DEPARTMENT OF TOXIC SUBSTANCES CONTROL
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

PROVEN TECHNOLOGIES AND REMEDIES GUIDANCE

REMEDIATION OF CHLORINATED VOLATILE ORGANIC COMPOUNDS IN VADOSE ZONE SOIL

APRIL 2010

PREFACE

The Department of Toxic Substances Control (DTSC) is issuing this Proven Technologies and Remedies (PT&R) guidance for immediate use on cleanups at hazardous waste facilities and Brownfields sites. The PT&R approach described herein is an option for expediting and encouraging the cleanup of sites with elevated concentrations of chlorinated volatile organic compounds (cVOCs) in the vadose zone. The approach is designed to ensure safe, protective cleanup and to maintain DTSC's commitment to public involvement in our decision-making process. Please see Chapters 1 through 3 for details regarding the PT&R approach and how to determine whether this guidance is suitable for a given site.

DTSC fully expects that application of the PT&R approach to cleanup of sites with cVOCs in the vadose zone will identify areas that can be improved upon as well as additional ways to streamline the PT&R cleanup process. As the protocols in this document are implemented, issues may be identified which warrant document revision. DTSC will continue to solicit comments from interested parties for a period of one year (ending April 30, 2011). At that time, DTSC will review and incorporate changes as needed.

Comments and suggestions for improvement of *Remediation of Chlorinated Volatile Organic Compounds in Vadose Zone Soil* should be submitted to:

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ACKNOWLEDGMENTS

This document was developed by the Department of Toxic Substance Control under the direction of Mr. Maziar Movassaghi, Acting Director and Mr. Stewart Black, Acting Deputy Director of the Brownfields and Environmental Restoration Program. Without their support, completion of this guidance would not have been possible.

The preparation of this guidance was achieved through the efforts of many individuals. The following people had primary responsibility for writing:

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This guidance has benefited greatly through input received from several sources, including:

- DTSC's Proven Technologies and Remedies Team;
- Director's Brownfields Revitalization Advisory Group;
- Internal reviewers of draft versions of the guidance; and
- External peer reviewers of the draft guidance.

In particular, the authors wish to thank the following individuals for their thoughtful technical support throughout the development of this guidance: Dan Gallagher, Lorraine Larsen-Hallock, Janet Naito, Debbie Oudiz, and Jesus Sotelo. The authors would also like to thank the following individuals for their contributions: Tizita Bekele, Jeff Brown, Michelle Dalrymple, Mike Finch, Bruce Garbaccio, Jose Marcos, Greg Neal, Paul Pongetti, Kathaleen Reed, and Will Rowe.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

ABBREVIATIONS AND ACRONYMS

AFCEE	Air Force Center for Engineering and the Environment
ARARs	applicable or relevant and appropriate requirements
ASTM	ASTM International (formerly known as American Society of Testing and Materials)
bgs	below ground surface
Cal/EPA	California Environmental Protection Agency
Cal-OSHA	California Division of Occupational Safety and Health
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHHSLs	California Human Health Screening Levels
CMS	Corrective Measures Study
COC	chemical of concern
CSM	conceptual site model
cVOC	chlorinated volatile organic compound
DQO	data quality objective
DTSC	Department of Toxic Substances Control
EDRP	excavation, disposal, and restoration plan
EE/CA	engineering evaluation/cost analysis
FS	Feasibility Study
HASP	health and safety plan
HSAA	Hazardous Substances Account Act
HWCL	Hazardous Waste Control Law
IC	institutional control
ITRC	Interstate Technology and Regulatory Council
LARWQCB	Los Angeles Regional Water Quality Control Board
LDR	land disposal restriction
LUC	Land Use Covenant
NCP	National Contingency Plan
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance

ABBREVIATIONS AND ACRONYMS (Continued)

PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PT&R	proven technologies and remedies
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RAP	Remedial Action Plan
RAO	remedial action objective
RAW	Removal Action Workplan
RCRA	Resource Conservation and Recovery Act
RSL	USEPA Regional Screening Level
RWQCB	Regional Water Quality Control Board
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
SWPPP	storm water pollution prevention plan
SWRCB	State Water Resources Control Board
TCE	trichloroethene
TPH	total petroleum hydrocarbons
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

EXECUTIVE SUMMARY

Widely used in the United States since the 1940s, chlorinated volatile organic compounds (cVOCs) are associated with a variety of uses, such as degreasing, cleaning, manufacturing processes, and dry cleaning operations. Approximately 15 percent of projects managed by the Department of Toxic Substances Control's (DTSC's) Brownfields and Environmental Restoration Program encounter cVOCs. Table ES-1 summarizes cVOCs commonly found during these environmental cleanup projects. Typically composed of one to two carbon atoms and one to six chlorine atoms (ESTCP, 2008), the properties of cVOCs allow wide dispersal in the environment and impacts to multiple environmental media (e.g., soil, soil vapor, groundwater, indoor air). A critical pathway for health risk assessment associated with cVOCs involves the potential health risks from indoor air exposures.

Table ES-1 Commonly Encountered Chlorinated VOCs

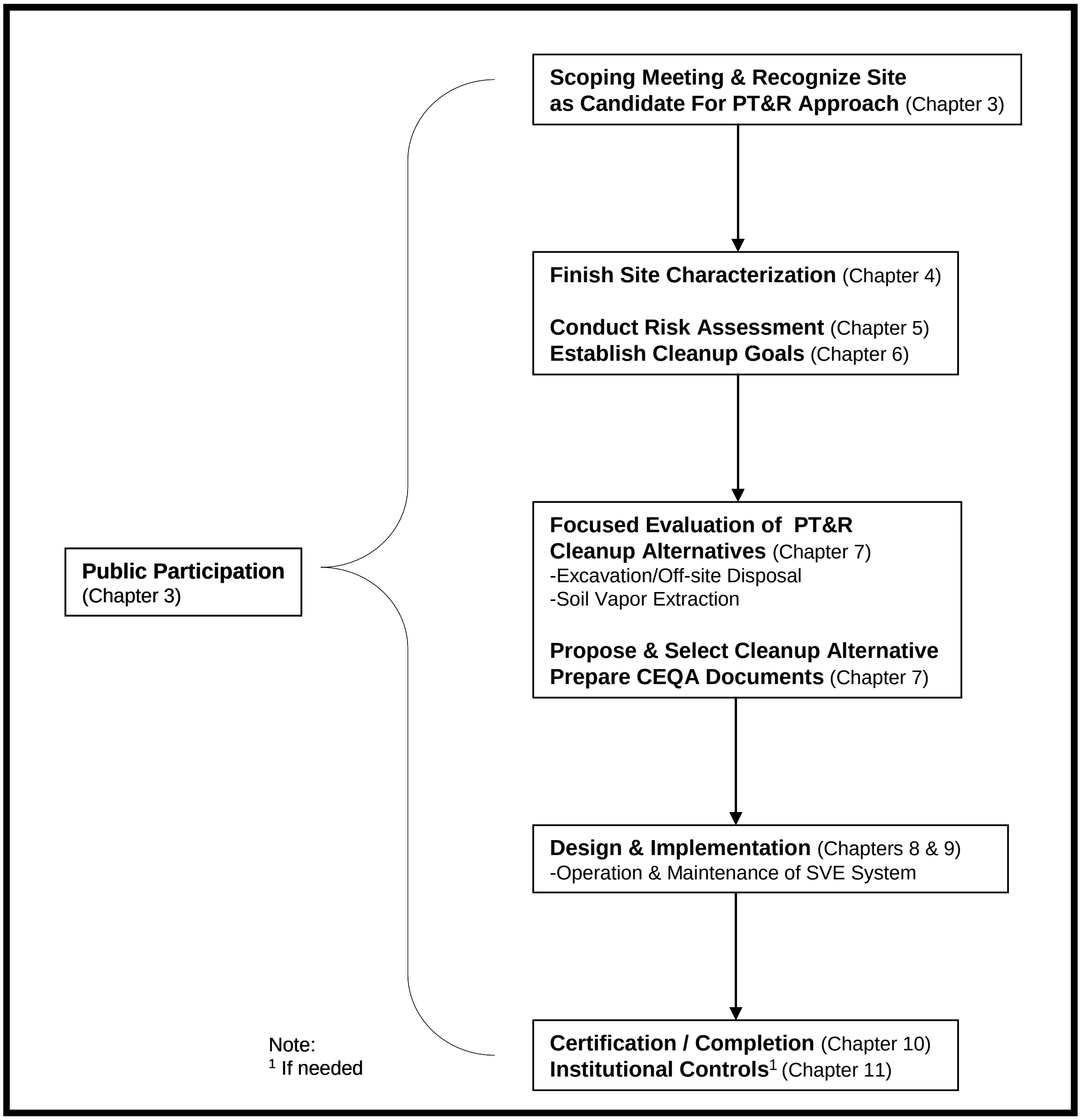
Carbon tetrachloride	1,1-Dichloroethane	1,1,2,2-Tetrachloroethane
Chlorobenzene	1,2-Dichloroethane	**Tetrachloroethylene**
Chloroethane	1,1-Dichloroethylene	**1,1,1-Trichloroethane**
Chloroform	1,2-Dichloroethylene	1,1,2-Trichloroethane
Chloromethane	1,2-Dichloropropane	**Trichloroethylene**
1,2-Dichlorobenzene	Ethylene dibromide	1,2,3-Trichloropropane
1,4-Dichlorobenzene	Methylene chloride	Vinyl chloride
Dichlorodifluoromethane	1,1,1,2-Tetrachloroethane	

Notes:
Table is not intended to be an all-inclusive list of cVOCs.
Bold indicates most commonly encountered cVOCs on DTSC cleanup projects.

DTSC has prepared this *Proven Technologies and Remedies Guidance – Remediation of Chlorinated Volatile Organic Compounds in Vadose Zone Soil* (PT&R guidance) as an option for expediting and encouraging cleanup of sites with elevated concentrations of cVOCs in vadose zone soil. The PT&R approach for cVOCs discussed herein (Figure ES-1) may be applied at operating or closing hazardous waste facilities and at Brownfields sites. This PT&R guidance can be used by any government agency, consultant, responsible party, project proponent, facility operator, and/or property owner addressing cVOCs in soil. Although expediting cleanup is emphasized, the PT&R approach is designed to ensure safe, protective remediation and to maintain DTSC's commitment to public involvement in our decision-making process.

Cleanup of contaminated sites may be governed by one or more federal or State laws, depending on such factors as the source and cause of the contamination, the type of chemical contamination found, and the type of operations conducted. The PT&R approach is consistent with these laws and will yield technically and legally adequate environmental solutions. The PT&R approach is also consistent with the U.S. Environmental Protection Agency (USEPA) presumptive remedy guidance (USEPA, 1996, 1997a).

Figure ES-1. General Overview of PT&R Approach for Sites with Vadose Zone Soils Impacted by Chlorinated VOCs.



This PT&R guidance is applicable on a case-by-case basis at sites where the remedial action objective (RAO) is to address vadose zone soils (i.e., unsaturated soils above the groundwater table) contaminated with cVOCs. The PT&R guidance will not be applicable to all sites with cVOC contamination in soil. Prior to applying this guidance to a site cleanup process, DTSC should be consulted and should concur with the use of the PT&R approach.

The results achieved through implementing the PT&R approach will depend on the site-specific RAOs which could range from removing as much cVOC mass as feasible during an interim removal action to achieving risk-based cleanup goals as part of the final remedy. The outcome of applying the PT&R approach may be the completion of an interim removal action, cleanup to levels that require on-going controls, or certification of the site for unrestricted use.

The PT&R approach (Figure ES-1) streamlines the cleanup process by (1) limiting the number of evaluated technologies to two PT&R alternatives; (2) facilitating remedy implementation; and (3) facilitating documentation and administrative processes. DTSC identified the two PT&R alternatives by conducting a study that reviewed and screened data for 90 sites throughout California where the primary contaminants were cVOCs in soil and where DTSC provided oversight of the soil cleanup. This study found that "excavation and off-site disposal" and "soil vapor extraction" (SVE) were the most frequently selected cleanup alternatives and therefore these remedies were selected as the PT&R alternatives for cVOCs in soil.

The objectives of this PT&R guidance are to:

- identify the types of sites that would be appropriate for application of the PT&R approach;
- identify the site data that should be collected to support the PT&R approach;
- provide an overview of guidance in characterizing risk and establishing cleanup goals;
- provide guidance for designing and implementing the PT&R alternatives; and
- provide sample documents, annotated outlines, and examples for the documents prepared as part of the cleanup process.

This PT&R guidance is not intended to replace the evaluation of innovative and new technologies. DTSC continues to encourage the use and evaluation of emerging technologies.

OVERVIEW OF PT&R APPROACH

Figure ES-1 and the following paragraphs summarize the steps of the PT&R approach. The PT&R approach uses the public participation process identified in the *DTSC Public Participation Policies and Procedures Manual* (DTSC, 2003).

Determine Suitability for PT&R Approach. To determine whether the PT&R approach is appropriate for a specific site, an evaluation should be conducted to determine whether the site characteristics make it amenable to the PT&R approach. Site characteristics that favor the PT&R approach are summarized in Table ES-2. Most notably, this PT&R guidance targets cleanup at sites where the primary environmental issue is cVOC contamination in vadose zone soils. Refer to Chapter 3 for details regarding these characteristics.

Table ES-2. Site Characteristics that Favor PT&R Approach

• Primarily cVOC contamination	• No emergency actions required
• Ability to address any groundwater impacts through a separate remedial technology	• No ecological habitat or sensitive receptors impacted[1]
• Soil impacts that can be addressed by excavation/disposal or SVE	• Exposure pathways and land use scenarios consistent with PT&R approach[1]

Note:
1 The approach recommended for selection of cleanup goals in this PT&R guidance considers the human health impacts of cancer risk and noncancer hazard for residential and industrial/commercial land use exposure scenarios (see Chapter 5 for details). If a site has potential impacts to ecological receptors or surface water, the PT&R approach is not applicable.

Characterization Phase. The characterization phase establishes the nature and extent of contamination in environmental media such as soil and soil gas. Under the PT&R approach, sufficient data should be collected to determine that the PT&R approach is applicable as well as to support any fate and transport modeling, risk assessment, remedy selection, and the engineering design. As data are gathered, they are evaluated to help determine whether further site characterization, risk assessment, or cleanup may be necessary.

Risk Assessment. Evaluation of potential risks to human health and the environment posed by contaminants at the site is part of the site characterization process and supports the risk management decision-making process. Depending on when a site begins using the PT&R approach, some risk assessment steps may have already been conducted and may be sufficient to support subsequent activities. A human health risk assessment is conducted to characterize potential cancer risks and noncancer health hazards. A scoping level ecological risk investigation is conducted to evaluate the potential for complete exposure pathways between ecological receptors and constituents of concern. Sites requiring further ecological assessment are beyond the scope of this PT&R guidance. The risk to groundwater quality is evaluated using measured groundwater concentrations and/or groundwater concentrations predicted by fate and transport modeling. The results of the risk assessments are used to establish appropriate site-specific RAOs and risk-based cleanup goals.

Site-Specific Evaluation and Selection of Remedial Alternatives. The remedy selection document is drafted in accordance with the requirements applicable to the site/facility. The alternative evaluation should demonstrate that the RAOs identified for the site can be met. The alternatives would generally include no action, excavation/

disposal, and/or SVE. The necessary California Environmental Quality Act (CEQA) documents may be prepared concurrently with the remedy selection document. Typically, the draft remedy selection and CEQA documents are circulated concurrently for public comment. The SVE alternative will require on-going operation and maintenance (O&M) until the RAOs are achieved, and therefore will require a regulatory oversight agreement.

Cleanup Design and Implementation. The technical and operational plans for implementing the proposed alternative may be included in the remedy selection document, if appropriate, or prepared as a separate document once a final response action is approved. Once the final response action is implemented, a report documenting its implementation is submitted to DTSC. There are several types of response action documents which may be applied to the PT&R approach, as discussed further in the main text of this PT&R guidance.

Certification / Completion. When the approved remedy for cVOCs in the vadose zone has been fully implemented, DTSC will determine through performance metrics (including confirmation sampling) whether the RAOs established in the remedy decision document have been achieved. The possible determinations are: the RAOs have been achieved; the response action has been fully implemented, is operating successfully, and on-going O&M is needed until the RAOs are achieved; and/or additional remediation is necessary. Based on these findings, DTSC will issue a certification letter, a completion letter, or a letter requiring additional work to address cVOCs in the vadose zone.

Long-term Stewardship. Long-term stewardship applies to sites and properties where management of contaminated environmental media is necessary to protect human health and the environment over time. On-going controls (such as institutional controls for contamination remaining in place) and other measures will be needed, as discussed further in Chapter 11.

1.0 INTRODUCTION

Chlorinated volatile organic compounds (cVOCs) are encountered by approximately 15 percent of cleanup projects managed by the Department of Toxic Substances Control's (DTSC's) Brownfields and Environmental Restoration Program. Widely used in the United States since the 1940s, cVOCs are associated with a variety of uses, such as degreasing, cleaning, manufacturing processes, and dry cleaning operations. These compounds are also present in some household products and automobile fluids. Releases to the environment have occurred through various mechanisms, including surface discharges, leaking underground storage tanks, and inadequate disposal practices. Unfortunately, cVOCs have properties that make them disperse widely in the environment. Their volatile nature leads to the formation of vapor plumes in soil. Small quantities of cVOCs can contaminate large volumes of water at concentrations exceeding health risk screening levels and can persist as sources of on-going contamination for long periods of time. When released as free product, cVOCs can migrate downward to significant depths (potentially hundreds of feet) and through fine grained deposits. In addition, cVOC vapors can migrate upwards to the surface and produce elevated concentrations within indoor air spaces. Potential health risks from indoor air exposures are a critical pathway for health risk assessment.

This *Proven Technologies and Remedies Guidance – Remediation of Chlorinated Volatile Organic Compounds in Vadose Zone Soil* (PT&R guidance) has been prepared to streamline the cleanup process (a generic term used to refer to corrective action and remedial action cleanup processes) at sites with vadose zone soils contaminated with cVOCs. The proven technologies and remedies (PT&R) alternatives discussed in this PT&R guidance were determined to be effective based on:

- engineering and scientific analysis of performance data from past State and federal cleanups and
- review of the administrative records and procedures used to implement the technologies.

This PT&R guidance is one of three documents developed under DTSC's PT&R efforts that outline an option for streamlining the cleanup process, thus increasing the number of acres that are cleaned up and returned to beneficial use. Analogous documents pertaining to metals and organochlorine pesticides in soil can be obtained from the DTSC Web-site (www.dtsc.ca.gov/SiteCleanup/PTandR.cfm). The PT&R approach described herein can be applied to operating or closing hazardous waste facilities and to Brownfields sites. Although expediting the cleanup process is emphasized, the PT&R approach is designed to ensure safe and protective remediation.

1.1 PURPOSE AND OBJECTIVE

The purpose of this PT&R guidance is to encourage and support the use of DTSC's experience and to provide guidance on PT&Rs for expedited cleanup of sites with cVOCs in vadose zone soil. The PT&R guidance is intended for use by any government agency, consultant, responsible party and/or property owner addressing potential cVOC contamination at a site. Prior to applying this PT&R guidance to a site cleanup process, the oversight agency must be consulted and must concur with use of the PT&R approach.

The objectives of the PT&R guidance are to:

- identify the characteristics that make a site conducive for application of the PT&R approach for cVOCs;
- provide recommendations for characterizing the nature and extent of contamination and collecting data needed to support the cleanup alternative evaluation;
- summarize guidance for characterizing risk and establishing cleanup goals;
- focus the site-specific evaluation of cleanup alternatives to the PT&R alternatives;
- provide guidance for post-cleanup evaluation to characterize the residual cVOC concentrations; and
- provide guidance on associated administrative requirements, such as documentation and implementation of the cleanup alternative selection process.

As discussed further in Section 1.3, the degree of cleanup achieved through implementing the PT&R approach will depend on the site-specific remedial action objectives (RAOs). Possible results of implementing the PT&R approach could include mass removal to the extent feasible, cleanup to levels requiring on-going controls, or cleanup to levels allowing unrestricted use.

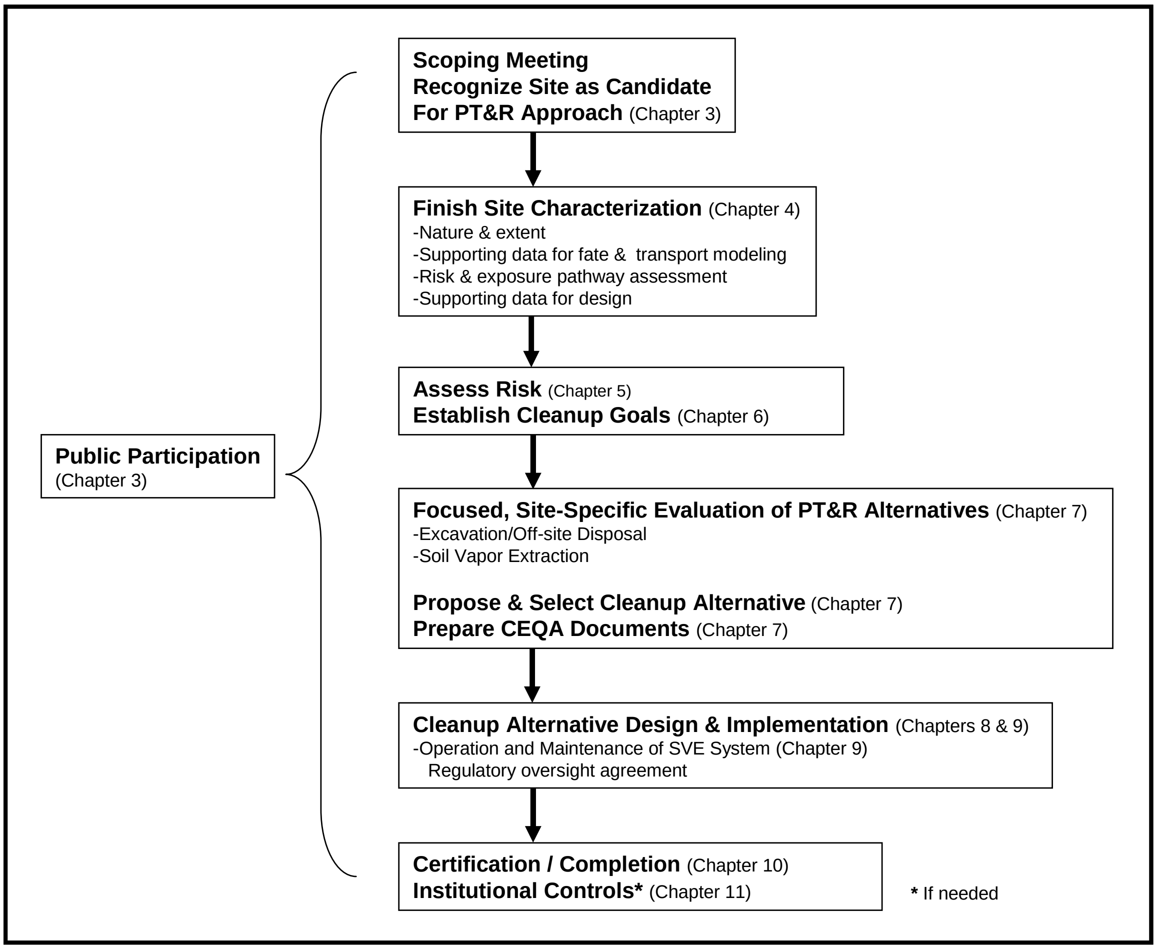
As illustrated in Figure 1, the PT&R approach follows typical steps used by standard cleanup processes. Because sites can begin applying the PT&R approach at various stages in the cleanup process, some topics discussed in this PT&R guidance may not be applicable to a given site. For example, risk characterization completed prior to initiating the PT&R approach could be used to support subsequent steps of the cleanup process. If risk characterization has not previously been conducted prior to using the PT&R approach, the approach described in Chapter 5 can be used to characterize the risk.

1.2 TECHNICAL BASIS FOR PT&R APPROACH AT SITES WITH VADOSE ZONE SOIL CONTAMINATED WITH CHLORINATED VOCs

DTSC conducted a study that reviewed and screened data for 90 sites where the primary contaminants were cVOCs in vadose zone soils (see Section 7.1 for details). The study identified the technologies that were consistently evaluated and technologies that were subsequently selected as the remedy. The results of the DTSC study revealed that “excavation and offsite disposal” (excavation/disposal) and/or “soil vapor extraction” (SVE) were the most frequently selected cleanup alternatives. Hence, excavation/disposal and SVE were selected as the PT&R alternatives for cVOCs in vadose zone soil.

The study also revealed that most sites had cVOC impacts to both vadose zone soil and groundwater. This typically resulted in selection of excavation/disposal and/or SVE to address the soil impacts and selection of another remedy to address the groundwater plume. Because groundwater cleanup times can be considerably longer than times for soil cleanups, the soil cleanup action was often implemented as an interim removal action to quickly address cVOC mass posing an on-going threat to groundwater.

Figure 1. PT&R Approach for Sites With Chlorinated VOCs in Vadose Zone Soil.



1.3 SCOPE AND APPLICABILITY

This PT&R guidance is designed to assist with the cleanup of cVOCs in vadose zone soil. The results achieved will depend on the site-specific RAOs and the overall purpose of implementing the PT&R approach (e.g., interim removal action, final remedy). A RAO could consist of removing as much cVOC mass as feasible during an interim removal action (such as to decrease the amount of cVOC mass migrating toward groundwater). When implemented as the final remedy, RAOs may establish risk-based cleanup goals to be achieved by the removal action. As applicable, the PT&R approach should be coordinated with the groundwater remedy so that cVOCs in groundwater do not recontaminate vadose zone soils and vice versa. The outcome of applying the PT&R approach may be the completion of feasible mass removal, cleanup to levels that require on-going controls, or certification of the site for unrestricted use.

As discussed further in Section 3.2, this guidance is intended for sites that meet the following conditions:

- cVOCs are the primary contaminant of concern;
- no emergency or time-critical removal actions required;
- cVOC impacts to unsaturated soil can be addressed by excavation/disposal and/or SVE;
- groundwater impacts can be addressed by a separate remedial technology; and
- exposure pathways, receptors (human health), and land use scenarios (residential, industrial/commercial) applicable to the site are consistent with the PT&R approach (see Chapter 5 for details).

The PT&R approach is not applicable to all sites with cVOC impacts to soil. As discussed further in Section 3.3, the PT&R approach for cVOCs may not be appropriate for sites with:

- mixtures of contaminants (e.g., more complex treatment may be required);
- shallow bedrock;
- ecological habitat or sensitive receptors; and
- surface water features.

If any of these conditions are present, this PT&R guidance may not be appropriate for the site and a more extensive cleanup technology evaluation should be conducted.

DTSC continues to encourage the use and evaluation of emerging technologies and therefore this PT&R guidance is not intended to replace evaluation of innovative and new technologies.

2.0 OVERVIEW AND ORGANIZATION

Cleanup of contaminated sites may be governed by one of several federal or State laws, including the:

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Resource Conservation and Recovery Act (RCRA)
- Hazardous Waste Control Law (HWCL)
- Hazardous Substances Account Act (HSAA)

The law applicable to a given site depends on such factors as the source, cause of the release, and cleanup process under which the site is being addressed. The PT&R approach operates consistently with these laws and will yield technically and legally adequate environmental solutions. Any procedural differences between cleanup authorities will not substantively affect the outcome of the cleanup. The remedies evaluated and selected must be: (1) protective of human health and the environment; (2) able to achieve RAOs and cleanup goals; and (3) able to control or remediate sources of releases.

The PT&R approach (Figure 1) is consistent with DTSC's conventional cleanup processes through which sites undergo:

- site characterization (also referred to as site investigation);
- risk assessment;
- remedy screening and evaluation, such as under a Feasibility Study (FS) or Corrective Measures Study (CMS);
- remedy selection; and
- implementation of the corrective action and/or remedial action.

The PT&R approach streamlines the remedy screening, evaluation, and selection phases. In addition to being used as guidance for selecting the final remedy for a site, the PT&R approach is also suitable for interim removal actions to prevent or minimize the spread of contamination while final cleanup action alternatives are being evaluated. Because the PT&R guidance identifies excavation/disposal and SVE as the preferred alternatives, the data needed to support the remedy selection phase are potentially focused and reduced, thus decreasing time and investigation costs.

The use of the guidance document may have the following benefits:

- **Time and cost savings**. The guidance streamlines the cleanup process by (1) limiting the number of evaluated technologies; (2) facilitating corrective action and/or remedial action implementation by providing samples and annotated outlines for key documents; and (3) facilitating documentation and administrative processes.

- **Focused site characterization to support cleanup design**. Data needed to support the cleanup design is collected during site characterization activities. Preferably, the PT&R approach should be initiated as early as possible in the assessment and/or characterization phase.

- **Focused remedy selection**. The evaluation of cleanup alternatives is focused on the two most commonly implemented alternatives.

- **Transparent process**. Stakeholders are identified and involved early and throughout the cleanup process.

The PT&R guidance is organized into twelve chapters:

Chapter 1 presents introductory information, including the purpose, objective, scope, and applicability of the PT&R guidance.

Chapter 2 provides an overview of the PT&R approach and summarizes the organization of the PT&R guidance.

Chapter 3 summarizes the site assessment to determine its suitability for the PT&R approach. Community assessment is also discussed.

Chapter 4 identifies site characterization objectives and identifies key reference materials for characterization activities.

Chapter 5 summarizes risk assessment approaches.

Chapter 6 describes the development of cleanup goals, risk management considerations, evaluation of short-term risks during remedy implementation, and post-cleanup risk evaluation.

Chapter 7 summarizes and documents the DTSC study that is the basis for the PT&R alternatives. This chapter also addresses the focused evaluation and selection of the cleanup alternative.

Chapter 8 summarizes the design and implementation considerations for the excavation/disposal alternative.

Chapter 9 summarizes the design and implementation considerations for the SVE alternative.

Chapter 10 addresses the completion or certification of the remedy for cVOCs in the vadose zone.

Chapter 11 discusses long-term stewardship considerations.

Chapter 12 provides the references cited in this guidance document.

3.0 SITE ASSESSMENT

The PT&R approach is initiated by assessing whether this guidance may be applied to a given site with cVOCs in vadose zone soil. As discussed in Section 3.1, the decision to apply the PT&R approach can be made in a project scoping meeting between DTSC and project proponents. A potential outcome of the scoping meeting might be that the PT&R approach is not appropriate for the site and that standard DTSC cleanup processes should be implemented.

Because it was not realistic to develop a guidance document that addresses every possible site scenario, Sections 3.2 and 3.3 identify favorable site characteristics and potential limitations for applying the PT&R approach. The presence of limitations does not necessarily preclude use of the PT&R approach. If limitations are identified, DTSC and project proponents would make a determination as to whether it is appropriate and worthwhile to apply the PT&R approach with site-specific adjustments.

3.1 PROJECT SCOPING

The project scoping objectives under the PT&R approach are the same objectives that are used under any DTSC cleanup process. These objectives include:

- establishing a management approach for the project;
- developing a site cleanup strategy which is protective of human health and the environment;
- developing a project plan (i.e., the step-by-step strategy to be used for the site cleanup);
- recognizing unique site conditions to be addressed during the cleanup process (e.g., cultural resources, sensitive human receptors);
- identifying and assessing stakeholders; and
- scoping public participation activities.

3.1.1 Scoping Meetings

DTSC staff and project proponents should hold one or more project scoping meetings. Typical discussion topics during these meetings include:

- site background, physical setting, current/past land uses, and unique site characteristics;
- status of site investigation and cleanup;
- conceptual site model (CSM; i.e., types and locations of releases, affected environmental media [e.g., soil, soil vapor, groundwater, indoor air], contaminant migration pathways, current and potential future receptors, exposure pathways [e.g., direct contact, inhalation, vapor intrusion into indoor air, drinking water], potential risks);

- regulatory framework for site cleanup;
- initial scope of work for completing site characterization, filling data gaps, and cleaning up the site;
- potentially applicable remedial technologies;
- preliminary identification of response actions and the implications of these actions (e.g., restricted land use, long-term stewardship);
- preliminary RAOs and cleanup goals;
- project planning, phasing, scheduling, and priorities; and
- stakeholder identification and public participation activities.

The scoping meeting would determine if the PT&R approach may be applied to all or part of the site cleanup, either as described in this PT&R guidance document or with site-specific adjustments (see Section 3.4). If the PT&R guidance is appropriate, the intended outcome of implementing the PT&R approach (e.g., mass removal, unrestricted use) and any long-term stewardship requirements associated with the contemplated cleanup approach should be addressed. If applicable, the scoping meeting should address how the PT&R approach for cVOCs in vadose zone soil will be coordinated with the groundwater remedy and/or vapor intrusion mitigation measures.

The outcome of the scoping meeting(s) may be summarized in a scoping document that includes:

- analysis and summary of site background and physical setting;
- summary of previous response actions, including all existing data;
- presentation of the CSM, human health risks, and data gaps;
- scope and objectives of remaining characterization and risk assessment activities;
- scope and objectives of the site cleanup;
- RAOs and cleanup goals;
- preliminary identification of possible response actions and data needed to support the evaluation of cleanup alternatives; and
- initial presentation of site remedial strategies (e.g., decision to apply the PT&R approach, coordination between PT&R approach and groundwater remedy).

3.1.2 Stakeholder Identification and Assessment

Stakeholder involvement is considered essential for the success of any cleanup action. At the onset of the proposed project, stakeholders should be identified and contacted for input. Stakeholders include any individuals, government organizations, environmental and other public interest groups, academic institutions, and businesses with an interest in the project. The identification of stakeholders is largely based on those entities or individuals who are already involved in the project, and contacting others with related interests or those who may be in close proximity to the site. Stakeholders provide information on the preferences of the community and may also identify unaddressed issues. Early identification of stakeholders is necessary to ensure effective and timely participation to meet stakeholder expectations, and to improve the decision-making process.

3.1.3 Public Participation Activities

The PT&R approach acknowledges the importance of early community outreach and uses the public participation process identified in the *DTSC Public Participation Policies and Procedures Manual* (DTSC, 2003). The manual addresses public participation components of the cleanup process and compliance with State and federal laws and regulations. Summaries of the public participation elements for each DTSC program, California Environmental Quality Act (CEQA), and various public outreach activities are included. Also provided are checklists and recommended content for the public participation plan, fact sheets, public notices, and other public outreach activities. A link to sample public participation documents is provided in Appendix D.

The vapor intrusion pathway may be a concern for some cVOC sites. The public participation process should begin as soon as it is determined that cVOCs are present and a vapor intrusion evaluation is necessary. The *Vapor Intrusion Mitigation Advisory* (DTSC, 2009a) outlines public participation considerations for sites with vapor intrusion issues.

3.2 SITE CHARACTERISTICS THAT FAVOR THE PT&R APPROACH

This PT&R guidance is intended for remediation at sites where the primary environmental issue is cVOCs in vadose zone soil. The site characteristics summarized in Table 1 favor application of the PT&R approach.

3.3 SITE CHARACTERISTICS THAT MAY LIMIT THE USE OF THE PT&R APPROACH

Table 2 summarizes site conditions that may limit application of the PT&R approach. Additional rationale for the limiting characteristics is provided in the following paragraphs. Some of the limiting characteristics described below may not be applicable if the PT&R approach is being used as an interim removal action.

3.3.1 General Characteristics

Time-Critical Cleanup/Emergency Response Actions. The approach used for time-critical cleanup or emergency response actions (i.e., removal actions that are imminent and must be carried out immediately) will be more streamlined than the PT&R approach and will be subject to different regulatory requirements than non-time critical cleanup actions.

Potential Ecological Risk. Sites located in areas that are designated as environmentally sensitive (e.g., wetland areas, wildlife refuges, endangered species habitat), or that have other characteristics that suggest potential ecological impacts, are not candidates for the PT&R approach. Ecological risks may be present at sites where potential habitat, ecological receptors, surface water drainages, and/or surface water features are present. Because the cleanup process may be more complex (including the development of appropriate cleanup goals and potential ecological impacts by implementation of the remedy), these types of sites may not be suitable for the PT&R approach.

Surface Water Features. Sites with surface water may not be suitable for the PT&R approach. Surface water and associated zones of water saturation introduce variability and uncertainty in the distribution, migration, and concentration of cVOCs in soil and soil gas, and complicate the design and implementation of remedies. Also, surface water potentially impacted by runoff or subsurface migration of cVOCs from contaminated soil may be linked to ecological risk or have other risk considerations. The cleanup goals and alternatives recommended by this guidance document do not consider these risks.

Complex Sites. The PT&R approach may not be appropriate for complex sites that require a more elaborate cleanup strategy than is offered by this approach. Large sites may require integration of multiple cleanup approaches and may need to consider ecological risk when selecting the cleanup alternative. Sites with off-site contamination or potential off-site receptors require an evaluation beyond the scope of the PT&R approach.

Table 1. Site Characteristics that Favor the PT&R Approach

Applicable PT&R Alternative(s)	Favorable Characteristic	Primary Rationale for Favorable Characteristic
• Excavation/disposal • SVE	cVOC contamination	• PT&R alternatives are most common remedies used to address cVOCs in vadose zone.
	No emergency actions required	• PT&R approach requires a planning period of at least six months.
	Industrial/commercial or residential land use scenario	• Residential and industrial/commercial exposure scenarios are the most common scenarios evaluated. Standard default assumptions are available.
	Human receptors only	• This guidance addresses health risk cleanup goals for human receptors.
	Groundwater impacts addressed by a separate remedy	• The PT&R alternatives do not directly address groundwater.
• Excavation/disposal	Readily accessible contamination	• Can be the most efficient means of removing impacts to shallow soils. Feasible depth for excavation is a site-specific decision.
	Co-located contaminants	• Likely more feasible if the same excavation activities would remove cVOCs as well as other contaminant types.
• SVE	Conditions conducive to effective SVE	• Conditions for effective SVE: homogeneous, permeable soils; adequate vadose zone thickness; volatile contaminants.

Table 2. Site Characteristics that Limit the PT&R Approach

Applicable PT&R Alternative(s)	Limiting Characteristic	Primary Rationale for Limiting Characteristic
• Excavation/ disposal • SVE	Multiple contaminant groups	• Multiple contaminant groups may be more efficiently cleaned up by alternate approaches.
	Emergency action required	• These actions have different regulatory requirements and require a faster response than can be achieved under the PT&R approach.
	Ecological habitat or sensitive receptors	• If the scoping-level ecological investigation identifies potentially complete exposure pathways, further assessment is necessary and is beyond the scope of this PT&R guidance.
	Potential for surface water impact	• Impacts to surface water may have associated ecological risks. The risk assessment approach recommended by this guidance addresses human health risk only.
	Land use or exposure scenario other than residential or industrial/commercial	• Other land use or exposure scenarios require site-specific evaluation and an adjustment to the PT&R approach. Default exposure assumptions generally are not available.
	Off-site contamination and potential receptors	• Adds complexity to the cleanup process and the evaluation of receptors. Requires an evaluation beyond the scope of this guidance.
• Excavation/ disposal	cVOC impacted soil cannot be excavated	• Excavation is only feasible up to certain depths (based on site-specific considerations). • Site infrastructure or conditions may preclude excavation.
	Multiple contaminant groups	• Multiple contaminant groups may limit disposal options. Multiple excavations required if contaminants are not co-located.
• SVE	Soils with low air permeability	• Fine-grained or high moisture content soils require a higher vacuum and typically require a longer remediation time, which increase the cost of SVE. SVE is not technically feasible in soil with very low permeability where sufficient air flow rates (pore gas velocity) cannot be created.
	Shallow groundwater	• Sites with shallow groundwater may be better addressed via the groundwater remedy.
	cVOC contamination near capillary fringe	• High moisture conditions near the capillary fringe decrease mass removal via SVE.
	Saturated soil	• SVE is not effective under saturated conditions.
	Heterogeneous soil	• Heterogeneity results in lower mass removal rates and prolongs operation time for the SVE system.
	Bedrock	• This guidance does not address SVE in bedrock.
	High soil organic matter content	• cVOCs sorb to soil organic matter, decreasing the mass removal rates and prolonging the operation time for the SVE system.
	Multiple volatile contaminant groups	• Other treatment options may be needed for multiple types of volatile contaminants.
	Non-volatile contaminants	• SVE is more effective for volatile compounds.

3.3.2 Excavation/Disposal

Inaccessible Soil Impacts. Soil impacted with cVOCs may not be accessible by excavation. Each site will have a maximum depth that is feasible for excavation. Some soil impacts may not be accessible because of buildings or other infrastructure. Excavation may be logistically infeasible because of adverse effects on site operations or activities.

Multiple Contaminant Groups. Excavation/disposal may not be suitable for sites that have a mixture of cVOCs and other contaminants and that may be more effectively or efficiently cleaned up by other approaches (such as when the contaminants are not co-located). Additional types of contaminants may affect soil disposal options.

3.3.3 Soil Vapor Extraction

Multiple Contaminant Groups. Mixtures of volatile contaminants generally require more complex SVE treatment systems (e.g., multiple treatments) than are described in Chapter 9. Contaminant matrices, such as high concentrations of oil and grease, pose additional complexities. Non-volatile contaminants cannot be addressed by SVE and would require a separate remedy.

Soil Properties. Low permeability, high soil organic matter content, and heterogeneous soils will have lower mass removal efficiencies. This guidance is not applicable for sites where SVE is being implemented to address cVOCs in bedrock.

Moisture Content. SVE is not effective in saturated soils. Low soil permeability is observed with higher soil moisture content, resulting in decreased mass removal efficiencies. SVE may not be effective in removing cVOC mass near the capillary fringe.

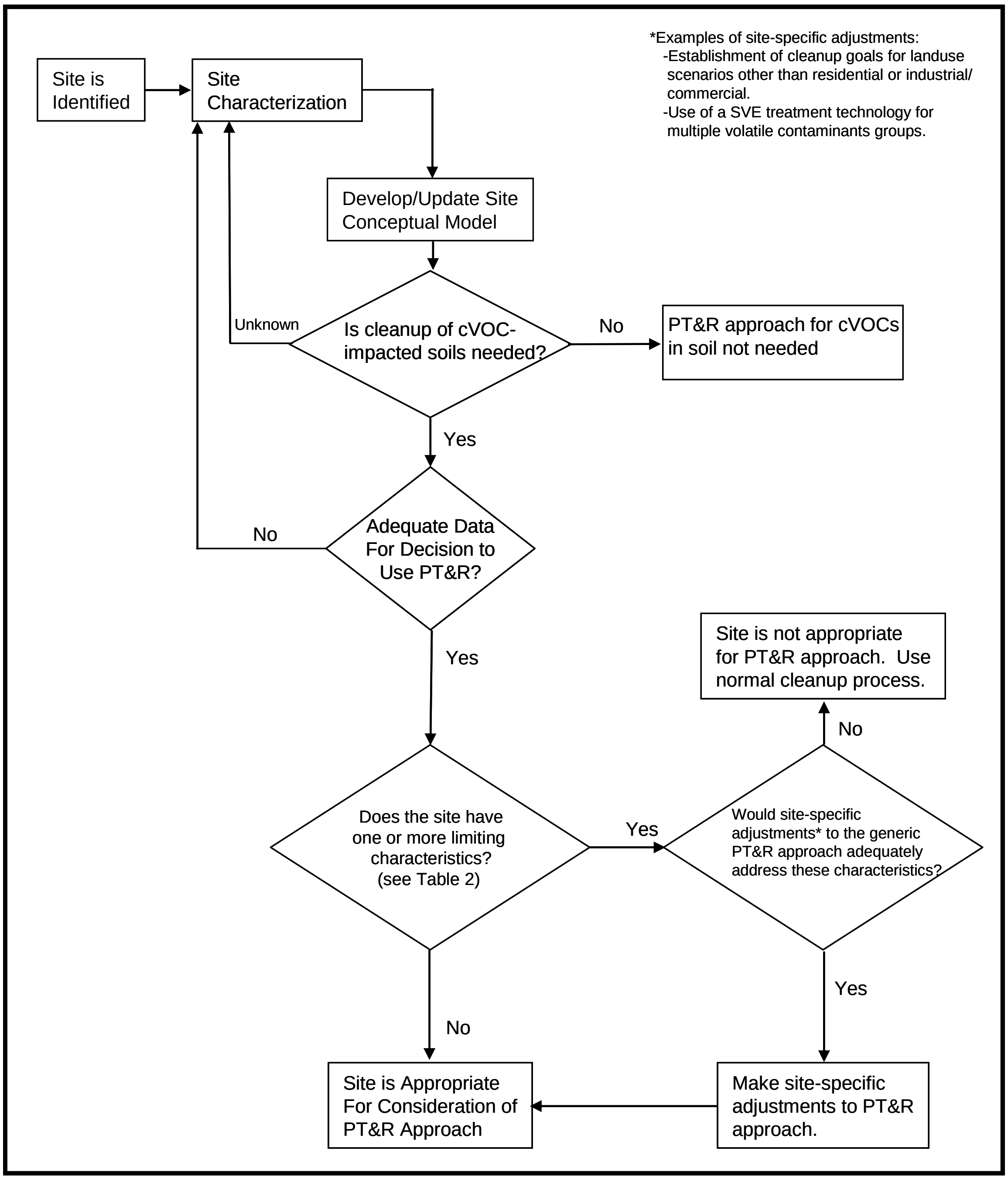
Shallow Groundwater. SVE is typically implemented at sites having sufficient vadose zone thickness to warrant its use. Sites with shallow groundwater may have high soil moisture content in the vadose zone or cVOCs contacting the capillary fringe, both conditions lead to inefficient removal of cVOCs by SVE. At sites with shallow groundwater, one option is to use excavation/disposal to address accessible cVOC-impacted soils and other remedial approaches to address the remaining cVOC mass in the subsurface.

3.4 DETERMINATION OF SUITABILITY FOR PT&R APPROACH

Figure 2 summarizes the recommended process for determining the suitability of the PT&R approach at a site. While a decision to apply the PT&R approach can be made at any point in the cleanup process, a site can be evaluated for suitability under the PT&R approach as soon as information is available that indicates a response action is necessary.

A CSM should be developed to assist with the determination of suitability for the PT&R approach. The CSM is intended to summarize all currently available information about the site, develop a preliminary understanding of the site, and identify data gaps. Appendix A provides the CSM for cVOCs in the subsurface. The identified data gaps should be used to determine whether sufficient information is available to make a decision that a site is suitable for the PT&R approach.

Figure 2. Process for Determining if the PT&R Approach for Chlorinated VOCs in Vadose Zone Soil is Appropriate for a Given Site



4.0 SITE CHARACTERIZATION

The primary objective of the characterization phase is to establish the nature, extent, and distribution of cVOC contamination (Section 4.1). Under the PT&R approach, another objective of the characterization effort is to collect the data needed to support any fate and transport modeling efforts (Section 4.2), and to support the engineering design (Section 4.3). Site characterization activities should be conducted in accordance with a DTSC-approved workplan, including a field sampling plan and a quality assurance project plan (QAPP). Appendix D includes a link to annotated outlines for a characterization phase workplan and a site characterization report.

The site characterization efforts should be designed to produce effective, decision quality data in a manner that is cost effective and timely. The Triad approach to data collection, described in the *Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management* (ITRC, 2003), should be considered for sites using the PT&R approach. The *Standard Practice for Expedited Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites* (ASTM, 2004) may also be useful. The approaches described in these guidances can focus work towards rapid site characterization decisions. Additional information about the Triad approach can be found at the following link: www.triadcentral.org.

Low-cost passive or real-time measurement technologies (such as passive soil gas sampling, membrane interface probes, grab groundwater sampling) may be useful techniques for characterizing sites with cVOC impacts. These techniques allow for data collection programs covering wider areal or vertical extent over shorter time frames than can be achieved by traditional methods. The techniques can then be followed by higher quality data collection methods (i.e., active soil gas sampling, permanent vapor monitoring well installation, permanent groundwater monitoring well installation) to characterize the site, support the risk assessment, and the remedy design.

The characterization phase should culminate with an updated CSM and an analysis to ensure that the PT&R approach is still applicable (see Chapter 3). Appendix A presents the CSM for cVOCs in the subsurface.

4.1 SOIL, SOIL GAS, AND GROUNDWATER

This section provides brief discussions of investigation strategies and available resources for investigating soil, soil gas, and groundwater. Because numerous guidance documents are available to assist with the design and implementation of site investigations, this guidance does not include an extensive discussion of site characterization.

Soil Gas. Soil gas investigations are useful to obtain vapor phase data at sites potentially affected by volatile contaminants. Both passive and active soil gas data can be useful for site characterization. Where practicable, soil gas sampling is preferred over soil matrix and groundwater sampling for assessing cVOC impacts, including characterization objectives such as source identification, determining spatial distribution, and assessing potential vapor intrusion risks. Soil gas sampling should consider the *Advisory – Active Soil Gas Investigation* (DTSC and LARWQCB, 2003; revision pending). Please check the DTSC web-site at the following link for updated versions of this advisory: www.dtsc.ca.gov/SiteCleanup/Vapor_Intrusion.cfm.

Soil Matrix. Soil matrix data provide the total cVOC concentration in subsurface soil which may be useful for defining the source location and high concentrations of cVOCs. In addition, soil matrix data are used to evaluate risks associated with direct contact exposure pathways for cVOCs in soil, such as the dermal contact, ingestion, and outdoor-air inhalation pathways. Soil matrix samples should be collected using the procedures described in the *Guidance Document for the Implementation of United States Environmental Protection Agency Method 5035: Methodologies for Collection, Preparation, Storage, and Preparation of Soils to be Analyzed for Volatile Organic Compounds* (DTSC, 2004).

Groundwater. Impacts to groundwater are often observed at sites with cVOC impacts to vadose zone soil and therefore should be evaluated as part of the site characterization activities. The California Environmental Protection Agency (Cal/EPA) has several guidance manuals for groundwater investigations (Cal/EPA, 1995) that can be used to characterize groundwater. In addition, resources included on the U.S. Environmental Protection Agency (USEPA; www.clu-in.org), Interstate Technology and Regulatory Council (ITRC; www.itrcweb.org), and ASTM International (ASTM; www.astm.org) websites may be useful.

4.2 DATA NEEDED TO SUPPORT MODELING EFFORTS

Fate and transport modeling is often used during the characterization phase for the purpose of evaluating the movement of cVOCs in the vadose zone, assessing the potential for cVOC migration to groundwater, developing soil cleanup goals for protection of groundwater, and estimating the potential risk posed by vapor intrusion into indoor air. Therefore, in addition to delineating concentrations of cVOCs in various environmental media (Section 4.1), site characterization should include sampling for site-specific soil properties to support these modeling efforts. For example, a site-specific screening analysis of the risk posed by the vapor intrusion pathway may require information regarding site stratigraphy and building parameters in addition to the following soil properties: bulk density, grain density, total porosity, grain size distribution, moisture content, fraction of organic carbon, and air permeability (DTSC, 2005a; revision pending). Other fate and transport models may require additional site-specific parameters, such as hydraulic conductivity, estimated recharge or infiltration rates, biodegradation rates, and chemical retardation factors. The input parameter requirements for the models anticipated for use at a site should be considered during workplan development.

4.3 DATA NEEDED TO SUPPORT DESIGN OF PT&R ALTERNATIVES

Under the PT&R approach, an objective of the characterization phase is to collect data needed to support the design process. Sufficient data should be collected to eliminate or minimize the need for additional field mobilizations during the site-specific remedy evaluation or design phases.

4.3.1 Excavation/Disposal

Data needed for design of the excavation can be collected with other site investigation activities. As applicable to a given site, the following data is necessary to adequately address the excavation limits and design:

- vertical and horizontal distribution of contaminants (i.e., areal extent of impacted soil and soil gas, depth of impact) and volume of soils to be excavated;
- identification of soil conditions that affect the selection of excavation equipment;
- depth to groundwater;
- climatology/seasonal variations (e.g., months with higher likelihood of rainfall events or higher groundwater table);
- survey map of site features (e.g., topography, existing structures, utilities, wells, surface water control measures, property boundaries);
- geotechnical data for each soil type (i.e., soil classification, Atterberg limits, moisture content, bulk density);
- structural contour map of the top of competent bedrock; and
- waste characterization (to support identification of applicable disposal options).

4.3.2 Soil Vapor Extraction

The data collected should be sufficient to identify the feasibility of SVE, to design a pilot-scale test (if needed), and to begin designing the SVE system. At a minimum, the following data should be collected in conjunction with the site characterization activities:

- depth and areal extent of cVOC impacts in the vadose zone;
- types and concentrations of cVOCs;
- nature and location of co-located contaminants that may affect SVE performance or selected treatment;
- depth to groundwater;
- soil moisture conditions;
- stratigraphy of the impacted zone (e.g., homogeneous sand, interbedded sands and silts);

- soil types and properties (e.g., structure, grain size distribution, air permeability, moisture content, organic carbon content); and
- survey map of site features (e.g., topography, existing structures, utilities, pavement), if applicable.

4.4 ADDITIONAL CHARACTERIZATION REFERENCES

The reader is referred to resources available on the DTSC, ITRC, USEPA, and ASTM websites, including the following references:

- *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 1994);
- *Data Quality Objectives Decision Error Feasibility Trials Software (DEFT)-Users Guide, EPA QA/G-4D* (USEPA, 2001a);
- *Guidance on Choosing a Sampling Design for Environmental Data Collection, for Use in Developing a Quality Assurance Project Plan, EPA QA/G-5S* (USEPA, 2002a);
- *Guidance on Systematic Planning Using the Data Quality Objective Process, EPA QA/G-4* (USEPA, 2006a);
- *Data Quality Assessment: A Reviewer's Guide, EPA QA/G-9R* (USEPA, 2006b);
- *Systematic Planning: A Case Study for Hazardous Waste Site Investigations (QA/CS-1)* (USEPA, 2006c);
- *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S* (USEPA, 2006d); and
- *Vapor Intrusion Pathway: A Practical Guideline* (ITRC, 2007).

5.0 RISK ASSESSMENT

Evaluation of potential risks to human health and the environment posed by contaminants at a site is part of the site characterization process and supports the risk management decision-making process to determine whether additional site investigation, further risk assessment, and/or remediation may be necessary. Depending on when a site begins using the PT&R approach, some risk assessment elements may have already been conducted and therefore do not need to be repeated.

Risk assessments range from simple screening assessments to site-specific, comprehensive risk assessments. A human health risk assessment should be conducted to characterize the potential cancer risks and noncancer health hazards posed by chemicals of concern (COCs) identified during site characterization (Section 5.2). A scoping-level ecological risk assessment should be conducted to determine whether further assessment of potential ecological impacts is necessary (Section 5.1). Cleanup goals and risk management considerations are addressed in Chapter 6.

5.1 ECOLOGICAL RISK ASSESSMENT

A scoping-level ecological investigation should be conducted to characterize the chemical, physical, and biological aspects of a site and to evaluate the potential for complete exposure pathways between ecological receptors and COCs (DTSC, 1996ab; USEPA 1997b). If the results of this qualitative assessment indicate further assessment is necessary (e.g., Phase I predictive assessment), then the PT&R process is not applicable to the site. Even if no currently-complete exposure pathways for ecological receptors are identified, the biological characterization of the site may become an important consideration for risk management decisions. For example, removal actions to protect human health may adversely impact ecological receptors or critical portions of their habitat.

5.2 HUMAN HEALTH RISK ASSESSMENT

For cVOCs in soil, vapor intrusion into indoor air is typically the most significant exposure pathway, and usually poses a greater risk from long-term (chronic) exposure than other exposure pathways. This section focuses on the soil vapor intrusion pathway, but also addresses evaluation of other exposure pathways for cVOCs in soil and groundwater.

Multiple lines of evidence should be used for evaluation of vapor intrusion into indoor air and associated health risks (ITRC, 2007). Typically, active soil gas samples are collected in the early stages of an exposure evaluation. Other lines of evidence include sampling data for passive soil gas samples, soil matrix, groundwater, sub-slab soil gas, and indoor air. Some or all of these lines of evidence are used in site characterization for defining the source location and nature and extent of cVOC contamination. Soil matrix data are also used for evaluating risks associated with direct contact exposure pathways for cVOCs in soil (Section 5.2.5). Measured and/or predicted groundwater COCs and concentrations are used to evaluate potential groundwater risks.

A screening level health risk assessment may be sufficient, depending on factors such as the complexity of the site, the degree of characterization of site contamination, and the anticipated remedy. Complex sites (such as those with multiple contaminants, impacts to multiple environmental media, and/or complex features) may require a site-specific comprehensive risk assessment subsequent to, or in lieu of, a screening risk assessment.

General guidance for conducting a site-specific comprehensive risk assessment is provided in *Risk Assessment Guidance for Superfund: Volume I--Human Health Evaluation Manual, Part A, Baseline Risk Assessment* (USEPA, 1989). Additional guidance for conducting risk assessments is available at the following agency websites:

- USEPA: http://www.epa.gov/oswer/riskassessment/risk_superfund.htm
- DTSC: http://www.dtsc.ca.gov/AssessingRisk/index.cfm.

The risk assessment process includes:

- identification of COCs and affected environmental media;
- identification of exposure pathways, land use, and potential human receptors;
- determination of exposure point concentrations;
- selection of toxicity criteria; and
- calculation and characterization of potential cancer risks and noncancer hazards.

5.2.1 Chemicals of Concern

All VOCs (both chlorinated and non-chlorinated) detected at the site should be included as COCs for risk assessment. In addition to detected VOCs, potential transformation products and other contaminants suspected to be present based on the CSM should be discussed and evaluated for potential inclusion in the quantitative risk assessment. Examples of transformation products include 1,2-dichloroethene and vinyl chloride from tetrachloroethene (PCE) and trichloroethene (TCE). High concentrations of primary contaminants in soil or soil gas might elevate analytical detection limits and preclude detection of other cVOCs. Further investigation and refined sampling and analytical methods may be needed to address these uncertainties.

5.2.2 Exposure Pathways and Land Use Scenarios

All potential exposure pathways and receptors identified in the CSM for current and potential future uses of the property should be described in the risk assessment. The land use and risk assessment exposure scenarios evaluated for this guidance are (1) residential and (2) industrial or commercial. Evaluation of off-site receptors or exposure scenarios other than default residential and industrial/commercial scenarios for the baseline risk assessment requires site-specific adjustment to the PT&R approach and additional consultation with the DTSC.

Exposure to VOCs in shallow soil can occur by several pathways, including inhalation of VOCs that have migrated from the subsurface into indoor air, inhalation of outdoor air, direct contact with soil (incidental ingestion and dermal contact), and ingestion of food products contaminated with cVOCs from soil or groundwater. Because vapor intrusion into indoor air of buildings is the most significant exposure pathway of concern for cVOCs at most sites, the vapor intrusion pathway is often the primary focus of risk assessments. However, other factors, such as the nature and extent of contamination or the current or potential land uses at a site, may warrant evaluation of risks associated with direct soil exposure pathways. DTSC should be consulted regarding evaluation of soil exposure pathways for sites with cVOC contamination.

Exposure to cVOCs that have migrated from vadose zone soil to groundwater, or are predicted by model simulations to reach groundwater (see Section 4.2), should be evaluated. Exposure pathways for cVOCs in groundwater include, but are not limited to, ingestion, dermal contact during showering/bathing, and inhalation of vapors released indoors from household use of groundwater. DTSC should be consulted regarding groundwater exposure pathways for sites with cVOC contamination.

5.2.3 Exposure Point Concentration

The approach used for estimating exposure point concentration at a given site depends on the matrix sampled, spatial and temporal scale of samples, spatial and temporal differences in COC concentrations, and land use.

Soil Gas. The maximum detected concentration of each COC in soil gas should be used as the exposure point concentration for the vapor intrusion risk assessment (DTSC, 2005a; Cal/EPA, 2005b). DTSC approval is required for use of any other metric for the exposure point concentration. Alternatively, point estimates of risk might be calculated using concentrations of COCs for each sampling location. Point estimates of risk are useful for spatial evaluation of contamination and risk at sites with multiple contaminants, and can be useful for evaluating remedial alternatives. For soil gas samples in which a site COC was not detected because of elevated detection limits (Section 5.2.1), the detection limit for the COC should be used as a proxy concentration (DTSC, 2005a). The distribution and extent of contamination at the site and the possible existence of localized areas of higher concentrations (i.e., hot spots) must be considered in both risk assessment and risk management.

Soil Matrix. For sites with high concentrations of cVOCs, soil matrix data can be used to identify locations with cVOC concentrations exceeding saturation limits for the soil and provide concentration data for soil exposure assessments. For sites at which the soil saturation limit for a cVOC is exceeded, the evaluation of vapor intrusion risk requires additional consultation with DTSC. Maximum detected concentrations of cVOCs in shallow soil matrix samples should be used for screening-level soil risk assessments (DTSC, 1994; and updates). In consultation with DTSC, the estimated average concentration (95 percent upper confidence limit of the arithmetic mean) may be used at sites with sufficient characterization of cVOCs in soil matrix.

Groundwater. Exposure point concentrations for cVOCs in groundwater should be based on concentration data collected from monitoring wells over a period of time that allows assessment of temporal trends. For sites at which cVOCs have not yet reached groundwater, concentrations predicted by modeling can be used to support risk estimates (see Section 4.2). A combination of monitoring data and modeling might be appropriate for estimating exposure point concentrations at some sites. The maximum measured or model-predicted concentration of cVOCs in groundwater should be used. DTSC approval is required for use of other metrics for the exposure point concentration.

The data quality objectives (DQOs) for data used to support the exposure point concentration for groundwater will depend on the exposure pathways being evaluated (e.g., vapor intrusion, drinking water). For example, evaluation of vapor intrusion focuses on concentrations at the water table (DTSC 2005a).

Both groundwater and soil gas data should be used to develop the exposure point concentration for the vapor intrusion pathway. Data from both media should be used to estimate the indoor air exposure concentration and the higher predicted exposure concentration should then be used for assessing vapor intrusion risks (DTSC, 2005a).

5.2.4 Health Risk Assessment for Vapor Intrusion into Indoor Air

The *Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air* (Vapor Intrusion Guidance; DTSC 2005a, revision pending) should be followed for conducting preliminary and/or site-specific screening evaluation of risks associated with VOCs. The Vapor Intrusion Guidance provides default attenuation factors for estimating indoor air concentrations from soil vapor concentrations for use in preliminary screening risk assessments and also describes procedures for estimating site-specific soil vapor attenuation factors and predicting indoor air VOC concentrations and risks. Current USEPA vapor intrusion guidance is provided in *Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (USEPA, 2002b). The most current toxicity criteria available from Cal/EPA and USEPA should be used. Cumulative cancer risks and noncancer hazards should be calculated for sites with multiple VOCs.

Although soil gas data are preferred for evaluation of vapor intrusion, preliminary risk screening with groundwater monitoring data might be conducted in limited cases. When groundwater data is used, the Vapor Intrusion Guidance should be followed and the vapor intrusion risk associated with both soil gas and groundwater should be evaluated. Soil sampling might be necessary at some sites, such as those with high concentrations of VOCs and/or where site conditions preclude soil gas sampling (see Section 4.1). In consultation with DTSC, an approach can be developed for evaluation of the soil vapor intrusion into indoor air pathway.

5.2.5 Health Risk Assessment for Exposures to cVOCs in Soil

In addition to soil vapor intrusion into indoor air, evaluation of risks associated with exposures to cVOCs in soil matrix may be warranted at sites with high concentrations of cVOCs in shallow soil (0 to 15 feet below ground surface). Emissions of cVOCs into outdoor air may be significant. DTSC should be consulted regarding evaluation of exposures to cVOCs in soil and application of DTSC guidance. Generally, the DTSC *Preliminary Endangerment Assessment Guidance Manual* (PEA Manual; DTSC, 1994; and updates) and updated exposure factors provided in *DTSC Human Health Risk Assessment Note 1: Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Military Facilities* (HHRA Note 1; DTSC 2005b) should be followed.

5.2.6 Health Risk Assessment for Exposures to cVOCs in Groundwater

The PEA Manual (DTSC, 1994; and updates) and updated exposure factors provided in HHRA Note 1 (DTSC, 2005b) should be used for assessment of risks associated with exposure to cVOCs in groundwater.

5.2.7 Human Health Screening Levels

Human health screening levels are risk-based concentrations of chemicals in specific environmental media. Risk-based concentrations (also referred to as health-based concentrations) are developed using a target cancer risk or noncancer hazard quotient. The calculations rely on multiple assumptions and factors for estimating contaminant environmental fate and transport and receptor exposures for a hypothetical (or specific) site. Generally, conservative default exposure assumptions are used to derive these screening levels. For carcinogens, risk-based concentrations are developed for both cancer risk and noncancer hazard, and the lesser (more protective) concentration is selected as the screening level.

Screening levels based on default assumptions can be used for screening risk assessments. Site-specific risk-based concentrations may also be developed. Screening-level and/or site-specific risk-based concentrations are used in development of RAOs and cleanup goals (Chapter 6).

For screening risk assessments, cancer risk and hazard are estimated by dividing the maximum concentration of each COC by the corresponding medium-specific screening level (see Sections 5.2.7.1, 5.2.7.2, and 5.2.7.3). The ratio of the exposure point concentration to the risk-based concentration is multiplied by the target risk or hazard quotient from which the risk-based concentration was calculated (10^{-6} risk and hazard quotient of 1 for screening assessments). When using risk-based screening levels for assessing risks, both cancer risk and hazard must be evaluated for carcinogenic COCs, and cumulative risk and hazard for multiple COCs and exposure pathways must be presented. For the vapor intrusion into indoor air pathway, the maximum detected concentration of each COC in soil gas is compared with the corresponding screening level for soil gas.

Risk-based concentrations for the residential scenario should be used for screening risk assessments. In addition to the residential scenario, risk assessments for industrial, commercial, and other land use scenarios might be conducted for the evaluation of remedies and the risk management decision process. Sites with individual chemical or cumulative cancer risks greater than 1 x 10^{-6} or noncancer hazards (hazard index) greater than 1 for the residential scenario should be considered for further risk management evaluation (see Chapter 6).

5.2.7.1 Screening Assessment for cVOCs in Soil Gas

The Vapor Intrusion Guidance (DTSC, 2005a, revision pending) should be used to develop risk-based screening levels for cVOCs in soil gas. Default soil gas attenuation factors provided in the Vapor Intrusion Guidance can be used to develop generic risk-based screening levels. Alternatively, the USEPA spreadsheet version of the Johnson and Ettinger model for vapor intrusion into indoor air and certain assumptions for building properties provided in the Vapor Intrusion Guidance can be used with data for site-specific soil properties to derive soil gas attenuation factors and screening levels. For sites or areas for which soil matrix samples are necessary in addition to soil gas data, Appendix E of the Vapor Intrusion Guidance provides procedures for using soil matrix data to estimate soil gas concentrations and discusses the limitations and uncertainties in using soil matrix data.

5.2.7.2 California Human Health Screening Levels

California Human Health Screening Levels (CHHSLs) are based on standard exposure assumptions and chemical toxicity values published by Cal/EPA and the USEPA, and can be used for evaluation of cVOCs in soil gas (Cal/EPA, 2005ab). The CHHSLs for cVOCs are risk-based concentrations for soil gas for the vapor intrusion/indoor air exposure pathway only. Soil gas CHHSLs were developed using the USEPA spreadsheet version of the Johnson and Ettinger model for soil vapor intrusion into indoor air.

The CHHSLs might not be adequately protective for estimating impacts to indoor air in structures with: basements; significant openings to the subsurface; preferential pathways for vapors (such as utility openings); or substandard ventilation systems. Sites with conditions significantly different from those assumed for the CHHSLs warrant a site-specific evaluation using the Vapor Intrusion Guidance (DTSC, 2005a; revision pending).

Toxicity criteria used for the CHHSLs should be reviewed prior to use and updated (i.e., adjust the screening level) as necessary. The current list of CHHSLs can be found at http://www.oehha.ca.gov/soil.html. The guidance document on use of CHHSLs for screening risk assessments (Cal/EPA, 2005b) should be consulted.

5.2.7.3 Soil Screening Levels for Soil Matrix

Risk-based screening levels for contact exposure pathways for COCs in soil can be developed using the PEA Manual (DTSC, 1994; and updates) and current exposure parameter values recommended in HHRA Note 1 (DTSC, 2005b). As applicable, CHHSLs for non-VOCs present at the site may be used for soil exposure pathways in the screening risk assessment.

USEPA Regional Screening Levels (RSLs) for soil matrix may be used for screening evaluation of soil exposure pathway risks for COCs (ingestion, dermal contact, inhalation of outdoor air). DTSC guidance on use of RSLs (DTSC, 2009bc), including adjustments for Cal/EPA toxicity criteria, should be followed. As with other screening levels, both cancer risk and hazard must be evaluated for carcinogenic COCs, and cumulative risk and hazard for multiple COCs must be estimated. The RSLs do not include the vapor intrusion pathway, and therefore should be used in conjunction with one of the aforementioned vapor intrusion assessments.

5.2.7.4 Screening Levels for cVOCs in Groundwater

The Vapor Intrusion Guidance (DTSC, 2005a, revision pending) should be used to develop risk-based screening levels for cVOCs in groundwater for the vapor intrusion pathway (Sections 5.2.4 and 5.2.7.1). A partitioning model is used to estimate groundwater concentrations from the risk-based soil vapor concentrations.

For exposures to groundwater via pathways other than vapor intrusion (ingestion, dermal contact from bathing, inhalation of vapors emitted into indoor air from household use of groundwater), the PEA Manual (DTSC, 1994; and updates) and updated exposure factors provided in HHRA Note 1 (DTSC 2005b) should be used for development of risk-based concentrations of cVOCs in groundwater.

USEPA RSLs for tap water may be used for screening evaluation of groundwater exposure pathway risks for COCs (ingestion, inhalation of vapors emitted into indoor air from household use of groundwater). DTSC guidance on use of RSLs (DTSC, 2009bc), including adjustments for Cal/EPA toxicity criteria, should be followed. As with other screening levels, both cancer risk and hazard must be evaluated for carcinogenic COCs, and cumulative risk and hazard for multiple COCs must be estimated. The RSLs for tap water do not include dermal exposure or the groundwater vapor intrusion pathway, and therefore they should be used in conjunction with one of the aforementioned assessments.

6.0 CLEANUP GOALS

The findings of the risk assessment (Chapter 5) can be used, along with consideration of site-specific characteristics, to guide establishment of RAOs and associated cleanup goals. This chapter discusses cleanup goals for the protection of human health and groundwater (Sections 6.1 and 6.2, respectively), risk management considerations (Section 6.3), short-term risks during remediation (Section 6.4), and assessment of risk posed by residual cVOC concentrations (Section 6.5).

6.1 Cleanup Goals for Protection of Human Health

Factors that are considered in the development and selection of risk-based cleanup goals include the health impact endpoint (cancer risk and/or noncancer hazard), the intended use of the property (e.g., residential, industrial/commercial), exposure pathways, and the number of COCs. Remedy selection at some sites may have to address multiple exposure pathways. Methods and scenarios for evaluation of human health risks and development of risk-based concentrations are described in Section 5.2, and include exposures by vapor intrusion into indoor air and exposures to COCs in soil and groundwater.

As a starting point for development of risk-based cleanup goals, an initial cleanup goal of 1×10^{-6} should be calculated for each carcinogenic COC. For noncancer hazard, the risk-based cleanup goal for each COC should be less than or equal to a cumulative hazard index of 1. When a site has multiple COCs that contribute significantly to calculated excess total risk or hazard, the risk-based cleanup goal for each COC may need to be adjusted to a lower concentration to reduce the overall cumulative risk and/or hazard to an acceptable range. Another option is to use point estimates of cumulative risk for spatial evaluation of risk, as indicated in Section 5.2.3. Risk management decisions that would allow cleanup goals with greater risks or hazards may be made on a site-by-site basis (Section 6.3).

Residential and industrial/commercial land use scenarios are considered under the PT&R approach. Recommended exposure assumptions may be found in the Vapor Intrusion Guidance (DTSC, 2005a; revision pending), HHRA Note 1 (DTSC, 2005b), or the documentation for CHHSLs (Cal/EPA, 2005ab). HHRA Note 1 includes default exposure assumptions for a construction scenario. Other land use and exposure scenarios (such as maintenance worker or park visitor scenarios) require use of site-specific exposure factors.

Human health screening levels such as CHHSLs (Section 5.2.7.2) may be considered as risk-based cleanup goals to streamline the remedy selection process. Soil gas screening levels for cVOCs are based on a single pathway of exposure—inhalation of soil vapors migrating from the subsurface into indoor air. For most sites, soil gas screening levels are adequately protective for soil exposure pathways. For sites at which soil gas samples are not feasible, DTSC should be consulted for development of indoor air risk-based concentrations for soil matrix and/or groundwater, or for an alternate approach.

6.2 Soil Cleanup Goals for Protection of Groundwater

If the PT&R approach is being implemented to decrease or eliminate an on-going threat to groundwater posed by cVOCs in vadose zone soil, the process of establishing cleanup goals should also consider soil and soil gas concentrations necessary to protect water resources. Cleanup goals protective of groundwater are established based on site-specific considerations and applicable policies, statutes, and regulations. Potentially applicable policies, statutes, and regulations include:

- State and federal statues and regulations;
- California State Water Resources Control Board (SWRCB) and California Regional Water Quality Control Board (RWQCB) policies;
- water quality control plans adopted by the SWRCB and RWQCB; and
- relevant standards, criteria, and advisories adopted by State and federal agencies.

DTSC has not identified a single methodology that can be used to establish soil cleanup goals for protection of groundwater. Examples of methods that could be used to establish cleanup goals include use of unsaturated zone fate and transport modeling (Section 4.2) and "lookup" tables of screening levels (e.g., USEPA RSLs for Soil for Protection of Groundwater). The method used for a given site should be selected in consultation with, and with the approval of, the regulatory agencies overseeing the site cleanup.

6.3 RISK MANAGEMENT

The final cleanup goal and remediation strategy is a risk management decision based on numerous factors. The risk-based point of departure for risk management decisions is 1×10^{-6} for cancer risk and a hazard index of 1 for noncancer risk. Sites with individual chemical risk or cumulative risk from multiple COCs in excess of these points of departure may require remediation. In general, risks that are less than 1×10^{-6} are called *de minimus* and are not considered to require regulatory intervention. The range of risk (excess cancer risk posed by a site) that is considered as potentially acceptable for risk management decisions starts at 1×10^{-6} (one in a million) and goes up to 1×10^{-4} (one in ten thousand).

Development of RAOs and final cleanup goals at a site involves consideration of the:

- nature and magnitude of human health risks and uncertainties,
- current and future land use,
- risk-based cleanup goals and other criteria or requirements (including the RAOs),
- potential impact to ecological receptors and/or their habitat,
- technical and economic feasibility,
- regulatory criteria, and
- community concerns.

Many factors are considered in the final risk management decisions and the acceptable risk for a project may be greater than the point of departure. Evaluation of each remedial alternative for the site should include an estimate of the reduction in risk and a determination of risk management measures needed for contamination remaining in excess of risk-based concentrations (see Sections 6.5, 8.5.1, and 9.3.8). Risk management decisions (including mitigation and control of potential exposure) and technical supporting information are presented in remedy selection documents (see Section 7.2).

6.4 SHORT-TERM RISKS DURING REMEDIATION

Short-term risks associated with implementation of a remedy should be considered during evaluation of remedial alternatives. For many sites, a qualitative evaluation of risks associated with implementation of remedial alternatives is sufficient, but other sites will require a more quantitative evaluation (USEPA, 1991ab). Releases of cVOCs from soil during cleanup activities might pose significant risks to people who live or work in the vicinity of the site and to workers who are involved in the site cleanup. Evaluation and selection of remedial alternatives should identify and consider measures to monitor and control short-term exposure and risks. This evaluation should include consultation with local agencies (e.g., air quality management district). Site safety plans should be developed. Implementation of certain remedies might require perimeter monitoring of vapors (see Sections 8.2.2 and 9.3.3). Community concerns associated with short-term risks are addressed through the public participation process (see Section 3.1.3).

6.5 POST-CLEANUP EVALUATION

Following the completion of the remedial action, a post-cleanup risk evaluation may be required when residual cVOC concentrations remain, as indicated by confirmation sampling results. Risks can be estimated using the same procedures as those used for the pre-remediation baseline risk assessment or another approach (such as site-specific risk assessment or screening risk assessment as summarized in Section 5.2).

Confirmation sampling approaches for soil excavations and SVE systems are discussed in Sections 8.5.1 and 9.3.8, respectively. Additional information for confirmation sampling associated with the PT&R alternatives is provided in Appendices C and E.

7.0 EVALUATION OF CLEANUP TECHNOLOGIES FOR CHLORINATED VOCs IN VADOSE ZONE SOIL

In a conventional cleanup process, if the results of the risk screening process indicate that a cleanup action is warranted, the next step is an evaluation of the technologies appropriate for remediation of cVOCs in soil. This chapter provides the administrative record, technical basis, and evaluation necessary for streamlining the cleanup alternative evaluation. This chapter also addresses the site-specific evaluation and remedy selection process for cleanup of cVOC contaminated soils. Much of the streamlining is achieved by the DTSC study summarized in Section 7.1. The streamlined approach for evaluating remedial alternatives can be documented by:

- including pertinent sections of this PT&R guidance in the administrative record[1] and
- including a discussion regarding the use of the PT&R approach for the cleanup alternative selection in the decision document.

7.1 TECHNICAL BASIS FOR PT&R GUIDANCE FOR SITES WITH CHLORINATED VOC CONTAMINATION IN VADOSE ZONE SOIL

DTSC conducted a study of sites where the primary COCs included cVOCs in vadose zone soil and for which DTSC provided oversight of the cleanup process. The objective was to identify the technologies that were consistently evaluated as potential remedies and to identify the remedies that were subsequently selected at a site. The study, equivalent to the screening and evaluations conducted under a FS or CMS, included the following activities:

- review of literature relevant to sites with cVOC contamination (see Appendix B for a summary of the technologies reviewed and applicable at sites with cVOCs in unsaturated soil);
- identification of a representative number of DTSC sites with cVOC contaminated soils;
- review of the decision documents to determine which cleanup alternatives were routinely either screened out or selected for the remedy; and
- identification of the rationale for selection of the remedy.

DTSC reviewed its EnviroStor database to identify sites with vadose zone soils impacted with cVOCs. The database evaluation identified 90 sites for which remedy selection or implementation had occurred as of June 2009. These cleanup decisions occurred as either an interim removal action or as a final remedy. Table 3 summarizes the types of sites included in the DTSC study.

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[1] Alternatively, include the PT&R guidance as an electronic appendix to cleanup alternative evaluation document.

Table 3. Cleanup Options Selected to Address Chlorinated VOCs in Vadose Zone Soil for the Sites Evaluated by DTSC Study

DTSC Site Type (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Corrective Action (16[2])	1	14	0	6	0	0
Military Facilities (19[2])	3	12	0	6	2	0
Schools (3)	0	1	0	2	0	0
State Response/ NPL[3] (33[2])	7	19	0	17	4	1
Voluntary Cleanup (19[2])	4	11	2	13	0	0

Notes:
[1] IC is institutional control. Usually used in conjunction with another cleanup option.
[2] Some sites in this category selected multiple cleanup options (i.e., this number is not simply the sum of values listed in this row).
[3] National Priorities List

The DTSC study compiled data about the site characteristics, including site activities, types of contaminants present, other affected media, and depth to groundwater. Notably, most of the sites reviewed had cVOC impacts to both vadose zone soil and groundwater and therefore had separate remedial alternatives for groundwater. The most frequently encountered contaminants included TCE, PCE, metals, and fuel-related compounds. Appendix B provides additional details regarding the characteristics of sites included in the DTSC study.

DTSC reviewed the cleanup alternative decision documents for the sites identified in the database review. The review focused on the cleanup alternatives that were considered and the factors that led to the selected cleanup alternative. DTSC evaluated three variables in detail:

- frequency of selection of the cleanup alternatives (Table 3);
- rationale for selection of the cleanup alternatives (described below); and
- rationale for rejection of the cleanup alternatives considered by the selection process (Table 4, Appendix B).

Based on this review, SVE and excavation/disposal were identified as the proven technologies for sites with cVOCs in vadose zone soil.

Table 4. Cleanup Options Considered for Chlorinated VOCs in Vadose Zone Soil for the Sites Evaluated by DTSC Study

Technology	No. of Site Alternatives Analyses Considering Technology	No. of Site Alternatives Analyses Rejecting Technology	Primary Reasons for Rejection During Cleanup Alternative Analysis[1]						
			Overall Protection	Compliance with ARARs[3]	Reduction of Toxicity, Mobility, Volume	Long-term Effectiveness	Short-term Effectiveness	Cost	Implementability
No Action	90	90	88	3	0	2	0	0	0
ICs[2] Only	34	32	29	2	1	2	0	0	0
Excavation/ Disposal	59	15	0	0	0	1	3	12	10
Soil Vapor Extraction	66	11	0	1	2	6	0	4	4
In Situ Treatment	17	15	1	0	1	10	0	6	10
Containment	20	13	6	2	4	3	0	1	1
Ex Situ Treatment	14	13	1	0	0	5	2	8	9

Notes:
1 National Contingency Plan (NCP) criteria
2 Institutional controls
3 Applicable or relevant and appropriate requirements

Review of the cleanup alternative decision documents indicates that SVE was the most frequently selected cleanup alternative for cVOCs in vadose zone soil. For many sites, the rationale for use of SVE as an interim removal action, or as a final cleanup alternative, was based on USEPA's designation of SVE as the primary presumptive remedy in *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with VOCs in Soils* (USEPA, 1993b). Additional rationale for selecting SVE included the ability to remove cVOC mass at depths greater than could be achieved by excavation/disposal, particularly where cVOCs in the vadose zone posed an on-going threat to groundwater. SVE was less likely to be chosen for sites with shallow groundwater, shallow VOC impacts, or where multiple contaminant groups were present.

Excavation/disposal was the next most frequently selected cleanup alternative for cVOCs in soil. This technology was often selected based on its demonstrated effectiveness in addressing shallow soil impacts or source areas and its ability to provide timely remediation of the site. Based on the sites reviewed, the alternative was selected for impacted soil volumes ranging from about 20 to 30,000 cubic yards and for sites with first groundwater encountered at depths less than about 20 feet bgs. When not selected, excavation/disposal was typically rejected based on cost or ability to implement at a given site.

Seventeen sites included in the DTSC study evaluated one or more *in situ* treatment technologies to address cVOCs in vadose zone soil. Of these sites, only two sites selected an *in situ* treatment technology. One site selected reductive dechlorination to remediate a cVOC source near the capillary fringe; SVE was selected as a contingent remedy. The other site selected a combination of SVE and *in situ* chemical reduction to address both cVOCs and hexavalent chromium. *In situ* treatment approaches were most often rejected based on concerns regarding the ability to effectively treat the cVOCs, unproven effectiveness of some treatment techniques, ability to control resulting impacts to groundwater, and implementability.

Twenty sites included in the DTSC study evaluated containment by capping as a remedial technology for soil impacts. The rationale for selecting containment as part of the cleanup approach was based on the ability to provide sufficient protection and the ability to implement with the current or planned land use. This technology was most frequently rejected based on the inability to reduce or sufficiently control the cVOC contamination, an incompatibility with the current or planned land use, and the requirement for long-term stewardship.

Fourteen sites included in the DTSC study evaluated *ex situ* treatment. All but one site rejected *ex situ* treatment primarily based on cost and implementability considerations. *Ex situ* treatment was selected at one site because the approach was determined to be feasible based on the volume of impacted soil (greater than 200,000 cubic yards) and the ability to reuse the treated soil on-site.

7.2 FOCUSED EVALUATION AND SELECTION OF CLEANUP ALTERNATIVE

Under State and federal law, an analysis of alternatives is required for sites undergoing remediation. Following an initial evaluation, a more detailed and focused evaluation that considers the site characteristics must be conducted on the PT&R alternatives. Because the cleanup alternative screening evaluation presented in Section 6.1 and Appendix B was conducted in accordance with the initial screening requirements of a FS and CMS, it may be used in lieu of a site-specific initial screening evaluation for sites undergoing the streamlined PT&R approach, provided that the use of the PT&R screening evaluation is cited in the administrative record.

The next step in the PT&R approach is to determine whether excavation/disposal or SVE is the most appropriate cleanup alternative. The alternatives evaluation may consist of a site-specific evaluation of the no action, excavation/disposal, and/or SVE alternatives. Focusing on these PT&R alternatives is consistent with the National Contingency Plan (NCP) when:

- the number of alternatives evaluated for a site are reasonable;
- the number of alternatives evaluated are based on the scope, characteristics, and complexity of the site; and
- detailed analyses need only be conducted on a limited number of alternatives that represent viable approaches to the cleanup.

Application of the PT&R approach in this guidance does not preclude consideration of additional cleanup alternatives if determined to be appropriate for a site. However, use of the PT&R approach would still reduce the burden associated with screening and evaluating those additional cleanup technologies being considered.

As illustrated in Figure 3, both alternatives have the potential to allow unrestricted use of the site. However, operation of a SVE system has a longer duration and typically necessitates a regulatory oversight agreement. The focused alternatives evaluation may be prepared under State or federal guidelines, as summarized in Table 5.

In addition to using the DTSC initial alternatives evaluation (Section 7.1), the following site-specific elements of the remedial alternative evaluation process should be addressed in the appropriate remedy selection document:

- identification of applicable federal/State/local requirements (known as applicable or relevant and appropriate requirements (ARARs) under some cleanup processes);
- establishment of site-specific RAOs; and
- evaluation of the PT&R alternatives and the no action alternative against the applicable NCP criteria[2]:

[2] Only the effectiveness, implementability, and cost criteria apply to the DTSC RAW process. For hazardous waste sites, the RCRA-balancing criteria can be used instead of the NCP criteria.

Threshold Criteria
1) overall protection of human health and the environment,
2) compliance with federal/State/local requirements,

Balancing Criteria
3) long-term effectiveness and permanence,
4) reduction of toxicity, mobility or volume through treatment,
5) short-term effectiveness,
6) implementability based on technical and administrative feasibility,
7) cost,

Modifying Criteria
8) State and local agency acceptance,
9) community acceptance.

Additional criteria may also be considered in the remedial alternative evaluation process for a given site. For example, an evaluation of the sustainability of each remedial alternative could be used to identify potential environmental stressors (e.g., resource depletion, physical disturbances) and their associated impacts. The *Interim Advisory for Green Remediation* (DTSC, 2009d) provides additional discussion regarding sustainability as a criterion in the remedy selection process.

Figure 3. Summary of PT&R Cleanup Alternatives

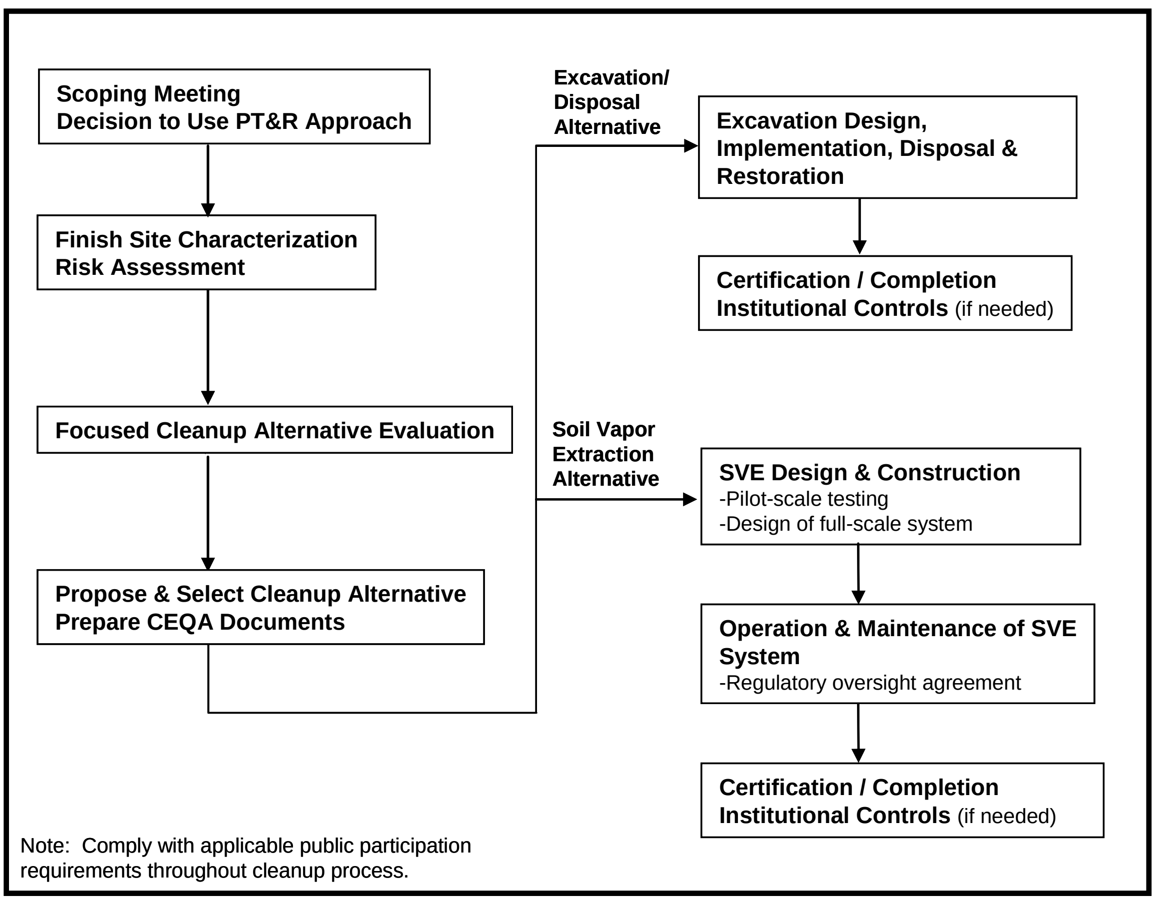


Table 5. State and Federal Guidelines for Focused Alternatives Evaluation

Law	Process	Description	Reference(s)
HSAA	Remedial Action Plan (RAP)[1]	Process for developing, screening, and detailed evaluation of alternative remedial actions for sites. Response action selection document under HSC §25356.1.	DTSC, 1995
	Removal Action Workplan (RAW) [1, 2]	Prepared when a proposed, non-emergency removal action or a remedial action is projected to cost less than $2,000,000. Response action selection document under HSC §25356.1.	DTSC, 1993, 1998
CERCLA	Feasibility Study (FS)	Process for the development, screening, and detailed evaluation of alternative remedial actions for sites.	USEPA, 1988, 1999
	Engineering Evaluation/ Cost Analysis (EE/CA)	Analogous to, but more streamlined than, the FS. Identifies the objectives of the removal action and analyzes the effectiveness, implementability, and cost of various alternatives that may satisfy these objectives.	USEPA, 1993a
RCRA or HWCL	Corrective Measures Study (CMS)[1]	Mechanism used by the corrective action process to identify, develop, and evaluate potential remedial alternatives.	USEPA, 1991c, 1994, 1997c
HSAA, HWCL, RCRA, CERCLA	Interim Measures[1] or Interim Actions	Actions to control and/or eliminate releases of hazardous waste and/or hazardous constituents from a facility prior to the implementation of a final corrective measure or remedy.	

Notes:
1 See Appendix D for link to example or sample documents.
2 A feasibility study is not required for RAW process. However, the RAW should evaluate effectiveness, implementability, and cost of various removal alternatives.
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
HSAA – Hazardous Substance Account Act
HWCL – Hazardous Waste Control Law
RCRA – Resource Conservation and Recovery Act

Regardless of the process used to evaluate and select the cleanup alternative for a site, the alternatives evaluation report generally should:

- discuss and present documentation showing that the PT&R approach is appropriate;
- identify and provide the rationale for the preferred alternative for the site;

- document the site-specific RAOs, regulatory requirements, and the detailed alternatives analysis;
- include preliminary design information for final remedy implementation; and
- discuss how the PT&R approach will be integrated with any groundwater remedial measures or vapor intrusion mitigation measures.

Necessary CEQA documents are usually prepared concurrently with remedy selection documents, if not sooner (see Section 7.4 for further discussion of CEQA requirements). Once approved by DTSC, the draft remedy selection and CEQA documents are circulated for public comment (DTSC, 2003).

The administrative record for the site should, among other things, include the following elements:

- copy of pertinent sections of this PT&R guidance (alternatively, include the PT&R guidance as an electronic appendix to cleanup alternative evaluation document); and
- responses to any comments pertaining to the decision to use the PT&R approach.

7.3 DESIGN AND IMPLEMENTATION OF SELECTED CLEANUP ALTERNATIVE

The operational and technical plans for implementing the selected cleanup alternative should be prepared and submitted to DTSC, either in the remedy selection document (if appropriate) or as separate submittals. Examples of operational plans include the health and safety plan, transportation plans, and confirmation sampling plan. The technical plans contain the specific engineering design details of the proposed cleanup approach, including designs for any long-term structures (e.g., SVE system). As applicable, the design plans should include the design criteria, process diagrams, and final plans and specifications for the structures as well as a description of any equipment to be used to excavate, handle, and transport contaminated soil. Field sampling and analysis plans that address sampling during implementation and confirmation sampling to assess achievement of the RAOs should also be prepared.

Chapters 8 and 9 provide further discussion of the design and implementation for the PT&R alternatives.

7.4 CALIFORNIA ENVIRONMENTAL QUALITY ACT

Remediation of cVOC contamination must meet all applicable local, State and federal requirements, including CEQA. CEQA (Pub. Resources Code, sec. 21000 et seq.) requires public agencies carrying out or approving a project to conduct an environmental analysis to determine if project impacts could have a significant effect on the environment. Public agencies must eliminate or reduce the significant environmental impacts of their decisions whenever it is feasible to do so.

All proposed projects for which the DTSC has discretionary decision-making authority are subject to CEQA if they potentially impact the environment. Examples of approval actions which require CEQA review and documentation include: RAPs, interim measures, RAWs, and corrective actions. For further information, DTSC's CEQA-related polices and procedures are available at www.dtsc.ca.gov.

8.0 DESIGN AND IMPLEMENTATION OF EXCAVATION / DISPOSAL ALTERNATIVE

This chapter describes the approach to be used to remove contaminated soil exceeding site cleanup goals for cVOCs (and other co-located contaminants, if identified). Please recognize that this chapter is intended as guidance. All elements discussed may not be applicable to a given site.

8.1 EXCAVATION, DISPOSAL, AND RESTORATION PLAN

A workplan should be prepared which identifies the logistical procedures and site activities associated with excavation, disposal and site restoration. The actual title of this plan will depend on the cleanup process applied to the site. For example, DTSC's Removal Action Workplan (RAW) process incorporates the required plan elements. DTSC's Remedial Action Plan (RAP) and corrective action processes often require preparation of a separate plan. However, additional streamlining under the PT&R approach could be achieved if the plan is included with another document (e.g., as an appendix to the RAP). For the purposes of this chapter, the workplan is referred to as the "excavation, disposal, and restoration plan" (EDRP). Appendix D provides a link to an EDRP sample and annotated outlines for supporting documents.

Major topics and elements of the EDRP include the following:

- site background
- nature and extent of contamination
- clean-up goals
- objectives and scope of plan
- project organization and schedule
- description of the technical basis for the approach (e.g., why excavation/disposal was selected as the cleanup alternative; estimated extent of excavation, estimated volume of soil to be excavated)
- pre-excavation activities;
- excavation activities
- dust control and air monitoring
- waste management
- backfill and site restoration activities
- quality assurance and quality control (QA/QC)
- health and safety monitoring
- reporting

The EDRP should be supported by the following documents, as applicable, which can be submitted separately or as appendices to the plan:

- site-specific health and safety plan (HASP)
- storm water pollution prevention plan (SWPPP)
- community air monitoring plan
- confirmation sampling plan (see Section 8.5.1, Appendix E)
- public participation plan (see Appendix D)
- stockpile sampling plan
- transportation plan (see Appendix D)

8.2 PRE- EXCAVATION ACTIVITIES

Prior to conducting fieldwork, a series of project management and regulatory tasks should be completed. The general areas that require preparatory activities include:

- site access
- permits
- location of underground utilities
- health and safety
- waste management
- scheduling of staff and equipment resources
- coordination with laboratory for analysis and assessment
- arrangements for sample management
- coordination with off-site disposal facility
- notifications (e.g., agencies, public)

Local jurisdictions, such as municipal public works departments and air districts, often require excavation or grading permits. Depending on the volume of soil to be excavated or disturbed, the RWQCB may specify waste discharge requirements, preparation of a SWPPP, and/or a National Pollution Discharge Elimination System (NPDES) permit. The key elements of the permit application specific to the location of the excavation should be identified. Some municipalities have restrictions on the type of equipment that can be used within a specified distance from water mains, sewer lines, and utility lines. In addition, air districts may require a similar application that identifies the mitigation measures to reduce or eliminate air dispersal of contaminants.

8.2.1 Dust Control and Air Monitoring

The EDRP should discuss the actions (specified in the remedy selection document) that will be implemented to control fugitive dust and cVOC emissions during implementation of the remedy. Dust control is required during construction, demolition, excavation, temporary containment, soil loading for transportation, and other earthmoving activities, including, but not limited to, land clearing, grubbing, scraping, travel on site, and travel on access roads to and from the site.

Most air districts and/or County environmental health departments have recommended or required dust mitigation measures and/or engineering controls. Applicable air pollution regulations, monitoring requirements, performance criteria, and acceptable control strategies should be cited and described. The following items are generally considered:

- wind breaks and barriers, or ceasing work when wind speeds are above a certain level;
- frequent water applications;
- application of soil additives;
- control of vehicle access;
- vehicle speed restrictions;
- covering of piles;
- use of gravel and rumble strips at site exit points to remove caked-on dirt from tires and tracks;
- decontamination and tracking pad to thoroughly wash and decontaminate vehicles before leaving the site;
- wet sweeping of public thoroughfares; and
- cause for work stoppage.

8.2.2 Work Zone and Community Air Monitoring

Dust mitigation measures and/or engineering controls, implemented in conjunction with real-time and time-weighted average dust monitoring, are intended to ensure that dust generated during project activities will not have an adverse impact on site workers, the environment, or the community.

In addition to dust mitigation measures, most air districts and/or County environmental health departments set action levels to control the emission of cVOCs from excavating, grading, and handling (storage and loading) activities. These activities can produce significant volatilization of cVOCs from contaminated soil into the local atmosphere. Air monitoring for cVOC concentrations should be conducted within the exclusion/ decontamination zone for site worker safety, and outside of the soil removal and decontamination/exclusions zones (fence-line monitoring) to ensure that potential exposure of sensitive off-site receptors to site contaminants will not have any adverse effects. Exclusion-zone monitoring of cVOCs for site worker safety is further discussed in Section 8.7, Health and Safety Monitoring.

Community air monitoring (outside of the site fence-line) should be considered for activities occurring near residential communities, schools, and other sensitive receptors (e.g., elderly or high use community areas) to ensure that the implementation of the remedy does not pose a potential threat to off-site receptors. Site-specific risk-based action levels should be calculated, in consultation with DTSC, and included in the design.

8.3 EXCAVATION ACTIVITIES

8.3.1 Cal-OSHA Standards for Trenching and Excavations

The EDRP should address the applicable California Division of Occupational Safety and Health (Cal-OSHA) safety requirements for excavations (Cal. Code Regs., tit. 8, §1540, §1541, §1541.1). These requirements state that workers exposed to potential cave-ins must be protected by shoring, sloping, or benching the sides of the excavation, or placing a shield between the side of the excavation and the work area. These safety standards also provide for protection of the stability of adjacent structures. Any excavation four feet or deeper must have adequate means of access/egress every 25 feet of lateral travel from workers. Excavations greater than four feet deep require testing for hazardous atmospheres and protection from hazards associated with water accumulation. Entry into some excavations/ trenches may require a Cal-OSHA permit and compliance with Cal-OSHA regulations for trenching and excavation.

8.3.2 Surface Water Control Measures

If there is the potential for rainfall during the excavation activities, the EDRP should address surface water runoff, erosion control, and sediment control measures. These measures should conform to State and local requirements and should provide for segregation of surface water runoff from impacted and non-impacted areas.

8.4 WASTE MANAGEMENT

8.4.1 Management and Profiling of Excavated Soil

Excavated soil should be managed in accordance with applicable State and federal requirements, and as recommended in *Management of Remediation Wastes Under RCRA* (USEPA, 1998). Excavated soil may be hauled directly off site for disposal (provided arrangements have been made with a disposal facility) or may be stockpiled on site for further profiling. The EDRP should describe the measures that will be used to control emissions during soil handling and the measures that will be used to minimize mixing of soil containing higher COC concentrations with less impacted soils. A schematic or scaled map of the areas to be excavated and the locations where soil will be stockpiled should be included. Excavated soil should be segregated and stockpiled based on the existing site data. Stockpiles are typically segregated according to the disposal options (see Table 6).

Table 6. Disposal Alternatives for Excavated Soil Under the PT&R Approach

LEVEL OF CONTAMINATION	DISPOSAL ALTERNATIVES
Concentrations below acceptable risk levels	Can be used to backfill the original excavation
Impacted at levels above acceptable risk levels but below hazardous levels (nonhazardous solid waste)	Off-site disposal at Class I, Class II, or Class III landfill (depending on their waste acceptance criteria)
RCRA hazardous waste or California-only hazardous waste	Treatment to meet land disposal restrictions may be required before off-site disposal at Class I landfill. See text for further discussion.

Temporary stockpiles should be managed as identified in the EDRP. The plan should comply with the applicable requirements of the California Code of Regulations, title 22, division 4.5 and stockpiling requirements for remediation waste staging found in Health and Safety Code Section 25123.3(b)(4)(B). The EDRP should designate the locations for placement of stockpiles, address measures to prevent migration and/or dispersal of the soil (e.g., liners, covers), describe the measures that will be used to control emissions, and identify the appropriate distance from the upper edge of any excavation. Representative samples should be collected and analyzed from the stockpiles to verify that the soil has been appropriately segregated and categorized.

If identified as a RCRA listed or characteristic waste or a California-only hazardous waste, contaminated soil that is excavated must be managed and disposed as such. Off-site management for RCRA hazardous wastes must be disposed in a landfill authorized to accept RCRA hazardous waste and must meet any applicable land disposal restrictions (LDRs). If the excavated soil exceeds specified LDR concentrations, the hazardous wastes must be treated to meet specific LDRs limits prior to land disposal. In addition, if the soil is a RCRA characteristic waste, all other underlying hazardous constituents found in the soil must meet their associated LDRs prior to disposal. Refer to *Management of Remediation Wastes Under RCRA* (USEPA, 1998) for optional LDR treatment standards for contaminated soils (typically ten times the concentration levels for a generated waste). If the excavated soil is below specified LDR concentrations, the soils do not need to be treated prior to land disposal and can be disposed of appropriately at a Class I landfill. Soil identified as California only hazardous waste is disposed of in a Class I landfill.

The sampling results from the soil stockpiles must be included in the waste profile form for the landfill operators to review and determine if the profile meets its acceptance criteria. Upon acceptance by a landfill, the stockpiled soil is loaded into the transport container (e.g., truck, rail car, bin) and transported to the landfill with appropriate documentation (e.g., under a hazardous waste manifest and LDR notification/ certifications for a Class I landfill, under a bill of lading for a Class II landfill).

8.4.2 Loading and Transportation

Soil transported for offsite management or disposal must be transported in accordance with applicable State and federal laws. Loading of transport containers should be adjacent to stockpiles or excavations, just outside designated exclusion zones. Any soil falling to the ground surface during loading should be placed back into the container. Loaded containers should be inspected to ensure that they are within acceptable weight limits and should be covered and inspected prior to departure to minimize the loss of materials in transit. The waste profile analyses should accompany the shipping document (i.e., bill of lading or hazardous waste manifest) to the offsite facility. Appendix D provides a link to an annotated outline for a transportation plan.

8.5 BACKFILL AND RESTORATION

Backfill operations can begin once the RAOs have been achieved, as demonstrated through confirmation sampling. Excavated areas should be restored to be consistent with future use and graded to ensure proper runoff.

8.5.1 Confirmation Sampling

Confirmation samples are collected to determine if the RAOs have been achieved and thus whether the removal action is completed. The scope of confirmation sampling activities is a function of the site-specific RAOs, the media to be sampled, and potential land re-use scenarios (e.g., residential, industrial). Appendix E provides further discussion of confirmation sampling for soil excavations.

Confirmation sampling activities should be conducted in accordance with an approved confirmation sampling plan (see Appendix E for annotated outline). Depending on site-specific circumstances and/or the site cleanup process, the confirmation sampling plan can be included as an appendix to a document (e.g., EDRP), incorporated into a document (e.g., RAW), or prepared as a standalone document. The plan and sampling activities should be prepared and implemented in accordance with standard geologic and engineering principles and practices using appropriately licensed and experienced professionals.

8.5.2 Borrow Source Evaluation

Borrow source evaluation should address the physical and chemical characteristics of the soil. Backfill soils should have physical properties consistent with engineering requirements for the planned site use. For example, the International Building Code typically requires a compaction between 90 and 95 percent. When selecting material for backfilling excavated areas, steps should be taken to minimize the chance of introducing soil to the site that may pose a risk to human health and the environment. As a general rule, fill should not be obtained from industrial areas, from sites undergoing environmental cleanups, or from commercial sites with potential impacts (e.g., former service stations, dry cleaners).

The *DTSC Information Advisory, Clean Imported Fill* (DTSC, 2001) suggests that two approaches can be used to demonstrate acceptable backfill materials: (1) providing appropriate documentation and conducting analyses as needed; or (2) collecting samples from the borrow area or borrow area stockpile and analyzing the samples for an appropriate list of parameters.

The selected analytes should be based on the source of the fill and knowledge of the prior land use. Table 7 summarizes potential contaminants based on the fill source area.

Table 7. Potential Contaminants Based on Land Use in Fill Source Area

FILL SOURCE AREA	POTENTIAL TARGET COMPOUNDS
Land near an existing freeway	metals, PAHs
Land near a mining area or rock quarry	metals, asbestos, pH
Agricultural land	pesticides, herbicides, metals
Residential or commercial land	VOCs, SVOCs, TPH, PCBs, metals, asbestos

From *DTSC Information Advisory, Clean Imported Fill* (DTSC, 2001)

A standard laboratory data package, including the QA/QC sample results, should accompany all analytical reports. Contaminants detected in the fill material should be evaluated for risk in accordance with the *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 1994) or the methods described in Chapter 5. If contaminant concentrations exceeding acceptance criteria are identified in the soil, the fill should be deemed unacceptable and new fill material should be obtained, sampled, and analyzed.

Fill documentation should include detailed information on the previous land use(s) in the area from which the fill is taken, the findings of any environmental site assessments, and the results of any testing. If the documentation is inadequate, samples of the fill material should be collected and analyzed for an appropriate list of parameters. This may be the best alternative when large volumes of fill material are anticipated or when larger areas are considered as borrow areas.

If limited fill documentation is available, samples should be collected from the potential borrow area and analyzed for an appropriate list of parameters. If fill material is not characterized at the borrow area, it will need to be stockpiled until analyses have been completed. Table 8 provides recommended sampling frequencies for the fill soil. In general, approximately one sample should be collected and analyzed per truckload. This sampling frequency may be modified upon consultation with appropriate regulatory agencies if all fill material is derived from a common borrow area.

Composite or incremental sampling for fill characterization may or may not be appropriate, depending on the quality and homogeneity of the source/borrow area and the potential contaminants. The *DTSC Information Advisory, Clean Imported Fill* (DTSC, 2001) provides further discussion on the use of composite samples for certain contaminant groups.

Table 8. Recommended Fill Material Sampling

EXTENT OF INDIVIDUAL BORROW AREA	NUMBER OF SAMPLES[1]
2 acres or less	Minimum of 4 samples
2 to 4 acres	Minimum of 1 sample for every 0.5 acres
4 to 10 acres	Minimum of 8 samples
Greater than 10 acres	Minimum of 8 locations with 4 subsamples per location
VOLUME OF BORROW AREA STOCKPILE	**NO. OF SAMPLES**
Up to 1,000 cubic yards	1 sample per 250 cubic yards
1,000 to 5,000 cubic yards	4 samples for first 1,000 cubic yards; 1 sample per each additional 500 cubic yards
Greater than 5,000 cubic yards	12 samples for first 5,000 cubic yards; 1 sample per each additional 1,000 cubic yards.

Notes:

1 The number of samples needed to characterize fill material is a site-specific decision.
From *DTSC Information Advisory, Clean Imported Fill* (DTSC, 2001)

8.6 QUALITY CONTROL / QUALITY ASSURANCE

The EDRP should address QA/QC procedures that will be followed during the excavation activities. For example, the EDRP should address field oversight and reporting, field documentation, and confirmation sampling. If a QAPP was prepared during the characterization phase, the plan may be amended to address the pertinent changes for the EDRP.

8.7 HEALTH AND SAFETY MONITORING

The HASP addressing site-specific excavation, restoration, and the health and safety issues should be included or referenced in the EDRP. The health and safety requirements should apply to all personnel, including contractors and subcontractors conducting work at the site. The HASP used during site characterization activities may be amended to include excavation and restoration activities. The HASP should be prepared in accordance with the requirements of California Code of Regulations, title 8, section 5192 and all applicable federal, State and local laws, ordinances, and regulations and guidelines.

The HASP should at a minimum address the following:

- identification of activities being carried out, the associated risks, and the measures in place to prevent injury;
- names and titles of personnel in charge;
- emergency action plan;
- location of HASP (a copy should be on site at all times);
- on-site safety awareness training for all personnel for all field activities identified (e.g. tail gate meetings and frequency);
- identification of hazards (job hazard analysis) and requirements for documentation and correction of hazards;
- air monitoring requirements to identify and measure site contaminant concentrations generated during the soil removal and decontamination activities and guide the selection of personal protective equipment;
- appropriate personal protective equipment and safety systems for each site activity identified; and
- assurance that all workers comply with the rules to maintain a safe work environment (e.g., disciplinary methods for workers who fail to comply).

8.8 COMPLETION REPORT

The EDRP should briefly identify the key elements that will be covered in a work completion report[3] (completion report) along with the anticipated date of submittal. The completion report should be prepared in conformance with standard geologic and engineering principles and practices using appropriately licensed and experienced professionals. A link to an annotated outline for the completion report is provided in Appendix D. At a minimum, the report should provide the following:

- summary of the work performed;
- any difficulties or unexpected conditions encountered;
- deviations from the approved workplan;
- the results of post-excavation sampling (i.e., before backfilling and restoration) and compliance with performance standards;
- determination as to whether the RAOs were met;
- results of the post-excavation evaluation for cVOCs (if applicable, see Section 6.5);
- written and tabular summary of disposal activities;
- as-constructed drawings and results of post-restoration activities, if applicable;
- health and safety activities including any analytical results;
- compliance with all permit requirements;
- copies of permits for the project; and
- copies of signed manifests and bills of lading.

[3] The title of this document will vary depending on the cleanup process.

9.0 DESIGN AND IMPLEMENTATION OF SOIL VAPOR EXTRACTION ALTERNATIVE

For sites that have selected SVE as an interim response action or as part of the remedy, this chapter describes the approach that could be used to design and implement SVE systems for the remediation of cVOCs in a manner that achieves site-specific RAOs. The intent is to enhance the efficiency, but not replace, site-specific decisions made on the basis of individual site characteristics, applicable laws and regulations, and the principles of good engineering design. Appendix C supplements this chapter by providing additional considerations and resources for the design and implementation of SVE systems. Please recognize that this chapter and Appendix C are intended as guidance. All elements discussed may not be applicable to a given site.

The content of this chapter is largely based on, and specifically recommends the use of, the U.S. Army Corps of Engineers (USACE) *Engineering and Design - Soil Vapor Extraction and Bioventing, EM-1110-1-4001* (USACE Manual; USACE, 2002). Please note that the USACE Manual has been developed for all nature of sites and therefore addresses multiple technical issues that are not relevant to the PT&R approach for cVOCs.

This chapter may be used as a checklist of actions that may be required in the implementation of SVE systems. Applicable sections of the USACE Manual should be referenced for details. In addition, useful reference materials relating to SVE may be obtained from the USEPA or the Air Force Center for Engineering and the Environment (AFCEE) websites (www.clu-in.org; www.afcee.af.mil).

9.1 SITE CHARACTERISTICS FAVORABLE FOR EFFECTIVE SVE SYSTEMS

As discussed in Section 3.2, certain site conditions favor effective application of SVE for cleanup of cVOCs in vadose zone soils, including:

- relatively homogeneous, permeable soils
- relatively low moisture content soils
- adequate vadose zone thickness
- relatively small capillary fringe thickness
- cVOCs located above capillary fringe
- low soil organic carbon content
- volatile contaminants

9.2 GENERAL CONSIDERATONS FOR SVE IMPLEMENTATION

9.2.1 Remedial Action Objectives

SVE systems can be operated to achieve a variety of RAOs, including the following common examples:

- removing as much cVOC mass as feasible prior to application of other remedial technologies

- removing cVOC mass to decrease cVOC emissions during a subsequent soil excavation
- removing cVOC mass posing an on-going threat to groundwater
- controlling vapor flow / mass removal around a building having a potential vapor intrusion risk
- achieving health risk-based cleanup goals

The range in potential RAOs results in differences in the performance metrics that are used to evaluate the success of the SVE system and to determine when it is appropriate to shutdown the system. For some RAOs, the performance metric could be based on the estimated mass remaining in the subsurface and/or a mass removal rate. For other RAOs, the performance metric could be based on demonstrating achievement of numerical risk-based cleanup goals.

9.2.2 Transitioning from Interim Removal Action to Final Remedy

To provide near term reduction of cVOC mass posing a risk to human health, the environment, and/or groundwater, SVE is often implemented as an interim removal action (also referred to as an interim measure under some cleanup processes) taken prior to selection and implementation of the final remedy. The SVE system may or may not be included as part of the final remedy. For example, SVE may be excluded from the final remedy if site-specific RAOs are achieved during the interim removal action or if SVE proves ineffective for site conditions. For sites requiring on-going remediation of cVOCs in the vadose zone, SVE can be included in the alternatives analysis for the final remedy (see Section 7.2) and, if appropriate, selected as the final remedy.

9.2.3 Coordination with Groundwater Remedy

As illustrated by the DTSC study discussed in Section 7.1, cVOC releases commonly generate both soil vapor and groundwater plumes. Depending on site conditions, the soil vapor and groundwater plumes have the potential to interact during the cleanup action. Offgasing of cVOCs from groundwater can act as an on-going source of cVOCs to the vadose zone. Likewise, a vapor plume can continue to contribute cVOC mass to groundwater. The PT&R approach should be coordinated with the groundwater remedy so that cVOCs in groundwater do not recontaminate vadose zone soils and vice versa.

The SVE system may not be effective in removing contamination near the capillary fringe or water table because the higher moisture content decreases air permeability and inhibits cVOC mass removal. Where a significant mass of cVOCs occurs in the capillary fringe or near the water table, additional remedial measures that target this zone may be needed and/or the contamination may need to be addressed by the groundwater remedy.

9.2.4 Vapor Intrusion

SVE systems may be implemented to reduce or alleviate vapor intrusion into buildings. However, it is important to recognize that advective transport of cVOC vapors by SVE system operation potentially could direct cVOC vapors toward or beneath occupied buildings, and possibly affect the indoor air quality which might otherwise be unaffected. These potential effects should be considered during the system startup and in the operation and maintenance (O&M) plan. Permanent shallow soil vapor monitoring points adjacent to the buildings and/or beneath building foundations may be needed to assess the potential for the SVE system to affect indoor air quality.

The design and operation of the SVE system should be coordinated with vapor intrusion mitigation systems in nearby buildings (DTSC, 2009a). Consideration should be given to potential conflicting needs, infrastructure needs, and project schedules as well as the potential for SVE system operation to affect the performance of these vapor intrusion mitigation systems.

9.2.5 Licensure Requirements

SVE systems should be designed, built, installed, operated, and maintained in conformance with standard geologic, engineering, and construction principles and practices using appropriately licensed and experienced professionals.

9.3 SVE IMPLEMENTATION ELEMENTS

This section briefly describes the major elements of the SVE system design and implementation process. The section subheadings are generally consistent with headings in the USACE Manual which should facilitate finding the topic in the USACE Manual for further details.

9.3.1 Characterization and Technology Screening

The primary criteria in selecting SVE technology options are air permeability of the porous medium and volatility of the contaminants. Principal data needs include:

- nature and extent of contamination
- CSM
- soil matrix properties
- air permeability
- organic carbon content
- moisture content
- depth to groundwater
- thickness of capillary fringe

Other considerations are site conditions that may affect the SVE system design or performance (such as building locations, utilities, infrastructure, pavement, accessibility, etc.). Additional considerations for technology screening include cost, implementation, and regulatory constraints and objectives.

Because cVOCs are the main COC considered under the PT&R approach, the technology screening process focuses on the treatment options for the extracted soil vapors. Appendix C provides additional information regarding potential treatment options.

The qualitative and quantitative information obtained during site characterization (Section 4.2.2) and the evaluation of the applicability of the PT&R approach (Section 3.4) should be sufficient to determine whether it is appropriate to use SVE.

9.3.2 Pilot-Scale Testing for SVE System

Pilot-scale testing is performed as a means of gathering important design information and to determine field-scale air-flow behavior. This testing usually measures pressures, flow rates, contaminant concentrations, and other parameters during air pumping tests. Typically, the pilot-scale testing is conducted as a discrete activity with a specific pilot test workplan and pilot test report. However, on a case-by-case basis, DTSC may consider proposals to go directly to full-scale application (forgoing a discrete pilot-scale test phase) if:

- an adequate soil vapor monitoring network is constructed as part of the initial system design;
- the design plan includes provisions for future system modification based on operational data;
- the design plan includes a detailed strategy and procedures for system startup, testing, validation, and commissioning;
- a system validation and startup report (containing the information typically presented in a pilot-scale test report) is submitted after implementation of the system startup and proveout; and
- DTSC is consulted and concurs with the decision.

Basic activities during a pilot test (or equivalent system validation/startup testing) include:

- determine design data needs;
- develop testing strategy;
- prepare test plan (e.g., pilot-scale test workplan);
- test performance and data analysis; and
- prepare test report (e.g., pilot test report, system validation and startup report).

Considerations for pilot or system validation/startup testing include:

- documentation of operational vacuum parameters to define initial SVE system effectiveness;
- implementation of monitoring well infrastructure consisting of multi-depth, discrete interval monitoring wells

  - located at appropriate distances from extraction wells (e.g., wells located closer to and farther away from the expected zone of influence from the extraction well) and
  - discretely screened in both permeable and the most recalcitrant soils;

- construction of monitoring well infrastructure having dedicated polyvinyl chloride materials (typically two inch diameter) with appropriate screen intervals (typically a three foot minimum screen interval as opposed to tubing with a six inch screen); and
- construction and blower capacity to add wells to the SVE system should operational data indicate the need for additional extraction well capacity.

9.3.3 Design of Full-Scale SVE System

A full-scale SVE system should be designed to maximize the removal of cVOCs from the subsurface in the most efficient and timely manner. The following data should be collected, using appropriate DQOs, to support the design:

- speciated chemicals and total VOCs present in soil vapor
- properties of the target compounds in the soil vapor
- location of cVOCs in relation to the water table
- characteristics of soil in the zone of interest
- advective and diffusive rate-limiting factors in cVOC removal
- design airflow rate and flow path to remove the contaminants from the subsurface

The major components of the SVE design process include:

- SVE design strategy
- design basis (including SVE system objectives and performance metrics)
- well location (see Appendix C for recommendations regarding well placement)
- overall pneumatic considerations
- well construction
- piping, valves, and manifold system
- condensate control
- particulate filters
- blower silencers
- blowers and vacuum pumps
- instrumentation and process control
- electrical systems planning
- effluent treatment methods (see Appendix C for discussion of common methods),
- water and vapor condensate storage, treatment, and disposal methods (including secondary containment)
- SVE treatment system housing
- emissions monitoring / control
- local air permit requirements
- noise control

Some of these design components offer an opportunity to consider green remediation concepts. For additional discussion, see the *Interim Advisory for Green Remediation* (DTSC, 2009d).

9.3.4 SVE System Construction

SVE system construction entails installation of all SVE system infrastructure including vapor extraction wells, vapor monitoring wells, piping, controls, utilities, and treatment system components. The design plan should include a narrative description of the SVE system and should be supported by appropriate calculations, drawings, and figures. Refer to the USACE Manual for details of the following design elements:

- applicable USACE and USEPA design policy and requirements
- design document content (see also Section 9.4.3)
- system construction / construction oversight

Applicable permits (typically from the local air district) should be obtained prior to system construction and operation. A construction completion report should be submitted to DTSC documenting the full-scale SVE system (see Section 9.4.4).

9.3.5 System Startup and Commissioning

During the SVE system startup and commissioning phase, the SVE system is evaluated to determine whether the system has been constructed as designed, equipment is operating within specifications, and if any modifications are needed. In addition, initial performance data are collected and evaluated. Appendix C outlines considerations for initial optimization of the SVE system.

The major elements to be addressed by this phase include:

- collection of baseline vapor data in all extraction and monitoring wells prior to system startup;
- equipment shakedown and testing;
- if the pilot test phase is incorporated into the system validation/startup process, the data requirements identified in Section 9.3.2 should be collected;
- system start-up / full-scale optimization;
- basic monitoring protocols for the SVE system that can be carried forward into long-term operation of the system; and
- data evaluation.

The system startup and commissioning phase should be documented in a system startup and validation report (see Section 9.4.5).

The design plan should include an overall strategy for commissioning, shakedown, and start-up activities of the SVE system. A start-up plan (or procedure) should consider the design objectives and system complexity and should include:

- checklists for each component or parameter that will be tested;
- minimum number of hours that each system, operation, or parameter should be tested; and
- how each component or system should be tested (i.e., what measurements should be made).

At the end of the start-up phase, the entire SVE system should be operating normally according to specifications.

9.3.6 Operation, Maintenance, and Monitoring

An O&M plan should be developed for the SVE system. The plan should provide the O&M strategy, operational guidelines, monitoring strategy, and system modification and optimization considerations. The O&M plan should be as flexible as possible and should include contingencies for possible operational problems. The elements of an O&M plan include:

- O&M strategy
- system objectives and performance metrics
- monitoring (including DQOs for each type of monitoring activity)
- well maintenance
- SVE treatment system O&M considerations
- SVE treatment system operation schedule
- recordkeeping
- continued system evaluation to ensure achievement of RAOs
- optimization strategy for SVE system
- reporting requirements (e.g., status reports, notifications)

The O&M plan should address routine procedures for operation, maintenance, sampling, analysis, and system modification, as well as non-routine activities such as troubleshooting and shutdown. The design strategy, and the assumptions adopted in the design, should be included in the operational requirements of the system. In addition, the plan outlines the project needs, site considerations, and system design.

The O&M plan should include strategies and/or a decision process for optimizing or improving the performance of the treatment system. Examples of potential system optimization or performance improvement measures might include increasing the SVE well density, operating in a pulse mode (see Appendix C), operating only SVE wells that are removing significant cVOC mass, and measures to increase air flow in areas with the highest cVOC concentration. The O&M plan should also include criteria or a decision framework for initiating rebound assessment (see Section 9.3.7) and for permanent system shutdown (see Section 9.3.8).

The O&M plan should address the steps to be taken should performance assessments indicate that the SVE system is insufficient to achieve site-specific RAOs (such as when the design basis zone of capture was inadequate or when cVOC concentrations are persistently elevated after prolonged system operation). Inadequate performance assessments may warrant system modifications and/or re-design (including additional extraction well installation).

9.3.7 Rebound Assessment

Rebound assessment is conducted when cVOC concentrations measured in vapor monitoring wells and extraction well effluent (while the system is active) meet the RAOs, and mass removal has become negligible. At this point, the SVE unit is shut down for an appropriate timeframe (see next paragraph) to evaluate whether subsurface concentrations rebound or whether subsurface RAOs have been achieved.

The timeframe for rebound assessment is a site-specific determination. The assessment should be based on data collected over sufficient duration so that the measured soil gas concentrations represent a return to equilibrium conditions and thus are appropriate for determining whether the RAO is met. Some assessment timeframes exceed one year and therefore should be integrated into project plans, especially when contemplating redevelopment. For sites where the rebound assessment period is too long for the planned redevelopment schedule, one option is to reduce the amount of time to observe the rebound response by decreasing the spacing of the vapor monitoring wells.

If soil vapor concentrations indicate a need for further vadose zone remediation during the rebound evaluation period, vapor extraction wells that can influence such areas of the site or zones requiring additional cVOC removal are restarted. Extraction should continue until subsurface vapor concentrations approach RAOs. This cycle continues until: soil gas concentrations in all vapor monitoring wells and extraction well effluent remain below RAOs for an appropriate timeframe (see above); or it becomes apparent that RAOs cannot be attained through SVE, at which point the system could be evaluated for permanent shutdown (see Section 9.3.8).

Appendix C provides additional considerations for rebound assessment.

9.3.8 System Shutdown, Closure, and Cleanup Confirmation

The decision to permanently shutdown a SVE system should be based on data obtained from the treatment system influent as well as depth-specific soil gas data obtained horizontally and vertically throughout the baseline extent of the soil gas plume (i.e., the extent of the plume prior to initiation of the SVE system). The soil gas data can be collected from existing vapor wells and additional soil gas borings (if needed) to ensure adequate coverage of the baseline plume extent. Cleanup confirmation should be based on an appropriate number of sampling events, conducted over an appropriate timeframe (see discussion in Section 9.3.7), to demonstrate that residual cVOC concentrations are stable and achieve the RAOs. Appendix C provides additional discussion of system shutdown, closure, and cleanup confirmation.

The design plan or O&M plan should identify the data requirements and decision framework needed to determine whether the SVE treatment should be shutdown and site RAOs have been achieved. The main elements of SVE system shutdown and cleanup confirmation include:

- shutdown strategy;
- sampling and analysis;
- evaluation of results;
- long-term monitoring requirements;
- rebound assessment (see Section 9.3.7); and
- closure report.

9.4 SVE SYSTEM DOCUMENTS

This section describes various documents that may need to be submitted for DTSC review and approval during the process of evaluating, designing, implementing, and operating a SVE system. Some documents discussed in this section may not be needed for a given site. Documents in addition to those described in this section may also be needed. Each document should include title and signature pages (with appropriate signatures and stamps/licensure) and a table of contents. The documents should be prepared in conformance with standard geologic and engineering principles and practices using appropriately licensed and experienced professionals.

9.4.1 Pilot-Scale Test Workplan

A pilot-scale test workplan should be prepared that addresses the following elements:

- project description
- remedial technology description
- test objectives (including performance metrics)
- experimental design and procedures
- management and staffing
- equipment and materials
- sampling and analysis
- data management
- data analysis and interpretation
- health and safety
- waste management and regulatory compliance
- community relations and public participation strategy
- reporting
- schedule

Appendix C includes an annotated outline for a SVE system pilot-scale test workplan.

9.4.2 Pilot-Scale Test Report

A pilot-scale test report should be prepared that addresses the following elements:

- introduction
- background
- objectives (including performance metrics)
- equipment (including the experimental setup, vapor collection system, vapor treatment systems, and monitoring equipment)
- monitoring and data collection (chemical concentrations, temperature, pressure/vacuum, flow rate, etc.)
- departures from the workplan
- results and discussion of physical parameters (e.g., air permeability, vacuum/ pressure distribution, radius of effective air exchange, vacuum/flow rate correlation)
- results and discussion for chemical parameters (e.g., extracted soil vapor, residual soil, recovered condensate, chemical data quality, emissions)
- conclusions regarding overall effectiveness of SVE
- recommendations for further data collection
- appendices presenting the laboratory analysis reports, QA reports, field data sheets, and well installation and boring logs

Appendix C includes an annotated outline for a SVE system pilot-scale test report.

9.4.3 Full-Scale Design Document

A design document should be prepared for the full-scale SVE system. The timing and mechanism for submitting the design document is a site-specific decision. The design may be submitted to DTSC for review and approval as one document or as separate documents depending on project-specific considerations and process. Based upon project needs, submittal and approval of a “conceptual” plan may be necessary prior to submittal and approval of the final system engineering plans. The system design may require a phased approach (such as discrete pilot-scale testing, system validation, startup testing, and agency review) prior to final approval.

The design document should include the minimum content discussed in this section. Additional content may be required depending upon site-specific conditions and the subsurface cleanup objectives. For example, for sites choosing to forgo the discrete pilot test phase (see Section 9.3.2), the design document should include a detailed protocol for system startup and validation. The design document should also discuss other documents that may be required for its proper implementation.

- **Introduction.** Identify the project, the purpose of the document, and the regulatory-basis for the SVE system.

- **Project Background.** Provide an overview of the rationale for use of SVE, current and future land use considerations, COCs, and other general project considerations. If appropriate, this section should also indicate how the SVE system is integrated with other subsurface remediation and vapor intrusion mitigation efforts.

- **Site Conditions Summary.** Provide an overview of the CSM and other pertinent information along with references to other documents. This section may reference previous documents (e.g., current conditions report, summary reports) which contain more detailed discussion of site conditions. The CSM discussion should summarize the following:
  - site geology
  - previous sampling efforts
  - list of COCs and maximum detected soil gas concentrations
  - plume maps and cross sections
  - remediation efforts and RAOs
  - potential remediation treatment / degradation by-products
  - ambient air quality considerations
  - estimates of the degree of indoor air impacts (such as Johnson and Ettinger modeling results), if applicable

- **Cleanup Goals and Objectives.** Identify the performance metrics and contingency measures for the SVE system. Reference section(s) identifying how the goals and objectives will be monitored and tested. As applicable, identify general institutional control (IC) requirements and/or use restrictions (such as prohibited construction and restricted building modifications).

- **Design Basis.** Identify the design assumptions and criteria to be met by the SVE system.

- **Construction Methods.** Identify the construction methods to be used once the design has been approved, including:
  - construction specifications
  - minimum material specifications
  - installation procedures
  - construction QC procedures
  - post-installation testing procedures

- **Design Calculations and Drawings.** Include the design calculations and drawings for the SVE system, including the basis for the estimated zone of capture.

- **Conceptual Drawings.** Include conceptual drawings indicating building locations, prescribed building envelopes, streets, driveways, hard-scape areas, utility easements, well design and placement, and other infrastructure considerations.

- **Remediation Approach.** Provide a detailed description of the proposed remediation approach, including any phasing (tier approach) concepts (see Section 9.3.5). Also, provide the following information:

  - technical basis for the design of the SVE system
  - construction and implementation requirements
  - any contingent systems which may be required
  - component specifications and verification of ability to meet performance measures
  - detailed testing procedures (including on-the-job instructions)
  - system validation and startup strategy and procedures
  - permit requirements from other agencies (such as a permit to construct and a permit to operate vapor treatment systems)
  - SVE system shutdown and/or exit strategy
  - reporting requirements
  - applicable engineering drawings and system diagrams

- **Implementation Mechanisms.** Address the Land Use Covenant (LUC) requirements, deed restrictions, construction QA/QC, soil management , waste management, transportation, and emission control/monitoring.

- **Financial Responsibility.** Identify the applicable financial responsibility requirements.

- **Health and Safety Plan.** Include a worker HASP that addresses such topics as worker training requirements, protective gear, and monitoring procedures.

- **Operation and Maintenance Plan.** As an appendix or as a separate stand-alone document, include an O&M plan that details the O&M requirements, monitoring requirements, implementation mechanisms, and responsibilities for tasks and final obligations. See Section 9.3.6 for recommended O&M plan content.

Appendix C includes an annotated outline for a full-scale SVE design document.

9.4.4 Construction Completion Report

A completion report should be submitted to DTSC after the full-scale SVE system has been constructed. If applicable, the content of this report could be incorporated into a system validation and startup report (see Section 9.4.5). The report should include as-built drawings of system components, a brief account of field activities associated with system installation and startup, QA/QC data, and other appropriate content to document construction of the SVE system.

9.4.5 System Validation and Startup Report

A system validation and startup report should be submitted that, at a minimum, contains the following:

- introduction
- background
- objectives (including performance metrics)

- SVE system equipment description (layout, drawings, initial calculations, etc.)
- system startup summary (e.g., test results, well configuration, monitoring data, instrument and system settings, flow rates)
- system operations summary (e.g., permit changes, treatment system changeouts, blower operating parameters, O&M activities)
- monitoring and data collection (e.g., chemical concentrations, temperature, pressure/vacuum, flow rate)
- results and discussion of physical parameters (e.g., air permeability, vacuum/ pressure distribution, radius of effective air exchange, vacuum/flow rate correlation)
- results and discussion for chemical parameters (e.g., extracted soil vapor, residual soil, recovered condensate, chemical data quality, emissions)
- O&M reporting
- conclusions regarding overall effectiveness of SVE, including an interpretation of the zone of capture of the system
- recommendations for on-going system operations and data collection
- supporting appendices (e.g., laboratory analysis reports, QA reports, field data sheets, and well installation and boring logs)
- permit compliance on air emissions

Appendix C includes an annotated outline for a system validation and startup report.

9.4.6 Status Reports

Status reports summarizing the performance of the SVE system should be submitted to DTSC at a frequency identified in the O&M plan. Appendix C outlines suggested content for these reports.

9.5 COMPLETION REPORT

Once remediation has been completed and RAOs are achieved (see Section 9.3.8), a completion report should be prepared to verify and document the activities and results of the cleanup. The completion report should be prepared in conformance with standard geologic and engineering principles and practice using appropriately licensed and experienced professionals.

10.0 CERTIFICATION / COMPLETION

When the approved remedy for cVOCs in the vadose zone has been fully implemented, DTSC will confirm through review of performance metrics (including confirmation sampling) that the RAOs have been achieved. The possible determinations are:

- the RAOs have been achieved for cVOCs;
- the response action has been fully implemented, is operating successfully, and on-going O&M is needed until the RAOs are achieved; and/or
- additional cleanup is necessary.

Based on the findings, DTSC will issue a certification letter, a completion letter, or a letter requiring additional work to address cVOCs in the vadose zone.

10.1 SITE CERTIFICATION

When DTSC determines that the approved remedy has been fully implemented, DTSC certifies the satisfactory completion of remedial action activities at the site.

- When DTSC determines that the approved remedy has been fully implemented and the remediation for cVOCs in the vadose zone results in a site restored to unrestricted residential standards, DTSC certifies that the required remedy has been completed and that no further remediation is necessary, unless new information is obtained. The site status on DTSC's EnviroStor database is changed from "Active" to "Certified".
- If the site has been remediated to standards appropriate for restricted use of the property, DTSC issues a certification letter that the site soil has been restored to levels agreed upon in the regulatory decision document. The certification letter is issued after any requirements for a LUC and/or O&M agreement and O&M plan are met. The site status on DTSC's EnviroStor database is changed from "Active" to "Certified/Operation and Maintenance".
- If the approved remedy includes actions requiring operation, maintenance, and monitoring (e.g., SVE systems), DTSC certifies that the remedy has been implemented once: (1) sufficient information has been submitted to verify that the remedy has been implemented and is functioning as proposed in the remedy selection document and in design plans; and (2) any LUC, O&M agreement, and O&M plan requirements have been met. The DTSC certification letter will describe the remedy implemented and will state that DTSC has continuous oversight and the responsible party is required to operate and maintain the measures necessary for on-going protection of public health and the environment. The Site status on DTSC's EnviroStor database is changed from "Active" to "Certified/Operation and Maintenance".

10.2 COMPLETION LETTER FOR INTERIM ACTIONS / INTERIM MEASURES

Removal actions may be implemented as interim actions or interim measures taken to begin the cleanup process while the final remedy is being evaluated and selected. Examples of this include actions taken to reduce the mass of cVOCs in the vadose zone, or actions taken to address cVOCs in the vadose zone while remedies for groundwater are being evaluated. For these cases, the site is not ready for certification following the implementation of these actions. Hence, DTSC will issue a completion letter acknowledging that the PT&R removal action has been implemented and that additional actions are required to address cVOCs at the site.

10.3 ADDITIONAL ACTIONS NEEDED

Achievement of the RAOs outlined in the remedy decision document may not be possible. For these cases, DTSC will issue a letter acknowledging that the removal action was implemented, noting that the RAOs were not achieved, and requiring that the remaining contamination should be addressed through a subsequent response action.

11.0 LONG-TERM STEWARDSHIP

Long-term stewardship applies to sites and properties where long-term management of contaminated environmental media is necessary to protect human health and the environment over time. This includes sites where remediation may take place over several years and sites where contaminated media will remain in place for a much longer period of time. This chapter discusses elements that may be required to meet the needs of long-term stewardship. The elements included in below may not apply to all sites based on site-specific conditions and remedial timeframes.

11.1 INSTITUTIONAL CONTROLS FOR CONTAMINATION REMAINING IN PLACE

ICs are used to stop or reduce the exposure of human and environmental receptors to residual contamination. ICs are non-engineering mechanisms used to ensure that the intended future land use is consistent with site cleanup and engineering controls, and that these measures maintain their integrity and effectiveness.

For sites necessitating ICs, California Code of Regulations, title 22, section 67391.1 requires the property owner to enter into a LUC to ensure that DTSC will have authority to implement, monitor, and enforce the protective restrictions. LUCs allow on-going use of the property as long as the remedy is not compromised by current or future development. LUCs are intended to protect public health and the environment by preventing inappropriate land use, increasing the probability that the public will have information about residual contamination, ensuring that long-term mitigation measures are carried out by protecting the engineering controls and remedy, and ensuring that subsequent owners assume responsibility for preventing exposure to contamination. The LUC should provide for an annual inspection and annual report to ensure that the LUC continues to be protective. The LUC should also provide for preparation and submittal of five-year reviews.

LUCs may include soil management plans to ensure that soil is handled in such a way to prevent human and ecological exposure. These plans address soil excavation, soil stockpiling, stockpile characterization, soil disposal, soil reuse, construction dewatering, worker training, health and safety, and site inspection.

California Code of Regulations, title 22, section 67391.1 requires that a LUC imposing appropriate limitations on land use shall be executed and recorded with the local county recorder's office when hazardous materials, hazardous wastes or constituents, or hazardous substances will remain at the property at levels which are not suitable for unrestricted land use. The regulation requires DTSC to clearly set forth and define land use limitations or covenants in a remedy decision document prior to approving or concurring with any facility closure, corrective action, remedial or removal action, or other response actions. In addition to these regulatory requirements, it may also be prudent to coordinate with the local planning department regarding the LUC requirements. Further information regarding LUCs is available on the DTSC website.

After the LUC is recorded, if a proposed use of the property is inconsistent with the LUC requirements and/or would increase the risk of exposure to contaminants at the site, additional actions must be conducted to ensure that the property meets cleanup standards appropriate for the proposed use. Additional sampling and risk characterization for further cleanup actions may be required, and the LUC may be rescinded or modified as appropriate.

11.2 REGULATORY OVERSIGHT AGREEMENT

A regulatory oversight agreement will be required for the period during which the SVE system is operated and until the site is certified. Examples include Corrective Action Consent Agreements and O&M Agreements.

11.3 OPERATION AND MAINTENANCE PLAN

Any regulatory oversight agreement should reference or include the DTSC-approved O&M plan that outlines the procedures and requirements for on-going O&M of the SVE system. Section 9.3.6 describes selected elements of an O&M plan.

11.4 CONTINGENCY PLAN

Any regulatory oversight agreement should reference or include a contingency plan that will be implemented in the event that an immediate response action is required to ensure protection of human health and the environment. Also, the contingency plan should address steps to be taken if performance assessment indicates that the removal action is insufficient and/or will not achieve the RAOs. The contingency plan may be a stand-alone document or may be included as an element of the O&M plan.

11.5 FINANCIAL ASSURANCE

Financial assurance can be accomplished by several mechanisms and will assure that sufficient monies are available to implement any required corrective action activities and on-going O&M activities, conduct necessary five-year reviews, and pay the regulatory oversight costs associated with those activities and IC implementation. These on-going costs should be included in the cost calculation utilized in the remedy selection process. The USACE Manual discusses considerations for estimating costs of constructing and operating SVE systems.

11.6 FIVE-YEAR REVIEW

The regulatory oversight agreement and the O&M plan should include provisions for conducting five-year reviews. The purpose of the five-year review is to ensure that the remedy remains protective of human health and the environment, is functioning as designed, and is maintained appropriately by O&M activities. The review generally addresses the following questions:

- Is the remedy functioning as intended?
- Are the cleanup objectives, goals, and criteria used at the time of cleanup alternative selection still valid?

- Have there been significant changes in the distribution or concentration of impacted soils at the site?
- Are modifications needed to make the remedy or the O&M plan more effective?

The five-year review may also include a remedy optimization evaluation (e.g., sustainability assessment), as discussed further in the *Interim Advisory for Green Remediation* (DTSC, 2009d).

The scope of the five-year review may be outlined in the O&M plan or in a separate workplan developed for a specific review. The following should be incorporated into the five-year review:

- notification of the community that the review is being conducted;
- inspection of the remedy;
- review of the data demonstrating the performance of the system;
- review of other components of the remedy; and
- preparation of a report that details the findings and recommendations of the review.

The *Comprehensive Five-Year Review Guidance* (USEPA, 2001a) may be a useful resource when conducting these reviews.

Depending on site-specific considerations, the inspection and/or technical assessment may be conducted by DTSC and/or the responsible party. DTSC will review the report and make recommendations, if necessary, to ensure that the remedy remains effective, to identify milestones toward achieving or improving effectiveness, and to provide a schedule to accomplish necessary tasks.

The five-year review report should be prepared in conformance with standard geologic and engineering principles and practice using appropriately licensed and experienced professionals.

12.0 REFERENCES

American Society of Testing and Materials (ASTM). 2004. Standard Practice for Expedited Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites, ASTM D6235 – 04.

California Environmental Protection Agency (Cal/EPA). 1995. Guidance Manuals for Groundwater Investigations. July. 10.39.0.144/SiteCleanup/Ground_Water_Investigations.cfm

Cal/EPA. 2005a. Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil. January. www.oehha.ca.gov/risk/pdf/screenreport010405.pdf

Cal/EPA. 2005b. Use of California Human Health Screening Levels (CHHSLs) in Evaluating Contaminated Properties. January. www.calepa.ca.gov/Brownfields/documents/2005/CHHSLsGuide.pdf

California Department of Toxic Substances Control (DTSC). 1993. Memorandum, Removal Action Workplans (RAWs). September. 10.39.0.144/SiteCleanup/upload/SMP_POL_RAWGuidance.pdf

DTSC. 1994. Preliminary Endangerment Assessment Guidance Manual. January. Reprinted June 1999. Errata sheet at end of Chapter 2.
10.39.0.144/SiteCleanup/Brownfields/upload/SMP_REP_PEA_CH1.pdf
10.39.0.144/SiteCleanup/Brownfields/upload/SMP_REP_PEA_CH2.pdf
10.39.0.144/SiteCleanup/Brownfields/upload/SMP_REP_PEA_CH3.pdf
10.39.0.144/SiteCleanup/Brownfields/upload/SMP_REP_PEA_Appendix.pdf

DTSC. 1995. Official Policy / Procedure, Remedial Action Plan (RAP) Policy, EO-95-007-PP. November. 10.39.0.144/LawsRegsPolicies/Policies/SiteCleanup/upload/eo-95-007-pp.pdf

DTSC. 1996a. Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities, Part A: Overview. July. www.dtsc.ca.gov/AssessingRisk/upload.overview.pdf

DTSC. 1996b. Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities, Part B: Scoping Assessment. July. www.dtsc.ca.gov/AssessIngRisk/upload.scope.pdf

DTSC. 1998. Guidance Memorandum, Removal Action Workplans – Senate Bill 1706. September 23. 10.39.0.144/SiteCleanup/upload/SMP_POL_RAWGuidance.pdf

DTSC. 2001. Information Advisory, Clean Imported Fill Material. October. 10.39.0.144/Schools/upload/SMP_FS_Cleanfill-Schools.pdf

DTSC. 2003. Updated Public Participation Policy and Procedures Manual. April. 10.39.0.144/LawsRegsPolicies/Policies/PPP/PublicParticipationManual.cfm

DTSC. 2004. Guidance Document for the Implementation of United States Environmental Protection Agency Method 5035: Methodologies for Collection, Preparation, Storage, and Preservation of Soils to be Analyzed for Volatile Organic Compounds. November. 10.39.0.144/SiteCleanup/upload/HWMP_Guidance_Method-5035.pdf

DTSC. 2005a[4]. Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Revised. February. 10.39.0.144/AssessingRisk/upload/HERD_POL_Eval_Subsurface_Vapor_Intrusion_interim_final.pdf

DTSC. 2005b. DTSC Human Health Risk Assessment Note 1: Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Military Facilities. October. www.dtsc.ca.gov/AssessingRisk/upload/HHRA_Note1.pdf

DTSC. 2009a. Vapor Intrusion Mitigation Advisory. April. Section 6.3.4 revised May 8, 2009. 10.39.0.144/SiteCleanup/upload/VI_Mitigation_Advisory_Apr09r.pdf

DTSC. 2009b. DTSC Human Health Risk Assessment Note 3: DTSC Recommended Methodology for Use of U.S. EPA Regional Screening Levels (RSLs) in Human Health Risk Assessment Process at Department of Defense Sites and Facilities. November. www.dtsc.ca.gov/AssessingRisk/upload/HHRA-Note-3.pdf.

DTSC. 2009c. DTSC Human Health Risk Assessment Note 4: Screening Level Human Health Risk Assessments. November. www.dtsc.ca.gov/AssessingRisk/upload/HHRA-Note-4.pdf

DTSC. 2009d. Interim Advisory for Green Remediation. December. www.dtsc.ca.gov/OMF/upload/GRT_Draft_-Advisory_-20091217_ac1.pdf

DTSC/ Los Angeles Regional Water Quality Control Board (LARWQCB). 2003[4]. Advisory – Active Soil Gas Investigations. January. 10.39.0.144/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf

Environmental Security Technology Certification Program (ESCTP). 2008. Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater. July. www.gsi-net.com/Publications/ER-0530-FAQ.pdf

Interstate Technology and Regulatory Council (ITRC). 2003. Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management. December. www.itrcweb.org/Documents/SCM-1.pdf

ITRC. 2007. Vapor Intrusion Pathway: A Practical Guide. January. www.itrcweb.org/Documents/VI-1.pdf.

U.S. Army Corps of Engineers (USACE). 2002. *Engineering and Design - Soil Vapor Extraction and Bioventing* (EM 1110-1-4001). June. http://140.194.76.129/publications/eng-manuals/em1110-1-4001/toc.htm

U.S. Environmental Protection Agency (USEPA). 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004. OSWER Directive 9355.3-01. October. www.epa.gov/superfund/resources/remedy/pdf/540g-89004-s.pdf

USEPA. 1989. Interim Final Risk Assessment Guidance for Superfund: Volume I--Human Health Evaluation Manual (Part A, Baseline Risk Assessment). EPA/540/1-89/002. December. www.epa.gov/oswer/riskassessment/ragsa/index.htm www.epa.gov/oswer/riskassessment/superfund_hh_exposure.htm

[4] Revision pending. Check DTSC web-site (www.dtsc.ca.gov/SiteCleanup/Vapor_Intrusion.cfm) for most current version.

USEPA. 1991a. Risk Assessment Guidance for Superfund: Volume 1—Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives). Interim. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA/540/R-92/004. Publication 9285.7-01C. December. www.epa.gov/oswer/riskassessment/ragsc/index.htm

USEPA. 1991b. Risk Assessment Guidance for Superfund: Volume 1—Human Health Evaluation Manual (Part C), Quick Reference Fact Sheet. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Publication 9285.7-01CFS. December.

USEPA. 1991c. Guidance for RCRA Corrective Action Decision Documents: The Statement of Basis, Final Decision, and Response to Comments. OSWER Directive 9902.6. February.

USEPA. 1993a. Guidance for Conducting Non-Time Critical Removal Actions Under CERCLA. EPA 540-R-93-057. August.

USEPA. 1993b. Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites With Volatile Organic Compounds in Soils. EPA 540-F-93-046.

USEPA. 1994. RCRA Corrective Action Plan. OSWER Directive 9902.3-2A. May www.epa.gov/epaoswer/hazwaste/ca/resource/guidance/gen_ca/rcracap.pdf

USEPA. 1996. User's Guidance to VOCs in Soils Presumptive Remedy. EPA/F-96/008. July. www.epa.gov/superfund/policy/remedy/presump/finalpdf/vc.pdf

USEPA. 1997a. Presumptive Remedy: Supplemental Bulletin Multiphase Extraction (MPE) Technology for VOCs in Soil and Groundwater. EPA 540-F-97-004. April. www.epa.gov/superfund/health/conmedia/gwdocs/voc/pdfs/finalapr.pdf

USEPA. 1997b. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments – Interim Final. EPA-R-97-006. June. www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm

USEPA. 1997c. Rules of Thumb for Superfund Remedy Selection. August. www.epa.gov/superfund/resources/rules/rulesthm.pdf

USEPA. 1998. Management of Remediation Wastes Under RCRA. EPA530-F-98-026. October. www.epa.gov/epaoswer/hazwaste/state/policy/pspd_mem.pdf

USEPA. 1999. A Guide to Preparing Superfund Proposed Plans, Record of Decisions, and Other Remedy Selection Decision Documents. EPA 540-R-98-031. July. www.epa.gov/superfund/resources/remedy/rods/pdf/sectiona.pdf

USEPA. 2001a. Comprehensive Five-Year Review Guidance. EPA 540-R-01-007. June. www.epa.gov/superfund/accomp/5year/guidance.pdf

USEPA. 2001b. Data Quality Objectives Decision Error Feasibility Trials Software (DEFT)-Users Guide, EPA QA/G-4D. September. EPA/240/B-01/007. www.epa.gov/quality/qs-docs/g4d-final.pdf

USEPA. 2002a. Guidance on Choosing a Sampling Design for Environmental Data Collection, for Use in Developing a Quality Assurance Project Plan, EPA QA/G-5S. EPA/240/R-02/005. December. www.epa.gov/quality/qa_docs.html

USEPA. 2002b. OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance). EPA530-D-02-004. November. www.epa.gov/osw/hazard/correctiveaction/eis/vapor.htm

USEPA. 2006a. Guidance on Systematic Planning Using the Data Quality Objective Process, EPA QA/G-4. EPA/240/B-06/001. February. www.epa.gov/quality/qa_docs.html

USEPA. 2006b. Data Quality Assessment: A Reviewer's Guide, EPA QA/G-9R. EPA/240/B-06/002. February. www.epa.gov/quality/qa_docs.html

USEPA. 2006c. Systematic Planning: A Case History for Hazardous Waste Site Investigation (QA/CS-1). EPA/240/B-06/0004. February. www.epa.gov/quality/qs-docs/casestudy-final.pdf

USEPA. 2006d. Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S. EPA/240/B-06/003. February. www.epa.gov/quality/qa_docs.html

GLOSSARY

Brownfields. Brownfields are properties that are contaminated, or thought to be contaminated, and are underutilized due to perceived remediation costs and liability concerns.

Capillary fringe. Zone of soil immediately above the water table. The soil pores in this zone act like capillary tubes casing groundwater to rise within the pore. The water in this zone is retained under suction. At the base of the capillary fringe most soil pores are completely filled with water. At the top of the capillary fringe, only the smallest soil pores are filled with water.

CERCLA. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted by Congress on December 11, 1980, and amended in 1986, by the Superfund Amendments and Reauthorization Act (SARA). This law provided broad federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. CERCLA established prohibitions and requirements concerning closed and abandoned hazardous waste sites, provided for liability of persons responsible for releases of hazardous waste at these sites; and established a trust fund to provide for cleanup when no responsible party could be identified.

CEQA. The California Environmental Quality Act (Public Resources Code, §21000 et seq) requires public agencies to consider and disclose the environmental implications of their decisions, and to eliminate or reduce the significant environmental impacts of their decisions whenever it is feasible to do so.

Chemical of concern (COC). Chemicals of concern (COCs) are the compounds exceeding screening levels and are carried forward into the risk assessment.

California Human Health Screening Levels (CHHSLs). Developed by the Office of Environmental Health Hazard Assessment (OEHHA) as a tool to assist in the evaluation of contaminated sites to estimate the degree of effort that may be necessary to remediate a contaminated property. CHHSLs are concentrations of contaminants in soil, soil gas, or indoor air that the Cal/EPA considers to be below thresholds of concern for risks to human health.

Cleanup goal. Concentration value against which the success or completeness of a cleanup effort is evaluated.

Conceptual site model (CSM). Tool to help organize and communicate information about the site characteristics. It provides a summary of how and where contaminants are expected to move, and who might be exposed to chemicals and how it explains what a problem is and why a response is needed.

Corrective Measures Study (CMS). The Corrective Measures Study is the mechanism for the development, screening, and detailed evaluation of alternative corrective actions under the corrective action process.

Exposure point concentration (EPC). The exposure point concentration (EPC) is a conservative estimate of the average chemical concentration in the environmental media.

Feasibility Study (FS). Under the National Contingency Plan process (used by DTSC under California HSC Chapter 6.8), the feasibility study is the mechanism for the development, screening, and detailed evaluation of alternative remedial actions.

Hazard Index: Refers to the cumulative, noncarcinogenic health hazard estimate for a site.

HSAA. Hazardous Substances Account Act, Health and Safety Code, division 20, chapter 6.8.

HWCL. Hazardous Waste Control Law, Health and Safety Code, division 20, chapter 6.5.

Institutional Control (IC). ICs are actions, such as legal controls, that help minimize the potential for human exposure to contamination by ensuring appropriate land or resource use.

Interim Actions. Interim actions are short-term response actions performed pursuant to CERCLA or HSAA to control on-going risks while site characterization is underway or before a final response action is selected.

Interim Measures. Interim measures are short-term response actions performed pursuant to RCRA or HWCA to control on-going risks while site characterization is underway or before a final response action is selected.

Land Disposal Restriction (LDR). The Land Disposal Restriction (LDR) program found in federal and State regulations requires waste handlers to treat hazardous waste or meet specified levels for hazardous constituents before disposing of the waste on the land. To ensure proper treatment, the regulations establish a treatment standard for each type of hazardous waste. The regulations list these treatment standards and ensure that hazardous waste cannot be placed on the land until the waste meets specific treatment standards to reduce the mobility or toxicity of the hazardous constituents in the waste.

Land Use Covenant (LUC). Written instruments used to require compliance with certain obligations and restrict use of property. Land use covenants run with the land and are recorded at the county recorder's office so that they will be found during a title search of the property deed.

National Contingency Plan (NCP). The National Oil and Hazardous Substances Pollution Contingency Plan [40 Code of Federal Regulations sections 300.1 - 300.920], more commonly called the National Contingency Plan or NCP, is the federal government's blueprint for responding to both oil spills and hazardous substance releases.

Non-time-critical removal action. Non-time-critical removal actions, as defined by CERCLA, are removal actions that the lead Agency determines, based on the site evaluation, are appropriate, and a planning period of at least six months is available before on-site activities must begin.

Preliminary Endangerment Assessment (PEA). Under DTSC (2004), the Preliminary Endangerment Assessment (PEA) includes activities performed to determine whether current or past waste management practices have resulted in the release or threatened release of hazardous substances or materials which pose a threat to public health or the environment.

RCRA. The Resource Conservation and Recovery Act, an amendment to the Solid Waste Disposal Act to address the huge volumes of municipal and industrial solid waste generated nationwide. Under RCRA, USEPA has the authority to control hazardous waste from the "cradle-to-grave." This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also sets forth a framework for the management of non-hazardous wastes. [Title 40 of the Code of Federal Regulations, Parts 239 through 282]

Remedial Action Plan (RAP). Under the HSAA, the RAP is the response action selection document for a remedial action for which the capital costs of implementation are projected to cost $2,000,000 or more.

Removal Action Workplan (RAW). Under the HSAA, the RAW is the response action selection document for a nonemergency removal action that is projected to cost less than $2 million at a hazardous substance release site. Typically, these are actions designed to stabilize or cleanup a site posing a threat to human health or the environment, either as an interim action or the final remedy.

Risk assessment: The scientific process used to estimate the likelihood that a chemical detected at a site may be harmful to people or the environment.

Risk management: The process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of scientific, legal, economic and social factors.

Risk screening. Process of identifying COCs that need to be cleaned up on the site based on potential risk to human health. Screening involves a comparison of site media concentrations with risk-based values (e.g., CHHSLs).

Screening level. Concentration value used to evaluate whether a cVOC poses a risk to human health and should be identified as a COC.

Site characterization. Process of determining the type, quantity, and location of contaminant releases at a site. Also includes assessment of site characteristics that affect how and where the contaminant may be moved and the how human health and the environment are or may be affected.

Soils. Loose material on the surface and in the subsurface of the earth consisting of solids (i.e., mineral grains, organic matter), water, and air.

Soil vapor. Air or gas phase compounds in soil pore spaces.

Soil vapor extraction (SVE). SVE is used to remediate vadose zone soil by applying a vacuum that induces the controlled flow of air to remove volatile and some semivolatile organic contaminants from the soil.

Time-critical removal action. Where a release or threatened release poses an imminent or substantial risk to health or environment and a timing period of less than six months exists, a time-critical removal may be employed to prevent a release of contaminants or minimize its risk. For these types of removal actions, evaluation and reporting requirements are kept to a minimum to expedite the response.

Vadose zone. The zone between the land surface and the top of the groundwater table. Water within this zone is referred to as soil moisture.

APPENDIX A
CONCEPTUAL SITE MODEL FOR
CHLORINATED VOLATILE ORGANIC COMPOUNDS

This appendix presents the conceptual site model (CSM) for chlorinated volatile organic compounds (cVOCs) in the environment to illustrate potential contaminant migration pathways from a release point into subsurface soil and groundwater. The CSM presented herein is a simplified description of complex real-world systems and serves as a framework to illustrate the behavior of cVOCs so that appropriate characterization and remediation strategies can be developed. This appendix is meant to help practitioners visualize and interpret the spatial variability of cVOCs in the subsurface and to assist practitioners in developing site-specific CSMs. Figure A-1 illustrates the conceptual model for cVOC transport, as adapted from Rivett (1995).

Subsurface cVOC contamination is caused by releases from sources such as landfills, leaking pipes, underground storage tanks, aboveground spills, and aboveground facilities with operations that use chlorinated solvents. Such subsurface cVOCs may exist as contaminated soil gas, contaminated soil, non-aqueous phase liquid (NAPL) in soil or groundwater, and as dissolved-phase contamination in groundwater. NAPL contamination can be of particular concern due to higher contaminant concentrations and its persistence in the environment.

NAPL Plumes

After a liquid cVOC release, the NAPL may be fully contained in the vadose zone or may penetrate the water table to form NAPL pools below the water table as well as leaving a trail of residual NAPL along its migration pathway in both the vadose zone and saturated zone. NAPL may also accumulate near the water table if downward migration is slowed by conditions in the capillary fringe, hard pan zones, or other subsurface features. Where this occurs, subsequent water table fluctuations can produce a “smear zone” of residual NAPL that affects cVOC distribution in the vadose and saturated zones. The presence of these smear zones also affects the types of remedies that will be effective at a given site.

Because cVOC releases typically occur at or near the ground surface, transport mechanisms in the vadose zone are primarily responsible for soil gas and water table plume formation. As shown in Figure A-1, soil gas and water table plumes can have similar spatial footprints. NAPL present in, or close to, the saturated zone will produce dissolved-phase groundwater plumes. These groundwater plumes can have lengths greater than a thousand feet for dissolved-phase cVOC constituents that are not readily biodegradable. Dense NAPL can penetrate below the water table and migrate under the influence of gravity in directions opposite of groundwater flow. Accordingly, dense NAPL sources can be present in different places than would be expected by simply mapping the advective flow of groundwater alone, making sources difficult to find and delineate. Dissolved-phase plumes will emanate from the entire continuous, vertical distribution of NAPL in the groundwater (see Figure A-1).

Soil Gas Plumes

When released to the vadose zone, the cVOC vapors will migrate laterally by diffusion in all directions, potentially tens of meters away from NAPL sources (Silka, 1988; Mendoza and Frind, 1990). The cVOC vapors also will migrate upward toward the ground surface (possibly intruding into buildings) and downward toward the water table, contaminating groundwater by direct contact. Also, cVOCs in soil gas contaminate groundwater by partitioning into infiltrating recharge water within the vadose zone pore space. These processes produce water table plumes that are wide (relative to the groundwater flow direction) and spatially coincident with soil gas plumes.

As shown in Figure A-1, soil gas contamination can migrate laterally upgradient of the groundwater flow direction, potentially contaminating the water table upgradient of the source area. Consequently, in many cases, cVOC contamination detected in groundwater monitoring wells upgradient from release points may not be attributable to offsite sources. Rather, cVOCs in upgradient wells may be caused by lateral diffusional transport of contaminated soil gas followed by subsequent direct contact with groundwater or partitioning into infiltrating recharge water. Also, as groundwater flows away from cVOC sources areas, the dissolved-phase contaminants may partition from the aqueous-phase back into the vadose zone, contaminating soil gas. This soil gas contamination, which is further from NAPL sources than predicted by radial diffusional migration, may produce soil gas concentrations that pose a risk via the indoor air exposure pathway. Therefore, even distal portions of cVOC groundwater plumes located under residential or commercial buildings may produce unacceptable indoor air exposure scenarios.

Groundwater Plumes

The plan views in Figure A-1 illustrate the discrepancies in plume widths that should be recognized when delineating groundwater contamination in the saturated zone. Water table plumes are wide and spatially coincident with soil gas contamination. Deeper plumes will not be much wider than the NAPL source zone due to the weakness of transverse and horizontal dispersion (Anderson et al., 1992). These deeper groundwater plumes can avoid detection if sampling locations are spaced inappropriately. Practitioners should also recognize that saturated zones separated by aquitards may have different groundwater flow directions. Therefore, a deep groundwater plume may have a different spatial orientation than its associated water table plume.

Aquifer homogeneity should also be considered when developing a CSM. For saturated zones within relatively homogeneous subsurface conditions, deep NAPL sources generate narrow dissolved-phase contaminant plumes, and are expected to be directly under the cVOC release point. However, in aquifers within heterogeneous subsurface conditions, deep NAPL sources also may be laterally offset from the release point. For heterogeneous conditions, investigation efforts should assess contaminant distribution in both high and low permeability materials.

CSM Development

The CSM is a representation of the nature, extent, and fate of cVOCs that allows assessment of the potential exposures to contamination. Stakeholders use the CSM to evaluate strategies to protect public health and the environment. The CSM is a scientific hypothesis that is tested, modified, and refined until confident decision-making is possible. Typically, a CSM integrates subsurface characterization with a pathway-exposure assessment, and contains the following elements: contaminant sources; potential release mechanisms; affected environmental media; exposure pathways; and human and ecological receptors. The CSM is developed early and updated throughout the site characterization process. The CSM is a communication tool to direct risk-specific site sampling. Additional information for the development of a CSM can be found in USEPA (1996), USEPA (2008), and DTSC (2008).

REFERENCES

Anderson, M. R., R. L. Johnson, and J. F. Pankow. 1992. Dissolution of Dense Chlorinated Solvents into Ground Water, 3. Modeling Contaminant Plumes from Fingers and Pools of Solvent. *Environmental Science and Technology*, v. 26, n. 5, p. 901 – 908.

Department of Toxic Substances Control. 2008. Appendix A1: Conceptual Site Model. In *Proven Technologies and Remedies Guidance -- Remediation of Metals in Soil*. August. www.dtsc.ca.gov/SiteCleanup/upload/Appdx_A1_083108.pdf

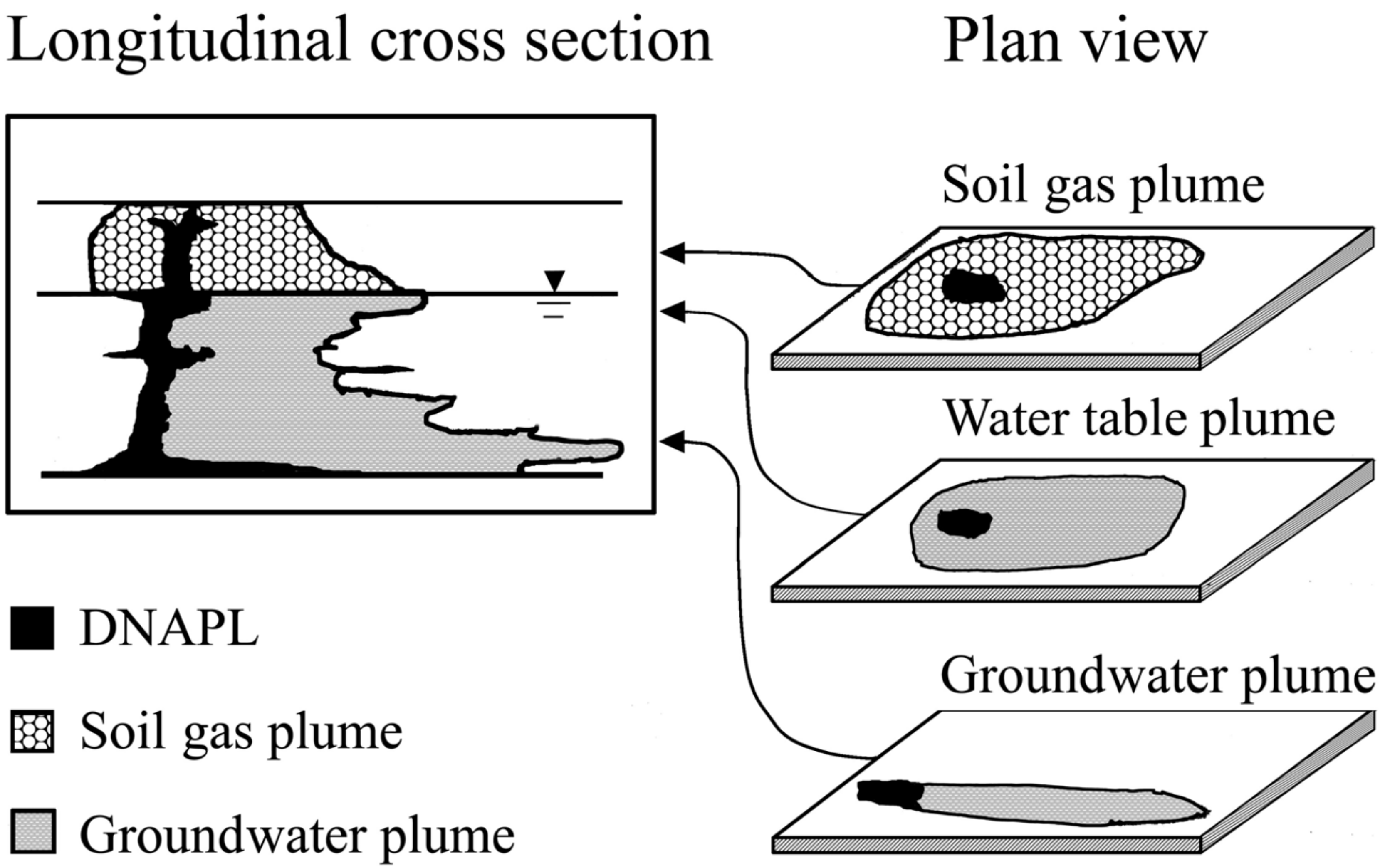
Mendoza, C. A., and E. O. Frind. 1990. Advective-Dispersive Transport of Dense Organic Vapors in the Unsaturated Zone, 2: Sensitivity Analysis. *Water Resources Research*, v. 26, n. 3, p. 388 – 398.

Rivett, M. O. 1995. Soil-Gas Signatures from Volatile Chlorinated Solvents: Borden Field Experiment. *Ground Water*, v. 33, n. 1, p. 84 – 98.

Silka, L. R. 1988. Simulation of Vapor Transport through the Unsaturated Zone – Interpretation of Soil-Gas Surveys. *Ground Water Monitoring Review*, v. 8, n. 2, p. 115 – 123.

United States Environmental Protection Agency (USEPA). 1996. Attachment A, Conceptual Site Model Summary. *Soil Screening Guidance: User's Guide*. Second Edition, EPA 540/R-96/018. July 1996. www.epa.gov/superfund/health/conmedia/soil/pdfs/attacha.pdf

USEPA. 2008. Module 6, Truth Serum for Environmental Decision-Making: Efficient and Effective Program Designs. *Short Course Manual for Best Practices for Efficient Soil Sampling Designs*. CERCLA Education Center. January.



NOTE: Adapted from Rivett (1995)

Figure A-1
CVOC Conceptual Site Model
Subsurface Characterization

APPENDIX B

SUPPORTING DOCUMENTATION FOR DTSC TECHNOLOGY SCREENING

TABLE OF CONTENTS

Table B-1 Cleanup Options Selected for cVOCs in Vadose Zone Soil and Characteristics of Sites Evaluated by DTSC Study

DTSC Site Type (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Corrective Action (16[2])	1	14	0	6	0	0
Military Facilities (19[2])	3	12	0	6	2	0
Schools (3)	0	1	0	2	0	0
State Response/ NPL (33[2])	7	19	0	17	4	1
Voluntary Cleanup (19[2])	4	11	2	13	0	0

Total number of sites represented: 90

Depth to First Groundwater (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
≤ 10 feet bgs (9[2])	2	3	0	6	1	0
>10 to 20 feet bgs (13[2])	3	5	0	10	2	0
>20 to 50 feet bgs (25[2])	4	15	1	14	0	1
>50 to 100 feet bgs (16[2])	3	14	0	2	1	0
> 100 feet bgs (12[2])	1	12	1	3	0	0

Total number of sites represented: 75 (Information on depth to groundwater not available for all 90 sites.)

Affected Media (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Soil / soil vapor only (4[2])	1	2	0	3	1	0
Groundwater (86[2])	13	60	2	40	5	1
Surface water (1)	0	0	0	1	0	0
Indoor air (22[2])	5	22	0	7	0	0

Total number of sites represented: 90

Table B-1 (Continued)

Primary cVOCs Detected	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Trichloroethene	12	45	2	33	4	1
Tetrachloroethene	12	40	1	30	5	1
Trichloroethane	6	10	0	8	2	0
Dichloroethane	1	7	1	3	1	0
Chloroform	0	3	0	1	0	0
Methylene chloride	1	1	0	1	0	0
Carbon tetrachloride	1	3	0	0	0	0
Other	0	9	0	1	0	0

Total number of sites represented: 88 (Information detected cVOCs not available for all 90 sites.)

Contaminants Other than cVOCs	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
None reported	4	13	1	10	2	0
Metals	8	24	1	22	2	1
Fuel-related compounds, including BTEX	7	26	0	21	3	1
Semi-volatile organic compounds	3	10	0	4	1	1
Polynuclear aromatic hydrocarbons	0	7	0	5	0	1
Polychlorinated biphenyls	3	6	0	9	2	1
Pesticides	0	4	0	5	1	0
Dioxins/furans	0	3	0	1	0	0
Other	1	8	0	5	0	0

Total number of sites represented: 86 (Information on other contaminants present not available for all 90 sites.)

Table B-1 (Continued)

Historical Site Activity (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Manufacturing/ industrial activities (38[2])	3	25	0	21	1	1
Aircraft manufacturing, operations, maintenance (12[2])	3	8	1	3	0	0
Metal plating, finishing (8[2])	1	5	1	3	1	0
Dry cleaners (8[2])	1	4	0	4	1	0
Solvent recycling/ reclamation (5[2])	1	4	0	3	0	0
Disposal (10[2])	2	3	0	5	2	0
Equipment maintenance/ repair (3[2])	2	2	0	3	1	0
Research facility, laboratory (3[2])	0	3	0	1	0	0
Chemical distribution, packaging (3[2])	1	3	0	0	0	0

Total number of sites represented: 90

Current or Planned Land Use (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
Commercial/ industrial (55[2])	10	38	2	22	3	1
Residential, potentially residential, mixed use (15[2])	3	7	0	13	1	0
School/ church (4[2])	0	2	0	3	0	0
Natural area (1)	0	1	0	0	0	0

Total number of sites represented: 75 (Information on potential future use not available for all 90 sites.)

Table B-1 (Continued)

Site Size (no. of sites)	Cleanup Option Selected (No. of Sites)					
	IC[1]	Soil Vapor Extraction	*In Situ* Treatment Technologies	Excavation & Off-site Treatment/ Disposal	Containment/ Capping	Excavation, *Ex Situ* Treatment, On-site Reuse
≤1 acre (15[2])	2	8	0	10	1	0
>1 – 10 acres (38[2])	7	23	2	21	2	0
>10 – 50 acres (19[2])	3	13	0	9	1	0
>50 – 100 acres (3)	0	1	0	1	0	1
> 100 acres (2[2])	1	1	0	0	1	0

Total number of sites represented: 77 (Information on site size not available for all 90 sites.)

Notes:
bgs below ground surface
BTEX Benzene, toluene, ethylbenzene, xylene
cVOCs chlorinated volatile organic compounds
NPL National Priorities List
1 IC is institutional control. Used in conjunction with another cleanup option.
2 Some sites in this category selected multiple cleanup options (i.e., this number is not simply the sum of frequencies listed in this row).

Table B-2 Technologies Applicable at Sites with Chlorinated VOCs in Vadose Zone Soil

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***Ex Situ* Technologies**[1]				
Excavation and Off-site Disposal	Impacted soil is excavated and isolated within an engineered disposal unit (e.g., landfill, CAMU).	• Wide variety of soils and contaminants.	• Cost. • Transportation of impacted soils to off-site disposal facility. • Does not lessen toxicity, mobility, or volume of hazardous wastes.	
Capping	Impacted soil is isolated in place beneath an engineered cap or excavated and isolated within an engineered disposal unit (e.g., landfill, CAMU).	• Wide variety of soils and contaminants.	• Long-term maintenance. • Land use restrictions. • Not protective if groundwater is shallow. • Likely will require a gas collection system to control contaminant vapor migration. • By itself, cannot prevent the horizontal flow of water through the waste, can only reduce the vertical entry of water into the waste.	
Slurry Phase Bioremediation	Slurry-phase bioreactors are used to treat halogenated VOCs using cometabolites and specially adapted microorganisms. Slurry is created by combining soil with water and other additives and mixing to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of treatment, the slurry is dewatered and treated soil is disposed of.	• Favored over *in situ* biological treatment for -heterogeneous soils, -low permeability soils, -areas where underlying ground water would be difficult to capture, or -when faster treatment times are required.	• Less reliable for treatment of cVOCs than other *ex situ* biological treatment options. • Requires bench and pilot scale studies. • Difficulty and cost of sizing materials prior to placement in reactor. • Nonhomogeneous and clayey soils can create materials handling problems. • Must remove free phase contaminants prior to treatment. • Cost of dewatering soil fines after treatment. • Requires acceptable method for disposing of nonrecycled wastewaters.	2, 5

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***Ex Situ* Technologies[1]**	**(Continued)**			
Biopiles	Excavated soils are mixed with soil amendments, placed in aboveground enclosures, and subjected to aerated bioremediation and composting process. Treatment units typically require liner, pad, leachate collection system, and aeration system.	• Can treat some cVOCs, though most commonly used to treat fuel-related compounds.	• Requires bench and pilot scale studies. • Questionable effectiveness for halogenated compounds in soil. • Volatile constituents tend to evaporate rather than biodegrade during treatment. • May require air emission controls. • May result in less uniform treatment than processes involving periodic mixing.	2, 3, 5
Landfarming (also known as Land Treatment)	Excavated soil is amended and applied into aboveground beds that are periodically turned over or tilled to aerate the soil. Treatment units typically require a liner and berms, and potentially a leachate collection system.	• Treating aerobically degradable, non-volatile contaminants. • Can treat some cVOCs, but most successfully used for treating petroleum hydrocarbons.	• Requires bench and pilot scale studies to verify that technology can meet RAOs. • May not be best treatment option for cVOCs based on cost and effectiveness. • Harder to degrade organic compounds having a higher degree of chlorination. • Concentration reductions greater than 95% and constituent concentrations less than 0.1 ppm are difficult to achieve. • Volatile constituents tend to evaporate rather than biodegrade during treatment. • Likely will require emission controls. • Difficult to control conditions affecting biological degradation (e.g., temperature, moisture). • Large amount of space is required.	2, 4, 5

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***Ex Situ* Technologies[1]**	**(Continued)**			
Composting	Controlled biological process which treats organic contaminants under thermophilic conditions (54 to 65° C). Contaminated soil is excavated and mixed with bulking agents and organic amendments. Three common designs include aerated static piles, in-vessel, windrow composting.	• Soils contaminated with biodegradable organic compounds.	• Substantial space is required. • Amendments cause volumetric increase. • Off-gas control and treatment may be required. In-vessel composting provides the best control of VOCs. When a vacuum is applied, aerated static piles offer some control of VOCs. • Most costly *ex situ* biological treatment option. • Design requirements (e.g., need for liner, aeration method, temperature) depend on type of design.	2, 5
Chemical Extraction	Contaminated soil and an extractant (e.g., solvent, acid) are mixed in an extractor. Extracted solution is separated into contaminants and extractant for treatment and further use. Physical separation steps are often used before chemical extraction to grade the soil into coarse and fine fractions (assuming much of contaminant is associated with fine fraction).	• Shown to be applicable for separation of organic contaminants such as in paint wastes, synthetic rubber process wastes, and petroleum refinery oily wastes. • Commercial-scale units are in operation, varying in regard to extractant employed, type of equipment used, and mode of operation. • Commonly used in combination with other technologies, such as solidification/stabilization, incineration, or soil washing.	• Some soil types and moisture content levels will adversely impact process performance. • Higher clay content may reduce extraction efficiency and require longer contact times. • Capital costs can be relatively high. • May be more economical at larger sites. • Extractant effects (e.g., acidity, toxicity) on treated soil may need to be addressed. • Less reliable than other *ex situ* physical/ chemical treatment options. • Typically requires longer cleanup time than other *ex situ* physical/ chemical treatment options.	2

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***Ex Situ* Technologies[1]**	**(Continued)**			
Dehalogenation	Soil is screened, processed with a crusher and pug mill, and mixed with reagents. Mixture is heated in a reactor. Replaces halogen molecules or causes decomposition and partial volatilization of contaminants.	• Typically used for halogenated SVOCs and pesticides. • Can be used to treat some halogenated VOCs. • Can be used for small-scale applications	• Generally more expensive than other technologies. • Concentrations of chlorinated organics greater than 5% require large volumes of reagent. • High clay and moisture content will increase treatment costs. • Capture and treatment of residuals may be difficult, especially when the soil contains high levels of fines and moisture.	2
Thermal Desorption	Soil is heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.	• Full spectrum of organic contaminants, including VOCs.	• May be less cost-effective than other treatment technologies. • Incidental combustion may occur in some thermal treatment units. • Emission controls and permitting requirements. • Particle size and materials handling requirements can impact applicability or cost at specific sites. • Dewatering may be necessary to achieve acceptable soil moisture content levels. • Clay and silty soils and high humic content soils increase reaction time.	2, 4
Incineration	High temperatures, 870-1,200 °C, are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	• Used to remediate soils contaminated with hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.	• Typically requires transport of impacted soils over long distances. • High cost and energy usage. • Feed size and materials handling issues can impact applicability or cost. • Off gases and combustion residuals generally require treatment.	2

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***In Situ* Technologies**				
Soil Vapor Extraction (SVE)	Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil via extraction wells.	• Volatile compounds. • Often promotes *in situ* biodegradation of low-volatility organic compounds. • Can remove contamination under existing structures.	• Higher vacuums required for soil with high percentage of fines or high degree of saturation, increasing costs and/or limiting effectiveness. • May be less effective in heterogeneous soil. • Reduced removal rates for high organic content or extremely dry soils. • Exhaust air may require treatment. • Residual liquids from off-gas treatment may require treatment/disposal. Spent activated carbon will require regeneration or disposal. • Not effective in saturated zone. • May not be able to address shallow VOC sources because of short circuiting. • Subsurface infrastructure (e.g., pits, vaults) may limit treatment effectiveness.	2, 6
Thermally Enhanced SVE	Heating is used to increase volatilization rate and facilitate extraction. Heating options include conductive heating, steam/hot air injection, and electrical resistance/ electromagnetic/fiber optic/radio frequency	• Option for treating VOCs if high moisture content is limiting the effectiveness of standard SVE.	• Same as for SVE. • Tight or high moisture content soil has reduced air permeability and requires more energy input to increase vacuum and temperature. • Soil with highly variable permeabilities may result in uneven delivery of gas flow to contaminated areas. • Hot air injection has limitations due to low heat capacity of air.	2

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***In Situ* Technologies**	**(Continued)**			
Thermal Desorption	Applies heat to impacted soil by *in situ* methods. Heat can destroy or volatilize organic chemicals. As chemicals change into gases, mobility increases, and gases can be extracted and treated in an *ex situ* treatment unit. Similar heating options as thermally-enhanced SVE.	• Used with a wide range of soil types and volatile contaminants. • Can remove contamination under existing structures.	• Uncertainty about uniformity of treatment because of variability in soil characteristics and because process efficacy is difficult to verify. • High utility costs.	2
Cometabolic Bioventing	Air and a volatile organic substrate (e.g., propane) are delivered to contaminated unsaturated soils by forced air movement to elicit production of monooxy-genase enzymes which consume the organic substrate and facilitate contaminant degradation.	• Lightly chlorinated compounds in vadose zone.	• Limited experience with technology, particularly with cVOCs. Requires bench scale and pilot testing to demonstrate effectiveness for a given site. • Difficulty of distributing gases in subsurface. • May be difficult to apply to shallow contamination.	5
Anaerobic Bioventing	Nitrogen and an electron donor (e.g., hydrogen, carbon dioxide) are delivered to contaminated unsaturated soils by forced air movement (injection) to produce reducing conditions, thereby facilitating microbial dechlorination.	• May be useful in treating highly chlorinated compounds.	• Emerging technology. Requires bench, pilot, and field demonstrations to confidently apply this technology. • Difficult to distribute gases in subsurface. • Design must compensate for poor permeability conditions. • May be difficult to apply to shallow contamination.	5

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***In Situ* Technologies**	**(Continued)**			
Soil Flushing	Water, or water containing a solubility-enhancing additive (e.g., surfactant), is applied to soil or injected into ground water to raise water table into contaminated soil zone. Contaminants are leached into ground water, which is then extracted and treated.	• Can be used to treat VOCs, but may be less cost-effective than other technologies.	• Potential for washing contaminant beyond capture zone. Should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured. • Water quality concerns with introducing surfactants to subsurface. • May alter the physical/chemical properties of the soil system (e.g., effective porosity). Can reduce contaminant mobility. • Low permeability or heterogeneous soils are difficult to treat. • Aboveground separation and treatment costs for recovered fluids can drive the economics of the process.	2
Chemical Oxidation	Chemically converts contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. Rate and extent of degradation of target compound are dictated by its chemical properties and susceptibility to oxidative degradation. Matching the oxidant and *in situ* delivery system to contaminants and site conditions is key to successful implementation and achieving performance goals.	• Capable of achieving high treatment efficiencies for cVOCs over short time periods.	• Potential contaminant mobilization. If applied to vadose zone soils, need to address mobilization of contaminants and oxidation byproducts to groundwater. • Requires bench and pilot scale studies. • Oxidant delivery problems due to reactive transport and soil heterogeneity. • Short persistence of some oxidants due to fast reaction rates. • Natural oxidant demand may be high for some soils (e.g., high organic matter content, high reduced minerals, carbonates, free radical scavengers). • Potential permeability reduction. • Health and safety concerns with handling strong oxidants.	2, 7

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
***In Situ* Technologies**	**(Continued)**			
Phytoremediation	Process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment.	• May be applicable for remediation of cVOCs in shallow soils.	• Depth of treatment zone is determined by plants used in phytoremediation. In most cases, it is limited to shallow soils. • Treatment effects may be seasonal. • Longer cleanup time than other technologies. • Can transfer contamination across media, e.g., from soil to air.	2, 8

1 *Ex situ* technologies assume excavation of soil prior to application of technology
2 Van Deuren and others (2002)
3 USEPA (2004)
4 ITRC (1997)
5 USEPA (2006)
6 USACE (2002)
7 Huling and Pivetz (2006)
8 USEPA (2005)

Table B-3 Evaluation of Technologies Applicable to Sites With Chlorinated VOCs in Soil Against National Contingency Plan Analysis Criteria

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST
Institutional Controls	• **Manages potential exposure by restricting access and future land use.**	• May not comply with ARARs.	• Uncertain because does not permanently address contamination.	• Not a treatment alternative.	• Does not create risks during implementation	• Easily implemented.	• Typically the lowest cost alternative.
Excavation and Off-site Disposal	• Protectiveness achieved by cVOC removal from site.	• Requires compliance with applicable State and federal requirements for waste handling, storage, transportation and disposal requirements.	• High long-term effectiveness for site. • Protectiveness at disposal site dependent on off-site management choices.	• Disposal reduces mobility. • Reduction in toxicity and volume depends on offsite management choices.	• Requires standard precautions necessary for protection of human health and environment during excavation, transport, and disposal. • **cVOC emissions may require control during excavation and handling.**	• **Easily implemented for shallow soils, if feasible site logistics**, and facility with adequate capacity for waste type, located within a reasonable distance of site. • Uses standard construction equipment and labor.	• Usually reasonable for small to medium volumes of contaminated soil. • May be **cost-prohibitive** for large volumes.

Note: Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC Study (see Chapter 7 of main text).

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA					
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST
Soil Vapor Extraction (after USEPA, 1993)	• Provides short-term and long-term protection by reducing concentration and exposure to cVOCs in soil. • Depending on site-specific conditions, prevents or decreases further groundwater contamination.	• Does not trigger land disposal requirements. • Because of limited disturbance, few impacts to water and sensitive resources are likely. • Potential to treat cVOC concentrations to levels that will prevent exceedance of groundwater cleanup levels. • Emission controls are needed to comply with air quality standards.	• Effectively removes contamination source. • **Proven technique for removing cVOCs from soil at depths with adequate air permeability.** • Requires some treatment of residuals. • Requires review during on-going operation. • Periodic reviews may be required if residual levels of cVOCs remain after system shutdown.	• Significantly reduces toxicity, mobility, or volume through treatment or removal of cVOCs. • Produces few waste streams.	• Potential air emissions easily controlled. • Generally involves relatively short timeframe to achieve RAOs. • Effective for treating cVOC mass under buildings. Can be performed on active sites. • Equipment is readily available.	• Readily available technology. • Proven technology. • Requires few engineering controls. • Requires soil gas sampling to monitor cleanup progress and demonstrate achievement of RAOs.	• Can be cost effective.

Note: Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC Study (see Chapter 7 of main text).

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST
Containment by Capping	• Contaminated soil remains in place. Depending on site conditions, **cVOCs may migrate laterally and vertically beneath cap unless controlled.** • Risk of exposure through inhalation, dermal contact and/ or incidental ingestion reduced through barriers. • **Groundwater protection** depends on depth to water, potential for cVOC migration, and cap design that reduces water migration through soil.	• Waste disposal requires compliance with ARARs.	• Long-term protection ensured through **continued cap maintenance, ICs, and, if needed, emissions controls.**	• **Not a treatment alternative.**	• Requires standard precautions for protection of human health and environment.	• Commercially available. • Demonstrated technology. • Necessary materials easily attainable. • Uses standard construction equipment and labor.	• Generally less expensive than most forms of treatment.

Note: Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC Study (see Chapter 7 of main text).

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST
In Situ Treatment	• Protectiveness achieved by transforming cVOCs and achieving target cleanup levels. • **Potential for cVOC mobilization to groundwater.**	• Requires compliance with applicable State and federal requirements for treatment process.	• Permanently destroys cVOCs, if reagent successfully placed in contact with impacted soils. • **Uncertain effectiveness.** • **Some technologies unproven for cVOCs in unsaturated soils.** • **Some technologies can be effective for specific cVOCs.**	• Reduces toxicity, mobility, and volume of soil contaminated with cVOCs.	• Requires standard precautions for protection of human health and environment during treatment process (e.g., reagent handling).	• Assess applicability through bench scale and treatability studies. • May require permit for treatment process. • Equipment availability depends on selected treatment process. • **Time to treat.** • Some treatments require large power source. • **Ability to achieve geochemical conditions needed for treatment.**	• Relatively high **cost**.

Note: Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC Study (see Chapter 7 of main text).

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST
Ex Situ Treatment	• Protectiveness achieved by treatment in above-ground units and achieving cleanup goals for on-site reuse or for land disposal.	• Requires compliance with applicable State and federal requirements for excavation, treatment transportation, storage, and disposal. • Emission controls likely needed to comply with air quality standards.	• **Some techniques can be effective for specific cVOCs.** • **May require additional technology if cleanup goals not achieved.**	• Removes cVOCs or transforms cVOCs to less toxic by-products.	• Potential short-term risks from emissions during excavation, treatment, soil handling, and transportation. • Requires standard precautions for protection of human health and the environment during treatment process.	• **May require bench and pilot scale studies.** • May have multiple treatment steps. • **On-site treatment requires space for treatment unit.** • **Off-site treatment requires transport to treatment facility.** • Administrative requirements for permitting treatment unit may delay project.	• Relatively high **costs,** particularly for off-site treatment and disposal.

Note: Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC Study (see Chapter 7 of main text).

REFERENCES

Huling, S.G. and B.E. Pivetz. 2006. *Engineering Issue: In Situ Chemical Oxidation*. EPA 600-R-06-072. August. www.epa.gov/ada/download/issue/600R06072.pdf

Interstate Technology and Regulatory Council (ITRC). 1997. *Technical Requirements for On-site Thermal Desorption of Solid Media Contaminated with Hazardous Chlorinated Organics*. September. www.itrcweb.org/Documents/TD-2.pdf

U.S. Army Corps of Engineers (USACE). 2002. *Engineering and Design - Soil Vapor Extraction and Bioventing* (EM 1110-1-4001). June. http://140.194.76.129/publications/eng-manuals/em1110-1-4001/toc.htm

U.S. Environmental Protection Agency (USEPA). 1993. *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites With Volatile Organic Compounds in Soils*. EPA 540-F-93-046. September. www.epa.gov/superfund/policy/remedy/presump/finalpdf/scts.pdf

USEPA. 2004. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers*. EPA 510-R-04-002. May. www.epa.gov/OUST/pubs/tums.htm

USEPA. 2005. *Use of Field-Scale Phytotechnology for Chlorinated Solvents, Metals, Explosives and Propellants, and Pesticides*. EPA 542-R-05-002. April. www.clu-in.org/download/remed/542-r-05-002.pdf

USEPA. 2006. *Engineering Issue: In Situ and Ex Situ Bioremediation Technologies for Remediation of Contaminated Sites*. EPA/625/R-06/015. October. www.clu-in.org/download/contaminantfocus/dnapl/Treatment_Technologies/epa_2006_engin_issue_bio.pdf

Van Deuren, J., T. Lloyd, S. Chhetry, R. Liou, and J. Peck. 2002. *Remediation Technologies Screening Matrix and Reference Guide*, 4th Edition. January. www.frtr.gov.

APPENDIX C

RESOURCES FOR DESIGN AND IMPLEMENTATION OF SVE SYSTEMS

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

ACRONYMS AND ABBREVIATIONS

Cal/EPA	California Environmental Protection Agency
CEQA	California Environmental Quality Act
cm/s	centimeters per second
CSM	conceptual site model
cVOC	chlorinated volatile organic compound
DQO	data quality objective
DTSC	California Department of Toxic Substances Control
GAC	granular activated carbon
GRA	Groundwater Resources Association of California
LARWQCB	Los Angeles Regional Water Quality Control Board
LEL	lower explosive limit
O&M	operation and maintenance
PT&R	proven technologies and remedies
QA	quality assurance
QC	quality control
QAPP	quality assurance project plan
RAO	remedial action objective
ROI	radius of influence
SVE	soil vapor extraction
SVM	soil vapor monitoring
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

Preface

This appendix supplements Chapter 9 of this guidance document by providing additional information about selected topics for soil vapor extraction (SVE) systems. The intent is to facilitate the design and implementation of SVE systems. Please refer to the main text of this guidance document for an overall discussion of the design and implementation of SVE systems as well as discussion of site characterization, cleanup technology screening and evaluation, and remedy selection. Please recognize that this appendix and Chapter 9 are intended as guidance. All elements discussed may not be applicable to a given site.

1.0 TREATMENT TECHNOLOGIES FOR SVE SYSTEM EFFLUENT

This discussion summarizes the likely treatment methods for SVE system effluent. A comprehensive discussion of the engineering design of air emission control devices is beyond the scope of this PT&R guidance and would duplicate information in *Engineering and Design - Soil Vapor Extraction and Bioventing* (USACE Manual; USACE, 2002) and *Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice* (USEPA, 2006). Off-gas treatment systems may not be necessary for a given SVE system if emissions are below regulatory levels or health-based goals (health risk analysis).

1.1 GENERAL OBJECTIVE OF EFFLUENT TREATMENT

Effluent treatment methods need to be designed to treat a wide range of volatile chemicals and concentrations. Chlorinated volatile organic compound (cVOC) concentrations can span several orders of magnitude between system startup and shutdown, and therefore the effluent treatment system must operate properly for the anticipated concentration ranges. The consequences of the treatment process itself must be considered in selecting the construction materials. Disposal of residuals such as spent carbon and condensate must also be addressed. The following considerations are needed for design of effluent treatment systems:

- initial and long-term concentration ranges
- complete analysis and speciation of the influent gas
- total flow rate range
- required removal efficiency
- availability of utilities
- required degree of control, monitoring, and automation
- noise generation
- condensate control and proper management (e.g., secondary containment)

Additional case-specific considerations may be applicable, such as local agency air emissions requirements or California Environmental Quality Act (CEQA)-identified mitigation needs. Communication between the designers of the subsurface and aboveground components is essential.

1.2 TYPICAL EFFLUENT TREATMENT OPTIONS

Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice (USEPA, 2006) provides detailed discussion of effluent treatment options for cVOCs, including thermal treatment, adsorption, and emerging technologies such as vapor condensation. This section discusses treatment technologies used by the majority of Department of Toxic Substances Control (DTSC) projects, namely granular activated carbon (GAC) and thermal treatment. Experience on DTSC projects has found that GAC is often the chosen method of treatment even though thermal treatment may be the most efficient and cost effective approach. Thermal treatment may be the best option for waste streams containing vinyl chloride because vinyl chloride does not adsorb onto GAC. Ketones, methane, chlorofluorohydrocarbons, and sulfur-containing compounds are examples of other compounds that are not suitable for GAC treatment.

1.2.1 Sorbents

Sorbents can remove many classes of organic compounds including aromatic, aliphatic, and halogenated hydrocarbon compounds. Adsorption of volatile contaminants occurs via chemical and physical attractive forces between liquid or gas phase molecules and the molecules of the solid sorbent activated carbon, zeolites, or synthetic polymers. Selection of an appropriate sorbent material is primarily a function of the contaminant to be adsorbed. Activated carbon is the most widely used adsorbent material and is the focus of the remainder of this discussion.

Many SVE systems utilize GAC in flow-through canisters which are relatively simple to operate when properly designed. A carbon adsorption design usually includes multiple columns which are operated either in series or in parallel. The series arrangement is generally operated so that the secondary and subsequent columns (if applicable) act as a backup when breakthrough occurs on the primary canister. When the lead column is removed from service, the lag column is moved up to the lead position and the new column (or regenerated column) is installed in the lag position. The pressure / temperature ratings of the GAC canisters must exceed the anticipated operating conditions of the SVE system equipment.

Adsorption is normally a reversible process. Under suitable conditions the materials that have accumulated in the carbon can be desorbed and the carbon can be re-used. Thermal reactivation is the most widely used regeneration technique. In SVE systems where carbon usage is low, on-site regeneration will not be cost-effective and the spent carbon should be either disposed of or regenerated offsite. For larger long-term SVE systems, onsite regeneration should be considered based on a complete life-cycle cost economic analysis. If possible, the designer should estimate the total carbon usage for the life of the project and compare the carbon cost with the capital and operation and maintenance (O&M) cost of the regeneration system. A similar economic analysis could be performed for comparison with catalytic and thermal oxidation, as discussed below.

1.2.2 Thermal Oxidation

The four general types of thermal oxidation systems available for controlling cVOC emissions include:

- direct flame thermal oxidizers
- "straight-through" flameless thermal oxidizers
- regenerative thermal oxidizers
- catalytic oxidizers

Although each type of system operates somewhat differently, the primary goal of thermal oxidation is to raise the temperature of the gas stream to a sufficient level to promote oxidation (or combustion) of the contaminant to carbon dioxide and water. The heat for thermal oxidation comes from heat input to the oxidizer in the form of supplemental fuel (either gas or electric) as well as from the heating value content (usually in British thermal units) of the cVOCs in the SVE vapor streams. In-line flame arrestors should be incorporated into the design when using thermal oxidizers. Placed just upstream of thermal oxidizers, flame arrestors can prevent fire from moving through piping, and can protect other parts of the SVE system from fire or explosion.

Issues to be considered when evaluating thermal oxidation options include:

- cost savings that can be achieved by heat recovery techniques
- adjustment of the amount of auxiliary fuel (or dilution air) to accommodate variations in mass loading
- for catalytic oxidation, consideration of the catalyst type and catalyst limitations (e.g., deactivators, overheating, lifespan)
- generation and treatment of acidic emissions (i.e., gases, liquids)
- potential generation of products of incomplete combustion (e.g., chlorinated dibenzo-p-dioxins, chlorinated dibenzofurans)
- lower explosive limit (LEL) of the waste stream[1]

Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice (USEPA, 2006) provides guidance on selecting a thermal treatment technology.

[1] The LEL is defined as the minimum concentration of chemical vapor in atmospheric air (i.e., 21% oxygen and at 20°C) that is sufficient to support combustion.

2.0 VACUUM, FLOW, AND ZONE OF CAPTURE ASSESSMENTS

2.1 VACUUM AND FLOW ASSESSMENT

Two main types of assessments may be performed during pilot-scale testing or validation/startup activities: step tests and steady-state tests. DTSC recommends use of both a step and steady-state vacuum/flow assessment.

2.1.1 Step Test

Step testing is used to determine the optimum sustainable flow from the subsurface. During step testing, the flow is incrementally increased over time as the vacuum level in the SVE well and vapor monitoring wells is documented. The flow rate is increased by manipulating the blower system.

2.1.2 Steady-State Test

The steady-state or constant rate test is implemented at the optimum flow rate to acquire vacuum data from the subsurface and to determine potential maximum influent cVOC concentrations for the SVE system and the optimal SVE well spacing. This vacuum data is obtained from multiple monitoring locations. Typically, an optimum flow rate is derived from step testing and used as a parameter in steady-state testing. The stabilized vacuum readings obtained from monitoring well infrastructure during steady-state testing are used to define the full-scale zone of capture of the SVE treatment system.

2.2 ZONE OF CAPTURE ASSESSMENT

Zone of capture is the most important parameter to be considered in the design of a SVE system because it controls the mass removal rate and thus the efficiency and timeframe for site cleanup. Also referred to as the zone of remediation, the zone of capture is defined as the greatest distance from a SVE well at which a sufficient vapor flow can be induced to adequately enhance volatilization and extraction of the soil contaminants. The rate of mass removal via volatilization is a function of the volume of air passing by the contaminated soil per unit of initial contaminant mass.

Experience with SVE systems has shown that, for effective mass removal rates, zone of capture typically ranges between 40 and 100 feet. A smaller zone of capture is often needed to enhance mass removal rates in heterogeneous or fine-grained soil. A smaller zone of capture may also be needed to improve mass removal efficiencies and thus meet specific project deadlines (e.g., timeframe to begin redevelopment). The zone of capture appropriate for a SVE system should be evaluated on a site-specific basis, preferably using the method described in Section 2.2.1 or 2.2.2. On a case-by-case basis, DTSC may consider proposals to demonstrate an appropriate zone of capture during the system startup and validation process (see Section 2.2.4 for further discussion).

Regardless of the method used to estimate the zone of capture, performance data collected during pilot testing and/or system startup and validation and on-going operations should be used to confirm the adequacy of the initial zone of capture estimate. If the evaluation indicates that the zone of capture estimate was inaccurate, the system may require modification so that the RAOs can be achieved. See Section 2.2.4 for further discussion.

2.2.1 Pore Gas Velocity Approach

The approaches described in USACE (2002) and DiGiulio and Varadhan (2001a) can be used for the quantification of SVE system zone of capture. These approaches are based on the pore gas velocity and consist of two general steps. First, air permeability of the subsurface is determined. Then, the subsurface pore velocities associated with a SVE well, and the resulting zone of capture, are calculated using the air permeability. Typically, the zone of capture is defined by soil pore velocities of 0.01 cm/s (DiGiulio and Varadhan, 2000, 2001a) or greater. (Note: The zone of capture is inversely proportional to the pore gas velocity.) SVE wells should be placed so that their zones of capture completely cover the area of contamination with a slight overlap.

USACE (2002) and DiGiulio and Varadhan (2001a) should be consulted for detailed description and the technical basis for zone of capture derived from pore gas velocity estimates. A generalized description of the pore gas velocity approach is summarized below. Other appropriate methods may also be used.

Step 1. Vacuum response data are used to estimate the permeability ratio (ratio of horizontal to vertical permeability) and horizontal air permeability of the subsurface. These estimates can be determined using software designed for SVE system data analysis. Typical input parameters include:

- vacuum response data for monitoring points around each SVE well tested
- estimate of flow conditions (e.g., steady state, transient)
- estimate of subsurface conditions (e.g., leaky, semi-confined)
- blower flow rate
- estimated gas-filled porosity

Multiple scenarios (using realistic input parameters) should be used to find a reasonable approximation of the permeability ratio and horizontal air permeability.

Step 2. The air permeability ratio, horizontal air permeability, and other input parameters are used to estimate the pore gas velocity. This estimate can be modeled using software designed for SVE data analysis using an appropriate model domain, grid, boundary conditions, and input parameters. Typical input parameters include:

- permeability ratio / air permeability (e.g., as described in Step 1)
- blower flow rate
- anisotropy angle in the main principal flow direction[2]

[2] Obtained from literature values with consideration of site conditions

- soil porosity
- irreducible water saturation[2]
- van Genuchten soil-water retention parameters[2]

Multiple simulations, using realistic ranges of input parameters, are conducted to calibrate the model with a set of input parameters that provides the least average error between observed and simulated vacuum measurements at monitoring points. The calibrated model is then used to simulate the vacuum distribution and calculate pore gas velocity. To design the SVE system, this pore gas velocity can then be used to calculate a critical pore gas velocity[3] that results in an advection-dominated system.

Step 3. The pore gas velocity obtained in Step 2 is used to estimate the zone of capture for each SVE well. The USACE Manual recommends that critical pore gas velocities of 0.001 and 0.01 cm/s be used for design purposes.

2.2.2 Semi-Analytical Approach

An approach for the quantification of SVE system zone of capture is available that does not rely on the use of air permeability and pore gas velocities. The approach, which is described in Johnson and Ettinger (1994), utilizes SVE well extraction rates and subsurface contaminant mass estimations. Johnson and Ettinger (1994) should be consulted for detailed description, the technical basis, and potential limitations for the quantification of zone of capture by this method. When using this method, SVE wells should be placed so that zones of capture completely cover the area of contamination with a slight overlap.

The zone of capture is determined using Equation 6 of Johnson and Ettinger (1994). Selected parameters used by Equation 6 are described below.

Vapor Extraction Rate. The extraction rate for a single SVE well should be determined through pilot testing or estimated from professional experiences at nearby sites.

Contaminant Mass. The subsurface contaminant mass should be accurately quantified using both soil gas and soil matrix data. To obtain the most representative estimates of contaminant mass, soil matrix samples should be collected using USEPA Method 5035 (DTSC, 2004). Soil gas samples should be collected in accordance with *Advisory – Active Soil Gas Investigations* (DTSC/LARWQCB, 2003; revision pending).

Remediation Time Estimates. The timeframe for achievement of cleanup around the SVE well is needed to quantify zone of capture. By increasing the remediation timeframes, the zone of capture also increases proportionately.

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[3] DiGiulio and Varadhan (2001b) defines a critical pore gas velocity as the pore gas velocity that results in slight deviation from equilibrium conditions (i.e., sufficient flow rate through soil to reduce cVOC concentrations in the soil gas phase and thereby create a driving force for further cVOC volatilization, desorption, and diffusion into soil gas for removal by advective transport).

Gamma parameter (γ). This parameter is a dimensionless measure of the progress of remediation. The value should be less than or equal to 1.0 for the quantification of zone of capture.

Alpha parameter (α). This parameter is the minimum volume of air per unit contaminant mass required to achieve cleanup under ideal conditions. The value should be at least 100 cubic meters of air per kilogram of contaminant mass for the quantification of zone of capture.

This semi-analytical approach is based upon the concept that the SVE effectiveness is a function of the volume of air that flows through the contaminated soil. Please note that zone of capture quantified with this method does not truly reflect the two-dimensional nature of the remediation process and should be used cautiously with contingencies to modify the SVE system as appropriate based upon post-implementation site-specific data.

2.2.3 Other Methods (Not Preferred)

Historically, the zone of capture has been referred to as the radius of influence (ROI) and has been derived using following methods that are no longer considered to be appropriate.

Pore Volumes. Assessment of minimum zone of capture is based on an estimate of the pore volume exchanges required to allow diffusion to reduce contamination to allowable levels. The total number of exchanges is divided by the maximum period of treatment to determine the exchange rate per year. The maximum flow rate of the SVE well is used in conjunction with the pore volume requirements to develop well spacing capable of achieving these treatment requirements. The method requires estimates of the contaminant mass in the vadose zone which can be difficult to quantify and typically provide a poor basis for a meaningful design zone of capture.

Graphical Regression. This method uses vacuum data collected from monitoring well infrastructure located around a central SVE well. Typically, this method uses a plot of steady-state vacuum levels versus distance from the central SVE well to the monitoring well data point. The zone of capture would be based on the volume of soil in which a selected minimum vacuum value (e.g., 0.2 inches of water) was present. However, vacuum response in the subsurface is independent of air permeability. Hence, the arbitrary selection of an observed vacuum as the definition of zone of capture is not a good indicator of the subsurface treatment zone.

As discussed further below, use of a zone of capture derived from these methods likely facilitates capture (containment) of contaminant vapors, but does not consider mass removal rates and other factors that can effect cleanup efficiency (e.g., contaminant/soil distribution, mass transfer considerations, chemical partitioning).

The graphical regressive method using subsurface pressure has been the method most often applied by practitioners. However, the zone of effective air exchange is often much smaller than a ROI based upon pressure measurements (Johnson and Ettinger, 1994; Beckett and Huntley, 1994; Shan et al., 1992) and does not provide an estimate of the zone of effective air exchange in the subsurface. This issue is best discussed in Chapter 3 of USACE (2002):

> *"Historically, r_e [radius of pressure influence] has been used as the basis of design for extraction well networks. Designers have interpreted the zone of vacuum influence around a well as also corresponding to the "capture zone" of the extraction well. By subsequently selecting an arbitrary distance within this zone of vacuum influence, designers have established well spacings for SVE well networks. Unfortunately, this is a completely inappropriate interpretation of this phenomenon. . .SVE designs should be based on pore gas velocities or the rates of pore gas exchange, which, are a function of both the pressure (vacuum) distribution around the extraction point and the associated soil air permeability."*

2.2.4 Contingencies for SVE System Modification Based on Performance Data

The methods described in Sections 2.2.1, 2.2.2, and 2.2.3 can be used to develop the SVE well spacing. Regardless of the method used, the adequacy of the initial SVE well spacing should be verified based on performance data collected during the system startup and validation, and on-going operations. If the performance data indicate that the initial zone of capture estimate is inadequate, the system should be redesigned.

On a case-by-case basis, DTSC may consider proposals to demonstrate an appropriate zone of capture during the system startup and validation process, provided that:

- an adequate vapor monitoring well network is constructed as part of the initial system design;
- the design plan includes provisions for future SVE well installation based on operational data;
- the design plan includes a detailed strategy and procedures for system startup, testing, validation, and commissioning;
- a system validation and startup report is submitted; and
- DTSC is consulted and concurs with the decision.

In this instance, professional judgment would be used to develop a realistic initial estimate of the likely zone of capture. This initial estimate would be based on site characterization, experience at similar or nearby sites, and site-specific RAOs.

The system startup and validation report and subsequent status reports (see Section 6.0) should provide results, discussion of physical parameters (air permeability, measured zone of capture, air exchange rate, etc.), discussion of concentration trends in vapor monitoring wells and SVE wells, and discussion of other soil gas flow parameters. If the zone of capture used as the design basis is inadequate to achieve site-specific RAOs, the reports should document or provide recommendations for system modifications (such as the installation of additional SVE wells). Persistently elevated concentrations even after system operation may be another indicator of the need for system modifications and re-design.

3.0 VAPOR WELL CONSTRUCTION AND PLACEMENT

3.1 SOIL VAPOR EXTRACTION WELLS

3.1.1 Construction

USEPA and USACE provide recommendations for SVE well construction. Typically, DTSC recommends a minimum of two-inch diameter SVE wells, but larger diameter wells should be considered if pressure loss is of concern.

3.1.2 Placement

To achieve maximum efficiency from a SVE well field, the SVE well screen intervals should be placed vertically to provide effective air flow through soils where cVOC concentrations exceed RAOs. The screen interval position should be determined through site characterization data (e.g., lithology, concentration etc,), modeling, startup testing, and/or pilot testing. Some wells should be targeted toward the interface between permeable and recalcitrant zones. At some sites, efficiency may be achieved by screening the SVE wells in the lower part of the target zone in order to reduce downward air flow from the ground surface, thus decreasing the air flow rate and resultant need to oversize blower and effluent treatment system. Well spacing should be selected to allow overlapping zone of capture between SVE wells. Overlapping zones of capture may produce “stagnant” zones that should be considered in the system design (GRA, 2007).

3.1.3 Additional Extraction Well Capacity

The number of SVE wells installed for a SVE system should be increased as necessary to meet the RAOs. The need for additional SVE wells should be evaluated based on pilot test data, initial performance data, system validation/startup performance data, and/or other monitoring data. Flexible system design (e.g., blower size, treatment capacity, vapor monitoring well location) will facilitate incorporation of additional SVE wells into the system.

3.2 SOIL VAPOR MONITORING WELLS

Monitoring well infrastructure is needed for design, operation, and closure activities. The monitoring wells are integral to the operation and closure activities associated with full-scale operation. Although multiple monitoring wells will be installed to support the pilot test or system validation/startup, additional monitoring wells may be needed based on the size of the full-scale SVE treatment system and if vapor monitoring wells are converted to SVE wells.

3.2.1 Construction

DTSC recommends construction of vapor monitoring wells with PVC materials and with a diameter of one to two inches (or larger to allow conversion to a SVE well). Typically, three to five foot interval screen intervals are preferred for vapor monitoring wells. Alternative construction methods consisting of dedicated, limited length screen intervals (i.e., six inches) attached to tubing are not recommended.

3.2.2 Well Placement

Multiple, multi-depth, discrete-interval monitoring wells should be located in different directions and varying distances from the SVE wells. At a minimum, vapor monitoring should occur at three locations from the SVE wells. Each monitoring location should screen multiple, discrete depths. The lateral and vertical placement of monitoring wells relative to the SVE wells should be based on the estimated zone of capture for the SVE well.

3.2.3 Screen Intervals

Monitoring wells should be screened in the most contaminated soils. Considerations for selecting potential zones for vapor monitoring well screen intervals include placement:

- in both permeable and recalcitrant zones
- at depths corresponding to desirable soil type
- with consideration of the SVE well screen intervals
- to allow evaluation of changes in the cVOC concentrations
- to allow evaluation of zone of capture
- to demonstrate achievement of the RAOs

4.0 OPERATIONAL ASSESSMENT FOR SVE SYSTEMS

Operational assessment of a SVE system is a combination of field instrumentation data (i.e., vacuum gage, photoionization detector, flow meter) and speciated cVOC analyses from the SVE treatment system (influent/effluent, SVE wells) and soil vapor monitoring wells. Initially, the SVE system is run at design specifications until monitoring data indicates a need for modifications to enhance cVOC recovery. Continued system operation will lead to a decrease in influent stream concentration that necessitates system optimization (Section 4.1) and eventually rebound assessment (Section 4.2). The USACE Manual (USACE, 2002) provides detailed discussion of these topics and additional resources are provided on the USEPA web-site (www.clu-in.org).

4.1 OPTMIZATION

Operation of the SVE system requires continuous optimization to ensure maximum contaminant recovery. The total mass (as evidenced by concentrations measured in SVE well effluent) typically decreases rather quickly within several weeks to a few months of operation and then reaches a condition where total concentration and mass removal rates have stabilized. In general, these conditions occur when the total cVOC concentration in combined extracted vapor does not vary by more than 1 to 5 percent during several consecutive monitoring events. The optimization effort should begin at the onset of the full-scale operation. However, when total cVOC concentrations stabilize, it becomes particularly important to optimize because it will shorten the operation time for the SVE system. This optimization effort should be documented in an appropriate report.

4.1.1 Potential Optimization Activities

Optimization activities generally consist of adjusting the SVE system air flow capacity such that the vapor extraction is occurring from the wells having the highest mass removal rates or closest to zones with cVOC concentrations exceeding RAOs. Potential optimization activities might include:

- rebalancing the air flow capacity to SVE wells with the highest mass removal rates and/or nearest to zones where RAOs have yet to be achieved; this rebalancing would include reducing air or eliminating flow at SVE wells producing low mass flow (e.g., wells completed in diffusion-limited areas) and increasing flow from SVE wells that are producing higher mass flow (indicative of an on-going source of vapors);
- reducing the overall system flow rate to address contaminant mass moving primarily by diffusive transport (by use of available frequency control, mechanical pulley changes, or change in blower capacity);
- further characterization of low permeability zones using advanced site characterization tools (such as membrane interface probes, SimulProbe®[4], or equivalent) to create a vertical profile of soil types, cVOC concentrations, and cVOC mass versus depth;
- vertically profiling existing SVE wells using PneuLog®[4] (or equivalent device) to obtain data on the vertical profile of advective and diffusive layers;
- placing additional short-screened SVE wells below or within diffusion-limited zones;
- alternating between SVE wells to reduce power and vapor treatment requirements (such as when diffusion limitations require extended remediation times and lower flow rates); and/or
- adjusting blower/total extraction rate to maximize the rate of contaminant removal.

[4] Use of trade names does not constitute endorsement by DTSC

Higher flow rates or vacuums will generally not improve cVOC removal from low permeability soils. Sites with relatively thin layers (i.e., less than 2 feet) of low permeability soils surrounded by high-permeability sands can be more effectively remediated by using smaller blowers and lowering the flow rates to better address contaminant vapors migrating primarily by diffusive transport. Accepting longer operating times at lower flow rates with less frequent monitoring and sampling is often the most cost-effective strategy for sites with low permeability soils.

4.1.2 Pulse-Mode Operation (Optional)

A SVE system can also be operated in “pulse” mode as a means of system optimization. For evaluation of optimization, the SVE system may be shutdown periodically to evaluate whether subsurface concentrations may “rebound” or “spike”. This evaluation is sometimes performed when mass recovery rates decrease. Stabilized total cVOC concentrations in SVE system influent should not be used as the sole basis to support the need for pulse-mode operation. For instance, at highly contaminated sites, the level of influent concentrations may become stabilized, but are high enough to result in significant mass removal (which supports continued SVE system operation). In addition, a number of factors will require evaluation in order to determine if the observed stabilized concentrations are truly reflective of conditions necessitating further optimization through pulse-mode operation.

The pulse-mode operation may begin once the influent concentrations are stabilized and reflective of low mass removal rates. Pulse-mode operation can be implemented in the following steps:

- completing other SVE system optimization actions (see Section 4.1.1);
- operating the SVE system until low mass rates and stabilized influent concentrations are present under optimized operational conditions;
- performing all necessary field and speciated analysis of influent, SVE well, and monitoring well concentrations while system is operational;
- performing all necessary field and speciated analysis of SVE and monitoring well concentrations at end of inoperative period;
- turning the SVE system off for an appropriate period based on concentration trends and/or discussions with DTSC (experience has shown that this is usually a few weeks to a few months);
- turning the SVE system back on and optimizing the operation based on results of latest analyses; and
- repeating this series of activities until analyses indicate that the SVE system is ready for rebound or closure assessment.

If significant mass recovery occurs during the pulse-mode operation of the SVE system, the operator should evaluate whether increased SVE well density would resolve the need for pulse mode operation by providing greater pore velocity in the subject areas.

4.2 REBOUND ASSESSMENT

Rebound assessment requires that the SVE unit is temporarily shut down to evaluate whether subsurface RAOs have been achieved. The timeframe for rebound assessment is a site-specific determination and should have sufficient duration so that the measured soil gas concentrations represent equilibrium conditions at steady-state. A site-specific timeframe for rebound assessment can be determined using the approach described in Johnson et al. (1999).

Rebound assessment requires collection of soil gas samples at equilibrium from SVE wells and vapor monitoring wells. The soil gas samples should be collected pursuant to the *Advisory – Active Soil Gas Investigations* (DTSC/LARWQCB, 2003; revision pending). Monitoring wells are preferred for this assessment because of the shorter screen intervals. These data are compared to the RAOs. Hence, rebound assessment requires:

- baseline samples from site characterization data and/or vapor monitoring wells just prior to pilot-scale testing or system startup;
- samples collected immediately prior to or just after cessation of SVE operations; and
- samples obtained during multiple sampling events at appropriate time increments after cessation of SVE operations. The number of samples should allow visual estimation of concentration trends. The time period over which the samples are collected should consider the estimated time for steady-state concentrations to be reached at each monitoring location.

When soil rebound concentrations indicate a need for further vadose zone remediation, the SVE system is restarted. Typically, only SVE wells that can influence zones requiring additional mass removal should be reactivated (as indicated by data obtained during the rebound assessment). Extraction continues until the concentration of the extracted gas in the inlet stream re-stabilizes and mass removal rates are low. At this point, another shutdown period with soil gas monitoring begins. The cycle continues until steady-state soil gas concentrations in all vapor monitoring wells remain below clean-up goals or until it is apparent that no further progress is being made by the SVE system. An appropriate number of sampling events should transpire over a period of time to demonstrate that residual cVOC concentrations are stable and that the RAOs have been achieved.

5.0 SVE REMOVAL ACTION MONITORING

This section identifies general considerations for the development of a site-specific monitoring approach used to evaluate SVE system performance and remediation progress.

5.1 MONITORING LOCATIONS

During SVE system operation, remedy performance and cleanup progress is monitored by collecting soil gas samples from: treatment system influent, treatment system effluent, SVE wells (Section 3.1), and soil vapor monitoring wells (Section 3.2). Vacuum measurements at SVE and vapor monitoring wells may also be needed. Collectively, these data are used to make decisions about system operations, modifications, optimization, rebound, and shut down (see Section 4.0).

5.2 SAMPLING FREQUENCY

Typically, SVE wells and soil vapor monitoring wells are sampled frequently during SVE system startup to ensure mass removal is occurring as expected and to provide a basis for system adjustments or modifications. Hence, during the SVE system startup, sampling of SVE wells and soil vapor monitoring wells on weekly (or more frequent) basis may be needed. These data are used to assess and adjust system operation. The concentration data obtained during this period are useful comparators when the system enters rebound assessment. The data may also be useful for identifying unknown cVOC sources within the zone of capture of the SVE system.

The sampling frequency can be reduced as the system and concentration behavior becomes better understood. Temporal plots of concentration are useful for evaluating the transition from frequent startup sampling to the reduced frequencies for routine monitoring of the system. For many sites this transition occurs about a month or so after startup.

During routine monitoring, the sampling frequency for a given well should consider its function, location, and concentration behavior. The selected frequency should also consider the expected duration of the removal action (e.g., more frequent sampling for short duration removal actions). Operating SVE wells are often monitored frequently (e.g., monthly, quarterly) to allow timely adjustments to system performance. Soil vapor monitoring wells containing relatively high concentrations may also be sampled relatively frequently (e.g., quarterly) to allow assessment and tracking of concentration behavior. Soil vapor monitoring wells containing relatively low concentrations may warrant a lower sampling frequency with a provision for resampling if unexpectedly high concentrations are detected. The well can be identified for more frequent sampling if the high concentration is confirmed by the resample.

5.3 EVALUATING SVE WELL DATA

SVE well data is used to determine whether concentrations fall within expected ranges and whether adjustments to the SVE system are needed. For example, if concentrations do not decrease by at least one order of magnitude within an expected timeframe (e.g., after 12 to 18 months of operation), the possible causes of the concentration behavior should be evaluated. Optimization measures such as increasing airflow from selected SVE wells or installing additional SVE wells may be appropriate. As another example, if a SVE well has a relatively low mass removal rate (such as might be caused by diffusion constraints), airflow from this well could be decreased, perhaps allowing increased airflow from another SVE well with a higher mass removal rate. A low mass removal rate may also indicate other potential problems (such as short-circuiting caused by poor annular seals).

5.4 EVALUATING SOIL VAPOR MONITORING WELL DATA

Soil vapor monitoring well data are evaluated to determine whether concentrations are behaving as expected and whether adjustments to the SVE system are needed. Persistently high cVOC concentrations after months of operation may warrant increased airflow from the nearest SVE well or adjustment of airflow in an interfering SVE well. Persistently high concentrations could also indicate the need for an additional SVE well (at an appropriate distance and depth interval). Another option is to use the vapor monitoring well as a SVE well (provided that the casing diameter is adequate and does not produce large fluid energy loss).

5.5 MONITORING DURING REBOUND EVALUATION

During a rebound assessment (Section 4.3), soil gas samples are collected and analyzed at appropriate time intervals. Data from soil vapor monitoring wells are preferred for rebound assessment because of the shorter screen intervals. Significant concentration rebound during the first few sampling events after system shutdown indicates a need to optimize and restart the SVE system. If no significant rebound occurs and the *in situ* concentrations have been monitored and evaluated over an appropriate period of time (pursuant to Johnson et al., 1999), the next step typically is an assessment of whether the system is ready for site closure (Section 7.0).

5.6 SAMPLING TO SUPPORT CLOSURE ASSESSMENT

The closure assessment for a SVE system (see Section 7.0) should be based on data obtained from the inlet stream and depth-specific soil gas data obtained throughout the baseline extent of the vapor plume. The depth-specific data can be collected from existing vapor monitoring wells and from soil gas borings completed in areas of the baseline plume extent that were not specifically monitored during the SVE removal action. The need to confirm the level of vadose zone treatment with soil matrix sample analysis is a site-specific determination that is dependent on the RAOs. Samples should be collected pursuant to Cal/EPA guidance (DTSC, 2004; DTSC/LARWQCB, 2003, revision pending).

6.0 STATUS REPORTS

Periodic status reports should be submitted to DTSC that summarize the performance of the SVE system. The status report contents should be based on pre-defined reporting needs and objectives. Typical topics addressed by status reports may include:

- total mass recovery (including basis for mass calculations)
- graph of cumulative mass removed
- influent/effluent concentration to treatment system
- individual well concentrations
- individual SVE well concentration trends
- trend analysis
- mass emission rate
- operating parameters
  - startup date
  - hours operated during reporting period
  - cumulative operating hours to-date
  - SVE wells in operation
  - operating vapor extraction rate
  - total air volume extracted during reporting period
  - carbon usage
  - caustic usage
  - utility water usage
  - power usage
  - wastewater discharged
  - operating temperature
- deviations to operating system
- causes of shutdown
- O&M activities
- equipment repair and replacement
- optimization efforts
- costs to operate, monitor, and maintain the SVE system
- significant events/activities during reporting period
- scheduled upcoming activities
- map of SVE system
- field documentation (maintenance logs, shutdown logs, checklists)

Additional topics may be appropriate based on site-specific considerations.

7.0 SYSTEM SHUTDOWN AND CONFIRMATION OF CLEANUP

In general, the site is ready for an analysis of SVE system shutdown after:

- the SVE system has been optimized to the extent feasible (Section 4.1);
- rebound assessment (see Section 4.2) indicates that RAOs have been achieved; and
- a sufficient period of time has passed since final system shutdown to allow residual cVOC concentrations to equilibrate to steady-state conditions.

A system may also be ready for shutdown when the performance assessment indicates that no further progress is being made and that additional remedial approaches would be needed to address the remaining contamination.

At sites where the SVE system has achieved RAOs, the closure analysis typically includes:

- preparation of plots of:
  - cVOC concentrations versus time (SVE and monitoring wells)
  - cumulative extracted mass versus time
  - mass removal versus time throughout the SVE operation (including any pulse-mode periods);
- depth-specific soil gas sampling (and soil confirmation sampling if applicable) to assess residual cVOC concentrations throughout the baseline plume extent (Section 5.6);
- documentation of the optimization and rebound assessment efforts (Section 4);
- confirmation sample data analysis and documentation;
- estimated total cVOC mass in the vadose zone after SVE treatment;
- assessment of the potential for residual cVOCs to pose an on-going threat to groundwater and/or human health;
- if residual cVOC concentrations pose a continued threat to groundwater, evaluation of whether the threat can be mitigated by an alternate vadose zone remedy and/or the groundwater remedy; and
- economic feasibility analysis for continued operation of the SVE system (if appropriate).

The USACE Manual (USACE, 2002) and DiGiulio and Varadhan (2001b) provide detailed discussion of SVE system shutdown and cleanup confirmation.

8.0 ANNOTATED OUTLINE FOR SVE SYSTEM PILOT TEST WORKPLAN

Preface: The following annotated outline identifies potential content for a SVE system pilot test workplan. This outline is not intended to be prescriptive and should be adjusted as appropriate for site-specific conditions. Some elements identified may apply to your site, while others may not. Additional elements than are addressed by the outline may also be needed. This outline is for guidance only, and is applicable on a case-by-case basis.

1.0 INTRODUCTION

Instructions: Provide a general description of the site and pilot test area. Present the purpose and scope of the pilot test, including the regulatory framework under which it is being conducted. Identify the performance measures and applicable data metrics to be collected. Identify the response agency. Outline the workplan organization.

1.1 Site History, Operations, and Features
1.2 Scope and Objectives of Pilot Test
1.3 Workplan Organization

2.0 SUMMARY OF EXISTING CONDITIONS

Instructions: This section should orient the reader to the site and provide sufficient background information so that the reader can evaluate the proposed design of the pilot test. Provide an overview of the site geology and hydrogeology. Identify the depth to water and typical water table fluctuation. Summarize available data on the nature and extent of contamination in soil, soil vapor, and groundwater. If applicable, describe results of previous pilot studies. Support this section with appropriate figures and tables.

2.1 Site Lithologic and Hydrogeologic Conditions
2.2 Soil Quality
2.3 Soil Vapor Quality
2.4 Groundwater Quality
2.5 Results of Previous Pilot Studies

3.0 SITE CONCEPTUAL MODEL FOR VOLATILE CONTAMINANTS

Instructions: Provide a narrative description and schematic diagram of the CSM for cVOCs. Clearly describe the source and current locations of contaminants. Provide figures showing the extent of the soil vapor plume in plan view and in cross-section. Describe the fate and transport of cVOCs in the vadose zone and groundwater. Discuss the potential exposure pathways for the cVOCs (e.g., inhalation from groundwater, vapor intrusion into indoor air, ingestion and dermal contact with contaminated groundwater). Describe any considerations associated with expected emissions from the SVE system.

3.1 Source and Current Location of Contaminants
3.2 Extent of Soil Vapor Contamination
3.3 Transport
3.4 Health Effects of Contaminants

4.0 SELECTION OF RESPONSE ACTION

Instructions: Indicate why the response action is being implemented (e.g., mitigate cVOC-impacted soil and soil vapor, protect of groundwater, protect human health, mass removal). Briefly describe why SVE is considered to be a proven technology and remedy or indicate that the PT&R approach to Remediation of Chlorinated VOCs in Vadose Zone Soils is being used. Provide the rationale for using SVE as the response action at the site.

4.1 Proven Technologies and Remedies
4.2 Soil Vapor Extraction and Treatment

5.0 DESIGN OF SVE PILOT TEST

Instructions: Identify the objectives of the pilot test (e.g., determine air permeability, zone of capture, flow rate/vacuum for blower sizing, condensate production, concentration trends, water table response). Provide a detailed description of the infrastructure that will be used to conduct the pilot test, including all wells, piping, blowers, and treatment components. Identify any noise or CEQA considerations for the pilot test. Indicate the instrumentation that will be used during the test (such as to measure vacuum/pressure, flow, temperature, and barometric pressure). Provide figures illustrating the SVE system layout, treatment system, and instrumentation.

5.1 Pilot Test Objectives
5.2 SVE and Soil Vapor Monitoring Well Design
5.2.1 Well Depths and Spacing
5.2.2 Design and Materials
5.3. Piping
5.4 Treatment System
5.5 Other Infrastructure
5.5.1 Blower
5.5.2 Valves
5.5.3 Monitoring Points
5.5.4 Sampling Ports
5.5.5 Instrumentation
5.5.6 Power Source
5.5.7 Condensate Collection, Storage, and Secondary Containment

6.0 SVE PILOT TEST SYSTEM INSTALLATION

Instructions: Identify the activities to be conducted prior to system installation (e.g., permitting, utilities clearance, stakeholder outreach). Identify health and safety issues associated with system installation. Describe the well installation methods, including drilling methods, any soil sampling and analysis that will be conducted as part of well installation, equipment decontamination, and handling of investigation-derived waste. Indicate the installation requirements for the piping system (e.g., soils management, damage protection, equipment decontamination). Describe the installation requirements for the treatment system and blower.

- 6.1 Pre-Installation Activities
  - 6.1.1 Permitting
  - 6.1.2 Utilities Clearance
  - 6.1.3 Community Relations
- 6.2 Health and Safety
- 6.3 Personnel and Responsibilities
- 6.4 Well Installation
  - 6.4.1 Drilling Methods
  - 6.4.2 Soil Sampling and Analysis
  - 6.4.3 Well Construction and Installation
- 6.5 Piping
- 6.6 Treatment System
- 6.7 Other Infrastructure
- 6.8 Decontamination
- 6.9 Waste Management

7.0 PILOT TEST SYSTEM OPERATION AND MAINTENANCE PROGRAM

Instructions: Outline the O&M program for the system. Provide the procedures for starting up and operating the system (e.g., duration, leak and blockage checks, test operational sequence, step testing, system operational parameter measurements, measurement locations). Identify the data analysis procedures (such as air permeability, zone of capture, system curve construction, mass removal rates, treatment efficiency). Describe the monitoring and sampling program to be implemented during the pilot test, including the measurement/analytical parameters, measurement/sampling frequencies, measurement/sampling locations, methods, and equipment. Identify the system shutdown strategy (e.g., how test completion will be determined, decommissioning, or incorporation into the final remedy). Indicate how the system performance will be evaluated and reported. Identify the type, content, and frequency of reporting. Identify contingencies in the event of system failure or unacceptable performance (i.e., specific actions to be taken, response times, contacts).

- 7.1 System Start-Up
- 7.2 Operating Strategy
  - 7.2.1 Procedures
  - 7.2.2 Data Analysis

7.2.3 Operation Schedule
7.2.4 Contingency Plan
7.3 Shutdown Strategy
7.4 Monitoring and Sampling Program
7.4.1 Operational Parameters
7.4.2 Chemical Parameters
7.5 Performance Evaluation and Reporting

8.0 PROJECT SCHEDULE

Instructions: Provide a schedule for implementing the pilot test.

9.0 REFERENCES

Instructions: Provide the references used to support the pilot test design and workplan.

TABLES
Geologic and Hydraulic Properties of Stratigraphic Layers
Geotechnical Parameter Test Methods

FIGURES
Site Location Map
Site Features Map
Cross Section of Site Stratigraphy
Conceptual Site Model of Vapor Distribution
Soil Vapor Plume Distribution (various depth intervals)
Groundwater Isoconcentration Contour Map
SVE Pilot Test Location Map
Proposed Pilot Test SVE and SVM Well Locations
Proposed Pilot Test SVE and SVM Screen Intervals
Schematic SVE and SVM Well Construction Diagrams
Schematic of SVE Treatment System Process Flow Diagram

APPENDICES
Field Data Sheets
Statement of Qualifications

9.0 ANNOTATED OUTLINE FOR SVE SYSTEM PILOT TEST REPORT

Preface: The following annotated outline identifies potential content for a SVE system pilot test report. This outline is not intended to be prescriptive and should be adjusted as appropriate for site-specific conditions. Some elements identified may apply to your site, while others may not. Additional elements than are addressed by the outline may also be needed. This outline is for guidance only, and is applicable on a case-by-case basis.

EXECUTIVE SUMMARY

1.0 INTRODUCTION

Instructions: Provide a general description of the site and pilot test area. Identify the purpose, scope, and objectives of the pilot test. Identify the performance measures and applicable data metrics. Indicate the regulatory framework under which the test was conducted. Identify the responsible agency. Outline the report organization. Reference the pilot test workplan.

1.1 Site History, Operations, and Features
1.2 Scope and Objectives of Pilot Test
1.3 Report Organization

2.0 PROJECT BACKGROUND INFORMATION

Instructions: Briefly orient the reader to the site and provide sufficient background information so that the reader can evaluate the pilot test results. Support this section with appropriate figures and tables.

2.1 Site Setting
2.2 Site Background

3.0 PILOT TEST DESCRIPTION, OBJECTIVES, AND PROCEDURES

Instructions: Provide an overall description of the pilot test, including the test objectives, equipment, and procedures. Also describe any departures or exceptions from the workplan.

3.1 Remedial Technology Description
3.2 Pilot Test Objectives
3.3 SVE Well Installation
3.4 Pilot Test Equipment
3.4.1 Wells and Piping
3.4.2 Vapor Collection System
3.4.3 Vapor Pretreatment System
3.4.4 Vapor Treatment System

3.4.5 Ancillary Systems
3.4.6 Monitoring Equipment and Instrumentation
3.5 Pilot Test Permitting
3.6 Pilot Test Procedures
3.6.1 Startup and Testing
3.6.2 Performance Tests
3.6.3 System Modifications During Startup

4.0 FIELD AND LABORATORY DATA

Instructions: Describe the monitoring and data collection activities conducted prior to and during the pilot test, including any departures/exceptions from the workplan. Describe the noise readings and locations, including comparison to local noise ordnance requirements. Examples of pre-test data include static water level data, soil and air temperature, static pressure, and atmospheric conditions.

4.1 Field Data
4.1.1 Pre-Test Data
4.1.2 Chemical Parameters
4.1.3 Temperature
4.1.4 Pressure/Vacuum
4.1.5 Flow Rate
4.1.6 Noise Readings and Locations
4.2 Laboratory Data
4.2.1 Geotechnical Data
4.2.2 Chemical Data
4.2.3 Data Quality

5.0 DATA ANALYSIS AND INTERPRETATION

Instructions: Provide an analysis of the test data with references to appropriate in-text tables, graphs, and figures. Include supporting documents as appendices.

5.1 Achievable Flow Rates
5.2 Zone of Capture
5.3 Field Permeability
5.4 Chlorinated VOC Removal Rate
5.5 Effectiveness of SVE
5.5.1 Treated Soil Vapor
5.5.2 Residual Soil
5.5.3 Recovered Condensate

6.0 CONCLUSIONS AND RECOMMENDATIONS

Instructions: Discuss the test findings and whether there is a need for additional work. If applicable, describe the design basis for the full-scale SVE system.

6.1 Overall Effectiveness of Technology
6.2 Needs for Further Study
6.3 Design Basis for Full-Scale System

7.0 REFERENCES

Instructions: Provide the references cited in the report and used as the basis for any calculations.

TABLES

Zone of Capture Data
Vacuum vs. Flow Data
Equipment List
Sampling and Analytical Method Summary
Removal Rate Summary
Zone of Capture Summary
Chemical Analytical Results Summary
Summary of Air Permeability Tests/Calculations
Well Construction Details
Full-Scale SVE Design Parameters

FIGURES

Site Location Map
Site Features Map
SVE Pilot Test Location Map
Cross Sections of Site Stratigraphy and Well Screen Intervals
Schematics of SVE System Layout
As-builts of SVE System
Construction Schematics
Representative Graphs of Air Flow vs. Applied Vacuum
Representative Zone of Capture for Selected Wells
Representative Graphs of Concentrations over Time
Representative Graphs of Response Vacuum vs. Distance
Map of Vacuum Response Isopleths

APPENDICES

Laboratory Analysis Reports
QA Reports
Field Data Sheets
Well Installation and Boring Logs
Air Permeability Evaluation
Zone of Capture Calculations and Evaluation
Flow Rate Calculations
Recovery Rate Calculations for Each Test Well
Graphs of Data for Each Test Well

10.0 ANNOTATED OUTLINE FOR SVE SYSTEM STARTUP AND VALIDATION REPORT

Preface: The following annotated outline identifies potential content for a SVE system startup and validation report, and can be used for sites that had a discrete pilot test phase as well as sites that choose to move directly into the startup/validation phase. As indicated in the outline, sites that moved directly into the startup/validation phase have additional content requirements (as discussed in Chapter 9 of the main text). This outline is not intended to be prescriptive and should be adjusted as appropriate for site-specific conditions. Some elements identified may apply to your site, while others may not. Additional elements than are addressed by the outline may also be needed. This outline is for guidance only, and is applicable on a case-by-case basis.

1.0 INTRODUCTION

Instructions: Provide a general description of the site and area addressed by the SVE system. Present the purpose and scope of the SVE removal action, including the regulatory framework under which it is being conducted. Identify the performance measures and applicable data metrics. Identify the response agency. Briefly orient the reader to the site and provide sufficient background information so that the reader can evaluate the results presented in the report. Outline the report organization.

1.1 Site History, Operations, and Features
1.2 Scope and Objectives of SVE Removal Action
1.3 Background
1.3 Report Organization

2.0 SVE SYSTEM COMPONENTS

Instructions: Identify and describe the various components of the SVE system. Include figures of the schematic layout of the treatment system as well as the overall system layout, including piping routes. If applicable, describe the construction and installation of the system components.

2.1 Vapor Extraction Wells
2.2 Vapor Monitoring Wells
2.3 Treatment Units
2.4 Vapor Extraction Blower
2.5 Conveyance Piping
2.6 Monitoring Stations
2.7 Utilities

3.0 SVE SYSTEM STARTUP SUMMARY

Instructions: Describe activities and findings during SVE system startup, including duration of startup activities, key dates, system settings and modifications, and the dates, types, and frequencies of monitoring. Describe the types and results of any tests (e.g., step, steady-state, isolation). Discuss the monitoring data obtained during system startup, including induced vacuum, field screening results, and laboratory sampling and analysis. As applicable, describe the system performance under various operational conditions (e.g., different SVE well configurations). If applicable, document the decision process that led to installation of additional SVE wells or a decision not to operate a given SVE well. As applicable, discuss data collected to address site-specific concerns (e.g., noise).

3.1 Baseline Soil Vapor Sampling
3.2 Initial Startup and Testing
3.3 Induced Vacuum
3.4 Field Screening
3.5 Laboratory Results
3.6 Instrumentation Settings
3.7 System Modifications During Startup

4.0 SVE SYSTEM OPERATIONS SUMMARY

Instructions: Describe the activities and results of the system operation following the initial startup period. Indicate the period of time reflected in the summary. Include an operation and maintenance summary (e.g., cumulative hours of operation, sorbent changeouts, sorbent consumption rate, system adjustments). Also discuss any administrative changes (e.g., changes to the permit requirements for the system emissions). Discuss inspections of the SVE system, monitoring events, and monitoring results. Identify any trouble-shooting activities, the measures taken, and the outcome.

4.1 Treatment Unit Issues
4.2 Operation and Maintenance Activities
4.3 Troubleshooting
4.4 Administrative Changes

5.0 DATA ANALYSIS

Instructions: Provide an interpretation of the data collected during the timeframe addressed by the report, including baseline data collected prior to system startup. Discuss the vacuum/pressure distribution induced by the SVE system. Estimate the pore gas velocity, zone of capture and mass removal rate induced by the SVE system.

5.1 5.1 Physical Parameters
5.1.1 Vacuum/Pressure Distribution
5.1.2 Flow Rate
5.1.3 Pore Gas Velocity

5.1.4 Zone of Capture

5.2 Chemical Parameters

5.2.1 Treatment Unit Influent and Effluent

5.2.2 Vapor Wells

5.3 Mass Removal Calculations

6.0 CONCLUSIONS AND RECOMMENDATIONS

Instructions: Provide conclusions regarding the system effectiveness as well as recommendations for on-going operation and maintenance of the SVE system.

7.0 REFERENCES

TABLES

- Well Completion Details
- Equipment Summary
- Operations and Maintenance Summary
- Sampling Program
- Summary of Samples / Data Collected
- Well Data
- Influent / Effluent Data
- Field Monitoring Data
- Field Operations Data
- Vacuum Distribution
- Flow Rate Calculations
- Well Pressure / Flow Relationships
- Calculation Summaries (air permeability, pore gas velocity, zone of capture)
- Test Results Summaries (step, steady-state, isolation)
- Mass Removal Summary

FIGURES

- Site Location Map
- Site Vicinity Map
- Site Plan and Well Locations
- Site Conceptual Model / Representative Cross Section
- System Layout / As-built
- Treatment System Schematic
- Schematic System Flow Diagram
- Isopressure Contours
- Concentration Distribution (multiple depth intervals)
- Time Concentration Graphs
- Cumulative Mass Removal
- Graphs of Test Data
- Zone of Capture Extent

APPENDICES

- Permits
- Field Forms and Notes
- Laboratory Analytical Reports
- Residue Disposal Documentation
- Calculations
- Well Completion and Boring Logs
- Construction QA/QC
- Documentation of Residue Disposal

11.0 ANNOTATED OUTLINE FOR SVE SYSTEM DESIGN DOCUMENT

Preface: The following annotated outline identifies potential content for a SVE system design document. This outline is not intended to be prescriptive and should be adjusted as appropriate for site-specific conditions. Some elements identified may apply to your site, while others may not. Additional elements than are addressed by the outline may also be needed. This outline is for guidance only, and is applicable on a case-by-case basis.

1.0 INTRODUCTION

Instructions: Provide a general description of the site and pilot test area. Indicate the purpose of the document. Identify the scope and RAOs of the SVE system (e.g., protect receptors from exposure to cVOCs at the surface, protection of groundwater quality, reduce groundwater cleanup time and cost, and/or restore contaminated areas to support existing and proposed land uses). Identify the performance measures and applicable data metrics. Reference a table summarizing the quantitative cleanup goals. Identify the responsible agency. Outline the document organization.

1.1 Site History, Operations, and Features
1.2 Purpose of Document
1.3 Scope and RAOs of SVE System
1.4 Document Organization

2.0 BACKGROUND INFORMATION

Instructions: Orient the reader by providing sufficient background information about the site. Provide a brief overview of the site geology and hydrogeology and direct the reader to key project documents for further information. Provide a synopsis of the current knowledge of the nature and extent of contamination in soil, soil vapor, and groundwater, with a focus on the contaminants to be addressed by the SVE system or that may need to be considered during SVE system operation. Give a brief overview of the SVE technology being applied and indicate why SVE was selected as the remedial technology for the site. If applicable, describe results of previous pilot studies. Support this section with appropriate figures and tables.

2.1 Soil Contamination
2.2 Soil Gas Contamination
2.3 Groundwater Contamination
2.4 SVE as Remedial Technology for cVOCs in Vadose Zone

3.0 CONCEPTUAL SITE MODEL FOR VOLATILE CONTAMINANTS

Instructions: Provide the CSM for the SVE system. Identify the principle sources of cVOC contamination and the locations of these sources. If relevant, explain how these sources have changed over time (e.g., small core zone in shallow subsurface surrounded by a soil vapor halo, initial core area expanded by a smear zone caused by dropping groundwater levels). Describe horizontal and vertical extent of the soil vapor plume prior to start-up of the SVE system (e.g., baseline plume extent). Briefly describe the geologic materials to be remediated with emphasis on the characteristics that may affect SVE effectiveness (e.g., grain size, grain size distribution, stratification, moisture content, water table position, organic carbon content). Summarize the conceptual air flow model for the site (e.g., extent of SVE well influence, induced vacuum, air flow characteristics, potential for "short circuiting", slower cleanup of finer grained zones).

3.1 Sources of cVOCs
3.2 Soil Vapor Plume
3.3 Geology
3.4 Conceptual Air Flow Model

4.0 SVE IMPLEMENTATION PROCESS

Instructions: Present the overall process for implementing the SVE system. Identify the permit and other administrative requirements. Identify the steps that will be used to startup and test the SVE system (e.g., baseline sampling of vapor wells, the sequence of system startup, flow rate testing, leak checks, monitoring frequencies, types of measurements/samples, treatment unit performance assessment). Discuss the activities associated on-going operation of the SVE system (e.g., measurements/ sampling to assess performance and status, inspections to ensure proper operation of equipment) and reference the O&M plan. Indicate what performance measures might trigger optimization and what steps might be taken to optimize system performance (e.g., modify system flow rates, taking a well off-line, placing additional wells on-line, treatment system adjustments). Outline an initial strategy for curtailment and closure of the SVE system. To assist with the decision process for curtailing or closing the SVE system, provide a table summarizing possible response actions for specific influent concentrations, air flow rates, and/or mass removal rates (e.g., continue operating a given SVE well if the concentration is above a certain value; if the concentration in a given SVE well falls below a given value, turn off a SVE well and evaluate concentration rebound after an appropriate period of time).

4.1 Startup and Testing
4.2 Long-term Operation
4.2.1 System Status and Performance Monitoring
4.2.2 System Optimization
4.3 Curtailment and Closure Strategy

5.0 FIELD SAMPLING PLAN FOR OPERATING SVE SYSTEM

Instructions: Present the rationale, methods, locations, and frequencies for measurement and sampling activities related to SVE system evaluation, startup, operation, optimization, rebound assessment, and eventual closeout. Indicate that field and laboratory work will follow procedures and protocol provided in the QAPP. Address all types of samples and measurements associated with the SVE system (e.g., soil vapor, scrubber sludge, vacuum measurements). Provide tables and figures summarizing the sampling/measurement frequencies for various system components.

5.1 Sampling Locations
5.2 Sample Collection Procedures and Analytical Methods
5.3 Field Quality Control Samples
5.4 Sampling Frequencies

6.0 SVE GENERAL DESIGN AND ENGINEERING CONSIDERATIONS

Instructions: Identify the SVE system components and provide the details regarding the design and function of each component. Indicate the design process for the SVE system (e.g., phased approach, total system approach) as well as the planned design submittals and content (e.g., drawing package will include treatment pad layout and details, piping and mechanical details, process and instrumentation diagram, and electrical single line diagram). Describe measures to be used for noise control and other considerations identified in the CEQA process. Describe the procurement process for the system components. Briefly discuss system operations, referring the reader to Section 4.0 for details. Identify the design and engineering documentation that will be prepared (e.g., design package, O&M plan, report addressing observations and difficulties encountered during the start-up period).

6.1 Soil Vapor Wells
6.2 Soil Gas Collection System
6.3 Vacuum System
6.4 Emission Control System
6.5 Utility Requirements
6.6 SVE System Implementation
  6.6.1 Engineering Design
  6.6.2 Procurement
6.7 Design Submittals
6.8 Construction Activities
6.9 Operations
  6.9.1 Startup and Initial Operations
  6.9.2 Long-Term Operations
  6.9.3 System Optimization
6.10 Documentation

7.0 SVE SYSTEM OPERATIONS REPORTING

Instructions: Indicate the types and frequency of reports to be provided. Identify the purpose, objectives, and typical content of each report.

7.1 Status Reports
7.2 Periodic Monitoring/Operations Reports

8.0 RESIDUALS MANAGEMENT

Instructions: Identify the residuals that will generated by the SVE system and how the residuals will be managed. Describe any requirements (such as secondary containment) for residual storage areas.

8.1 Liquids/Water
8.2 Sediments/Solids

9.0 QUALITY ASSURANCE PROJECT PLAN

Instructions: Present the organization, functions, procedures, and specific QA and QC activities designed to achieve the DQOs for the SVE system.

9.1 Project Management
- 9.1.1 Title and Approval Sheet
- 9.1.2 Table of Contents
- 9.1.3 Distribution List
- 9.1.4 Project Organization
- 9.1.5 Problem Definition/Background
- 9.1.6 Project/Task Description and Schedule
- 9.1.7 Data Quality Objectives and Criteria for Measurement Data
- 9.1.8 Special Training Requirements/Certification
- 9.1.9 Documentation and Records

9.2 Measurement/Data Acquisition
- 9.2.1 Sampling Process Design
- 9.2.2 Sampling Method Requirements
- 9.2.3 Sample Handling and Custody Requirements
- 9.2.4 Analytical Methods Requirements
- 9.2.5 Quality Control Requirements
- 9.2.6 Instrument Testing, Inspection, and Maintenance Requirements
- 9.2.7 Instrument Calibration and Frequency
- 9.2.8 Inspection/Acceptance Requirements for Supplies and Consumables
- 9.2.9 Data Acquisition Requirements (Non-Direct Measurements)
- 9.2.10 Data Management

9.3 Assessment/Oversight
- 9.3.1 Assessments and Response Actions
- 9.3.2 Reports to Management

Instructions: Provide the references cited in the document.

12.0 REFERENCES

Beckett, G.D. and D. Huntley. 1994. Characterization of Flow Parameters Controlling Soil Vapor Extraction. *Groundwater*, v. 32, p. 239 - 247.

DiGiulio, D.C. and R. Varadhan. 2000. Steady-State Field-Scale Gas Permeability Estimation, Pore-Gas Velocity Calculation, and Streamline Generation in a Domain Open to the Atmosphere. *Remediation: The Journal of Environmental Cleanup Costs, Technologies and Techniques*, v. 10, n. 4, p. 13 - 25.

DiGiulio, D.C. and R. Varadhan. 2001a. Limitations of ROI Testing for Venting Design: Description of an Alternative Approach Based on Attainment of a Critical Pore-Gas Velocity in Contaminated Media. *Ground Water Monitoring and Remediation*, v. 21, n. 1, p. 97 – 114.

DiGiulio, D.C. and R. Varadhan. 2001b. *Development of Recommendations and Methods to Support Assessment of Soil Venting Performance and Closure*. EPA 600-R-01-070. September. www.epa.gov/ada/download/reports/epa_600_r01_070.pdf

Department of Toxic Substances Control (DTSC). 2004. Guidance Document for the Implementation of United States Environmental Protection Agency Method 5035: Methodologies for Collection, Preparation, Storage, and Preservation of Soils to be Analyzed for Volatile Organic Compounds. November. 10.39.0.144/SiteCleanup/upload/HWMP_Guidance_Method-5035.pdf

DTSC/ Los Angeles Regional Water Quality Control Board (LARWQCB). 2003 (revision pending). Advisory – Active Soil Gas Investigations. January. 10.39.0.144/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf

Groundwater Resources Association of California (GRA). 1997. Innovative Soil Gas Monitoring and Remediation Applications. GRA Seminar Series. September.

Johnson, P.C., M.W. Kemblowski, and R.L. Johnson. 1999. Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces: Site-Specific Alternatives to Generic Estimates. *Journal of Soil Contamination*, v. 8, no. 3, p. 389 - 421.

Johnson, P.C. and R.A. Ettinger. 1994. Consideration for the Design of In Situ Vapor Extraction Systems: Radius of Influence vs. Zone of Remediation. *Ground Water Monitoring and Remediation*, v. 14, n. 3, p. 123-128.

Shan, C., R. Falta, and I. Javandel. 1992. Analytical Solutions for Steady State Gas Flow to a Soil Vapor Extraction Well. *Water Resources Research*, v. 28, n. 4, p. 1105 - 1120.

United States Army Corps of Engineers (USACE). 2002. *Engineering and Design: Soil Vapor Extraction and Bioventing*. Department of the Army, Document No. 1110-1-4001, June 2, 2002. 140.194.76.129/publications/eng-manuals/em1110-1-4001/toc.htm

United States Environmental Protection Agency (USEPA). 2006. *Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice*. EPA 542-R-05-028. March. www.clu-in.org/download/remed/EPA542R05028.pdf

APPENDIX D

LINK TO ADDITIONAL RESOURCES

The following resources from the *PT&R Guidance – Remediation of Metals in Soil* are also applicable to cVOCs.

- Annotated Outline for Site Characterization Report
- Example for Bridging Memorandum
- Remedial Action Plan Sample
- Scope of Work for Corrective Measures Study
- Excavation, Disposal, and Restoration Plan Sample
- Annotated Outline for Excavation Completion Report
- Characterization Phase Workplan (Outline)
- Example for Statement of Basis
- Removal Action Workplan Sample
- Scope of Work for Interim Measures
- Transportation Plan (Outline)
- Public Participation Sample Documents

These appendices can be downloaded individually at the following location: www.dtsc.ca.gov/SiteCleanup/PTandR.cfm

APPENDIX E
CONFIRMATION SAMPLING FOR SOIL EXCAVATIONS

Introduction

Confirmation sampling is conducted to determine whether the remedial action objectives (RAOs) for the soil excavation have been achieved. The remediation by excavation may address all or some of the following exposure pathways.

Soil Matrix RAOs. Soil matrix RAOs are developed for groundwater protection (soil leaching to groundwater pathway) and alleviation of direct contact exposure scenarios (dermal, ingestion, and particulate inhalation). Confirmatory soil matrix sampling involves the collection of samples from the floor and sidewalls of the excavation to demonstrate that contaminated soil was successfully removed.

Soil Gas RAOs. Soil gas RAOs typically are developed to alleviate vapor intrusion and outdoor air exposure. To verify that residual soil gas contamination is protective of human health, soil gas samples are collected around the perimeter of the excavation, and below the excavation footprint and/or within excavation backfill.

Confirmation sampling results can be used to support a post-remediation evaluation of risk (see Sections 6.5 and 8.8 of the main text).

Confirmation Sampling Plan

Confirmation sampling activities should be conducted in accordance with an approved confirmation sampling plan. The plan should consider the following:

- Soil gas and soil matrix samples should have the highest possible data quality objectives (DQOs).
- Statistical strategies that employ grids to facilitate the unbiased selection of sampling points should be used as appropriate. These strategies should provide a 95-percent confidence level of verifying the presence or absence of contamination.
- Flexibility to modify the sampling approach based on field observations and sampling results should be included. For example, non-statistical sampling may be used to evaluate areas where soil staining, odors, or hot spots are observed.
- Logistical considerations that may affect confirmation sampling approaches should be considered (e.g., sampling the sidewalls of a shored excavation).

The following resources may be useful in the development of the confirmation sampling plan:

- *Advisory – Active Soil Gas Investigations* (DTSC/LARWQCB, 2003)[1]

[1] Check the following link for the most current version of the document: www.dtsc.ca.gov/SiteCleanup/Vapor_Intrusion.cfm#Vapor_Intrusion_Guidance_Documents

- *Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Revised* (DTSC, 2005)[1]
- *Guidance Document for the Implementation of United States Environmental Protection Agency Method 5035: Methodologies for Collection, Preparation, Storage, and Preparation of Soils to be Analyzed for Volatile Organic Compounds* (DTSC, 2004)
- *Guidance on Choosing a Sampling Design for Environmental Data Collection for Use in Developing a Quality Assurance Project Plan, EPA QA/G-5S* (USEPA, 2002)
- *Guidance on Systematic Planning Using the Data Quality Objective Process, EPA QA/G-4* (USEPA, 2006a)
- *Data Quality Assessment: A Reviewer's Guide, EPA QA/G-9R* (USEPA, 2006b)
- *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S* (USEPA, 2006c)
- *SW-846 On-Line* (USEPA, SW-846 On-Line)
- *Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management* (ITRC, 2003)

Additional resources are available on the USEPA and Interstate Technology and Regulatory Council (ITRC) web-sites (www.clu-in.org; www.itrcweb.org), among other sources. Attachment A of this appendix provides an annotated outline for a confirmation sampling plan.

Soil Matrix Samples

Soil matrix samples are typically collected from the floor and sidewalls of the excavation using the sampling design identified in the confirmation sampling plan. These samples should be collected in accordance with USEPA Method 5035 (DTSC, 2004). Soil matrix sampling strategies based on incremental sampling methodology (ISM) are the subject of growing interest in the field of environmental restoration. However, ISM has yet to be fully accepted by the scientific community. The ITRC is currently developing ISM guidance and provides links related resources on its web-site[2]. If ISM is being considered for a given site, DTSC should be consulted to obtain concurrence with its use in confirmation sampling.

Post-excavation soil matrix sampling should occur as soon as possible after completion of excavation activities. Soil matrix samples should not be obtained from exposed excavation surfaces. Rather, soil matrix samples should be collected approximately six to eight inches interior to the exposed surface to alleviate potential sample bias due to the volatilization of contaminants.

[2] www.itrcweb.org/teampublic_ISM.asp

Soil Gas Samples

Soil gas samples should be collected from the around the perimeter of the excavation, and within and/or below the excavation footprint to evaluate the effectiveness of the remedy on eliminating the possibility of vapor intrusion. These samples should be collected at least five feet from exposed soil surfaces to minimize the effects of atmospheric influences on sample representativeness. Soil gas samples should be collected in accordance with DTSC/LARWQCB (2003) which recommends the installation of semi-permanent soil vapor probes.

Non-excavated subsurface cVOC sources can potentially contaminate clean backfilled material through vapor transport. Hence, where excavations are above contaminated groundwater or adjacent to cVOC hot spots, soil gas monitoring will be necessary to determine if the RAOs have been achieved. The duration of the post-excavation monitoring within the backfilled material and adjacent to the excavation pit should be based upon the time needed to re-establish subsurface equilibrium. The time to reach steady-state conditions can be determined using the methods described in Johnson et al. (1999). These timeframes can be lengthy for large excavations. If these monitoring timeframes are incompatible with schedules for property redevelopment, consideration should be given to expanding the size of the proposed excavation.

References

Department of Toxic Substances Control (DTSC). 2004. *Guidance Document for the Implementation of United States Environmental Protection Agency Method 5035: Methodologies for Collection, Preparation, Storage, and Preservation of Soils to be Analyzed for Volatile Organic Compounds*. November. 10.39.0.144/SiteCleanup/upload/HWMP_Guidance_Method-5035.pdf

DTSC. 2005 (revision pending). *Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Revised*. February. 10.39.0.144/AssessingRisk/upload/HERD_POL_Eval_Subsurface_Vapor_Intrusion_interim_final.pdf

DTSC/ Los Angeles Regional Water Quality Control Board (LARWQCB). 2003 (revision pending). *Advisory – Active Soil Gas Investigations*. January. 10.39.0.144/lawsregspolicies/policies/SiteCleanup/upload/SMBR_ADV_activesoilgasinvst.pdf

Interstate Technology and Regulatory Council (ITRC). 2003. *Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management*. December. www.itrcweb.org/Documents/SCM-1.pdf

Johnson, P.C., M.W. Kemblowski, and R.L. Johnson. 1999. Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces: Site-Specific Alternatives to Generic Estimates. *Journal of Soil Contamination*, v. 8, no. 3, p. 389 - 421.

USEPA. 2002. *Guidance on Choosing a Sampling Design for Environmental Data Collection for Use in Developing a Quality Assurance Project Plan, EPA QA/G-5S*. EPA/240/R-02/005. December. www.epa.gov/quality/qa_docs.html

USEPA. 2006a. *Guidance on Systematic Planning Using the Data Quality Objective Process, EPA QA/G-4*. EPA/240/B-06/001. February. www.epa.gov/quality/qa_docs.html

USEPA. 2006b. *Data Quality Assessment: A Reviewer's Guide, EPA QA/G-9R*. EPA/240/B-06/002. February. www.epa.gov/quality/qa_docs.html

USEPA. 2006c. *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S*. EPA/240/B-06/003. February. www.epa.gov/quality/qa_docs.html

USEPA. SW-846 On-Line: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. http://www.epa.gov/waste/hazard/testmethods/sw846/online/index.htm

ATTACHMENT A
ANNOTATED OUTLINE
CONFIRMATION SAMPLING PLAN FOR SOIL EXCAVATIONS

Preface: The following annotated outline identifies potential content for a confirmation sampling plan. The outline is not intended to be prescriptive and should be adjusted as appropriate for site-specific conditions. Some elements identified may apply to your site, while others do not. Additional elements than are addressed by the outline may also be needed. This outline is for guidance only, and is applicable on a case-by-case basis.

1.0 INTRODUCTION

Instructions: Describe the site location, description, and history. Identify the purpose, scope and objective of the confirmation sampling. Identify the responsible agency, project organization, and responsibilities. If the confirmation sampling plan is a stand-alone document, this section should be more comprehensive.

- 1.1 Site Location, Description, and History
- 1.2 Purpose, Scope, and Objectives of Confirmation Sampling
  - 1.2.1 Demonstrate Achievement of RAOs
  - 1.2.2 Waste Characterization
- 1.3 Responsible Agency
- 1.4 Project Organization and Responsibilities

2.0 SUMMARY OF EXISTING SITE DATA

Instructions: Briefly summarize the existing site data. Identify the estimated nature and extent of contamination. Include figures, such as plume maps and geological cross sections, that support the discussion.

3.0 SUMMARY SOIL REMOVAL ACTIONS

Instructions: Describe the soil removal actions to be taken prior to confirmation sampling. Identify the RAOs, cleanup goals, and regulatory criteria. Support the discussion with appropriate figures (e.g., a figure showing the estimated vertical and lateral extent of the excavation). Describe the approach to excavation activities and confirmation sampling (e.g., sequencing of excavation, logistical considerations, confirmation sampling, laboratory turnaround time, data evaluation and decision to backfill excavation).

- 3.1 Summary of Soil Removal Objectives
  - 3.1.1 Extent of Excavation
  - 3.1.2 Waste Characterization
  - 3.1.3 [Other appropriate subsections as applicable]
- 3.2 Cleanup Goals and Regulatory Criteria
- 3.3 Role and Timing of Confirmation Sampling in the Decision Process

4.0 CONFIRMATION SAMPLE COLLECTION

Instructions: Describe the sampling design that will be used to confirm that soil excavation efforts have achieved RAOs. Provide the objectives and rationale for sample locations and frequencies. Identify considerations for the timing of sample collection relative to excavation and/or backfill activities. If applicable, describe the method for establishing a sampling grid. Identify the sampling requirements and contingencies for unexpected conditions. Provide general sample collection and preservation procedures, and analytical methods. Reference the applicable field sampling plan.

- 4.1 Sampling Objectives
- 4.2 Sampling Design and Rationale
- 4.3 Sample Locations and Depths
  - 4.3.1 Rationale for Soil Sampling
  - 4.3.2 Rationale for Soil Gas Sampling
- 4.4 Sampling Requirements
- 4.5 Sampling and Analysis
  - 4.5.1 General Sample Collection Procedures
    - 4.5.1.1 Soil Matrix
    - 4.5.1.2 Soil Gas
  - 4.5.2 Laboratory Analytical Methods
  - 4.5.3 Quality Assurance/Quality Control
- 4.6 Contingencies for Unexpected Conditions

5.0 CONFIRMATION SAMPLE COLLECTION FOR WASTE CHARACTERIZATION

Instructions: Describe the sample collection methods for characterizing excavated soil prior to disposal or reuse and to identify the need for treatment prior to disposal. Indicate the sample collection frequency and rationale. Identify the sample requirements (e.g., discrete samples, composite samples). Provide general sample collection and preservation procedures, and analytical methods. Reference the applicable field sampling plan.

- 5.1 Sampling Objectives
- 5.2 Sampling Design and Rationale
- 5.3 Sample Locations
- 5.4 Sampling Requirements
- 5.5 Sampling and Analysis
  - 5.5.1 General Sample Collection Procedures
  - 5.5.2 Laboratory Analytical Methods
  - 5.5.3 Quality Assurance/Quality Control

6.0 DATA QUALITY OBJECTIVES

Instructions: Describe the DQOs, including analytical issues (e.g., method detection limits), QA/QC limitations on data, reproducibility, accuracy and precision, and other issues related to objectives of the confirmation sampling. Reference the applicable quality assurance project plan.

7.0 DATA EVALUATION

Instructions: Describe how the data will be evaluated (1) to support the decision to continue or stop the excavation and (2) to determine appropriate disposal or reuse of excavated soil and identify any treatment requirements. Include detailed descriptions of how the cleanup goals will be applied, the statistical evaluations that will be performed, and any other methods to be used. If appropriate, include decision matrices and/or flow charts to assist with the decision process.

7.1 Determination of Adequacy of Excavation

7.2 Determine Disposal, Reuse, and Treatment Requirements for Excavated Soil

8.0 REPORT

Instructions: Describe the format and schedule for reporting the confirmation sampling and data analysis results. Include all the elements of a standard investigation report, including conclusions and recommendations based on the data and data analysis.

9.0 HEALTH AND SAFETY PLAN

Instructions: A health and safety plan for confirmation sampling activities should be included as a separate section or appendix.

10.0 REFERENCES

Instructions: List all references cited in the plan.

APPENDICES

Field Sampling Plan (FSP)*
Quality Assurance Project Plan (QAPP)*

*The confirmation sampling plan should be supported by a field sampling plan (FSP), and a quality assurance project plan (QAPP). If to be developed in conjunction with the confirmation sampling plan, annotated outlines for a generic FSP and a generic QAPP are included in Appendix A2 of the *PT&R Guidance – Remediation of Metals in Soil*[3]. Alternatively, the confirmation sampling plan can reference an existing FSP or QAPP that adequately supports the confirmation sampling activities.

[3] www.dtsc.ca.gov/SiteCleanup/upload/Appdx_A2_083108.pdf