	Vapor	10000 ppmv

B. Laboratory Report

The complete laboratory report is typically attached as an appendix to the site assessment report. A summary table with field sample identifications, lab sample identifications, if different, and analytical results must be included in the main text of the site assessment report. All laboratory data submitted to DEH must include the following minimum information.

1. Site/job identification (e.g., site address, city)
2. Sample identification and laboratory identification

Official laboratory letterhead paper must be used. Mobile laboratories must indicate a "mobile laboratory" (or equivalent) and the location where analyses were performed.

3. Quality assurance and quality control (QA/QC) data

See Table E-1 in Appendix E.VIII.

4. Analysis method, extraction and preparation methods, units reported (e.g., mg/kg), and limits of detection
5. Copies of all analytical data
6. If appropriate, submit a copy of the chromatogram of the highest concentration of each contaminant found in the initial site assessment report. For example, if the results indicate only gasoline is present, you may want to provide a copy of the chromatogram of the highest gasoline result detected. If the results indicate gasoline in some samples and a mixture of gasoline and diesel in other samples, you may want to submit at least two chromatograms. Non-compliance with method procedure (i.e. holding times, temperature issues, etc.) must be explained in the laboratory report.
7. Chain-of-custody and sample analysis request documents must be submitted with all laboratory analyses data reports. The analysis request may be reflected on the chain-of-custody document. Date of sample collection must be clearly noted on the chain-of-custody document.
8. Remarks as necessary (e.g., condition of sample, appropriate container, excess holding times)

See Table E-1 in Appendix E.VIII for additional information.

9. Analytical results are expected to be within the laboratory's control limits. Written explanation will be required for analyses outside of these limits.

Note: Additional information for some issues may be necessary. If DEH requires additional laboratory or analytical information not outlined in this Manual, the request will be made in writing to the responsible party (RP).

C. Laboratory QA/QC Reporting

In the laboratory, quality assurance and quality control (QA/QC) are a set of protocols designed to verify and maintain a desired level of quality in the analytical process. QA/QC requires careful planning, continued inspection, and appropriate corrective action.

The QA/QC requirements for analyses submitted to DEH are summarized in Table E-1 of Appendix E.VIII.

D. Field QA/QC

QA/QC in field work refers to field procedures that can affect sample results and methods used to check the quality of field techniques. The purpose of this guideline is to describe acceptable quality check procedures for use in routine environmental investigations carried out in San Diego County that are evaluated by DEH.

This guideline does not present detailed field procedures; these will be found in other sections of this manual and in published handbooks (e.g., EPA SW-846, RCRA Technical Enforcement Guidance Document [TEGD], SWRCB LUFT Manual). It is assumed that field workers will use their best professional practices when collecting samples. (Note: Do not assume that the procedures in this guideline are suitable for unusual cases, or that they will be accepted by other regulatory agencies.)

E. Blanks

A. Trip Blank

A trip blank is a sample container of matrix material prepared in the lab, carried into the field, and returned to the lab with the samples without being opened. The purpose of the trip blank is to pick up any cross contamination between sample containers, and to show if the container or the preservative has added contamination to the sample. It must be the same type of container, from the same batch of containers, as is used to store the samples. It must be prepared and sealed before arrival at the site. Preservation and packaging must match that of the field samples.

Trip blanks for water are straightforward to prepare and can be quite useful, since water cleanup levels are often close to the limits of analytical detection. One water trip blank for each unique combination of preservation and packaging should be carried during each

groundwater-sampling event. The blank should be prepared with distilled water of known quality. Preparation must be done in an area free of airborne contamination.

Trip blanks for soil are difficult to prepare and of questionable value. The amount of contamination released from or adsorbed onto soil is dependent on the soil composition. Preparation of a functional soil blank requires detailed study of site soil characteristics. Therefore, no trip blank is necessary for soil.

To help avoid cross contamination during storage and transport, contaminated samples should be segregated from apparently clean samples, and water samples should be separated from soil samples. Blanks should travel with the clean(er) samples, since impact on those samples is more critical and detectable. Samples and blanks should be stored at the required temperature and preservatives used where required to prevent biologic degradation. These procedures are also to be followed even when mobile labs are utilized.

Equipment Blank

An equipment blank is prepared on site by passing clean matrix material through decontaminated or factory-sealed sampling equipment. The water used must be free of volatile organic contaminants. Presumably, this picks up contamination from the equipment, from the air, from the sample container, and through sample cross contamination during storage and transport.

An equipment blank is needed for water analysis. One water equipment blank should be prepared for each day of water sampling at a site; it should be prepared after sampling has been completed. No equipment blanks are needed for soil for the same reasons as for trip blanks. Some published protocols call for field blanks, which check for contamination via air at a sampling site. DEH does not consider these necessary for hydrocarbon investigations.

Analysis of Blanks

Analysis of blanks may or may not be needed. If some sample analysis results are "non-detect," inadvertent contamination is obviously not systematic and there is no need to analyze the blanks. If all samples are grossly contaminated and confirm field observations, analysis of the blanks is not needed. Analysis of blanks can be useful if:

- Unsuspected materials are detected in the samples,
- All samples yield nearly equal results, or
- Sample results are borderline for opening or closing a case.

Prompt consultation with DEH staff is essential if any of the above conditions are encountered. Blanks must be analyzed within the specified holding time. The decision on the need for blank analysis is the responsibility of the consultant and RP. If the quality of data is suspect and blank results have not been provided, DEH may require re-sampling. Results of blank analyses are not used to correct analytical values. Rather, they indicate a need to find the source of the problem and to take corrective action, including re-sampling if necessary.

F. Duplicate Samples

Duplicates are samples taken in sequence to show natural variability. Closely spaced soil or rock samples are expected to have variable contaminant chemistry. This can be caused by abrupt changes in soil characteristics that influence the amount of contamination retained. Knowing where a sample comes from in the geologic framework of the site is more valuable than arbitrarily taking a second sample adjacent to the first.

Sequential groundwater samples will vary in chemistry. This is influenced by sample collection method, well purging method, and well recharge characteristics. Because no acceptable difference between duplicates can be specified, and because trends over time and space are used to evaluate the condition of a contaminated site, duplicates are not required.

G. Background Samples (Required If Background Contamination Suspected)

If background contamination is suspected, the contaminant needs to be quantified and confirmed as background. The consultant must defend any case of suspected background contamination. Background soil or rock samples must be in the same geological material as the contamination. Background water samples must be taken upgradient of, but close to, the contaminated area; they must be from the same water-bearing zone as the contaminated samples. (NOTE: In San Diego County, naturally occurring metals in soil, contaminated imported fill, and chlorinated solvents in groundwater have caused background problems.)

H. Containers, Preservation and Holding Time

Correct handling of samples is needed to eliminate bias and cross contamination prior to laboratory analysis. See EPA SW-846 for correct handling procedures.

XI. WASTE CHARACTERIZATION AND SOIL REUSE

Soil that is disturbed and accumulated at a contaminated site through excavation, drilling, or other means must be characterized to determine the concentration of any contaminants for proper disposition. Examples of stockpiled soil include:

- Excavated soil from a UST removal
- Excavated soil placed back into a UST pit
- Graded soil
- Soil cuttings from borings or well construction
- Imported clean soil mixed with contaminated soil

All stockpiled soil that is associated with an unauthorized release, spill, or other release, and that is not intended to be transported off-site or is to be transported to an unregulated site, must be sampled and analyzed in accordance with the following statistical procedure. This procedure provides a uniform approach for demonstrating the contaminant level within a uniform soil mass. Prior approval must be obtained from DEH and/or the RWQCB for off-site transport or reuse on-site of any soil associated with an unauthorized release, or that is otherwise contaminated.

The RWQCB has adopted a resolution for the reuse of inert soil contaminated with Title 22 metals. RWQCB Resolution Number R9-2007-0104, Conditional Waiver Number 8 (Waiver) sets specific

criteria for the reuse of soils contaminated with Title 22 metals. In order for inert soil to be considered eligible for this Waiver, a number of criteria must be met as outlined in the aforementioned Resolution. Soil Screening Levels are separated into two tiers depending on current or proposed site use with the primary distinction being allowable Title 22 metal concentrations. For more information on this Waiver, please reference RWQCB Resolution Number R9-2007-0104.

A. Soil Reuse Guidance

As indicated above, DEH must approve the sampling, handling, or reuse of contaminated or potentially contaminated soil. While no guidance can be comprehensive enough to address every site or situation, DEH offers the following general guidance for the reuse of contaminated or potentially contaminated soil.

1. Offsite Soil Reuse

- Soil contaminated with Title 22 metals only, must be evaluated and conform to Tier 1 criteria in accordance with RWQCB Resolution Number R9-2007-0104, Conditional Waiver Number 8.
- Soil potentially contaminated with constituents other than Title 22 metals must be below DEH approved laboratory reporting limits and must not appear to be impacted by visual inspection or odor.
- Soil potentially contaminated with hydrocarbons must not contain hydrocarbon concentrations above a laboratory reporting limit of 10 milligrams per kilogram as identified by EPA Method 8015 – Extended Range. Reporting limits for VOCs, chlorinated hydrocarbons, and other compound specific contaminants must be approved by DEH in advance of soil excavation and export.

2. Onsite Soil Reuse

- Soil contaminated with Title 22 metals only, must be evaluated and conform to Tier 1 criteria for residential use and Tier 2 criteria for commercial use in accordance with RWQCB Resolution Number R9-2007-0104, Conditional Waiver Number 8.
- Concentrations and locations of constituents of concern must be shown to be protective of human health and the environment, including groundwater, as identified by a receptor pathway evaluation.
- Soil contaminated with hydrocarbons must not exhibit concentrations greater than the residual NAPL saturation level as identified in Table 5-8.
- Contaminants must be adequately assessed in order to determine if the aforementioned guidance has been satisfied.

B. Sampling Protocol for Stockpiled Soil

1. Stockpiled soil that is designated for disposal to a permitted hazardous waste or specified waste facility, or to a treatment/recycling facility, must be sampled and analyzed in accordance with the receiving facility's requirements. These facilities may have different

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- requirements than those presented below. Copies of all laboratory data and hazardous waste manifests, or other transportation documents generated for the soil treatment or disposal, must be submitted to DEH to demonstrate the proper handling and disposal of contaminated soil.
2. DEH will not accept composite soil samples for characterizing contaminated soil stockpiles. Only discrete samples will be accepted, because of the losses of volatile contaminants during sample handling and the dilution of non-volatile contaminants.
 3. All stockpiled soil associated with an unauthorized release, spill, or other release that is not intended to be transported off site to a permitted facility, or has not been previously characterized through in situ sampling, must be sampled in accordance with the protocol outlined below. This protocol provides a uniform approach for demonstrating the contaminant level within a soil mass. Prior approval must be obtained from DEH and the RWQCB for off-site transport or reuse on-site of any soil associated with an unauthorized release, spill, or other release, including soil taken from areas of the site outside of the spill or release.
 4. Procedures in EPA Publication SW-846 provide a method for determining the mean concentration of a given contaminant within a soil mass and the appropriate number of samples necessary to calculate this mean to within a specified confidence level. Initial sampling should generate a minimum number of samples/analyses as described below. Additional sample analyses may be required to meet the confidence levels given in SW846; therefore, archiving of samples may be appropriate. Archived samples must be appropriately preserved and analyzed within the maximum holding time specified in SW-846. The minimum number of discrete samples initially required is given below:
 - Stockpiles less than 10 cubic yards: a minimum of two (2) samples must be collected, one from each half of the stockpile. Select sample points randomly within each half.
 - Stockpiles from 10-20 cubic yards: a minimum of three (3) samples must be collected, one from each third of the stockpile. Select sample points randomly within each third.
 - Stockpiles from 20-100 cubic yards: a minimum of four (4) samples must be collected, one from each quarter of the stockpile. Select sample points randomly within each quarter.
 - Stockpiles from 100-500 cubic yards: a minimum of one (1) sample for each 25 cubic yards or portion must be collected (e.g., a 130-cubic yard stockpile would require 6 samples). Section the stockpile into 25 cubic yard portions and obtain a minimum of one (1) sample from each 25 cubic yard portion. Select sample points randomly within each 25 cubic yard portion of the stockpile.
 - Stockpiles over 500 cubic yards: contact DEH for guidance on the minimum samples necessary.
 5. Random sample points must be selected from locations on a three-dimensional grid. The presence of materials such as boulders, debris, etc., may make strict application of this requirement impractical. In such cases, it is appropriate to obtain the sample as close as possible to the randomly selected point without altering the spirit of the random selection

process. For hydrocarbon contaminants, sample collection in either metal tubes or glass jars is acceptable, provided every effort is made to minimize the loss of volatile constituents. Metal tubes are preferred, since they will minimize aeration of the samples. Containers should be completely filled, capped, and placed on ice immediately.

6. Stockpiled soil is assumed to have a non-homogeneous distribution of contaminants. If a stockpile previously characterized by this protocol is split for any reason (such as to excise a portion expected to be highly contaminated from a non- or lesser-contaminated portion), the remaining mass must be re-sampled as a new stockpile per the previously described protocol to establish its mean contaminant concentration. Note that it is not necessary to consider each individual stockpile separately. At the discretion of the consultant, stockpiles expected to contain similar contaminant conditions can be considered part of the same soil mass for the purpose of SW-846 sampling.
7. Information on stockpiled soil evaluation must be submitted to DEH and must include the following:
 - An estimate of the volume of contaminated soil involved
 - A description of the contaminant (e.g., gasoline, diesel, aviation fuel)
 - A description of the sampling methodology and the sample location/selection process
 - A plot plan detailing the stockpile and sample locations
 - A copy of all sample results, chain of custody documents, and QA/QC supporting data
 - A one-page summary of the laboratory results for the stockpile sampling
 - Statistical calculations for all stockpiles greater than 20 cubic yards. Note: A Stockpile Statistics Worksheet (Table 5-13) and Tabulated Values of Students 't' (Table 5-14) are provided as an aid in completing these calculations.
 - A statement by the RP or by a registered professional (e.g., PG, RCE, Registered Environmental Health Specialist, or equivalent) certifying the level of contamination as determined using the SW-846 statistical process.
8. Data generated by field instrument methodologies such as photo-ionization and flame ionization detectors are not acceptable for quantifying contaminant concentrations.

C. Sampling Protocol for Containerized Soil

The RP or consultant often chooses to manage soil by placing it in containers (e.g., storage bins, 55-gallon drums) for security or aesthetic reasons. The characterization of soil placed in storage bins will typically follow the same sampling protocol as described above for stockpiled soil. However, the characterization of soil placed in drums may require the review of boring logs and site sampling/analytical data, as well as the collection of soil samples from selected drums. Please contact the DEH caseworker for specific direction concerning the characterization of soil stored in drums.

TABLE 5-13: STOCKPILE STATISTICS WORKSHEET¹

1	List sample results from laboratory	1	2	3
	Analytical Method: _____	4	5	6
	Units (e.g., mg/kg): _____	7	8	9
2	Determine number of sample values n	$n =$		
3	Calculate sample mean with $n =$ number of sample measurements $\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$	$\bar{x} =$		
4	Calculate sample variance $s^2 = \frac{\sum_{i=1}^n x_i^2 - \frac{(\sum_{i=1}^n x_i)^2}{n}}{n - 1}$	$s^2 =$		
5	Calculate sample standard deviation $s = \sqrt{s^2}$	$s =$		
6	Calculate degrees of freedom $df = n - 1$	$df =$		
7	Calculate standard error of the mean $s_{\bar{x}} = \frac{s}{\sqrt{n}}$	$s_{\bar{x}} =$		
8	Obtain <i>student's t value</i> corresponding to the degree of freedom value determined in #6 above (See attached table of values on next page)	$t_{20} =$		
9	Calculate the confidence interval $CI = \bar{x} \pm t_{20} s_{\bar{x}}$	$CI =$		
10	Obtain regulatory threshold for the contaminant of concern RT	$RT =$		
11	Calculate $\Delta = RT - \bar{x}$	$\Delta =$		
12	Estimate minimum number of samples $n_{\min} = \frac{t_{20}^2 s^2}{\Delta^2}$	$n_{\min} =$		

¹ In accordance with the California Code of Regulations, Title 22, Section 66694, DEH follows the sampling guidelines set forth in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Third Edition*, US Environmental Protection Agency, 1986. This worksheet is based on information found in Volume II, Part III, Chapter 9 of "SW-846" and is provided as an aid for stockpile characterization. For circumstances requiring data manipulation beyond that indicated on the worksheet, refer to "SW-846."

TABLE 5-14: TABULATED VALUES OF STUDENT'S 't' FOR EVALUATING SOLID WASTES	
Degrees of Freedom ¹ <i>df</i> (<i>n</i> -1)	Tabulated value ² t_{.20} (80% confidence interval)
1	3.078
2	1.886
3	1.638
4	1.533
5	1.476
6	1.440
7	1.415
8	1.397
9	1.383
10	1.372
11	1.363
12	1.356
13	1.350
14	1.345
15	1.341
16	1.337
17	1.333
18	1.330
19	1.328
20	1.325
21	1.323
22	1.321
23	1.319
24	1.318
25	1.316
26	1.315
27	1.314
28	1.313
29	1.311
30	1.310
40	1.303
60	1.296
120	1.289

¹ Degrees of freedom (*df*) are equal to the number of samples (*n*) collected less one.

² Tabulated '*t*' values are for a two-tailed confidence interval and a probability of 0.20 (80% confidence level). The same values are applicable to a one-tailed confidence interval and a probability of 0.10 (90% confidence level).