DEPARTMENT OF TOXIC SUBSTANCES CONTROL
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

PROVEN TECHNOLOGIES AND REMEDIES GUIDANCE

REMEDIATION OF ORGANOCHLORINE PESTICIDES IN SOIL

FEBRUARY 26, 2010

PREFACE

The Department of Toxic Substances Control (DTSC) is issuing this Proven Technologies and Remedies (PT&R) guidance document 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 organochlorine pesticides in soil. The approach is designed to ensure a 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 organochlorine pesticides in soil will identify areas that can be improved upon as well as additional ways to streamline the 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 February 28, 2011). At that time, DTSC will review and incorporate changes as needed.

Comments and suggestions for improvement of *Remediation of Organochlorine Pesticides in Soil* should be submitted to:

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

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ABBREVIATIONS AND ACRONYMS

AOC	area of contamination
ARARs	applicable or relevant and appropriate requirements
ASTM	ASTM International (formerly known as American Society for Testing and Materials)
bgs	below ground surface
Cal/EPA	California Environmental Protection Agency
Cal-OSHA	California Occupational Safety and Health Administration
Caltrans	California Department of Transportation
CAMU	corrective action management unit
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHHSL	California Human Health Screening Level
cm/s	centimeters per second
CMS	Corrective Measures Study
COC	chemical of concern
CSM	conceptual site model
DBCP	dibromochloropropane
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DTSC	Department of Toxic Substances Control
DDT	dichlorodiphenyltrichloroethane
EDRP	excavation, disposal, and restoration plan
EE/CA	engineering evaluation/cost analysis
EPC	exposure point concentration
ET	evapotranspiration
FML	flexible membrane liner
FS	Feasibility Study
ft	feet
HASP	health and safety plan
HSAA	Hazardous Substances Account Act
HSC	California Health and Safety Code
HWCL	Hazardous Waste Control Laws
IC	institutional control
IM	interim measure
ITRC	Interstate Technology and Regulatory Council

ABBREVIATIONS AND ACRONYMS (Continued)

LCCA	life-cycle cost analysis
LDR	land disposal restriction
LUC	land-use covenant
µg/kg	microgram per kilogram
mg/kg	milligram per kilogram
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OCP	organochlorine pesticide
OEHHA	Office of Environmental Health Hazard Assessment
O&M	operation and maintenance
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PEA	Preliminary Endangerment Assessment
PI	plasticity index
PRG	Preliminary Remediation Goal (now replaced by Regional Screening Levels)
PT&R	proven technologies and remedies
PVC	polyvinyl chloride
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
RWQCB	Regional Water Quality Control Board
SVOCs	semi-volatile organic compounds
SWPPP	storm water pollution prevention plan
UCL	upper confidence limit
USEPA	U.S. Environmental Protection Agency
USCS	Unified Soil Classification System
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

DTSC has prepared this *Proven Technologies and Remedies Guidance – Remediation of Organochlorine Pesticides in Soil* (PT&R guidance) as an option for expediting and encouraging cleanup of sites with elevated concentrations of organochlorine pesticides (OCPs) in soil. The PT&R approach discussed in this guidance (Figure ES-1) may be applied at operating or closing hazardous waste facilities and at Brownfields sites. This guidance can be used by any government agency, consultant, responsible party, project proponent, facility operator, and/or property owner addressing OCPs compounds 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.

This PT&R guidance is applicable on a case-by-case basis at sites where the primary environmental concern involves soils contaminated with OCPs. The PT&R guidance will not be applicable to all sites with OCP contamination. For example, this guidance may not be applicable to sites where OCPs have impacted water resources or where ecological impacts may be present. Prior to applying this PT&R guidance, the oversight agency should be consulted and should concur with the use of this approach.

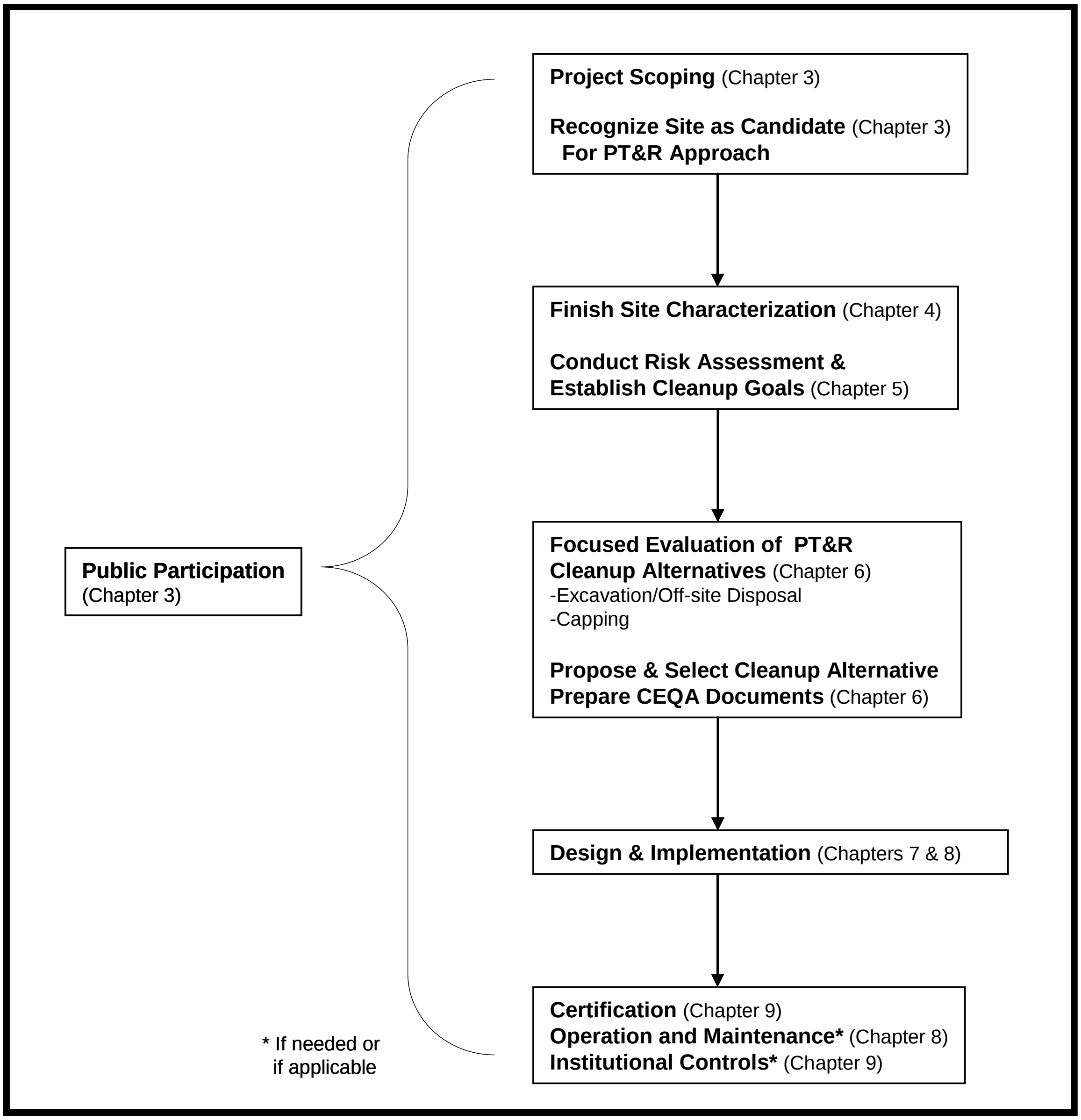
The PT&R approach (Figure ES-1) streamlines the cleanup process by (1) limiting the number of evaluated technologies to two PT&R alternatives; (2) facilitating remedy implementation; and (3) facilitating documentation and administrative processes. DTSC identified the two PT&R alternatives by conducting a study that reviewed and screened data for 80 sites throughout California where the primary contaminants were OCPs in soil and where DTSC provided oversight of the soil cleanup. This study found that "excavation and off-site disposal" and "containment by capping" were the most frequently selected cleanup alternatives.

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 guidance in assessing risk and establishing cleanup goals;
- provide guidance for designing and implementing the PT&R alternatives; and
- identify DTSC resources that can be used to facilitate the cleanup process.

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

Figure ES-1. General Overview of PT&R Approach for Sites with OCP-Contaminated Soils.



SUMMARY OF PT&R APPROACH

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

Determine Suitability for PT&R Approach. To determine whether the PT&R process is appropriate for your site, you should evaluate existing investigation data to determine whether the site characteristics make it amenable to a streamlined scoping, site characterization, remedy selection, and remedy implementation. This PT&R guidance targets cleanup at sites where the primary environmental issue is OCP contamination in soil. Table ES-1 summarizes the site characteristics that favor the PT&R approach. Refer to Chapter 3 for further discussion regarding these characteristics.

Table ES-1. Site Characteristics that Favor PT&R Approach for OCPs in Soil

▪ Primarily OCP contamination	▪ No emergency actions required
▪ Shallow contamination	▪ Low potential for surface water impact[2]
▪ No ecological habitat or sensitive receptors impacted[2]	▪ Low potential for groundwater impact[1, 2]

1 Preferred characteristic for containment/capping alternative.
2 The approach recommended for selection of cleanup goals in this PT&R guidance considers the health impact endpoint, intended use of the property, and number of contaminants. If a site has potential impacts to ecological receptors, groundwater, or surface water, the PT&R approach for establishing cleanup goals is not applicable.

Characterization Phase. The characterization phase establishes the nature and extent of contamination in soil. Sufficient data should be collected to determine that the PT&R approach is still applicable and to support remedy selection and the engineering design. As data are gathered, they are compared to screening levels to help determine whether further site characterization, risk assessment, or cleanup may be necessary.

Risk Assessment. A human health risk assessment is conducted to estimate the potential cancer risks and noncancer health hazards. The PT&R approach uses the risk assessment guidance provided in: (1) *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 1994) and (2) *Use of California Human Health Screening Levels (CHHSLs) in Evaluating Contaminated Properties* (Cal/EPA, 2005). In addition, the approach provided in the *School (Site) Environmental Assessment Manual* (DTSC, pending) may be used.

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 results of the site investigation lay the groundwork for demonstrating the applicability of the PT&R approach to the project conditions. The analysis of alternatives should reference this PT&R guidance and complete the evaluation of the alternatives that meet the remedial action objectives (RAOs). The alternatives would generally include no action, excavation/disposal, and/or containment/capping. Necessary documents for the California Environmental Quality Act (CEQA) may be prepared concurrently with the alternatives evaluation report. The draft remedy selection and CEQA documents are circulated for public comment.

As shown in Figure ES-1, the excavation/disposal alternative has the potential to allow unrestricted use of the site whereas the containment/capping alternative will require long-term stewardship.

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.

Certification of Remedy Completion. When the response action has been fully implemented, DTSC will certify the site. Before DTSC issues this certification letter, any requirements for a Land Use Covenant (i.e., Covenant to Restrict Use of Property) or other institutional controls must be met, as well as any requirements of an operation and maintenance (O&M) agreement or O&M plan.

CHAPTER 1
INTRODUCTION

The Department of Toxic Substances Control (DTSC) has developed this *Proven Technologies and Remedies Guidance – Remediation of Organochlorine Pesticides in Soil* (PT&R guidance) as an option for expediting and encouraging the cleanup of organochlorine pesticides (OCPs) in soil. OCPs have a history of widespread use in the United States, primarily between the 1940s and 1970s. During this time period, OCPs were used for public health vector control, agricultural crop production, and pest control around structures. Although most OCPs were banned or withdrawn from use in the 1970s, these compounds persist in the environment today. OCPs can be found in surface soil associated with historical agricultural and termite control pesticide applications. Deeper OCP impacts may be observed in pesticide mixing areas and land disposal areas. OCPs can also accumulate in aquatic sediments. A wide range of chronic and acute health effects have been associated with OCPs including, but not limited to, neurological effects, birth defects, and cancer.

OCPs in soil are encountered in approximately 15 percent of all sites addressed by DTSC's Brownfields and Environmental Restoration Program. For smaller projects (<$2,000,000), the percentage of sites addressing OCPs is about 25 to 30 percent. For larger projects (>$2,000,000), the percentage of sites with OCPs is about 10 to 20 percent. Table 1 summarizes the characteristics of the OCPs most commonly encountered by DTSC soil cleanup projects.

This PT&R guidance has been prepared to streamline the corrective action and remedial processes, herein after referred to as the "cleanup process", at sites with OCP-contaminated soils. The PT&R guidance outlines an option for streamlining the cleanup process, thus increasing the number of acres that are cleaned up and put back into beneficial use. The PT&R approach discussed herein can be applied at operating and closing hazardous waste facilities and at 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 provide guidance on PT&R alternatives to expedite cleanup of sites with OCPs in soil. The PT&R guidance is intended for use by any government agency, consultant, responsible party and/or property owner addressing potential OCP 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 its use.

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 OCPs in soil;

Table 1 Organochlorine Pesticides Most Often Encountered in Soil Cleanups Overseen by DTSC

OCP COMPOUND	TYPICAL USE	DATES OF USE IN U.S.	CANCER RISK
DDT/DDD/DDE[1]	▪ Control of mosquitoes and lice. ▪ Agriculture (widespread). ▪ Termiticide	1939 – 1972	Probable human carcinogens
Chlordane	▪ Control of insects on crops, home lawns, and gardens. ▪ Termiticide.	1948 – 1988	Probable human carcinogen
Dieldrin	▪ Widely used pesticides for crops, especially corn and cotton ▪ Termiticide.	1948 – 1987	Probable human carcinogen
Toxaphene[2]	▪ Most common pesticide used in agricultural applications (esp. cotton). ▪ Insect control on livestock and fish in lakes. ▪ Used in combination with DDT or methyl parathion.	1947 – 1990	Reasonably anticipated to be a human carcinogen
Heptachlor/ heptachlor epoxide[3]	▪ Heptachlor was a commercial pesticide for insects in homes, buildings ▪ Used on food crops. ▪ Termiticide.	1952 – 1988	Possible human carcinogen
Lindane (γ-BHC)	▪ Insecticide on fruit, vegetable, and forest crops. ▪ Used in ointments, lotions, creams, and shampoos for the control of lice, and mites (scabies) in humans ▪ Used as insecticide-based seed dressing.	1940 – present	Suggestive evidence of carcinogenicity

Notes:
1 DDD and DDE are breakdown products of DDT.
2 Toxaphene is a complex mixture of compounds. See Appendix E for additional information.
3 Heptachlor epoxide is a breakdown product of heptachlor.

BHC – benzene hexachloride
DDD – dichlorodiphenyldichloroethylene
DDE – dichlorodiphenyldichloroethane
DDT – dichlorodiphenyltrichloroethane

- provide recommendations for characterizing the nature and extent of contamination and collecting data needed to support the cleanup alternative;
- provide guidance in establishing screening levels and cleanup goals;
- focus the site-specific evaluation of cleanup alternatives to the PT&R alternatives (see Section 1.2); and
- provide guidance on associated administrative requirements, such as documentation and implementation of the cleanup alternative selection process.

1.2 TECHNICAL BASIS FOR PT&R APPROACH AT SITES WITH OCP CONTAMINATION IN SOIL

DTSC conducted a study that reviewed data from 80 sites throughout California where OCPs were the primary contaminants in soil and DTSC provided or is providing oversight (see Section 6.1). The objective of the study was to identify the technologies that were consistently selected for evaluation and to determine the frequency at which these technologies were selected as the remedy. The results of the study revealed that "containment by capping" and/or "excavation and offsite disposal" were the most frequently selected cleanup alternatives. Hence, excavation/disposal and containment/capping were selected as the PT&R alternatives.

1.3 SCOPE AND APPLICABILITY

This document is applicable at sites where the primary environmental concern involves soils contaminated with OCPs. However, the PT&R guidance may not be applicable to all sites with OCP contamination. In general, the PT&R approach may not be appropriate for sites:

- where stakeholder concerns would be addressed more efficiently under a different cleanup process or approach;
- with deep OCP impacts (e.g., impacted soils at depths not feasible for excavation/disposal or at depths near the water table);
- with OCP impacts to sensitive habitat or ecological receptors;
- that may benefit from the use of innovative technologies;
- with OCP impacts to environmental media other than soil (e.g., groundwater, surface water, sediment); and
- impacted by multiple chemicals of concern (i.e., chemicals of concern in addition to OCPs) that will impact the selection of the cleanup alternative.

In these instances, the PT&R approach is not appropriate and a more extensive cleanup technology evaluation should be conducted.

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.

CHAPTER 2
OVERVIEW AND ORGANIZATION

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

- 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 the 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 cleanup objectives and standards; and (3) able to control or remediate sources of releases.

The PT&R approach is consistent with DTSC's conventional cleanup processes. In a conventional cleanup process, sites undergo:

- site characterization (also referred to as site investigation);
- 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. The PT&R approach is suitable for final remedies, for interim measures, or for 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 containment/capping as the PT&R 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 sample 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.

- **Focused remedy selection**. The evaluation of cleanup alternatives is focused on the PT&R alternatives.

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

As illustrated in Figure 1, the PT&R approach follows the requirements of the standard cleanup processes. Preferably, the PT&R approach should be initiated as early as possible in the assessment and/or characterization phase.

The PT&R guidance is organized into ten 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 and community assessment to determine if the site is suitable for the PT&R approach.

Chapter 4 summarizes the necessary site characterization data to support the cleanup process.

Chapter 5 presents the procedures for establishing health screening criteria and establishing site-specific cleanup goals.

Chapter 6 summarizes and documents the study and evaluation conducted by DTSC that is the basis for the PT&R approach for OCP-contaminated soils. This chapter also addresses the focused evaluation and selection of the cleanup alternative.

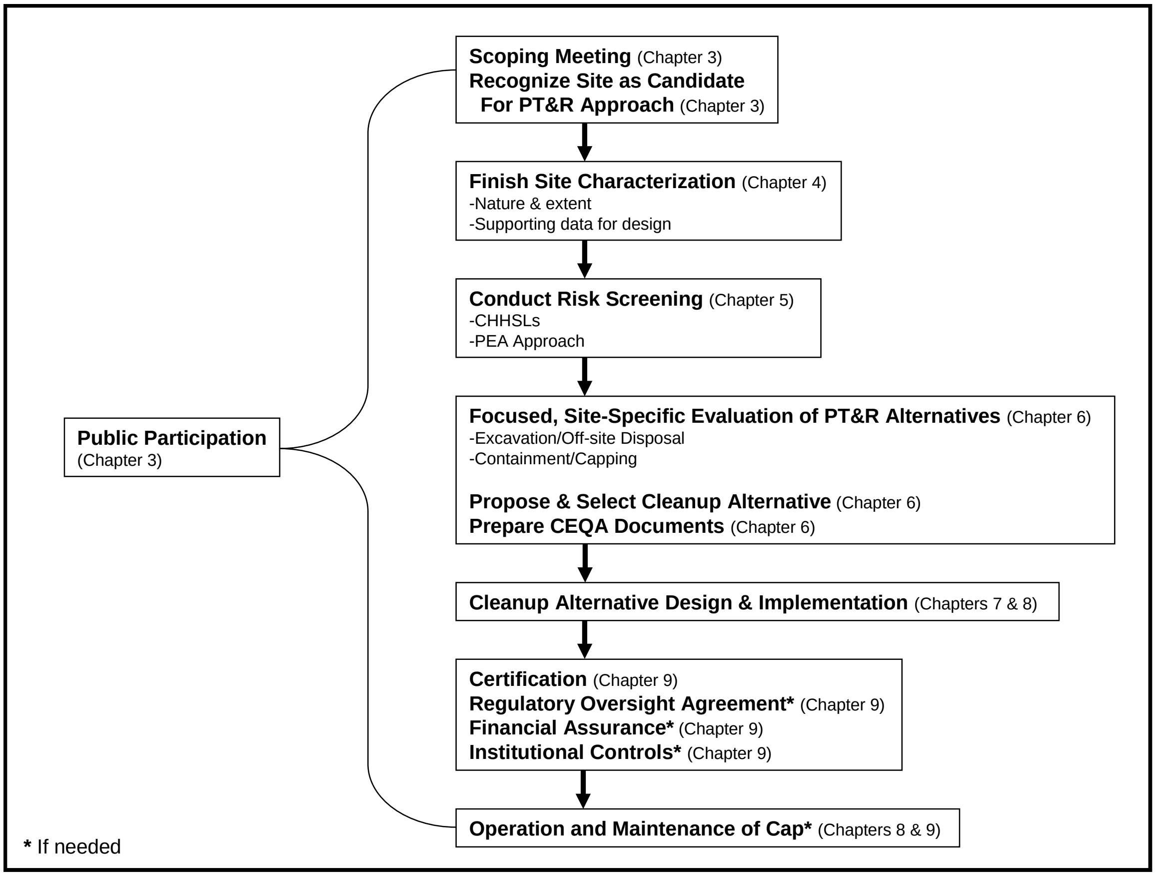
Chapter 7 summarizes the design and implementation considerations for the excavation/disposal alternative.

Chapter 8 summarizes the design and implementation considerations for the containment/capping alternative.

Chapter 9 addresses the site certification process.

Chapter 10 provides the references cited in this PT&R guidance.

Figure 1. PT&R Approach for Sites With OCP-Contaminated Soils



CHAPTER 3
SITE ASSESSMENT

The PT&R approach is initiated by assessing whether this guidance may be applied to a given site with OCP-impacted soil. Typically, some soil chemical data for the site (such as would be obtained during a Preliminary Endangerment Assessment [PEA] or equivalent investigation) will be needed to support this assessment. As discussed in Section 3.1, the decision to apply the PT&R approach can be made in a project scoping meeting between DTSC staff and project proponents. A potential outcome of the scoping meeting is that the PT&R approach is not appropriate for the site and the 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 need to 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;
- assessing risks and hazards from the site;
- 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 receptors, endangered species);
- identifying and assessing stakeholders; and
- scoping public participation activities.

3.1.1 Scoping Meetings

DTSC 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 previous cleanup actions;

- current conceptual site model (CSM) for the site (i.e., types and locations of releases, affected environmental media, contaminant migration pathways, current receptors, potential future receptors, exposure pathways);
- 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;
- 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 guidance document or with site-specific adjustments (see Section 3.4). If the PT&R approach is appropriate, the potential for an unrestricted use outcome that is offered by the excavation/disposal alternative versus the long-term stewardship associated with the containment/capping alternative should be addressed. The outcome of the scoping meeting(s) may be summarized in a scoping document, including:

- analysis and summary of site background and physical setting;
- summary of previous response actions, including all existing data;
- presentation of the CSM, health risks, and data gaps;
- scope and objectives of remaining characterization and risk assessment activities;
- scope and objectives of the site cleanup;
- 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).

3.1.2 Stakeholder Identification and Assessment

Stakeholder involvement is considered essential for the success of any cleanup action. Soon after a site is identified, stakeholders should be identified and contacted for input. Stakeholders include any individuals, government organizations, environmental and other public interest groups, academic centers, 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 other contacted groups and individuals who have related interests or are 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 decision-making.

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 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. Checklists and recommended content for the community survey, public participation plan, fact sheets, public notices, and other public outreach activities are provided. Appendix D provides a link to public participation document samples.

3.2 SITE CHARACTERISTICS THAT FAVOR THE PT&R APPROACH

This PT&R guidance is intended for cleanup at sites where the primary environmental issue is OCP contamination in shallow soils. Table 2 summarizes site characteristics that favor application of the PT&R approach. As discussed further in Section 3.3, it may still be possible to use this PT&R guidance with site-specific adjustments.

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

FAVORABLE CHARACTERISTIC	APPLICABLE PT&R ALTERNATIVE(S)	PRIMARY RATIONALE FOR LIMITING CHARACTERISTIC
Primarily OCP contamination	• Excavation/disposal • Containment/capping	This guidance document pertains to OCPs. Multiple contaminant groups may be better addressed by other cleanup approaches.
No emergency actions required		PT&R approach requires a planning period of at least six months.
Low potential for surface water impact		Impacts to surface water may have associated ecological risks. The screening levels recommended by this guidance do not address ecological risk.
No ecological habitat or sensitive receptors		The screening levels recommended by this guidance document do not address ecological risk.
Low potential for groundwater impact		The screening levels recommended by this guidance document do not address protection of groundwater.
Shallow contamination	• Excavation/disposal	This guidance addresses immobile OCPs which should be entrained in shallow soil. The excavation alternative has depth constraints. The depth feasible for excavation is a site-specific decision.
OCPs in immobile form	• Containment/capping	OCPs in mobile forms may continue to migrate downward even after cap placement. The screening levels and RAOs recommended by this guidance document do not address protection of groundwater.

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

OCPs in Mobile Forms. The PT&R approach applies to OCPs in forms that are largely immobile in soil and therefore have been retained in the upper portion of the soil profile. The compound 1,2-dibromo-3-chloropropane (DBCP), which is extremely mobile in soil and very persistent in aqueous phase, is probably not appropriately addressed by the PT&R approach. DBCP can also be volatile and pose potential impact to indoor air depending upon depth to groundwater and soil type. Likewise, at aerial applicator mixing / washout sites, the diesel carrier may facilitate transport deeper into the vadose zone or to groundwater. Sites with potential for facilitated transport of OCPs are likely not suitable for the PT&R approach.

Shallow Groundwater. The PT&R alternatives are not intended to be the sole cleanup approach for sites where the OCP-impacted soils are in contact with groundwater or where the contaminated soils extend to the top of the capillary fringe. If the PT&R approach is applied to the soils, additional cleanup measures may be needed to address the OCP impact to groundwater and, consequently, the PT&R approach may not be the most effective or efficient approach. This guidance document does not address cleanup measures for groundwater or recommend cleanup goals for the protection of groundwater. Sites located in the Central Valley of California may be in DBCP study areas and their appropriateness for PT&R approach should be determined on a site-specific basis.

Multiple Contaminant Groups. This guidance may or may not be suitable for sites where OCPs are co-located with other contaminants. For example, the approach may be appropriate where multiple contaminant groups have a similar vertical and lateral distribution and can both be addressed by the same cleanup strategy. In other instances, multiple contaminant groups may be more effectively or efficiently cleaned up by other approaches. Additional types of contaminants may affect soil disposal options.

Potential Ecological Risk. Sites located in areas that are designated as environmentally sensitive (e.g., wetland areas, wildlife refuges, endangered species habitat), or 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, these types of sites may not be suitable for the PT&R approach.

Surface Water Features. Sites with surface water features that are potentially impacted by runoff from OCP-impacted soils may not be suitable for the PT&R approach because surface water and sediment impacts 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. For example, large sites may not be suitable for the PT&R approach because these sites may require integration of multiple cleanup approaches and may need to consider ecological risk when selecting the cleanup alternative.

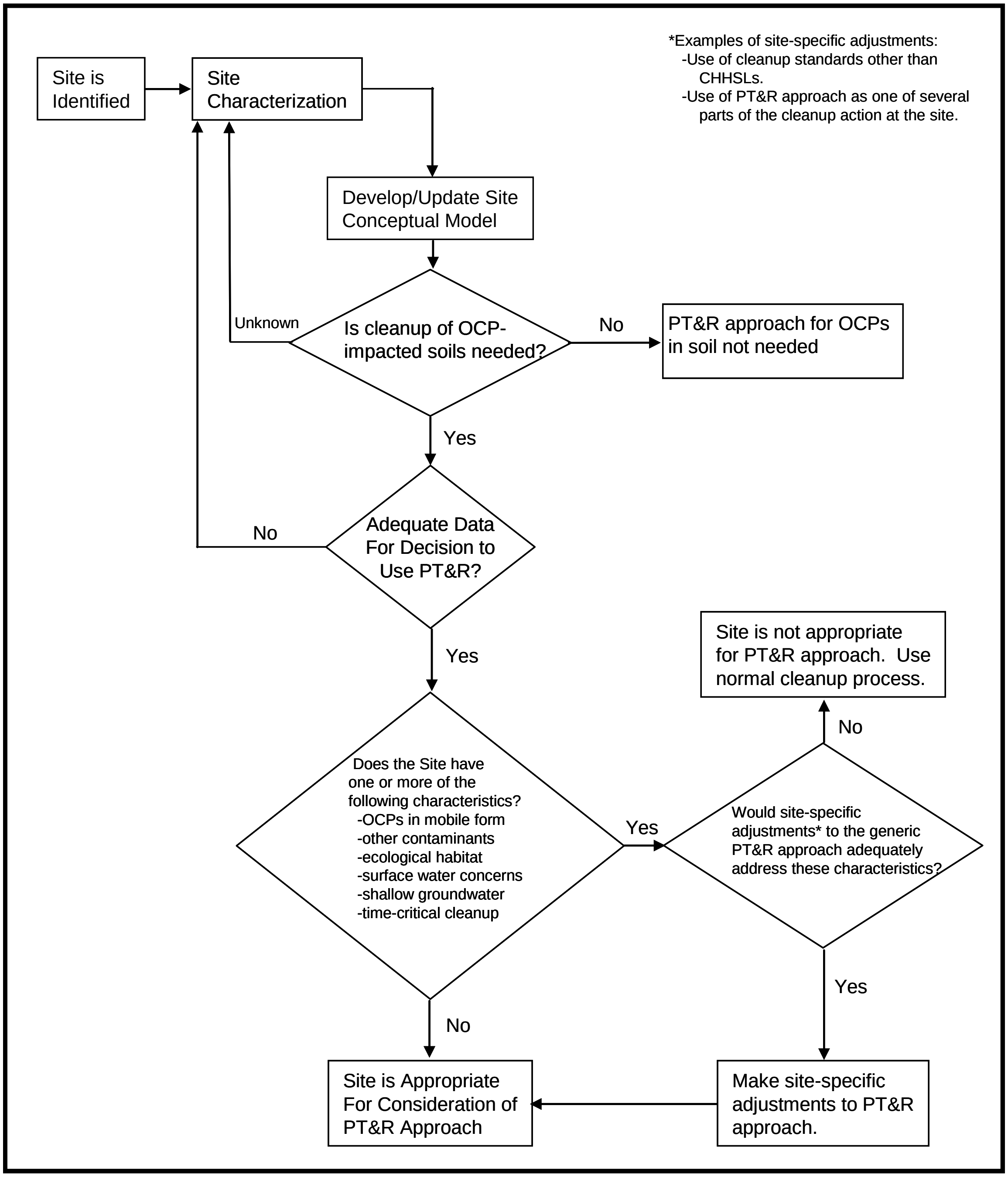
Time-Critical Cleanup/Emergency Response Actions. The approach used for time-critical cleanup or emergency response actions (i.e., removal actions that are imminent and must be carried out immediately) will be more streamlined than the PT&R approach and will be subject to different regulatory requirements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

3.4 DETERMINATION OF SUITABILITY FOR PT&R APPROACH

Figure 2 summarizes the recommended process for determining the suitability for applying the PT&R approach to 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 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. Example CSMs for OCP-impacted sites are provided in Appendix A. 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 OCPs in Soil is Appropriate for a Given Site



CHAPTER 4
SITE CHARACTERIZATION

The primary objective of the characterization phase is to establish the nature, extent, and distribution of OCP contamination in soil. Under the PT&R approach, another objective of the characterization effort is to collect the data needed to support the remedial design (see Sections 7.1 and 8.2). Sufficient data should be collected to move the project from the characterization phase through the design phase. The culmination of this step should be to prepare an updated CSM (see Appendix A) and to ensure that the PT&R approach is still applicable (see Section 3.4).

Site characterization should be conducted in accordance with a DTSC-approved workplan, including a field sampling plan and a quality assurance project plan (QAPP). Characterization phase workplans and reports should be prepared and executed in conformance with standard geologic and engineering principles and practices by appropriately licensed professionals. DTSC guidance useful for the development of characterization workplans and reports include:

- *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 1994)
- *Interim Guidance for Sampling Agricultural Properties (Third Revision)* (DTSC, 2008a)
- *Final Report Residential Pesticide Study* (DTSC, 2006b)
- *School (Site) Environmental Assessment Manual* (DTSC, pending)
- annotated outlines for a characterization phase workplan and report (see Appendix D for link)

Information on site characterization can also be obtained from the DTSC, U.S. Environmental Protection Agency (USEPA), Interstate Technology and Regulatory Council (ITRC) websites, as well as other sources. In particular, the following references may be useful:

- *Guidance on Systematic Planning Using the Data Quality Objective Process, USEPA QA/G-4* (USEPA, 2006a)
- *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)
- *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)
- *Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management* (ITRC, 2003b)
- *Data Validation Memorandum, Summary of Level II Data Validation* (DTSC, 2006a)
- *Information Advisory, Clean Imported Fill Material* (DTSC, 2001)
- *Human Exposure Based Screening Numbers Developed to Aid Estimation of Cleanup Cost for Contaminated Soil* (OEHHA, 2005)

CHAPTER 5
RISK SCREENING, CLEANUP GOALS, AND RISK MANAGEMENT

Following the site characterization, a human health screening evaluation for chemicals of concern (COCs) should be conducted to estimate the cancer risks and noncancer health hazards. The risks and hazards are used in the risk management decision-making for determining whether further site characterization, risk assessment, or cleanup may be necessary for the site. Several assumptions and exposure factors are used when conducting a risk screening, including identification of COCs, land use, exposure pathways, and exposure point concentrations (EPCs). Guidance for conducting a risk screening evaluation is provided in the:

- *Preliminary Endangerment Assessment Guidance Manual* (PEA Manual; DTSC, 1994)
- *School (Site) Environmental Assessment Manual* (DTSC, pending)
- *Use of California Human Health Screening Levels (CHHSLs) in Evaluating Contaminated Properties* (Cal/EPA, 2005)

5.1 IDENTIFICATION OF CHEMICALS OF CONCERN

Once the site has been characterized, the next step is to identify what COCs are present at the site. Although certain OCPs may appear ubiquitously in soil in California they are not naturally occurring chemicals and are not subject to background comparison techniques. Thus, all detected OCPs are considered to be COCs. However, California Human Health Screening Levels (CHHSLs) may be used as a point of departure with the caveat that if there are multiple chemicals detected, a ‘risk ratio’ should be performed by using the CHHSL calculator. CHHSLs should not be used as de facto screening numbers to eliminate chemicals from the risk assessment without a comprehensive assessment of site conditions (i.e., consideration as to whether the standard exposure assumptions and chemical toxicity values used to derive the CHHSL are appropriate for application to the site; factoring carcinogenic OCPs into the estimate of cumulative risk).

Arsenic contamination may be co-located with OCPs since the use of arsenicals as pesticides is widespread. If arsenic is a potential issue at a site, please refer to the *PT&R Guidance – Remediation of Metals in Soil* (DTSC, 2008b). Because both of the PT&R documents offer similar remedies, a combined approach to OCP and arsenic contamination may be appropriate.

5.2 EXPOSURE POINT CONCENTRATION (EPC)

Following the identification of COCs, the appropriate soil concentrations to be used in the health risk assessment must be determined. The PEA Manual recommends the use of the maximum concentration for initial screening purposes. Other statistical approaches may also be appropriate, including the calculation of the 95 percent upper confidence limit (UCL) on the arithmetic mean concentrations. Use of this approach is dependent on the size of the data set (a minimum of ten samples are necessary), distribution of contamination on the site, and the possible existence of localized hot spots. The selection of EPCs for the site should be justified based on whether soil contamination is localized (i.e., hot spots), spread across the site, or in a defined area of concern. It is not appropriate to statistically minimize soil concentrations by inclusion of soil data from large areas of the site which are not impacted. If it is unclear whether the data set or site characterization support the statistical estimation using the 95 percent UCL, then the maximum concentrations should be used in risk estimates.

5.3 HEALTH RISK SCREENING

All risk screening approaches should take into consideration the final end use of the property. For the purposes of the PT&R approach only, residential (unrestricted) or industrial/commercial land uses are considered. The CSM should include all potential exposure pathways for inclusion in the health risk assessment.

5.3.1 California Human Health Screening Levels (CHHSLs)

Health risk assessment screening can be accomplished by the comparison of the appropriate soil concentrations (EPCs; Section 5.2) to CHHSLs. The current list of CHHSLs and the accompanying *Use of California Human Health Screening Levels (CHHSLs) in Evaluating Contaminated Properties* (Cal/EPA, 2005) can be found at www.CalEPA.ca.gov. A spreadsheet calculator for CHHSLs is available on the California Environmental Protection Agency (Cal/EPA) website.

Cumulative cancer risks and non-cancer hazards should be calculated. Either individual or cumulative cancer risks greater than 1×10^{-6} or non-cancer hazards greater than 1 should be considered for further risk management evaluation.

5.3.2 DTSC Preliminary Endangerment Assessment

Risk screening assessment may be performed using the PEA Manual (DTSC, 1994) or the *Schools (Site) Environmental Assessment Manual* (DTSC, pending) instead of the comparison to the CHHSLs. The PEA process should be used if CHHSLs are not available for all chemicals found on the site.

After the COCs and soil concentrations (EPCs; Section 5.2) have been identified, cancer risks and hazards should be calculated. Cumulative cancer risks and non-cancer hazards should be calculated according to the PEA Manual. Either individual or cumulative cancer risks greater than 1×10^{-6} or non-cancer hazards greater than 1 should be considered for further risk management evaluation.

5.4 HEALTH-BASED CLEANUP GOALS

Factors that are considered in the development and selection of cleanup goals include the health impact endpoint (carcinogen vs. non-cancer hazard), the intended use of the property for appropriate exposure scenarios, and the number of COCs. For the purposes of this PT&R guidance, several conditions are not considered in the selection of cleanup goals, including potential impacts to ecological receptors, groundwater, and surface water. If any of these conditions exist, then this recommended PT&R approach for establishing cleanup goals is not applicable (see Chapter 3).

For carcinogenic OCPs, the generally accepted cleanup level should not be greater than a concentration that is equivalent to 1×10^{-6} cancer risk. For OCPs with non-cancer hazard, the generally accepted cleanup goal must not be greater than hazard index of 1. Cleanup goals with higher risks may be appropriate for a given project and the risk management decisions should be made on a case-by-case basis.

Selection of a cleanup goal is dependent on the end use of the property. For the purpose of the PT&R two future scenarios are considered. The first is a residential or unrestricted land use and the second is a industrial/commercial land use. Both of these future land-use scenarios have standard exposure pathway assumptions for persons who may come into contact with the soil. For the purposes of the PT&R guidance, these exposure assumptions should be identical to either the assumptions used in the development of CHHSLs or the PEA Manual. When properties are remediated to industrial/commercial cleanup goals or waste is left in place under a cap, institutional controls (ICs) may be required in order to ensure the continued health protectiveness of the selected solution. Please refer to Section 9.3 for further discussion.

If a site has multiple COCs that contribute significantly to excess total risk or hazard, the risk-based cleanup goal for each of the COCs may need to be adjusted to a lower concentration to reduce the overall cumulative risk and/or hazard to an acceptable range.

For sites where this PT&R guidance is applied, CHHSLs (see Section 5.3.1) may be considered as cleanup goals as a means of streamlining the selection process. CHHSLs for OCPs are based on the direct exposure of humans to contaminants in soil via incidental soil ingestion, dermal contact, and inhalation of dust in outdoor air. Use of a cleanup goal other than the CHHSL value may be necessary, such as:

- when overseeing regulatory agencies do not concur with the proposed use of CHHSLs. The use of CHHSLs as cleanup goals requires concurrence of both the responsible party and overseeing regulatory agencies.
- where a value less than the CHHSL is needed to address a local, State, or federal requirement (Chapter 6).

CHAPTER 6
EVALUATION OF CLEANUP TECHNOLOGIES FOR OCP-IMPACTED SOIL

In a conventional clean up action, 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 OCPs in soil. This chapter provides the administrative record, technical basis, and evaluation necessary for streamlining the cleanup alternative evaluation. Also addressed are the site-specific evaluation and remedy selection processes for cleanup of OCP-contaminated soils. Much of the streamlining is achieved by the DTSC study summarized in Section 6.1. 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
- a discussion regarding the use of the PT&R approach for the cleanup alternative selection in the decision document.

6.1 TECHNICAL BASIS FOR PT&R GUIDANCE TO ADDRESS SITES WITH OCP CONTAMINATION IN SOIL

DTSC conducted a study of sites where the primary contaminants of concern were OCPs in soil. The study objectives were to identify the technologies that were consistently evaluated as potential remedies and to identify the remedies that were subsequently selected at a OCP-impacted site. The study is equivalent to the screening evaluations conducted under a Feasibility Study (FS) or Corrective Measures Study (CMS).

The DTSC study included the following activities:

- review of literature relevant to sites with OCP soil contamination (see Appendix B for table summarizing the technologies applicable to OCPs in soil);
- identification of a representative number of DTSC sites with OCP-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 remedy.

DTSC reviewed its EnviroStor database to identify sites with OCP-contaminated soils. The database evaluation identified 80 sites for which remedy selection or implementation occurred as of December 2008. 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 for Sites Evaluated by DTSC Study

DTSC SITE TYPE (NO. OF SITES)	ICS ONLY	OFF-SITE REUSE	CONSOLIDATION ON-SITE, IC	CAPPING IN PLACE, CONSOLIDATE & CAP, CAMU, IC	EXCAVATE & DISPOSE	IN SITU TREATMENT	THERMAL OR CHEMICAL TREATMENT WITH ON-SITE REUSE OR DISPOSAL
School Site (31*)	1	1	0	0	29	0	0
Military Facility (16*)	3	0	0	5	10	0	1
Voluntary Cleanup (20*)	1	1	2	4	7	4	2
State Response/ NPL (13*)	0	0	2	4	10	0	1

* Some sites selected multiple cleanup options (i.e., this number is not simply the sum of values listed in this row).
CAMU is corrective action management unit.
IC is institutional control.
NPL is National Priorities List.

DTSC reviewed the cleanup alternative decision documents for 80 sites identified in the database review. The review focused on the cleanup alternatives that were considered and the factors that led to selecting the cleanup alternative. The document review also considered the project type, site activities, types of OCPs present, types of other contaminants present, other affected media, and impacted volume. Based on the data collected, 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 the decision documents reviewed, the most frequently reported OCPs requiring a soil response action include DDT, DDE, chlordane, dieldrin, and toxaphene. The data indicate that excavation/disposal was the most frequently selected cleanup alternative and containment/capping was the next most frequently chosen cleanup alternative. The selection of the cleanup alternative as the preferred approach appears to be influenced by proven effectiveness, ability to meet the project timeframes, foreseeable future land use and volume of impacted area. Containment/capping was selected if a cap was compatible with the current and foreseeable future land use and the associated land-use restrictions were not an issue with interested parties.

The review of DTSC projects identified several projects for which *in situ* bioremediation was used to cleanup OCPs in shallow soils. Although insufficient performance data are available to identify *in situ* bioremediation as a proven technology, Tables B-2 and B-3 describe the technology and Appendix C provides case histories of DTSC projects that used *in situ* bioremediation.

Table 4 summarizes the frequency of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) criteria used to support rejection of a particular cleanup alternative for the 80 sites included in the DTSC study. A detailed summary of the primary rationale for selecting and rejecting a given technology is provided in Appendix B. The excavation/disposal alternative frequently was rejected based on cost. Containment/capping were most often rejected due to existing or planned land use, or because of the long-term operation and maintenance (O&M) requirements.

Table 4. Cleanup Options Considered for the Sites Evaluated by DTSC Study

	Reason for Rejecting During Cleanup Alternative Analysis						
Technologies	Overall Protectiveness	Compliance with ARARs	Reduction of Toxicity, Mobility, Volume	Long-term Effectiveness	Short Term Effectiveness	Cost	Implementability
No Action	53	6	0	0	0	0	0
ICs Only	4	2	0	1	0	0	0
Excavation/Disposal	0	0	0	0	0	15	0
CAMU	0	0	0	3	0	0	0
Consolidation/Capping	0	13	0	4	0	8	0
Treatment (non-specific)	0	0	5	0	0	12	9

ARAR is applicable or relevant and appropriate requirement
CAMU is corrective action management unit
IC is institutional control

6.2 FOCUSED EVALUATION AND SELECTION OF CLEANUP ALTERNATIVE

Under State and federal law, an analysis of alternatives is required for sites undergoing remediation. Following a screening evaluation, a more detailed and focused evaluation that considers the site characteristics must be conducted on the cleanup alternatives. The cleanup alternative screening evaluation presented in Section 6.1 and Appendix B may be used in lieu of a screening evaluation for sites using the 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 which PT&R alternative is the most appropriate cleanup alternative. The alternatives evaluation may consist of a site-specific evaluation of the no action, excavation/ disposal, containment/capping alternatives, or a combination of these remedial options. Focusing on these PT&R alternatives is consistent with the 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 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, excavation/disposal has the potential to allow unrestricted use of the site. The containment/capping alternative, however, has long-term stewardship requirements which typically necessitate a regulatory oversight agreement. The focused alternatives evaluation may be prepared under State or federal guidelines, as summarized in Table 5.

Figure 3. Summary of PT&R Cleanup Alternatives for OCPs in Soil

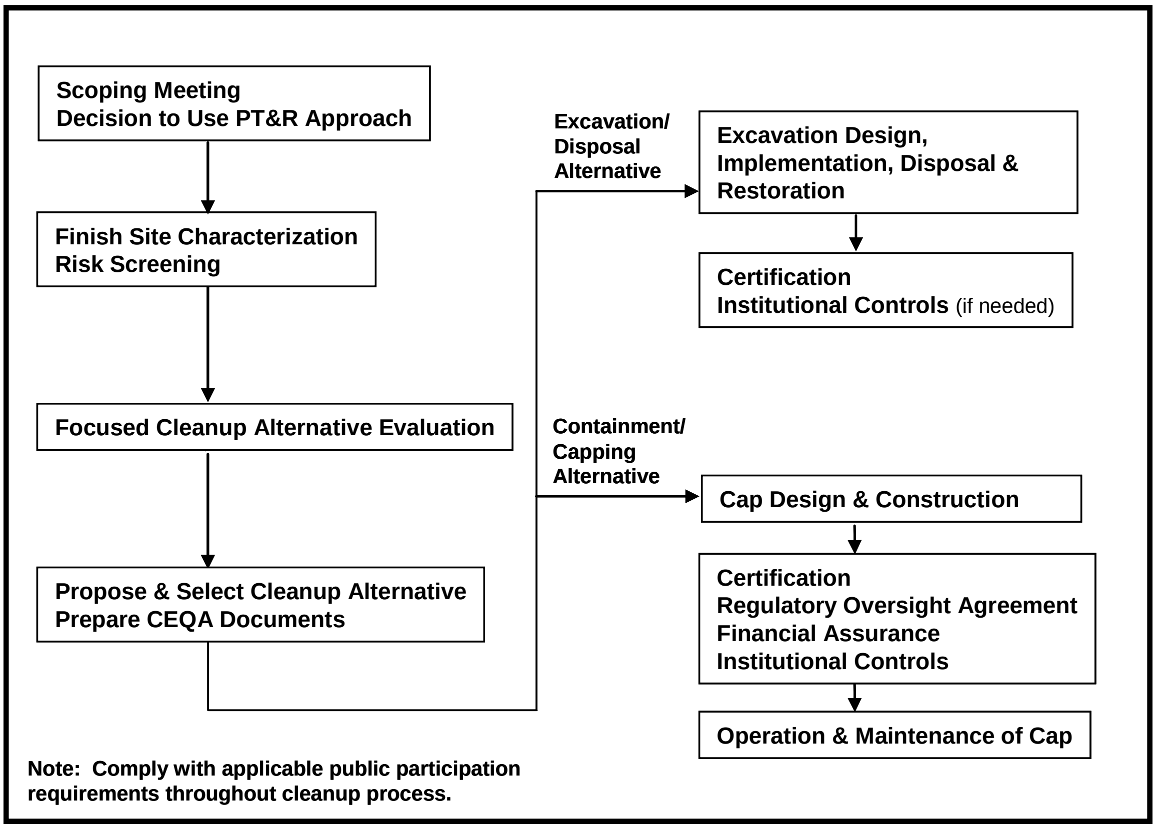

Table 5. State and Federal Guidelines for Focused Alternatives Evaluation

Law	Process	Description	Suggested 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]	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)[1,2]	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, 1993
RCRA or HWCL	Corrective Measures Study (CMS) [1]	Mechanism used by the corrective action process to identify, develop, and evaluate potential remedial alternatives.	USEPA, 1991a, 1994, 1997a
HSAA, HWCL, RCRA, CERCLA	Interim Measures[1] (IM) 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.	

1 See Appendix D for link to example or sample document.
2 A feasibility study is not required for RAW process. However, the RAW should evaluate the effectiveness, implementability, and cost of various 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

In addition to using the DTSC initial screening evaluation (Section 6.1), 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 (referred to as applicable or relevant and appropriate requirements [ARARs] under some cleanup processes)
- establishment of site-specific RAOs
- evaluation of the PT&R cleanup alternatives and the no action alternative against the applicable NCP criteria[2]:

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

[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.

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, 2009) provides additional discussion regarding sustainability as a criterion in the remedy selection process.

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; and
- include preliminary design information for implementation of the final remedy.

Necessary CEQA documents are usually prepared concurrently with the remedy selection documents, if not sooner (see Section 6.4). 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 public comments pertaining to the decision to use the PT&R approach.

6.3 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 provided as separate submittals. Examples of operational plans include the health and safety plan, transportation plans, and soil 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., a cap). 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 soil confirmation sampling to assess achievement of the cleanup objectives could also be prepared.

Chapters 7 and 8 provide further discussion of the design and implementation for the PT&R alternatives.

6.4 CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA)

Remediation of OCPs in soil must meet all applicable local, State and federal requirements, including the 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.

CHAPTER 7
DESIGN AND IMPLEMENTATION OF EXCAVATION / DISPOSAL ALTERNATIVE

This chapter describes the approach to be used to remove soil exceeding site cleanup goals for OCPs and other co-located contaminants.

7.1 DATA NEEDED TO SUPPORT EXCAVATION DESIGN

At a minimum, the following data are necessary to adequately address the excavation limits and design:

- vertical and horizontal distribution of contaminants (i.e., areal extent of impacted soils, depth of impact) and volume of soils to be excavated;
- identification of soil conditions that affect the selection of excavation equipment;
- depth to groundwater (including seasonal high and low stands);
- climatology / seasonal variations;
- survey map of site features (e.g., topography, existing structures, utilities, wells, surface water control measures, property boundaries, areas to be shored), if applicable;
- geotechnical data for each soil type (i.e., Unified Soil Classification System [USCS] classification, Atterberg limits, moisture content, bulk density), if applicable; and
- structural contour map of the top of competent bedrock, if applicable.

Preferably, these data will be collected during the characterization phase of the project (see Chapter 4) rather than requiring another field mobilization during the design phase.

7.2 PROFESSIONAL LICENSURE REQUIREMENTS

Soil excavations should be designed and executed in conformance with standard geologic, engineering, and construction principles and practices by appropriately licensed and experienced professionals. Likewise, workplans, reports, and other documents associated with soil excavations should be prepared in conformance with standard geologic and engineering principles and practices by appropriately licensed and experienced professionals.

7.3 EXCAVATION, DISPOSAL, AND RESTORATION PLAN (EDRP)

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 RAW process incorporates the required plan elements into the RAW. DTSC's 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 a sample EDRP.

Major topics and elements of the EDRP include the following:

- site background
- nature and extent of contamination
- cleanup 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.

- site-specific health and safety plan (HASP)
- storm water pollution prevention plan (SWPPP)
- community air monitoring plan
- soil confirmation sampling plan
- public participation plan
- stockpile sampling plan
- transportation plan

These documents can be submitted separately or as appendices to the plan. Selected topics related to the excavation, design, and restoration plan are discussed further in the following sections.

7.4 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
- schedule staff and equipment resources
- coordination with laboratory for analysis and assessment
- arrangements for sample management
- coordination with off-site disposal facility
- notifications

Local jurisdictions, such as municipal public works departments and air districts, often require excavation or grading permits be obtained. Depending on the volume of soil to be excavated or disturbed, the Regional Water Quality Control Board (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, the State Air Resources Control Board and air districts may require a similar application that identifies the mitigation measures to reduce or eliminate air dispersal of contaminants.

7.4.1 Dust Control and Air Monitoring

The EDRP should reiterate the actions (specified in the remedy selection document) that will be implemented to control fugitive dust and 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 to act as dust suppression
- application of soil additives
- control of vehicle access
- vehicle speed restrictions
- covering of soil 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
- cause for work stoppage

7.4.2 Work Zone and Community Air Monitoring

Dust mitigation measures and/or engineering controls, 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.

To ensure that the implementation of the remedy does not pose a potential threat to off-site receptors, community air monitoring (outside of the site fence line) should be considered for larger excavations, near developed areas (including industrial/ commercial areas), and for activities occurring near residential communities, schools, and other sensitive receptors (e.g., elderly or high use community areas). This may be required by some County environmental health departments. Site-specific risk-based action levels should be calculated, in consultation with DTSC, and included in the EDRP.

7.5 EXCAVATION ACTIVITIES

7.5.1 Cal-OSHA Standards for Trenching and Excavations

The EDRP should address the applicable California Occupational Safety and Health Administration (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.

7.5.2 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.

7.6 WASTE MANAGEMENT

7.6.1 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

LEVEL OF CONTAMINATION	DISPOSAL ALTERNATIVES
Concentrations below acceptable risk levels	Could 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 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 LDR concentrations prior to land disposal. In addition, if the soil is a RCRA characteristic waste, all other underlying chemicals 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 for a Class I landfill, under a bill of lading for a Class II landfill).

7.6.2 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.

7.7 BACKFILL AND RESTORATION

Backfilling typically occurs after the cleanup objectives have been met. Confirmation samples are collected from the sides and bottom of the excavation to confirm that the clean up goals have been achieved. Appendix D provides a link to an annotated outline for a soil confirmation sampling plan. Once the cleanup goals have been achieved, backfill operations can begin. Backfill soils should have physical properties consistent with engineering requirements for the planned site use. The Uniform Building Code typically requires a compaction between 90 and 95 percent. The excavated areas should be restored to be consistent with the existing or planned land use and graded to ensure proper runoff.

7.7.1 Borrow Source Evaluation

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 at some future time. As a general rule, backfill 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, OCPs
Residential or commercial land	VOCs, SVOCs, TPH, PCBs, OCPs, asbestos

From *DTSC Information Advisory, Clean Imported Fill* (DTSC, 2001)
OCP is organochlorine pesticide
PAH is polynuclear aromatic hydrocarbon
PCB is polychlorinated biphenyl
SVOC is semi-volatile organic compound
TPH is total petroleum hydrocarbon
VOC is volatile organic compound

A standard laboratory data package, including the QA/QC sample results should accompany all analytical reports. Chemicals detected in the fill material should be evaluated for risk in accordance with the PEA Manual (DTSC, 1994) or against the CHHSLs. 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.

Documentation should include detailed information on the previous land use(s) in the area where the fill is taken, the findings of any environmental site assessments, and the results of any testing. If such documentation is inadequate, samples of the fill material should be collected and analyzed for an appropriate list of parameters. This alternative may be the best option when very 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. Approximately one sample should be collected and analyzed per truckload. Table 8 provides recommended sampling frequencies for the fill soil. This sampling frequency may be modified upon consultation with appropriate regulatory agencies if all fill material is derived from a common borrow area.

Table 8. Recommended Fill Material Sampling

EXTENT OF INDIVIDUAL BORROW AREA	NUMBER OF SAMPLES
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.

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

Composite 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.

7.8 QUALITY CONTROL / QUALITY ASSURANCE

The excavation, disposal and restoration plan should address the QA/QC procedures that will be followed. If a QAPP was prepared during the characterization phase, the plan may be amended to address the pertinent changes for the EDRP. Soil confirmation samples are typically collected to ensure that the clean up objectives have been met. The approximate locations, number of samples, and the associated detection limits should be identified in a soil confirmation sampling plan (see Appendix D for link to an annotated outline for a soil confirmation sampling plan). The documentation of activities should be included, ensuring site activities were conducted in accordance with the approved workplan.

Under unusual circumstances the removal action may not be carried out as planned because conditions not anticipated in the workplan were encountered. Institutional controls (ICs) or other actions may be required if the cleanup goals cannot be achieved (see Section 9.3). An addendum to the remediation and CEQA documents may be necessary if a substantive change is made to the remediation approach.

7.9 HEALTH AND SAFETY MONITORING

The HASP that addresses site-specific excavation, restoration, and 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
- for each activity, 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 field activities identified (e.g., tail gate meetings)
- 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 soil removal and decontamination activities, and to guide selection of personal protective equipment
- appropriate personal protective equipment and safety systems for each site activity identified
- assurance that all workers comply with the rules to maintain a safe work environment. (e.g., disciplinary methods for workers who fail to comply)

7.10 COMPLETION REPORT

The EDRP should briefly identify the key elements that will be covered in a completion of work report[3] (completion report) along with the anticipated date of submittal. Appendix D provides a link to an annotated outline for the completion report. 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
- post-excavation sampling results (i.e., before backfilling and restoration), and compliance with performance standards
- determination as to whether the goals and objectives of the cleanup were met
- written and tabular summary of disposal activities
- as-constructed drawings and results of post-restoration activities on habitat if applicable

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

- health and safety activities including any analytical results
- compliance with all permit requirements
- copies of permits for the project
- copies of manifests and bills of lading

7.11 CERTIFICATION

When the final cleanup actions are fully implemented, DTSC issues a certification letter that the site has been remediated to levels required in the regulatory decision document. Any required land-use covenant (LUC) and enforceable agreement must be executed prior to site certification. See Section 9.3 for further discussion regarding LUCs.

CHAPTER 8
DESIGN AND IMPLEMENTATION OF CONTAINMENT / CAPPING ALTERNATIVE

This chapter describes the approach that could be used to select the type of cover/cap to be installed at a site and to prepare a cap/cover design and implementation plan. General guidelines are provided and are intended to enhance the efficiency of, but not replace, site-specific decisions based on individual site characteristics, applicable laws and regulations, and the principles of good engineering design.

The intent of this chapter is to provide guidance for the preparation of a cap/cover design and implementation plan. This plan should include the design for a cover/cap system that:

- is fully protective of human health and the environment,
- achieves site-specific RAOs,
- is compatible with reasonably foreseeable future uses of the site, and
- meets specific regulatory requirements under which the site is being addressed.

Under the PT&R approach, a basic cap design must (1) effectively eliminate ingestion, inhalation, and dermal contact exposure pathways and (2) preclude contaminant dispersion via air and surface water run-off. As site complexity increases, or where site-specific circumstances produce additional objectives, this chapter provides the latitude to pursue a full range of design options.

8.1 DESIGN OBJECTIVES

For some of the sites addressed under the PT&R process where containment/capping is selected as the preferred remedy, the protection of human health and the environment can be assured by meeting the following RAOs:

- elimination of receptor contact with contaminants in shallow soil which exceed cleanup goals; and
- isolation of contaminated soil to eliminate wind and surface water dispersion.

As a result, the installation of a soil cover, or a cover constructed of a single layer of asphalt and/or concrete, along with provisions for appropriate long-term stewardship may be adequate. For other sites, additional RAOs may be identified in the remedy selection document and may necessitate adoption of a more complex design.

Often, site-specific considerations may affect the design selected for a site. The cap design may need to consider planned development or future use of the property, or may be connected to the site physical location, features, or surroundings. Some examples of site-specific considerations include:

- anticipated future use of the property (both short and long term)
- utilization of construction features such as a building foundation or parking lot as a cover/cap

- climatic conditions and their impact on construction materials and cap performance
- storm water management
- potential seismic impacts to the cap
- erosion control
- support for vegetation
- O&M needs

8.2 INFORMATION NEEDED TO SUPPORT CAP SELECTION AND DESIGN

Table 9 summarizes the data and information that may be needed to adequately support the selection and design of an appropriate cover/cap. Preferably, these data will be collected during the characterization phase of the project (see Chapter 4) rather than requiring another field mobilization during the design phase.

Table 9. Information Needed to Support Cap Selection and Design

ALL COVER/CAP TYPES
• Lateral and vertical extent of impacted soils exceeding cleanup goals • Assessment of the mobility of contaminants (i.e., the potential for groundwater impacts) based on historical observations, methodical evaluations, and/or modeling • Depth to groundwater (including high and low stands) • Survey map of site and surrounding features (e.g., topography, existing structures, utilities, wells, surface water control measures, property boundaries) • Geotechnical data for native and imported soil types (e.g., USCS classification, Atterberg limits, moisture content, bulk density, saturated hydraulic conductivity, shrink-swell potential) • Identification of site conditions that affect the selection of construction equipment
SOIL AND EVAPOTRANSPIRATION COVERS/CAPS
• Climatology/seasonal variations • Identification of native plant species • Estimates of evapotranspiration rates • Location and soil properties of borrow materials (see Table 8) to be used for cap construction

8.3 PROFESSIONAL LICENSURE REQUIREMENTS

The cap should be designed, constructed, and maintained in conformance with standard geologic, engineering, and construction principles and practices by appropriately licensed and experienced professionals. Likewise, the design plan, reports, and other documents associated with the cap should be prepared in conformance with standard geologic and engineering principles and practices by appropriately licensed and experienced professionals.

8.4 DESIGN CONSIDERATIONS

8.4.1 Factors to Consider When Selecting an Appropriate Cap

Existing and planned land use. To the extent possible, cover/cap design should be compatible with both short and long-term land use plans. This may entail integrating cap design into the construction of site improvements such as utilizing building foundations or parking lot improvements as design elements. Or, it could involve designing the cap to allow future construction to occur with minimal disruption of contaminated materials.

Migration potential. An assessment should be made to determine the potential for infiltration-driven migration and the corresponding degree of infiltration control that is needed by the cap design. This evaluation should be based on data collected during pre-remediation activities. While the need for infiltration control will most often be captured as a RAO, significant design decisions will still need to be made due to the multitude of design options that are capable of achieving the degree of infiltration control that will likely be required.

Climatic conditions. Climatic conditions such as high rainfall or extremely low temperatures may indicate a need for enhanced cap design features. Conversely, low rainfall and high year-round evapotranspiration rates may support a simple soil cover design. Sea level rise associated with climatic changes may also need to be considered.

Foundation conditions. When the subgrade soil does not meet strength and compressibility requirements, additives can be combined with the in-place soil to improve its properties. This alternative uses either cement or lime to stabilize clay or sandy soil. The cement stabilization alternative is recommended for unsuitable soils with small percentages of clay and a high percentage of sand. Lime stabilization is recommended for unsuitable soils with a high percentage of clay.

Build-up of gases. If substances may be present in the vapor phase below the cap (e.g., methane), the design may need to allow controlled venting through the cap.

Terrain. Site factors such as very uneven terrain or location within a floodplain may complicate cap design and could potentially eliminate capping as a viable remedy.

RCRA cap versus "non-RCRA" cap. Installation of a RCRA standard cap in accordance with Subtitle C or equivalent may be necessary if the remedy is being pursued under certain regulatory requirements, or if those requirements are identified as applicable regulatory requirements in the remedy selection document.

8.4.2 Consolidating Impacted Soils

The consolidation of impacted soils may be desirable or necessary prior to cover/cap construction at many sites. Consolidation may be used to clean up the edges of a single contiguous contaminated area to make it more geometrically regular, reduce the size of the area being capped, or to combine soils from one or more contaminated areas into a single area at a site. Anticipated future land use or specific development plans may also result in consolidation being identified as an appropriate step prior to cap construction.

In most cases and depending on site-specific circumstances, consolidation of impacted soils can be accomplished through the application of either the Area of Contamination (AOC) approach or in accordance with Corrective Action Management Unit (CAMU) regulations (Cal. Code Regs., tit. 22, §66264.550, §66264.551, §66264.552, §66264.552.5).

For the purpose of implementing a consolidation and capping remedy under this guidance, the AOC approach is generally preferred unless site-specific conditions or regulatory considerations make the use of the CAMU regulations, and their added flexibility, necessary. Those parties interested in pursuing a consolidation and capping remedy are cautioned to work closely with DTSC to ensure that the appropriate option is selected and properly implemented.

The following information on the AOC approach and CAMU regulations is intended only as a brief summary. Refer to the detailed discussions presented in the AOC references provided below and the CAMU regulations in order to fully review the complexities involved in their use.

Area of Contamination (AOC) Approach

The AOC approach will provide an adequate basis for the consolidation of impacted soils at many of the sites being cleaned up in accordance with this PT&R guidance. It is based on an interpretation of federal regulations which allow for the movement of hazardous wastes within a contiguous area of generally dispersed contamination without being considered land disposal and without triggering LDRs or minimum technology requirements.

The AOC approach was initially discussed in detail in the preamble to the NCP (55 *FR* 8758-8760, March 8, 1990). The NCP discusses using the concept of "placement" to determine what requirements might apply within an AOC. The placement of hazardous wastes into a land-based unit is considered land disposal, which would trigger LDRs and other requirements. The NCP provides that, "placement does not occur when waste is consolidated within an AOC, when it is treated in situ, or when it is left in place." The concept of placement can similarly be applied in determining that consolidation within an AOC does not, in and of itself, constitute a release of a hazardous substance.

While no formal designation of an AOC is necessary, appropriate regulatory oversight is recommended to ensure that the AOC approach is properly applied. Additionally, for most consolidation and capping remedies, regulatory oversight and approval will be necessary to:

- take advantage of certain permit exclusions,
- ensure that the remedy is properly designed,

- ensure that the remedy will remain protective over the long term through the use of ICs and implementation of proper O&M activities, and
- obtain agency certification of the completed response action.

The AOC approach may not be applicable to some sites because of the nature and timing of the original release, or as a result of the specific regulatory authority under which the sites are being cleaned up.

Additional information regarding the AOC approach can be found in the following documents:

- preamble to the NCP (55 *FR* 8758-8760, March 8, 1990)
- *Management of Remediation Wastes Under RCRA* (USEPA, 1998)
- *Area of Contamination Policy* (USEPA, 1996)

Corrective Action Management Unit (CAMU) Approach

CAMUs can provide an effective means for implementing consolidation with capping remedies at impacted sites being cleaned up in accordance with this PT&R guidance. They provide similar features to those of the AOC approach with the added flexibility of being able to receive wastes from more than one contaminated area and being constructed in an uncontaminated area at a facility. CAMUs must be formally designated by DTSC. They may be used only for managing remediation wastes associated with corrective action or cleanup at a facility. CAMUs must be located within the contiguous property under the control of the owner or operator where the wastes to be managed in the CAMU originate. One or more CAMUs may be designated at a site.

The placement or consolidation of remediation wastes into or within a CAMU does not constitute land disposal of hazardous wastes, does not trigger LDRs, and does not create a unit subject to minimum technology requirements.

For further information, review the CAMU regulations (Cal. Code Regs., tit. 22, §66264.550, §66264.551, §66264.552, §66264.552.5).

8.4.3 Source of Borrow Materials

The source of borrow materials to be used for cap construction is identified during the design phase. In addition to material and transportation costs, the selection process for borrow materials should consider the preferred properties of each layer and the objective that the materials will not introduce new contamination to the site (see Section 7.7).

8.4.4 Storm Water Runoff Control

Surface water collection and diversion may be needed to control run-on and run-off. This may include use of subsurface drainage controls (e.g., inlet grates, piping) that collect and redirect runoff/run-on from rainfall events from the asphalted surface to a retention pond or other predetermined location.

8.4.5 Erosion Control

Design of the cap should include measures to control erosion around the cap perimeter and on the main body of the cap. Additional erosion control measures will be needed for soil caps, such as selecting an appropriate side slope ratio to minimize erosion, and such as incorporating an upper vegetation layer.

8.4.6 Side Slope of Cap

Applicable cap side slopes are dependent on regulatory requirements and guidelines that vary from locality to locality. An example of side slopes would be a ratio of 5:1 (20 percent), where five is the horizontal run and one is the vertical rise. Generally, the maximum side slopes that can be implemented are 3:1 (33 percent). Steeper slopes may cause the underlying layers of sand, gravel, or geotextiles to slide or fail along the contact interface. Also, steeper slopes increase maintenance and the potential for erosion and soil loss. The benching of slopes at steeper grades may be needed to control potential erosion and promote stability of the cap.

8.5 TYPES OF CAPS

As indicated in Sections 8.1 and 8.4, the type of cover/cap used at a site depends on a variety of site-specific factors. Caps may be temporary and/or final, their selection and design may be based upon site-specific RAOs, or they may be subject to prescriptive requirements in accordance with the regulatory authority under which they are being addressed. They may consist of a generic standard design, a composite of multiple elements of standard designs, or a unique design that addresses an unusual combination of site-specific objectives. It is anticipated that covers/caps selected for PT&R sites will consist of one or more of the following types (listed in order of increasing complexity):

- soil cover/cap
- evapotranspiration (ET) cover
- asphalt and/or concrete cover/cap
- low permeability composite soil and vegetation cover/cap
- geosynthetic/composite cap
- standard RCRA cap (RCRA Subtitle C cap)

The California Department of Transportation (Caltrans) has developed substantial information on the design and properties of both asphalt and concrete utilized in highway construction (e.g., Caltrans, 2009). There is also a great deal of information available on the design requirements for a RCRA Subtitle C cap available through USEPA and other sources. In 1991, the USEPA issued a revised guidance document, *Design and Construction of RCRA/CERCLA Final Covers* (USEPA, 1991b), that addresses closure and final cover for hazardous waste facilities. The ITRC guidance, *Technical and Regulatory Guidance for Design, Installation, and Monitoring of Final Landfill Covers* (ITRC, 2003a), draws information from these and other sources in an effort to provide foundational information on the cover/cap types listed above. Refer to these source materials if more detail is desired.

8.5.1 Soil Cover/Cap

Soil covers/caps can range from a single layer of vegetated soil to multiple layers with varying hydraulic conductivities. Under favorable conditions a single layer of vegetated clean native soil, or soil with properties similar to native soils, may be sufficient to achieve site-specific goals. In other cases climatic conditions, contaminant mobility characteristics, regulatory concerns, or land use issues may dictate a multilayered design.

For a single layer, design consideration should be given to:

- cap thickness for the purpose of minimizing the potential for accidental/incidental penetration of the clean cap material into the underlying contaminated soil;
- utilization of a demarcation layer (permeable mat) between the cover material and underlying contamination to indicate when contaminated materials have been or might be encountered;
- relationship between compaction and both water-holding capacity and support of vegetation;
- long-term care of the cover; and
- land use and construction plans.

For single layer designs, a minimum cover thickness of approximately two feet will be adequate for most sites provided that animal intrusion risks are low. As infiltration and surface water management issues become more important, soil with higher water-holding capacity and the use of ET-enhancing vegetation may help address those concerns. Where the construction of buildings or other improvements is likely to occur, design properties will need to be adjusted to address those building needs without compromising the health and environmental protectiveness of the cover.

Where single layer designs are found to be unsuitable, a multilayered design consisting of different soil types may be appropriate. Multilayer designs can provide infiltration control, drainage management and support for vegetative covers or future construction through the careful selection and design of soil layers. Good design practices dictate that specific soil properties be exploited to achieve the desired results. Table 10 identifies various soil properties that should be considered when selecting soils for various layers in the soil cover.

Table 10. Critical Parameters for Soil Cap Material

PARAMETER	PREFERRED PROPERTIES	RECOMMENDED TESTS
Materials	The primary requirement is that the material is capable of being compacted to produce a suitable low conductivity layer or substrate.	
Fines	The soils should contain at least 20% fines. Soil screened on a dry-weight basis of passing a No. 200 sieve are considered fines.	ASTM D-422, ASTM D-1140 ASTM D-2487, USCS Soil Classification, ASTM D-3282, AASHTO Soil Classification tests
Plasticity Index (PI)	The soils should have a PI of at least 10%. Some soils with slightly lower PI may still be suitable. Soils with PIs greater than 30 to 40% may be to difficult to work with as they may form hard chunks when dry and sticky when wet. Ideally soils with a PI between 10 to 35% are good for this purpose.	ASTM D-4318, Atterberg Limit Test
Percentage of Gravel	A maximum of 10% gravel is generally acceptable. The percentage of gravel is defined as the amount of soils retained on a No. 4 sieve.	ASTM D-422, ASTM D-2487, USCS Soil Classification, ASTM D-3282, AASHTO Soil Classification tests
Stones and Rocks	Soil containing stones or rocks larger than 1 to 2 inches should not be used in liner materials.	ASTM D-2487, USCS Soil Classification, ASTM D-3282, AASHTO Soil Classification tests
Water Content	The water content of the soil at the time it is compacted is an important variable controlling the engineering properties of the soil liner.	ASTM D698 Proctor Test, ASTM D1557, Modified Proctor Test, ASTM D-2216, ASTM D-3017 ASTM D-4643
Compactive Strength	The hydraulic conductivity of a soil that is compacted wet of optimum moisture content could be lowered one to two orders of magnitude by increasing the energy of compaction.	ASTM D-698; ASTM D-1556, ASTM D-2167, ASTM D-2922, ASTM D-2937, California Test Method (CTM) 301
Size of Clods	Soils with low plasticity do not form very large clods. For soils that form clods, the clods need to be remolded into a homogeneous mass that is free of large inter-clods if low hydraulic conductivity is to be achieved.	

Soil caps may be utilized to provide increased separation between contaminated soils and building foundations, thereby minimizing the potential for construction worker exposure to contaminants during site preparation and utility installation activities. When overlain by building foundations, or other constructed surface features, the combined “cap” system will result in an easy to maintain, health and environmentally protective long-term solution for many contaminated sites.

In summary, site-specific RAOs in conjunction with site-specific considerations such as climatic conditions, future land use and development plans will guide the selection and design of suitable soil caps.

8.5.2 Evapotranspiration (ET) Cover

Because of the water retention properties of soils and the fact that most precipitation returns to the atmosphere via ET, it is possible to devise a cover that meets the requirements for remediation and yet does not contain a barrier layer. Successful ET cover design and construction requires understanding of plant growth requirements and soil properties. ET covers are generally used in arid areas where clay and other barriers may not be ideal because of the high potential for cracking and settlement. Resources for design, construction, and long-term management of ET covers are provided on the ITRC and the Desert Research Institute websites (www.itrcweb.org and www.dri.edu, respectively). A fact sheet on ET landfill cover systems is also available (USEPA, 2003).

8.5.3 Asphalt / Concrete Cap

Asphalt and/or concrete pavement is a suitable cap for many sites. Both asphalt and concrete are especially well suited as a cap for developed areas where there is a need to combine containment with continued or new commercial or industrial use (e.g., parking lot, building foundation). Paving requires higher maintenance than caps with soil or synthetic elements, and is prone to cracking and deterioration. Paving may increase storm water run-off and could increase erosion of surrounding areas. However, these problems can be easily addressed through appropriate design, inspection and maintenance activities. Storm water runoff associated with a cap that is integrated into a site development project is no different than would be expected from the development itself and would normally be addressed through development-related storm water management requirements. For stand alone pavement caps, storm water control features can be incorporated into the design.

An asphalt cap may consist of two or more components, including:

- top cover of asphalt or concrete (may be multiple layers);
- base rock; and
- on a case-by-case basis, an impervious layer, that may be below the base rock and a protective layer or may be sandwiched between asphalt layers.

Top Cover of Asphalt or Concrete. In addition to isolating contaminated soil, pavements may be engineered to distribute stresses imposed by loading such as traffic or building(s) to the subgrade. Where loading is a significant design factor, the subgrade condition is a principal factor in selecting the pavement structure. Before a pavement is engineered, the structural quality of the subgrade soil should be evaluated to ensure that it has adequate strength to carry the predicted loads during the design life of the pavement. The pavement should also be engineered to limit the expansion and loss of density of the subgrade soil.

The top cover material for the asphalt cap is normally comprised of hydraulic asphalt concrete, which serves as a hydraulic barrier as well as a physical barrier. Asphalt can be designed with consideration for vehicle use, or it can be modified for the purpose of enhancing its weatherability and permeability characteristics. Refer to the *California Department of Transportation Highway Design Manual* (Caltrans, 2009) for traffic load/design criteria.

Base Rock. The base rock layer is used to support the asphalt/concrete layer. The crushed base rock will be spread over the entire area of the cap. The typical range of base rock material depth is 6 to 12 inches and is dependent upon the type of loading that is anticipated.

Optional Impervious Layer. An impervious layer which reduces the amount of infiltration may be added to the design when site-specific conditions indicate the need. The barrier formed by the impervious layer reduces the potential for contaminant migration toward groundwater. This layer in a pavement cap may consist of a flexible membrane liner (FML), or it may be incorporated as a fabric and liquid asphalt layer between two asphalt lifts.

FMLs provide a low hydraulic conductivity layer that is placed beneath a protective layer of sand or fabric which separates it from the base rock. There are several acceptable materials that are commonly used, including:

- 40 mil high density polyethylene (HDPE)
- 60 mil HDPE
- 80 mil HDPE
- 30 mil polyvinyl chloride (PVC)
- 40 mil PVC

8.5.4 Geosynthetic/ Composite Cap

A geosynthetic/composite cap may consist of two to five layers. At a minimum it will consist of a geosynthetic clay layer and an overlying soil layer that is typically vegetated. Often a drainage layer is included immediately above the geosynthetic clay layer. A low-permeability soil may be added to reduce permeability and a rodent control layer may also be incorporated. This complex design, although implementable, is generally more difficult to install and more expensive than soil or asphalt/concrete caps. For sites using the PT&R approach, the number of layers included in the geosynthetic/composite cap will depend on RAOs, the site location, climatic conditions, ET rates, soil layer water-retention capacity and drainage considerations.

Soil Layer. The soil layer serves as the final (top) layer of the cap. The soil is used in conjunction with vegetation to reduce erosion and infiltration of rainwater, enhance ET and to protect the underlying layer(s) of the cap from water and wind erosion and dehydration. The typical thickness of the topsoil layer will range from 12 to 24 inches. The material used for the top soil layer will be selected on the basis of site-specific considerations. It should have good soil water-holding capacity, and be capable of supporting appropriate vegetation. Appropriate compaction will be necessary to provide structural stability within the overall cap design without adversely impacted the rooting of the vegetated cover.

Drainage Layer. A drainage layer consisting of high permeability materials may be installed immediate above the geosynthetic clay layer to allow drainage of infiltrating water and to prevent downward movement of water into the impacted soil. This layer will generally range from 6 inches to one foot in thickness and will consist of soil having a hydraulic conductivity of approximately 1 x 10^{-2} centimeters per second (cm/s).

Geosynthetic Clay Layer. The geosynthetic clay layer is composed of a manufactured product consisting of two non-woven fabrics sandwiching a layer of bentonite that acts as a barrier to prevent significant infiltration through the cap. The low-permeability geosynthetic clay layer has a hydraulic conductivity on the order of 1 x 10^{-7} to 1 x 10^{-6} cm/s.

8.5.5 RCRA Standard Cap

RCRA Subtitle C (subparts G, K, and N) establishes the minimum requirements for cap systems designed and constructed for the containment of hazardous waste. Standard RCRA Subtitle C caps are designed to provide containment and hydraulic protection for a performance period of a minimum of 30 years. The surface barrier is comprised of five layers with a combined minimum thickness of 5.5 feet and a vegetated erosion-control surface. A RCRA standard cap typically includes the layers with the characteristics listed in Table 11.

Table 11. Typical Requirements for RCRA Caps

LAYER[1]	REQUIREMENTS FOR SUBTITLE C CAP[2]	REQUIREMENTS FOR SUBTITLE D CAP[2]
Top Vegetation	Thickness varies from >6 inches dependent on site conditions.	Thickness varies from >6 inches dependent on site conditions.
Soil Layer	Minimum of 2 feet in thickness of graded soils at slope of 3 to 5%.	Thickness varies from >6 inches dependent on site conditions. Thickness of top vegetation and soil layers combined should be a minimum of 24 inches.
Drainage Layer[3]	Minimum of 1 foot in thickness and constructed of soil having a minimum hydraulic conductivity of 1x10^{-2} cm/s or equivalent.	N/A
Impervious Layer[3]	Minimum of 2 feet in thickness of compacted natural or amended soils with a hydraulic conductivity of 1x10^{-7} cm/s in contact with geomembrane.	Minimum of 18 inches in thickness of compacted natural or amended soils with a hydraulic conductivity of 1x10^{-5} cm/s.
Leveling Layer	May vary in thickness from 6-18 inches to form a layer for construction of the overlying layers.	May vary in thickness from 6-18 inches to form a layer for construction of the overlying layers.

1 Layers in order from surface to increasing depth.
2 Final covers must be designed and constructed to have a permeability less than or equal to natural subsoils.
3 Varies in geosynthetic/composite cap.

8.6 IMPLEMENTATION CONSIDERATIONS

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

- site access
- grading, air, and other permits
- underground utilities
- environmental and cultural protection
- health and safety
- waste management
- staff and training
- support and equipment
- notifications

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.

8.6.1 Dust Control and Air Monitoring

Control of fugitive dust and emissions is required by local air districts and, if not identified as a project element in the remedy selection process, may be identified as a mitigation measure under the CEQA process. Therefore, a fugitive dust control and monitoring plan should be developed for the project. Dust control applies to any construction, demolition, excavation, 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. Please refer to Section 7.4.1 for further discussion of the fugitive dust control and monitoring plan.

8.6.2 Community Air Standards

Activities occurring near developed areas, and particularly near residential communities, schools, and other sensitive receptors (e.g., elderly or high use community areas) should be considered in the dust control planning. Adequate protection of exposure to contaminants contained in the dust should be considered as part of the dust control measures.

If appropriate, community air monitoring should be conducted 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 community air monitoring plan.

8.6.3 Borrow Material Management

The design and implementation plan will need to provide for staging of borrow materials that are transported to the site for use in cap construction. Staging should be implemented to prevent the placement of clean material within contaminated areas unless provisions are included for use of an appropriate barrier. Generally, staging within contaminated areas with the use of a barrier will not be accepted except in cases where acceptable clean areas are not available.

8.6.4 Safety Standards

The design and implementation plan should address applicable Cal-OSHA health and safety requirements.

8.7 DESIGN AND IMPLEMENTATION PLAN

The engineered cap design and implementation plans will be presented in a cap design and implementation plan (see link to annotated outline in Appendix D). The plan may be contained in the remedy selection document or as a stand-alone document. In general, plans for less complex projects will be included in the remedy selection document. The oversight agency should be consulted on specific submittal requirements.

8.8 COMPLETION REPORT

A completion report documenting the cap construction should be prepared. It should include as-built drawings as well as material testing results. Appendix D provides a link to an annotated outline for a completion report.

8.9 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.

8.9.1 Institutional Controls (ICs)

ICs such as land-use covenants (LUCs) will be required due to hazardous substances remaining on-site at concentrations which preclude unrestricted use of the property. Further discussion of ICs and LUCs is provided in Section 9.3.

8.9.2 Financial Assurance

Financial assurance will be required to 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. Depending on the specific cap design employed, financial assurances may also need to include the costs of cap replacement. These on-going costs should be included in the cost calculation utilized in the remedy selection process. Financial assurance can be accomplished by several different mechanisms.

Life-cycle cost analysis (LCCA) is a useful tool for comparing the value of alternative cap structures and strategies. LCCA is an economic analysis method that compares the initial cost, future cost, and user-delayed cost of different cap alternatives. Although not specific to caps, the *Life-Cycle Cost Analysis Primer* (U.S. Department of Transportation, 2002), the *Full Cost Accounting for Municipal Solid Waste Management: A Handbook* (USEPA, 1997b), and *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (USEPA, 2000) describe the methods and techniques used in LCCA. Software programs such as RACER[4] can be used to create cost estimates for the LCCA methodology.

LCCA is an integral part of the decision-making process for selecting the cap type and design. Present worth or value analysis is often used for comparing cost alternatives with varying durations.

8.9.3 Regulatory Oversight Agreement

A regulatory oversight agreement will be required because contaminants have been left in place that may pose a threat to human health and the environment if the cover is not maintained as designed. Example regulatory oversight agreements include post-closure care permits and Operation and Maintenance Agreements.

8.9.4 Operation and Maintenance (O&M)

Any regulatory oversight agreement or enforceable mechanism should reference or include the approved O&M plan that outlines the procedures and requirements for on-going O&M of the cap. The purpose of the O&M plan is to ensure that the cap is maintained in good condition so that it remains protective of public health and the environment. Appendix D provides a link to a sample document for an O&M plan. Selected elements of the O&M plan are highlighted below.

Inspections. The O&M Plan should provide for inspections of the cap to ensure that it is functioning as intended. These inspections should be conducted on a routine basis as well as after unplanned events (e.g., earthquake, on-site construction activities) that may have affected cap integrity.

Repairs and Maintenance. The cap should be maintained in a manner that ensures it is functioning as intended. Examples of cap maintenance include vegetation control; and repairs due to cover erosion, asphalt cracking, settlement, and subsidence. For asphalt and concrete caps, periodic sealing of the cap surface will be necessary. Repairs and maintenance of the cap should be performed according to the procedures and the timeframes specified in the O&M plan.

Reporting, Recordkeeping, and Notifications. The O&M plan should outline the recordkeeping requirements for O&M activities and should provide for submittal of periodic inspection summary reports. The O&M plan should identify the site activities or

[4] Mention of any trade names or commercial products does not constitute endorsement or recommendation of the Department of Toxic Substances Control.

conditions that require notification of the regulatory agencies. The plan should also identify the timeframe and mechanism (e.g., verbal, written) for the required notifications.

8.9.5 Contingency Plan

Any regulatory oversight agreement or enforceable mechanism 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. The contingency plan may be a standalone document or may be included as an element of the O&M plan.

8.9.6 Five-Year Review

Under CERCLA and State law, five-year reviews are required for a remedial action that results in hazardous substances remaining at the site. Any regulatory oversight agreement or enforceable mechanism, as well as 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 cap or O&M plan more effective?

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

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 review of the cap/cover portion of a remedy would typically consist of:

- notifying the community that the review is being conducted;
- inspecting the cap to: document the condition of the cap; determine if necessary actions are required to maintain or improve cap integrity; and ensure the cap is meeting the intended performance objectives; and
- preparing a report that details the findings of the review.

As applicable to a given site, other components of the remedy should also be addressed by the review.

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

CHAPTER 9
SITE CERTIFICATION

When the cleanup process is completed, DTSC will certify that the required cleanup has been completed and that no further cleanup is necessary, unless new information is obtained or site conditions change. DTSC will determine whether the residual concentrations of OCPs in soil are protective of public health and the environment based on the cleanup levels established in the regulatory decision document. The possible determinations are:

- adequate cleanup has been achieved (e.g., closure of a hazardous waste management unit);
- additional cleanup is necessary; and/or
- ICs are required to manage the remaining contamination.

9.1 CERTIFICATION OF ACTION

When a site cleanup is satisfactorily completed, DTSC issues a certification letter that the site has been cleaned up to levels required in the regulatory decision document. The certification letter is issued after any requirements for a LUC or other ICs, and regulatory oversight agreement (including establishment of a financial assurance mechanism) are met. These documents will state that DTSC has continuous oversight and the responsible party is required to maintain any measures necessary for on-going protection of public health and the environment.

9.2 OPERATION AND MAINTENANCE

Sites that have waste left in place (such as sites which select a cap as the cleanup alternative) will be required to have an O&M plan (see Section 8.9.4). The mechanism under which O&M is conducted depends on the type of site.

9.3 INSTITUTIONAL CONTROLS FOR CONTAMINATION REMAINING IN PLACE

Where future land and water uses may not be compatible with residual OCPs contamination or where cleanup involves leaving OCP-impacted soils in place, ICs are used to stop or reduce the exposure of human and environmental receptors. ICs are non-engineering mechanisms used to ensure that the intended future land use is consistent with site cleanup and engineering controls (e.g., caps) maintain their integrity and effectiveness. Examples of ICs for sites where contamination remains in place include LUCs, public notice, signs, and fencing.

For sites requiring 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 cleanup 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.

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 use of the land. It requires DTSC to clearly set forth and define land use limitations or covenants in a cleanup decision document prior to approving or concurring in any facility closure, corrective action, remedial or removal action, or other response actions. Further information regarding LUCs is available at www.dtsc.ca.gov.

CHAPTER 10
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GLOSSARY

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

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The Comprehensive Environmental Response, Compensation, and Liability Act, 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.

California Environmental Quality Act (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 discretionary decisions whenever it is feasible to do so.

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.

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

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 RCRA corrective action process.

Exposure pathway. The way a chemical comes into contact with a receptor.

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 FS 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. The cumulative hazard index is the sum of the hazard quotients for individual chemicals.

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 (DTSC titles this instrument as the “Covenant to Restrict Use of Property, Environmental Restoration”) 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.

Pesticide. A pesticide is defined as an agent used to kill or control any pest, including insects, rodents, birds, unwanted plants (weeds), fungi, and micro-organisms (bacteria and viruses). This term applies to herbicides, fungicides, microbiocides, rodenticides, and other products used to control pests, including substances used as insect or plant growth regulators, insect mating disruptors, egg sterilants, defoliants, or desiccants. Many products found in households are classified as pesticides (e.g., cockroach sprays and baits, rat poison, pet flea collars, products that kill mold and mildew, and kitchen disinfectants).

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.

Resource Conservation and Recovery Act (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 million 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 actions are designed to stabilize or cleanup a site posing a threat to human health or the environment, either as an interim action or as a final remedy.

Risk assessment. The scientific process used to estimate the likelihood that a chemical detected at a site may be harmful to human health 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 compound 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.

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

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.

APPENDIX A

EXAMPLE CONCEPTUAL SITE MODEL

TABLE OF CONTENTS

Note: For a general CSM overview and CSM checklist, see Appendix A1 of *PT&R Guidance – Remediation of Metals in Soil* (DTSC, 2008b). Link is provided in Appendix D.

EXAMPLE CONCEPTUAL SITE MODEL (NARRATIVE FORMAT)

Site Description

The site is covers approximately 20 acres within an unincorporated area of Red Bluff in Tehama County. The site consists of two parcels, referred to as the western and eastern parcels. The site is currently unoccupied, but is being considered for residential development. The site is located within a rural area having primarily agricultural use with occasional residential lots. The property to the south and east has also been proposed for residential development.

The western parcel contains a residence, a metal and a wooden barn, a metal well house, a grain silo, a septic tank, two pole mounted transformers, and a burn pile. Approximately three quarters of the western parcel was planted with walnut trees. The eastern parcel consists of a residence, two metal sheds, a well house, a wooden shed, a pole-mounted transformer, and a septic tank. Approximately one half of the eastern parcel was planted with walnuts trees. Both parcels had been non-irrigated pastureland at one time. The features of each parcel are shown on Figure 1.

The site slopes at about a 1 percent grade toward the northwest. No surface water features are present. There are no known cultural resources at the site.

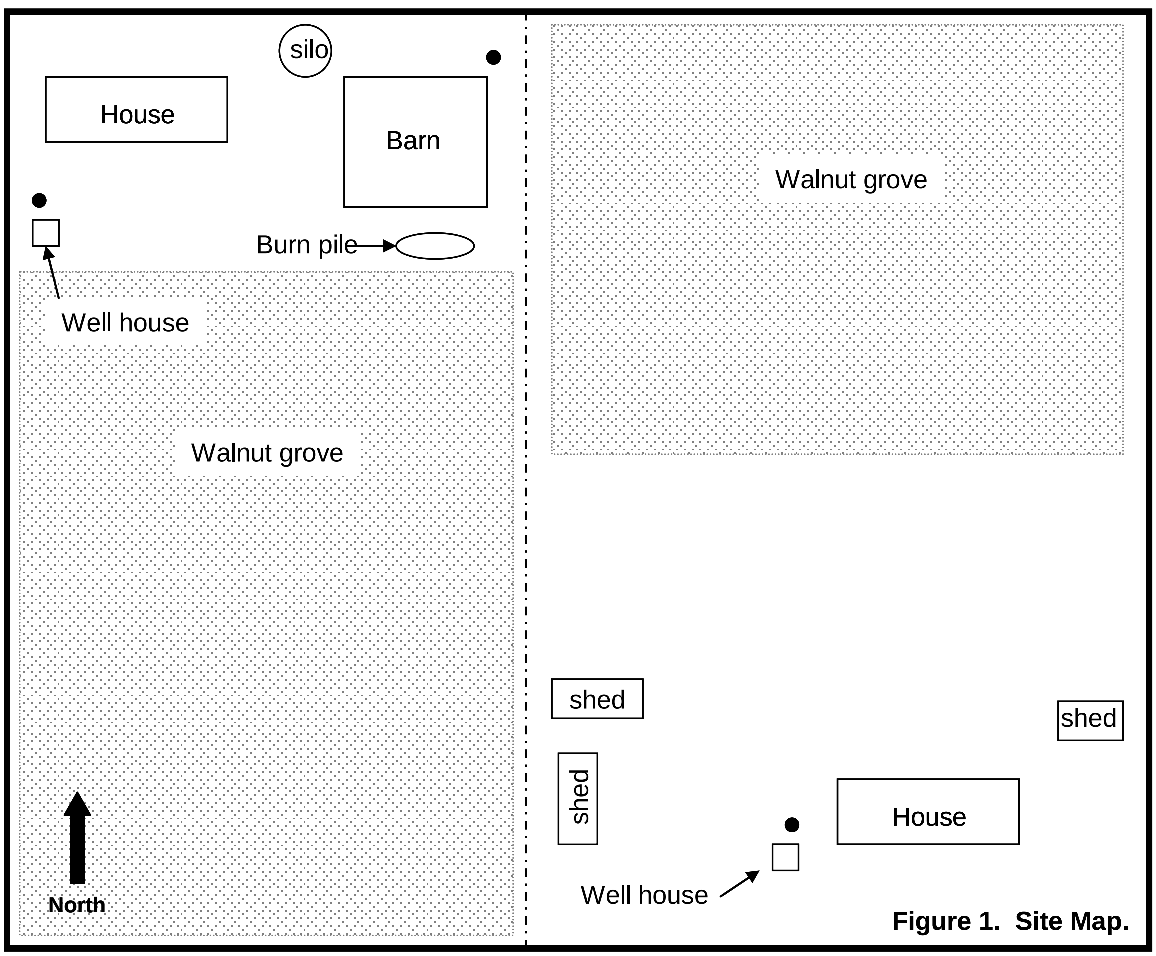


Figure 1. Site Map.

Site Geology and Hydrogeology

The site is underlain by approximately 200 feet of unconsolidated alluvial/fluvial deposits consisting of sands and gravels with occasional silt/clay interbeds. Depth to groundwater at the site generally ranges from 50 to 60 feet bgs. The regional groundwater flow direction is toward the north-northwest. The local groundwater flow direction may be influenced by nearby water supply wells.

Nature and Extent of Contamination

During the Preliminary Environmental Assessment (PEA), the site was investigated for arsenic, lead, and OCPs in soil samples collected from the agricultural fields and around the structures. The sampling results indicated that concentrations of five OCPs exceeded screening levels around the footprint of both residences to depths of up to 2 feet bgs (see Figures 2 and 3). The agricultural fields had OCP concentrations below risk-based levels of concern. Table 1 summarizes the maximum detected concentrations for arsenic, lead, and OCPs.

Table 1. Maximum Concentrations in Soil

Compound	Maximum Concentration (mg/kg)	Screening Level (mg/kg)
Arsenic	6	10[1]
Lead	24	150[2]
Chlordane	35	0.43[2]
DDD	1.48	2.3[2]
DDE	1.06	1.6[2]
DDT	1.70	1.6[2]
Dieldrin	2.50	0.035[2]

Notes:
1 Site-specific background concentration
2 CHHSL for residential land use

Human Health Risk

The PEA identified potential risk to human receptors from chemical contamination at the site. The risk assessment identified the five detected OCPs as COCs for human receptors. The exposure pathways for the risk assessment included soil ingestion, dermal exposure, and inhalation of particulates. The risk assessment evaluated the residential scenario. Exposure point concentrations (EPCs) of site contaminants were estimated using maximum measured concentrations in soil. Using these EPCs, the cumulative health risk calculation resulted in a cancer risk of 1.6×10^{-4} and a hazard quotient greater than 1.

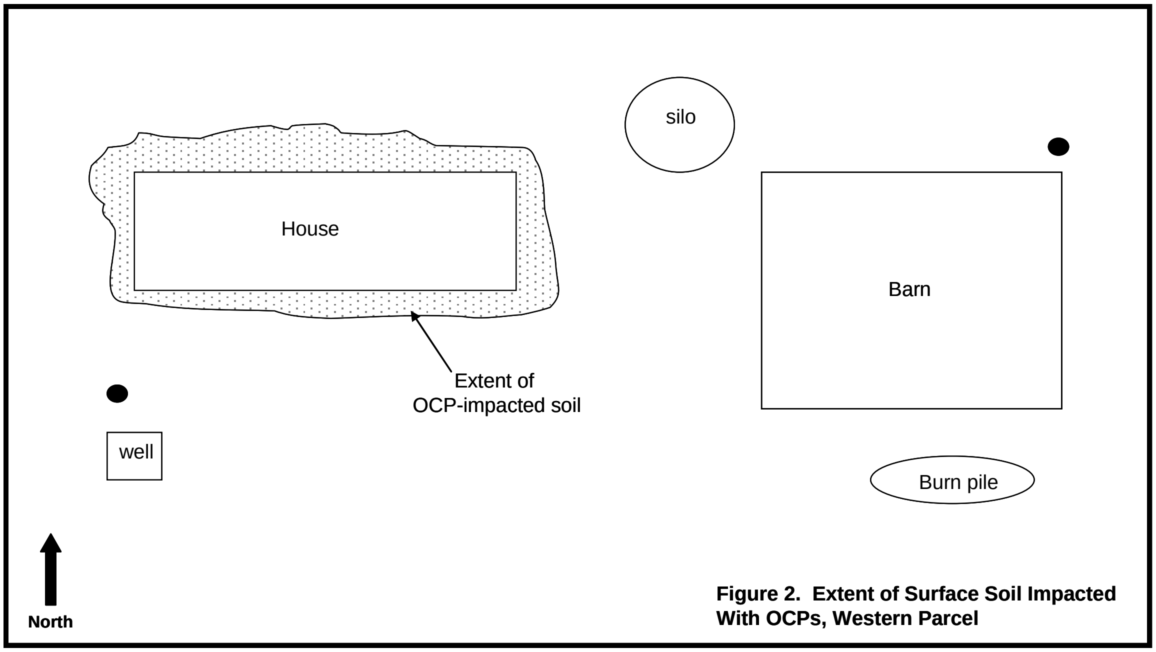


Figure 2. Extent of Surface Soil Impacted With OCPs, Western Parcel

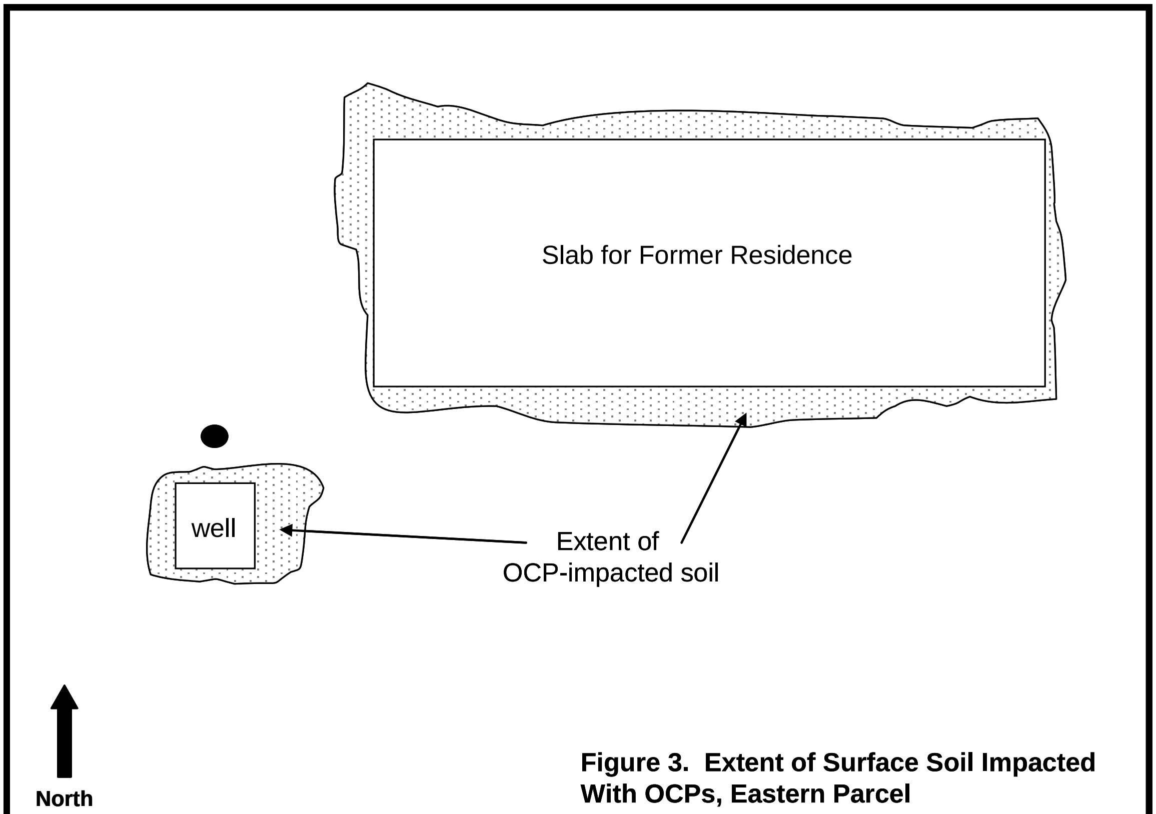


Figure 3. Extent of Surface Soil Impacted With OCPs, Eastern Parcel

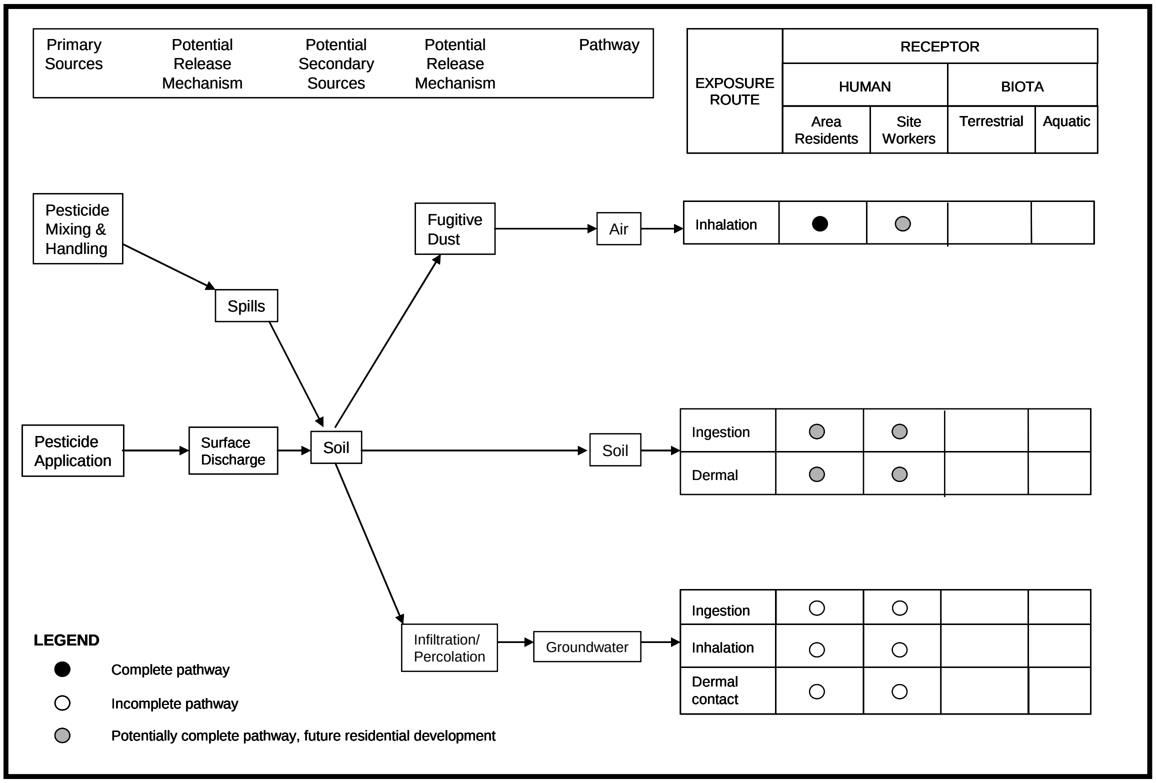
Ecological Risk

Based on a field summary by a qualified biologist, the potential risk to ecological receptors is considered to be limited because of the low quality habitat at and near the site.

Conclusions

OCPs are present in surface soil surrounding the houses and the well house in the eastern parcel at concentrations posing an unacceptable risk for unrestricted residential land use. Potential remedies for reducing or preventing potential exposure to OCPs by the ingestion, dermal contact, and inhalation pathways include soil excavation or paving around the building foundations.

EXAMPLE PATHWAY-EXPOSURE CSM



APPENDIX B

SUPPORTING DOCUMENTATION FOR DTSC TECHNOLOGY SCREENING

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Table B-1 Cleanup Options Selected and Characteristics of Sites Evaluated by DTSC Study

DTSC Site Type (No. of Sites)	Cleanup Option Selected (Number of Sites)							
	IC Only	Consolidate & IC	Excavate & Off-site Reuse	Capping & IC	CAMU & IC	Excavation & Off-site Disposal	Thermal / Chemical Treatment & Disposal/ Reuse	In situ Bioremediation
Schools Properties (31)	1	0	1	0	0	29	0	0
Military Facility (16*)	3	0	0	2	3	10	1	0
Voluntary Cleanup (20*)	1	2	1	4	0	7	2	4
State Response/ NPL (13*)	0	2	0	4	0	10	1	0

Total number of sites represented: 80

Cubic Yards of Impacted Soil (No. of Sites)	Cleanup Option Selected (Number of Sites)							
	IC Only	Consolidate & IC	Excavate & Off-site Reuse	Capping & IC	CAMU & IC	Excavation & Off-site Disposal	Thermal / Chemical Treatment & Disposal/ Reuse	In situ Bioremediation
≤ 100 (4)	0	0	0	0	1	3	0	0
>100, ≤ 1000 (23*)	0	0	0	0	1	23	1	0
>1000, ≤ 10,000 (23*)	0	0	0	3	0	18	1	1
> 10,000 (20*)	0	4	2	7	2	10	2	1

Total number of sites represented: 70 (volume of impacted soil not available for all 80 sites)

Maximum Depth of Impacted Soil (No. of Sites)	Cleanup Option Selected (Number of Sites)							
	IC Only	Consolidate & IC	Excavate & Off-site Reuse	Capping & IC	CAMU & IC	Excavation & Off-site Disposal	Thermal / Chemical Treatment & Disposal/ Reuse	In situ Bioremediation
≤2 feet (23*)	2	2	1	2	1	13	0	3
>2, ≤5 feet (18*)	0	1	1	2	0	14	0	1
>5, ≤10 feet (12*)	0	1	0	1	2	13	2	0
> 10 feet (5*)	0	0	0	2	0	3	2	0

Total number of sites represented: 58 (maximum depth of impact not available for all 80 sites)

Table B-1 (Continued)

OCPs Present	Cleanup Option Selected (Number of Sites)							
	IC Only	Consolidate & IC	Excavate & Off-site Reuse	Capping & IC	CAMU & IC	Excavation & Off-site Disposal	Thermal / Chemical Treatment & Disposal/ Reuse	In situ Bioremediation
DDD/DDE/DDT	3	4	2	9	1	37	4	3
Chlordane	3	0	1	2	2	37	2	2
Dieldrin	0	1	0	5	2	32	2	2
Toxaphene	1	2	1	3	0	10	3	2
Other	0	1	0	2	2	16	2	1

Total number of sites represented: 80

Other Contaminants Present	Cleanup Option Selected (Number of Sites)							
	IC Only	Consolidate & IC	Excavate & Off-site Reuse	Capping & IC	CAMU & IC	Excavation & Off-site Disposal	Thermal / Chemical Treatment & Disposal/ Reuse	In situ Bioremediation
Metals	4	2	2	3	1	39	1	1
VOCs	0	0	1	2	1	11	1	0
SVOCs, PAHs, PCBs, dioxins	2	2	1	3	1	12	2	0
TPH, BTEX	1	1	0	1	0	10	0	1
Other pesticides	0	0	0	0	0	1	1	0
None reported	0	2	0	4	2	9	2	3

Total number of sites represented: 73 (information on other contaminants not available for all 80 sites)

Notes:
*Some sites selected multiple cleanup options. Hence, this number is not simply the sum of values listed in this row.

BTEX – benzene, toluene, ethylbenzene, xylenes
CAMU – corrective action management unit
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
IC – institutional control
NPL – National Priorities List
OCP – organochlorine pesticide
PAHs – polynuclear aromatic hydrocarbons
PCBs – polychlorinated biphenyls
SVOCs – semivolatile organic compounds
TPH – total petroleum hydrocarbons
VOCs – volatile organic compounds

Table B-2 Technologies Applicable at Sites with OCPs in Soil

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
Ex Situ Technologies				
Isolation (Excavation & disposal, consolidation & capping)	Impacted soil is isolated beneath an engineered cap or within an engineered disposal unit (e.g., landfill, CAMU).	• Applicable to a wide variety of soils and immobile contaminants.	• Long-term maintenance. • Land-use restrictions. • May not be protective if groundwater is shallow.	
Incineration	High temperatures (870-1,200 °C) are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	• Able to treat high concentrations of organic compounds.	• Limited number of commercial incinerators. • Cost to transport soil to off-site incinerator. • High cost and energy usage. • Feed size and materials handling issues can impact applicability or cost. • Off gases and combustion residuals generally require treatment. • May not meet destruction/ removal efficiency requirements.	2
Gas Phase Chemical Reduction (GPCR)	Hydrogen reacts with chlorinated organic compounds at high temperatures ($\geq$850°C) and low pressure. By-products include methane, hydrogen chloride, and small amounts of low molecular weight hydrocarbons (e.g., benzene).	• Capable of treating high concentrations of DDT and hexachlorobenzene.	• High power requirements. • Requires pre-treatment by thermal desorption. • Solid residues require disposal. • Used liquor requires treatment and disposal. • Some uncertainty as to whether emissions contain dioxins/furans.	1, 3
Pyrolysis	Induces chemical decomposition of organic materials via heat in absence of oxygen. Operates under pressure at temperature of 430°C (800°F). Organic materials transformed into gases, small quantities of liquid and solid residue.	• Can be used to treat pesticides.	• Requires drying of the soil prior to treatment to achieve low soil moisture content (<1%). • Specific feed size and materials handling requirements that impact applicability or cost at specific sites. • High moisture content increases treatment costs.	2, 3

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
Ex Situ Technologies (Continued)				
Mechanochemical Dehalogenation (MCD™)	Mechanical energy (ball mill) is used to promote reductive dehalogenation of OCPs. Contaminants react with a base metal and hydrogen donor to generate reduced organics and metal salts. Produces nonhazardous by-products. Multistep process involving excavation, soil drying (<2% moisture), treatment of gaseous emissions, soil screening, and the MCD™ process.	• Able to treat high concentrations of aldrin, dieldrin, DDT/DDD/DDE, lindane. • Soils with low clay content. • Amenable to small-scale applications.	• Limited experience and vendors. • Experience to-date suggests that soil composition (especially clays) affects process performance. • Capture and treatment of residuals (volatilized contaminants captured, dust, and other condensates) may be difficult, especially when the soil contains high levels of fines and moisture. • Multi-step process.	1, 2, 3
Anaerobic Bioremediation	Promotes degradation of toxaphene in soil by native anaerobic organisms through biostimulation with biological amendments (e.g., blood meal, phosphates). Homogenized soil is transferred to a lined cell and covered with water and a plastic sheet to promote anaerobic conditions.	• Relatively low toxaphene concentrations. • Soil texture appropriate for incorporating amendments. • Presence of active toxaphene-degrading bacteria.	• Requires bench-scale test to determine applicability and to estimate treatment duration. • Space requirements for treatment cells. • May require odor mitigation. • Treatment time can range from five weeks to two years. • Not appropriate for extremely cold climates. • Does not achieve more than 90 percent contaminant reduction. Leaves residual concentrations of toxaphene and camphenes. • Debris potentially contaminated with toxaphene will require testing to determine appropriate disposal.	1, 3

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
Ex Situ Technologies (Continued)				
Xenorem™	Uses an enhanced composting technology consisting of organic amendments and aerobic and anaerobic treatment cycles. Complex, multi-step process involving soil excavation, screening, mixing, and amendment followed by cyclical amendment and mixing.	• Relatively low concentrations of chlordane, DDT, dieldrin, and toxaphene.	• Requires bench-scale studies to determine length of anaerobic phase. • Limited experience with method. • In one application, unable to meet cleanup standards for OCPs after a year of treatment. • Organic amendment applications last about 14 weeks. • Amendments can increase final soil volume by up to 40%.	1, 3
In Situ or Ex Situ Technologies				
GeoMelt™	Uses heat to destroy persistent organic compounds or permanently immobilize them into a vitrified end product. Typically requires excavation, pretreatment, mixing, feeding, melting, and vitrification. Commercially available as both fixed and transportable units.	• Low to high concentrations of dieldrin, chlordane, heptachlor, DDT, and hexachlorobenzene. • Relatively low moisture content soils.	• High power usage. • By-products include solid residues, scrubbing liquors, carbon filters, and gas emissions. • Vitrified waste-filled refractory container disposed at an appropriate landfill.	1, 3
DARAMEND®	Three-step bioremediation technology that promotes degradation of toxaphene and DDT through amendment-enhanced treatment and sequential anoxic and oxic conditions. Reagents include DARAMEND® organic amendment, zero valent iron, and water. Uses land farming practices in two-foot treatment layer. On-going maintenance and number of treatment cycles will vary by site and soil type.	• Relatively low concentrations of DDT and toxaphene. • Soil texture appropriate for incorporating amendments and periodic tilling.	• Typically requires bench-scale or pilot-scale studies • May be technically or economically infeasible at high contaminant concentrations. • For ex situ applications, space requirements for treatment cells. • May require screening to remove debris from soil. • Management of soil moisture content to facilitate biological activity while minimizing leachate production. • High humic content may slow down cleanup via increased organic adsorption and oxygen demand.	1, 3

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
In Situ Technologies				
Bioremediation	Nutrients and proprietary soil amendments are used to stimulate existing or added bacteria in the soil to metabolize OCPs into salt, carbon dioxide and water. On-going maintenance and number of treatment cycles will vary by site and soil type.	• Applicable to most soils and low to moderate concentrations of some OCPs. • Soil texture appropriate for incorporating amendments and periodic tilling. • Presence of appropriate indigenous bacteria.	• Similar to DARAMEND® • Cool temperatures may inhibit biodegradation rates.	4
Chemical Oxidation	Oxidants are used to chemically convert OCPs to non-hazardous or less toxic. Rate and extent of OCP degradation 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.	• Potentially capable of achieving high treatment efficiencies. • More commonly applied to groundwater contamination.	• OCPs are considered reluctant to recalcitrant compounds for treatment via chemical oxidation. • Intermediate reaction products for OCPs not fully understood. • Health and safety concerns with handling strong oxidants, generation of off-gas, heat, dust, and creating flammable conditions. • May not be cost effective if large oxidant quantities are required. • Mobilization of contaminants and oxidation byproducts to groundwater may be a concern for some sites. • 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).	5, 6

Table B-2 (Continued)

TECHNOLOGY	DESCRIPTION	APPLICABILITY	LIMITATIONS / CONSTRAINTS	REF.
In Situ Technologies				
Isolation by Capping	Impacted soils are isolated by placement of a low permeability barrier to surface water infiltration.	• Applicable to most soils and OCPs. • Frequently used to address impacted soils in industrial areas.	• Long-term maintenance. • Land-use restrictions. • May not be protective if groundwater is shallow.	

Notes:
CAMU corrective action management unit
DDD dichlorodiphenyldichloroethane
DDE dichlorodiphenyldichloroethylene
DDT dichlorodiphenyltrichloroethane
OCP organochlorine pesticide

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Table B-3 Evaluation of Technologies Applicable to Sites With OCPs in Soil Against NCP Analysis Criteria

Technology	NCP Criteria						
	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability	Cost[1]
Institutional Controls	**Manages potential exposure by restricting access and future land use.**	May not comply with ARARs.	Uncertain because does not remove 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 OCP removal from site.	Requires compliance with applicable state and federal 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 off-site management choices.	Requires standard precautions necessary for protection of human health and environment during excavation, transport, and disposal. Requires dust control.	Easy to implement if facility available with adequate capacity for waste type is located within a reasonable distance from site. Uses standard construction equipment and labor.	Usually reasonable for small to medium volumes of soil. May be **cost** prohibitive for large volumes.
Containment by Capping	Protectiveness is achieved by barriers that prevent dermal contact and/or ingestion. Protectiveness of groundwater depends on depth to water, OCP mobility, cap design.	Requires compliance with applicable state and federal waste disposal requirements. **On-site containment requires institutional controls.**	Long-term protection ensured through continued cap maintenance and institutional controls. Long term effectiveness for ecological/ human health risks and groundwater are contingent on cap design.	Not a treatment alternative. However, some OCPs may degrade over time without specific treatment.	Requires standard precautions for protection of human health and environment. Requires dust control if soil is excavated and consolidate beneath cap.	Commercially available. Demonstrated technology. Necessary materials easily attainable. Uses standard construction equipment and labor. Technically and administratively feasible.	May be **cost** prohibitive though generally less expensive than most forms of treatment.
Vitrification ▪ GeoMelt™	Protectiveness achieved by destroying OCPs or by immobilizing OCPs in a solid block of glass-like material.	Treatment may require location- or action-specific ARARs. Generation of off-gas may trigger chemical-specific ARARs.	Limited data on long-term effectiveness of immobilized OCPs. High long-term effectiveness if able to destroy OCP.	Reduces toxicity and mobility by destroying or immobilizing OCPs. Generally decreases volume.	Presents potential short-term risks from air release during excavation for ex situ treatments and on-site treatment units.	Requires **multiple treatment steps** and pilot testing. In situ methods still in demonstration phase. Limited commercial availability. Requires substantial energy source.	Typically higher **cost** than other cleanup alternatives.

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH ARARS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST[1]
Thermal Destruction or Treatment ▪ Incineration ▪ GPCR ▪ Pyrolysis	Protectiveness is achieved by inducing temperature and chemical conditions that destroy, transform, or decompose OCPs to less toxic byproducts.	Requires compliance with applicable state and federal requirements for waste excavation, transportation, treatment, storage, disposal and air quality.	Thermal treatments offer a long-term solution by destroying OCPs or transforming OCPs to less toxic byproducts.	Contaminant toxicity, volume and mobility is reduced through destruction, or transformation of OCPs to non-hazards by-products (gaseous, solid residues, liquors).	Potential short-term risks from air release during excavation for ex situ treatments and on-site treatment units. Potential short-term risks from handling and transporting waste for off-site treatments. Relatively short timeframe to achieve cleanup levels.	**May require treatability studies. Some treatments have commercially available treatment units for on-site use. Construction and/or permit requirements for onsite treatment units may be difficult. Limited off-site incineration capacity.**	Relatively higher cost than other types of treatment.
Mechanochemical Dehalogenation	Protectiveness is achieved by reductive dechlorination of OCPs using mechanical energy, a catalyst, and a hydrogen donor to produce non-hazardous by-products.	Requires compliance with applicable state and federal hazardous waste treatment, storage, and disposal requirements. Excavation, construction, and operation of on-site treatment units may require compliance with location-specific ARARs. Emission controls may be needed to ensure compliance with air quality standards.	Limited data on effectiveness of process.	Permanently transforms OCPs to less toxic by-products.	Presents potential short-term risks from air release during excavation for ex situ treatments and on-site treatment units. Relatively short timeframe to achieve cleanups.	Requires **multiple treatment steps** and bench scale testing. Limited commercial availability.	Typically higher **costs** than other cleanup alternatives.

Table B-3 (Continued)

TECHNOLOGY	NCP CRITERIA						
	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	COMPLIANCE WITH ARARS	LONG-TERM EFFECTIVENESS	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST[1]
Biological Treatment	Protectiveness is achieved by microbial transformation of OCPs to less toxic by-products under controlled or managed environmental conditions.	Requires compliance with applicable state and federal hazardous waste treatment, storage, and disposal requirements. Excavation, construction, and operation of on-site treatment units may require compliance with location-specific ARARs. Emission controls may be needed to ensure compliance with air quality standards.	Permanently destroys target OCPs. Reduces contaminant levels. Duration of treatment determines final contaminant levels. Reduces overall toxicity between pre- and post-treatment.	Reduces toxicity, mobility, and volume of soil contaminated with OCPs through treatment.	Manage fugitive dust emissions during soil excavation or landfarming activities. Requires measures for protection of human health during excavation, handling, and treatment. **Cleanup times** vary based on whether in situ or ex situ treatment is used and the ability to maintain optimal environmental conditions. Ex situ treatment times are faster. In situ treatment times vary with on ability to control environmental conditions conducive to OCP degradation.	Treatment techniques are established and require moderate effort to implement. Commercial additives and treatment units available. **Assess applicability through bench and treatability studies.** Ex situ methods may have multi-stage process and require treatment unit. In situ methods use landfarming techniques.	Costs vary based on applied technology and duration of treatment. In situ treatments generally cost less than ex situ treatments.
In Situ Chemical Oxidation	Protectiveness achieved by transforming OCPs to less toxic by-products and achieving target cleanup levels. Potential for mobilization to groundwater.	Requires compliance with applicable state and federal requirements for treatment process.	Permanently destroys OCPs, if successful. Uncertain effectiveness for some OCPs.	If successful, reduces toxicity, mobility, and volume of soil contaminated with OCPs. Uncertainty in type and persistence of reaction intermediates.	Requires precautions for protection of human health and environment during treatment process (e.g., reagent handling). Cleanup times vary based on oxidant effectiveness and control of environmental conditions that affect reaction.	Assess applicability through bench scale and treatability studies. May require permit for treatment process. Ability to achieve geochemical conditions needed for treatment.	Costs vary depending on volume and type of reactant needed.

Table B-3 (Continued)

Notes:

Bold indicates major reason(s) rejected during alternatives analysis for sites evaluated by DTSC study (see Table 3 of main text of this guidance).

ARAR – applicable or relevant and appropriate requirement
GPCR – gas phase chemical reduction
NCP – National Contingency Plan
OCP – organochlorine pesticide

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APPENDIX C

CASE HISTORIES OF *IN SITU* BIOREMEDIATION OF OCPs IN SOIL

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PREFACE

The DTSC study (see Appendix B) identified several projects for which *in situ* bioremediation was used to cleanup low to moderate concentrations of OCPs in shallow soils. Although insufficient performance data are available to identify *in situ* bioremediation as a proven technology, *in situ* bioremediation may be a viable, cost effective technology for some sites. Hence, this appendix provides case histories of select DTSC projects that used *in situ* bioremediation.

CASE HISTORY 1:
IN SITU BIOREMEDIATION OF ORGANOCHLORINE PESTICIDES

SITE INFORMATION

Site Name: Borello Property

Site Description: The Borello Property is a 14-acre vacant lot which used was as an orchard for approximately 100 years. The property was rezoned for residential use. Every surface sample and more than half of the deeper samples (to depths of 1.5 feet bgs) exceeded residential levels for toxaphene and dieldrin (up to 6.2 and 0.4 milligrams per kilogram [mg/kg], respectively). Table 1 summarizes the concentrations of OCPs prior to treatment. Figure 3 shows the sample locations.

BIOREMEDIATION PROCESS

Soil Amendment: The Gene Expression Factor (the Factor) is a soil amendment which helps the existing bacteria in the soil to metabolize the pesticides into salt, carbon dioxide and water. The Factor is a proprietary soil amendment consisting of a synthesized protein genetically similar to the DNA of a specific bacteria living within the soil at the site. The protein within the Factor is similar to the protein originally destroyed by the pesticides, thus genetically inhibiting the indigenous bacteria from metabolizing pesticides. The Factor restores the indigenous bacteria back to their near original condition, enabling the bacteria to metabolize the pesticides into inert substances.

Bench Scale Testing: The Factor used at the Borello Property was analytically determined by a series of microbiological and biochemical experiments conducted on soil from the Borello Property. The experiments identified the indigenous bacteria responsible for breaking down the OCPs as *Xanthomonas* and *Actinomycetes.*

Treatability Study: A treatability study (conducted by Terrasearch, Inc. and Resource Technologies Environmental) was used to determine whether the Factor would be effective in helping the indigenous bacteria to breakdown the OCPs. The study was also used to evaluate the appropriate quantity of nutrients (nitrogen and phosphorus).

Once the baseline laboratory results were obtained and evaluated for the appropriate quantity of nutrients (nitrogen and phosphorous), the area was deep ripped and roto-tilled with the ashes of the former orchard. The maximum depth of tilling was at least 1.5 feet. Once the areas were deep tilled with the ashes and nutrients, the Factor was applied to the soil in Grid 9 on October 25, 2004. The soil was mixed four times and kept moist by irrigating two to three times per week.

On November 9, 2004, six soil samples were collected (9A-0.5; 9A-1; 9A-2; 9B-0.5; 9B-1 and 9B-2) at two random locations within Sample Grid 9. At each location, soil samples were collected at 0.5, 1.0, and 2.0 ft bgs and analyzed for total OCPs. Four of the soil samples (collected at 1 and 2 ft bgs) were analyzed for pH. The laboratory analytical results of the soil samples indicated a substantial decrease in toxaphene, dieldrin, DDT and DDE concentrations compared with the original laboratory results from Grid 9 (Table 2). The laboratory results indicated that toxaphene had biodegraded to below detection limits and dieldrin concentrations decreased by 50 percent in the 0.5-ft sample.

Full-Scale Remediation: Approximately three tons of cow manure, one ton of lime, and 4,200 gallons of nitrogen fertilizer were mixed into the top two feet of soil in May 2005. These soil amendments were added to enhance bacterial growth and the property was irrigated at least four times a week. In June 2005, the Factor was added to the soil using a farm hopper. The hopper evenly spread and mixed the Factor to a depth of approximately 18-inches over the entire property. Irrigation activities continued through July 2005.

On July 27, 2005, confirmation borings CB-1 through CB-25 (near the original boring locations advanced in March 2004) were collected to a depth of approximately 2 ft bgs. The confirmation boring locations are shown on Figure 3. At each location, soil samples were collected from four depth intervals (0.5, 1, 1.5, and 2 ft bgs). The shallowest sample interval (0.5 ft bgs) from each location was analyzed for OCPs while the deeper samples were placed on hold pending the laboratory analytical results of the shallow samples.

The laboratory analytical results of confirmation soil samples are shown on Table 3. With a few exceptions, OCPs were not detected (i.e., concentrations were less than 1 to 50 micrograms per kilogram [µg/kg]). Toxaphene, DDT, and DDE were detected in a single sample, but were not detected by the duplicate sample. Dieldrin was detected in five samples at concentrations ranging from 1.2 to 1.8 µg/kg. Because all concentrations were below the remedial goal, no contingent sample intervals were analyzed.

Five additional soil samples (B1-1; B2-0.5; B3-1; B4-0.5; B5-0.5) were collected for bacterial plate counting on August 18, 2005. Laboratory analytical results of the heterotrophic plate count analysis determined that the bacterial populations have declined to background levels ranging from 87,000 to 160,000 cell function units per gram of soil (CFU/g).

On September 7, 2005, DTSC approved the Completion Report for the Borello Property. DTSC concluded that the site had been remediated to unrestricted residential levels.

Project Cost: This remediation process was designed to be delivered as a low cost on site in-situ remediation option. Use of the Factor to break down the OCPs cost approximately $471,530.

Timeframe: The site was cleaned up in approximately one month.

CONSIDERATIONS WHEN APPLYING THE FACTOR

Bench Scale Study Needed. The applicability of the Factor for remediation of OCPs must be determined on a site-by-site basis. A bench scale study should be used to determine whether soil conditions are conducive for use of the Factor. Examples of limiting factors include OCP concentrations that inhibit microbial activity, regions of consistent low temperatures, water availability, and the presence of organic carbon.

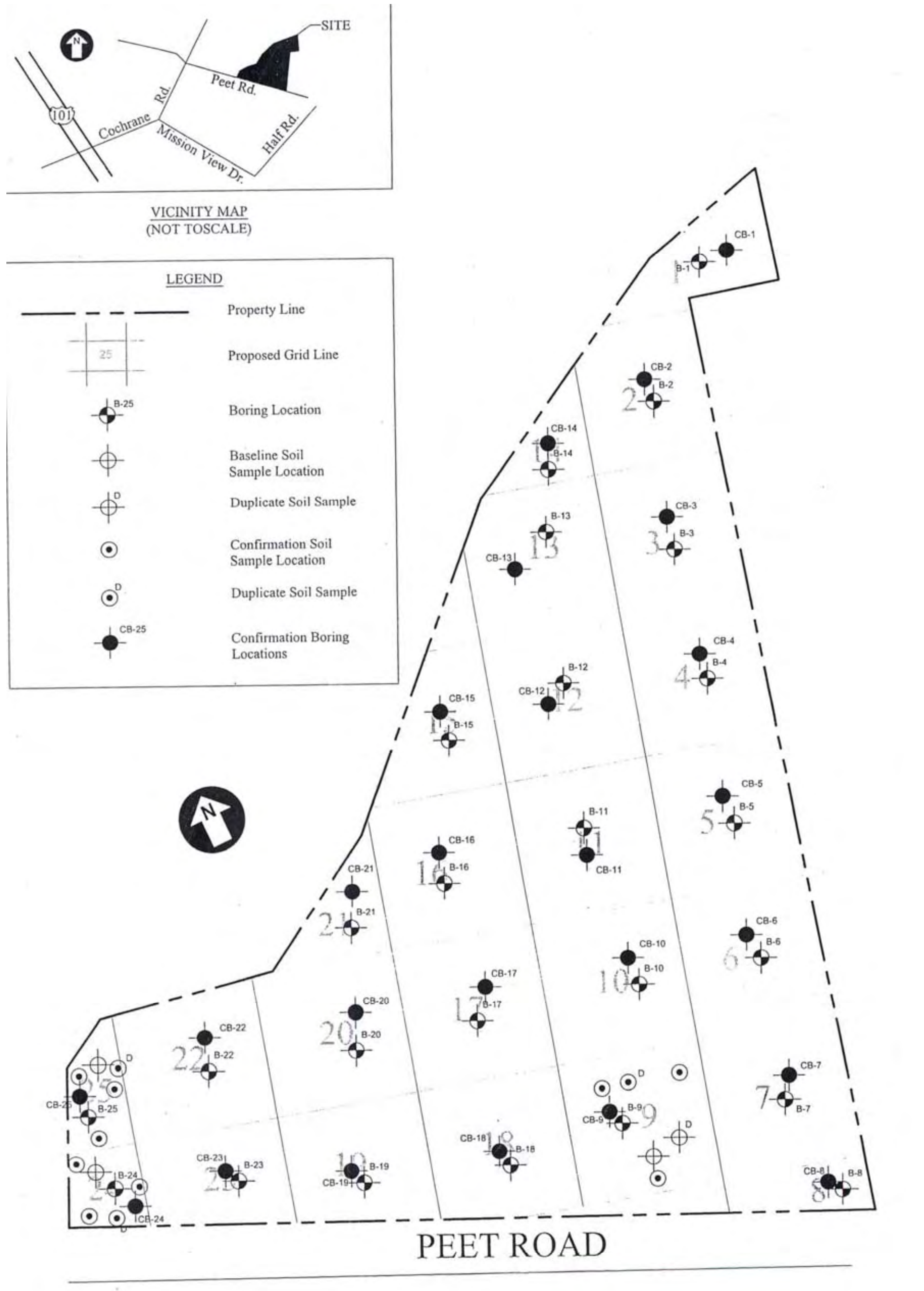
Training and Equipment. While the nature of some contaminants and the presence of other pollutants may require application by a trained and certified applicator, under normal circumstances a successful treatment can be achieved by any applicator with a working knowledge of spreader calibration and dry product soil applications and a tractor with equipment sufficient to incorporate the product at depths of up to 24 to 36 inches.

Incorporation into Soil. Incorporation of the Factor is an essential element of a successful treatment. It must be well incorporated into the target soil or the treatment will not be successful. Multiple passes with a plows, discs, tillers or other equipment will ensure adequate incorporation and contact between the indigenous microbial population with the Factor.

REFERENCES

Terrasearch, Inc. 2005. Removal Action Workplan at Borello Property, Cochran and Peet Roads, Morgan Hill, California. June 20.

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.



Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

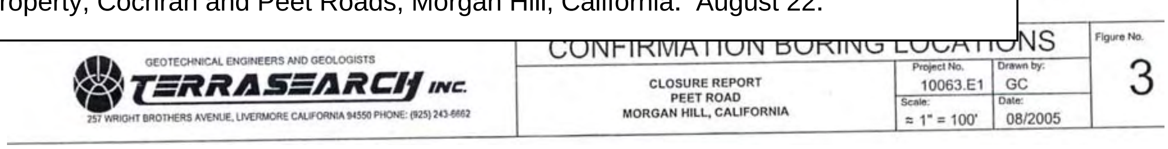


TABLE 1
RESULTS OF BASELINE SOIL SAMPLES

Sample ID	Depth (feet)	Toxaphene (μg/kg)	DDT (μg/kg)	DDE (μg/kg)	DDD (μg/kg)	Endosulfan II (μg/kg)	γ-Chlordane (μg/kg)	α-Chlordane (μg/kg)	Dieldrin (μg/kg)
B1-0.5	0.5	**1,600**	**100**	**310**	<20	<20	<20	<20	**58**
B2-0.5	0.5	**1,800**	**39**	**350**	**34**	**20**	**27**	<20	**120**
B3-0.5	0.5	**1,700**	**110**	**450**	**25**	**22**	<20	<20	**80**
B4-0.5	0.5	**1,600**	**100**	**400**	**24**	**21**	<20	<20	**90**
B5-0.5	0.5	**2,100**	**160**	**580**	**28**	**23**	<20	<20	**160**
B6-0.5	0.5	**2,200**	**150**	**560**	**26**	**25**	<20	<20	**190**
B7-0.5	0.5	**1,200**	**80**	**260**	<20	**22**	<20	<20	**62**
B8-0.5	0.5	**1,200**	**66**	**270**	<20	<20	<20	<20	**72**
B9-0.5	0.5	**1,300**	**63**	**240**	<20	<20	<20	<20	**130**
B10-0.5	0.5	**2,500**	**100**	**620**	**38**	**23**	<20	<20	**370**
B11-0.5	0.5	**1,800**	**120**	**420**	**25**	**24**	<20	<20	**120**
B12-0.5	0.5	**1,900**	**120**	**500**	**26**	**22**	<20	<20	**80**
B13-0.5	0.5	**2,100**	**140**	**470**	**20**	**25**	<20	<20	**97**
B14-0.5	0.5	**1,800**	**75**	**220**	**22**	**22**	<20	<20	**41**
B15-0.5	0.5	**1,500**	**91**	**300**	**23**	**21**	**20**	<20	**52**
B16-0.5	0.5	**2,600**	**190**	**610**	**37**	**30**	**28**	<20	**170**
B17-0.5	0.5	**2,000**	**140**	**540**	**28**	**25**	<20	<20	**150**
B18-0.5	0.5	**1,500**	**75**	**340**	**21**	**23**	<20	<20	**130**
B19-0.5	0.5	**1,800**	**110**	**390**	**21**	<20	<20	<20	**160**
B20-0.5	0.5	**2,200**	**180**	**600**	**32**	**26**	<20	<20	**140**
B21-0.5	0.5	**1,900**	**93**	**460**	**25**	<20	**27**	<20	**110**
B22-0.5	0.5	**2,100**	**120**	**450**	**<20**	**23**	**39**	**54**	**140**
B23-0.5	0.5	**1,700**	**120**	**330**	**24**	<20	**21**	<20	**80**
B24-0.5	0.5	**6,200**	**270**	**980**	<100	<100	**150**	**200**	**400**
B25-0.5	0.5	**2,100**	**170**	**360**	**25**	**24**	**28**	<20	**140**
PRGs[1]	--	*440*	*1,700*	*1,700*	*2,000*	*370,000*	*1,600*	*1,600*	*30*
CHHSL[2]		*460*	*2,300*	*1,600*	*1,600*	*n/a*	*430*	*430*	*460*

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

TABLE 1 (Continued)

Sample ID	Depth (feet)	Toxaphene (μg/kg)	DDT (μg/kg)	DDE (μg/kg)	DDD (μg/kg)	Endosulfan II (μg/kg)	γ-Chlordane (μg/kg)	α-Chlordane (μg/kg)	Endrin (μg/kg)	Dieldrin (μg/kg)
B1-1.0	1.0	<1,000	<20	**39**	<20	<20	<20	<20	<20	**28**
B2-1.0	1.0	**1,300**	**63**	**230**	<20	<20	**20**	**26**	<20	**60**
B3-1.0	0.5	<100	<2	**5.9**	<2	<2	<2	<2	<2	<2
B4-1.0	0.5	<100	**3.5**	**11**	<2	<2	<2	<2	<2	**2.9**
B5-1.0	1.0	<1,000	**30**	**200**	<20	<20	<20	<20	<20	**74**
B6-1.0	1.0	<1,000	<20	**46**	<20	<20	<20	<20	<20	<20
B7-1.0	1.0	<1,000	**52**	**170**	<20	<20	<20	<20	<20	**55**
B8-1.0	1.0	**1,600**	**54**	**450**	28	<20	<20	<20	**25**	**100**
B9-1.0	1.0	**2,800**	**210**	**610**	<20	**22**	<20	<20	**21**	**360**
B10-1.0	1.0	<1,000	**56**	**120**	<20	<20	<20	<20	<20	**73**
B11-1.0	1.0	**2,200**	**75**	**470**	**37**	**24**	<20	**21**	**22**	**180**
B12-1.0	1.0	**2,300**	**110**	**490**	**35**	<20	**27**	**34**	<20	**100**
B13-1.0	1.0	**2,800**	**110**	**380**	**51**	**21**	**59**	**78**	**37**	**250**
B14-1.0	1.0	<1,000	**30**	**81**	<20	<20	<20	<20	<20	**46**
B15-1.0	1.0	<1,000	<20	**42**	<20	<20	<20	<20	<20	<20
B16-1.0	1.0	**130**	**5.9**	**15**	<2	<2	<2	<2	<2	**17**
B17-1.0	1.0	<1,000	<20	**43**	<20	<20	<20	<20	<20	<20
B18-1.0	1.0	<500	**10**	**30**	<10	<10	<10	<10	<10	**11**
B19-1.0	1.0	<500	<10	**16**	<10	<10	<10	<10	<10	<10
B20-1.0	1.0	**910**	**69**	**200**	<10	**10**	<10	**15**	<10	**100**
B21-1.0	1.0	<500	<10	**13**	<10	<10	<10	<10	<10	**23**
B22-1.0	1.0	<500	<10	**24**	<10	<10	<10	<10	<10	<10
B23-1.0	1.0	**1,100**	**97**	**250**	<10	**13**	**17**	**28**	<10	**87**
B24-1.0	1.0	**1,100**	**73**	**220**	<10	**10**	**29**	**42**	<10	**87**
B25-1.0	1.0	<1,00	<2	**3.7**	<2	<2	<2	<2	<2	<2
PRGs[1]	---	*440*	*1,700*	*1,700*	*2,400*	*370,000*	*1,600*	*1,600*	*18,000*	*30*
CHHSSL[2]		*460*	*2,300*	*1,600*	*1,600*	*n/a*	*430*	*430*	*460*	

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

TABLE 1 (Continued)

Sample ID	Depth (feet)	Toxaphene (µg/kg)	DDT (µg/kg)	DDE (µg/kg)	DDD (µg/kg)	Endosulfan II (µg/kg)	γ-Chlordane (µg/kg)	α-Chlordane (µg/kg)	Endrin (µg/kg)	Dieldrin (µg/kg)
B2-1.5	1.5	<500	**19**	**45**	<10	**10**	<10	<10	<10	**19**
B5-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B7-1.5	1.5	<500	**10**	**20**	<10	<10	<10	<10	<10	<10
B8-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B9-1.5	1.5	**1,900**	**180**	**290**	<10	<10	**11**	<10	**36**	**270**
B10-1.5	1.5	**3,200**	**450**	**800**	**54**	**55**	<50	<50	**96**	**490**
B11-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B12-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B13-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	**24**
B14-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B20-1.5	1.5	<500	<10	**14**	<10	<10	<10	<10	<10	**12**
B23-1.5	1.5	<500	**11**	**16**	<10	<10	<10	<10	<10	<10
B24-1.5	1.5	<500	<10	<10	<10	<10	<10	<10	<10	<10
B9-2.0	2.0	<100	**3.4**	**6.7**	<2	<2	<2	<2	<2	**12**
B10-2.0	2.0	<100	**3.8**	**11**	<2	<2	<2	<2	<2	**4.5**
PRGs[1]	--	*440*	*1,700*	*1,700*	*2,000*	*370,000*	*1,600*	*1,600*	*18,000*	*30*
CHHSSL[2]		*460*	*2,300*	*1,600*	*1,600*	*n/a*	*430*	*430*	*460*	

DDT = 1,1,1-trichloro-2,2-bis-(p-chlorophenyl)ethane using USEPA Method 8080.
DDE = 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene using USEPA Method SW846 8080.
mg/kg = Milligrams per kilogram, equivalent to parts per million (ppm).
µg/kg = Micrograms per kilogram, equivalent to parts per billion (ppb).
< = Less than laboratory detection limit.
1 = USEPA Region IX Preliminary Remediation Goals, October 2004.
2 = California Human Health Soil Screening Levels

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

TABLE 2
TREATABILITY STUDY RESULTS (GRID 9)
March 25, 2004 and November 9, 2004

Sample ID	Depth (feet)	Toxaphene (μg/kg)	DDT (μg/kg)	DDE (μg/kg)	DDD (μg/kg)	Endosulfan II (μg/kg)	γ-Chlordane (μg/kg)	α-Chlordane (μg/kg)	Dieldrin (μg/kg)
B9-0.5	0.5	**1,300**	**63**	**240**	<20	<20	<20	<20	**130**
B9-1.0	1.0	**2,800**	**210**	**610**	<20	**22**	<20	<20	**21**
B9-1.5	1.5	**1,900**	**180**	**290**	<10	<10	**11**	<10	**36**
9A-0.5	0.5	<500	**33**	**120**	<10	<10	<10	<10	**49**
9A-1	1	<500	<2	**3.7**	<2	<2	<2	<2	<2
9A-2	2	<500	**23**	**84**	<10	<10	<10	<10	**33**
9B-0.5	0.5	<500	**33**	**110**	<10	<10	<10	<10	**55**
9B-1	1	<500	<2	**4.5**	<2	<2	<2	<2	**2.7**
9B-2	2	<500	**3.8**	**10**	<2	<2	<2	<2	**5**
PRGs[1]		*440*	*1,700*	*1,700*	*2,000*	*370,000*	*1,600*	*1,600*	*30*
CHHSL[2]		*460*	*2,300*	*1,600*	*1,600*	*n/a*	*430*	*430*	*460*

DDT = 1,1,1-trichloro-2,2-bis-(p-chlorophenyl)ethane using USEPA Method 8080.
DDE = 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene using USEPA Method SW846 8080.
μg/kg = Micrograms per kilogram, equivalent to parts per billion (ppb).
< = Less than laboratory detection limit.
1 = USEPA Region IX Preliminary Remediation Goals, October 2004.
2 = California Human Health Soil Screening Levels
Samples collected in March 2004 are designated as B9 and samples collected in November 2004 are designated 9A and 9B

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

TABLE 3
CONFIRMATION SOIL SAMPLE RESULTS
July 25, 2005

Sample ID	Depth (feet)	Toxaphene (μg/kg)	DDT (μg/kg)	DDE (μg/kg)	DDD (μg/kg)	Endosulfan II (μg/kg)	γ-Chlordane (μg/kg)	α-Chlordane (μg/kg)	Dieldrin (μg/kg)
CB1-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB2-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB3-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB4-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	**1.3**
DCB4-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB5-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB6-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
DCB6-0.5	0.5	**130**	**9.4**	**38**	<1	<1	<1	<1	***73***
CB7-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB8-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB9-05	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB10-05	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB11-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB12-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	**1.2**
CB13-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	**1.4**
CB14-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
DCB14-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB15-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB16-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
DCB16-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB17-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB18-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB19-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB20-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB21-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	**1.8**
CB22-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB23-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB24-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
CB25-0.5	0.5	<50	<1	<1	<1	<1	<1	<1	<1
Average	---	***52.7***	***1.28***	***2.27***	***<1***	***<1***	***<1***	***<1***	***3.54***
PRGs	---	*400**	*1,700*	*1,700*	*2,000*	*370,000*	*1,600*	*1,600*	*25**

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

TABLE 3 (Continued)

Sample ID	Depth (feet)	Toxaphene (µg/kg)	DDT (µg/kg)	DDE (µg/kg)	DDD (µg/kg)	Endosulfan II (µg/kg)	γ-Chlordane (µg/kg)	α-Chlordane (µg/kg)	Dieldrin (µg/kg)
CB1-1	1	<50	<1	<1	<1	<1	<1	<1	<1
DCB1-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB2-1	1	<50	<1	<1	<1	<1	<1	<1	<1
DCB2-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB5-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB7-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB8-1	1	<50	<1	<1	<1	<1	<1	<1	<1
DCB8-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB9-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB10-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB11-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB12-1	1	<50	<1	<1	<1	<1	<1	<1	**1.4**
CB13-1	1	<50	<1	<1	<1	<1	<1	<1	<1
DCB13-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB14-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB18-1	1	<50	<1	<1	<1	<1	<1	<1	<1
DCB18-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB20-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB23-1	1	<50	<1	<1	<1	<1	<1	<1	<1
CB24-1	1	<50	<1	<1	<1	<1	<1	<1	<1
Average	---	***<50***	***<1***	***<1***	***<1***	***<1***	***<1***	***<1***	**1.02**
PRGs[1]	---	*400**	*1,700*	*1,700*	*2,400*	*370,000*	*1,600*	*1,600*	*25**

Sample ID	Depth (feet)	Toxaphene (µg/kg)	DDT (µg/kg)	DDE (µg/kg)	DDD (µg/kg)	Endosulfan II (µg/kg)	γ-Chlordane (µg/kg)	α-Chlordane (µg/kg)	Dieldrin (µg/kg)
CB9-1.5	1.5	<50	<1	<1	<1	<1	<1	<1	<1
CB10-1.5	1.5	<50	<1	<1	<1	<1	<1	<1	<1
Average	---	***<50***	***<1***	***<1***	***<1***	***<1***	***<1***	***<1***	**<1**
PRGs[1]	---	*400**	*1,700*	*1,700*	*2,000*	*370,000*	*1,600*	*1,600*	*25**

DDT = 1,1,1-trichloro-2,2-bis-(p-chlorophenyl)ethane using USEPA Method 8080.
DDE = 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene using USEPA Method SW846 8080.
mg/kg = Milligrams per kilogram, equivalent to parts per million (ppm).
µg/kg = Micrograms per kilogram, equivalent to parts per billion (ppb).
< = Less than laboratory detection limit.
CB6-0.5 = Confirmation soil sample.
DCB6-0.5= Duplicate confirmation soil sample.
PRGs = USEPA Region IX Preliminary Remediation Goals, October 15, 2004.
* = Site Specific PEA Remediation Goals determined in the RAW.

Terrasearch, Inc. 2005. Closure Report for Bio-Remediation Activities at Borello Property, Cochran and Peet Roads, Morgan Hill, California. August 22.

CASE HISTORY 2:
IN SITU BIOREMEDIATION OF ORGANOCHLORINE PESTICIDES

SITE INFORMATION

Site Name: Mantegani Property

Site Description: The Mantegani property is a 0.8-acre vacant lot used as a nursery from 1931 to 1987. The site location is shown on Figure 1. The site was planned to be developed for residential use. Site investigations identified elevated concentrations of DDT and dieldrin in the upper two feet of soil across the property, corresponding to about 2,200 cubic yards of OCP-impacted soil. The highest DDT and dieldrin concentrations were 7.6 and 0.97 milligrams per kilogram (mg/kg), respectively. The initial cleanup goals for DDT and dieldrin were 1.39 and 0.025 mg/kg, respectively. Table 1 summarizes the concentrations of the OCPs prior to treatment. Figure 2 shows the pre-treatment sampling locations.

BIOREMEDIATION PROCESS

Soil Amendment: The Gene Expression Factor was used. See description provided in Case History #1.

Bench Scale Testing: A 12 week bench-test, conducted on soil collected from the site, was completed in September 2005. Analyses were performed to identify the most effective Factor for bioremediating the property. The analytical results showed that the Factor was effective in reducing the concentrations of dieldrin and DDT. All bench test samples with pesticide detections greater than the residential cleanup levels at the beginning of the bench test were reduced to levels below the residential cleanup levels after the twelve week run was completed. The indigenous bacteria responsible for breaking down the dieldrin and DDT at this site include *Xanthomonas* and *Actinomycetes*.

Full-Scale Remediation: On May 12, 2006, four two-ton bags of the Factor blended with approximately 15 tons of cow manure, two tons of lime, and 0.25 tons of urea nitrogen were mixed into the upper two feet of soil using a tractor equipped with rippers and discs. The Factor was thoroughly mixed into the subgrade soil and irrigated. The soil was ripped and blended weekly from May 12, 2006 until July 15, 2006 with weekly irrigation to ensure adequate moisture within the sub-grade soil. From June through October 2006, soil samples were collected from the surficial soil for OCP and pH analysis to evaluate remedial performance.

<u>Evaluation of Remediation Performance</u>

On June 12 and July 12, 2006, surface soil samples were collected at various locations to monitor and evaluate pesticide destruction rates. Figure 2 illustrates the progress of OCP degradation. As shown in the figure, degradation of DDT proceeded rapidly (approximately 95% of the DDT degradation occurred during the first two months). Degradation of dieldrin took longer (approximately 60% destruction after two months, 73% destruction after 2.5 months).

Soil pH measurements collected with the June and July samples indicated that the soil pH levels were borderline for maintaining efficient bioremediation. On August 7, 2006, 500 pounds of lime and 250 pounds of urea were applied to the site in an effort to increase pH within the soil and add nutrients to the soil. The soil was turned and disked and allowed to set for two weeks with periodic irrigation.

Additional sampling conducted on August 25 and 30, 2006, determined that approximately 96% of the DDT and 73% of dieldrin had been degraded. All OCP constituent concentrations were below their Preliminary Remediation Goals (PRGs) except for dieldrin. Soil sampling conducted in September and October had results similar to those reported in August.

On December 6, 2006, approximately 50 pounds of sodium bicarbonate was applied to the surface soil at the site. Natural infiltration of the dissolved sodium bicarbonate (rather than mixing lime into the soil) was thought to immediately increase the soil pH beneath the site.

Confirmation Sampling

On December 20, 2006 and January 4, 2007, confirmation soil samples (CF13-1 through CF28-1) were collected from random locations and analyzed for OCPs and pH. The confirmation sample locations are shown on Figure 3 and the sampling results are shown on Table 3. The laboratory analytical results indicated DDT concentrations ranging from <1 to 260 µg/kg and dieldrin concentrations ranging from <1 to 170 µg/kg). All OCP constituent concentrations were detected below their PRGs with the exception of dieldrin. The confirmation data suggested 97% destruction of DDT and 82% destruction of dieldrin since May 2006.

Final Outcome. Bioremediation using the Factor effectively neutralized OCPs, with the exception of dieldrin. However, dieldrin was reduced from a concentration of 970 to 170 µg/kg, and indicated a final site-averaged dieldrin concentration of 55 µg/kg. The *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 1994) risk calculations were used to evaluate the residual concentrations of dieldrin in soil. These calculations indicate that the 95 percent upper confidence limit (UCL) of the mean residual dieldrin concentration (0.129 mg/kg) equals an approximate soil risk of $5x10^{-6}$. Although the calculated risk level associated with the residual dieldrin concentrations is above the original cleanup goal target of $1x10^{-6}$, there is sufficient uncertainty in the risk assessment process to make distinguishing between the target level and the calculated levels unrealistic. Therefore, DTSC agreed to revise the site cleanup goal to 0.129 mg/kg.

Treatment of Dieldrin. Multiple applications of lime were required to buffer the pH in the soil and assist the facultative bacteria in reducing dieldrin concentrations across the site. The inability to decrease dieldrin concentrations to below 25 µg/kg was most likely due to the lower temperatures in South San Francisco, higher chlorination of dieldrin relative to DDT, and generally lower pH of the soil. Higher soil temperatures in the spring and summer months were expected to continue reducing the residual dieldrin levels to the initial cleanup goal.

Project Cost: This remediation process was designed to be delivered as a low cost on site in-situ remediation option. Use of the Factor to break down the OCPs cost approximately $114,900.

Timeframe: The Factor effectively treated DDT after one month of application. Additional time was required to treat dieldrin.

REFERENCES

Terrasearch, Inc. 2006. Removal Action Workplan at Mantegani Property, 735 Commercial Avenue, South San Francisco, California. February 1.

Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California. January 30.

TABLE 1
LABORATORY ANALYSIS OF SURFICIAL SOIL SAMPLES FOR ORGANOCHLORINE PESTICIDES BEFORE TREATMENT
MANTEGANI PROPERTY, SOUTH SAN FRANCISCO, CALIFORNIA
May 17, 2005

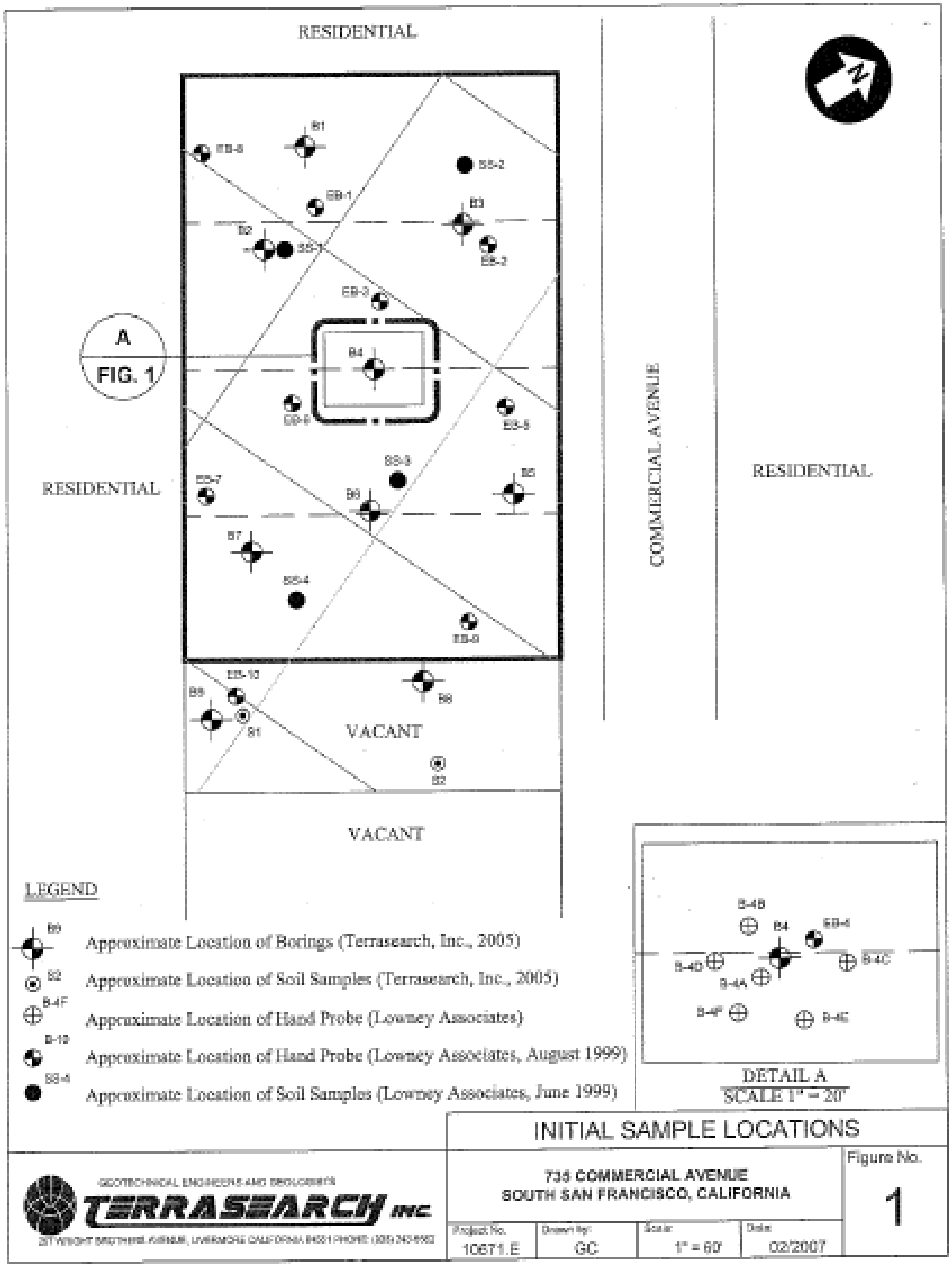
Sample ID	Depth (feet)	Toxaphene (µg/Kg)	DDT (µg/Kg)	DDE (µg/Kg)	DDD (µg/Kg)	Endosulfan II (µg/Kg)	γ-Chlordane (µg/Kg)	α-Chlordane (µg/Kg)	Dieldrin (µg/Kg)
B1-1	1	<200	5,500	1,100	<5	<5	62	63	820
B1-2	2	<200	88	38	<5	<5	<10	<10	34
B2-1	1	<200	7,600	1,200	260	<5	85	92	970
B2-2	2	<200	21	9.2	<5	<5	<10	<10	<5
B3-1	1	<200	200	88	22	<5	61	73	55
B3-2	2	<200	13	14	<5	<5	19	19	<5
B4-1	1	<200	2,500	900	430	<5	35	38	430
B4-2	2	<200	<5	5.4	<5	<5	<10	<10	<5
B5-1	1	<200	1,300	780	270	<5	41	45	680
B5-2	2	<200	5.8	22	6.7	<5	<10	<10	15
B6-1	1	<200	49	92	35	<5	<10	<10	81
B6-2	2	<200	8.8	29	11	<5	<10	<10	13
B7-1	1	<200	1,400	720	270	<5	<10	<10	530
B7-2	2	<200	110	330	56	<5	<10	<10	22
B8-1	1	<200	74	90	38	<5	<10	<10	50
B8-2	2	<200	380	240	260	<5	13	18	230
B9-1	1	<200	56	45	16	<5	260	280	200
B9-2	2	<200	2,200	920	580	<5	32	32	890
S1	0.5	<200	16	38	26	<5	<10	10	25
S2	0.5	<200	<5	7.4	6.5	<5	<10	<10	8.2
Average		<200	1,076	333	114.56	<5	30.4	33.5	252.66
Cleanup Goal		400	1,700	1,700	2,000	370,000	1,600	1,600	25

Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California, January 30.

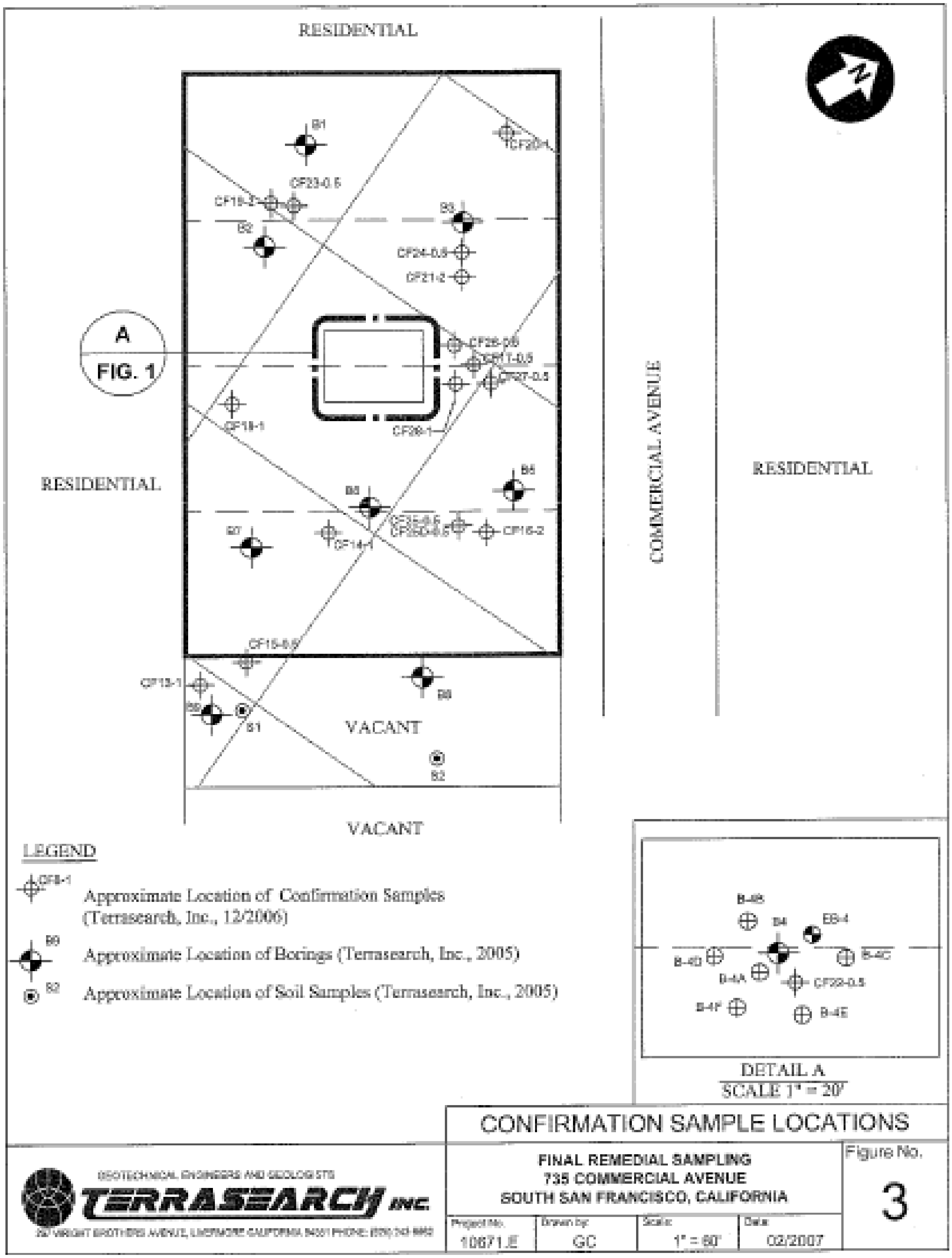
TABLE 2
LABORATORY ANALYSIS OF SURFICIAL SOIL SAMPLES FOR ORGANOCHLORINE PESTICIDES AFTER TREATMENT
MANTEGANI PROPERTY, SOUTH SAN FRANCISCO, CALIFORNIA
December 2006 and January 2007

Sample ID	Depth (feet)	Toxaphene (µg/Kg)	DDT (µg/Kg)	DDE (µg/Kg)	DDD (µg/Kg)	Endosulfan II (µg/Kg)	γ-Chlordane (µg/Kg)	α-Chlordane (µg/Kg)	Dieldrin (µg/Kg)
CF13-1	1	<250	99	37	<5	<5	<5	<5	<5
CF14-1	1	<250	<5	43	<5	<5	<5	<5	<5
CF15-0.5	0.5	<100	6	6.5	<2	<2	<2	<2	<2
CF16-2	2	<50	<1	<1	<1	<1	<1	<1	<1
CF17-0.5	0.5	<250	260	190	<5	<5	<5	18	170
CF18-1	1	<50	1.4	3.2	<1	<1	<1	<1	<1
CF19-2	2	<50	<1	<1	<1	<1	<1	<1	<1
CF19D-2	2	<50	2.2	2.5	<1	<1	<1	<1	<1
CF20-1	1	<50	4.8	<1	<1	<1	<1	<1	<1
CF21-2	2	<50	<1	<1	<1	<1	<1	<1	<1
CS21D-2	2	<50	<1	1.8	<1	<1	<1	<1	<1
CF22-0.5	0.5	<250	180	100	<5	<5	<5	8.6	<5
CF23-0.5	0.5	<1000	240	150	<20	<20	<20	<20	160
CF24-0.5	0.5	<500	99	68	<10	<10	<10	<10	88
CF25-0.5	0.5	<2500	<50	73	<50	<50	<50	<50	160
CF25D-0.5	0.5	<1000	77	60	<20	<20	<20	<20	150
CF26-0.5	0.5	<1000	180	110	<20	<20	<20	<20	110
CF27-0.5	0.5	<1000	99	89	<20	<20	<20	<20	110
CF28-1	1	<1000	97	80	<20	<20	<20	<20	78
Average		<497	71	53	<9.9	<9.9	<9.9	10.8	55
Cleanup Goal		400	1,700	1,700	2,000	370,000	1,600	1,600	25

Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California, January 30.



Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California, January 30.



Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California, January 30.

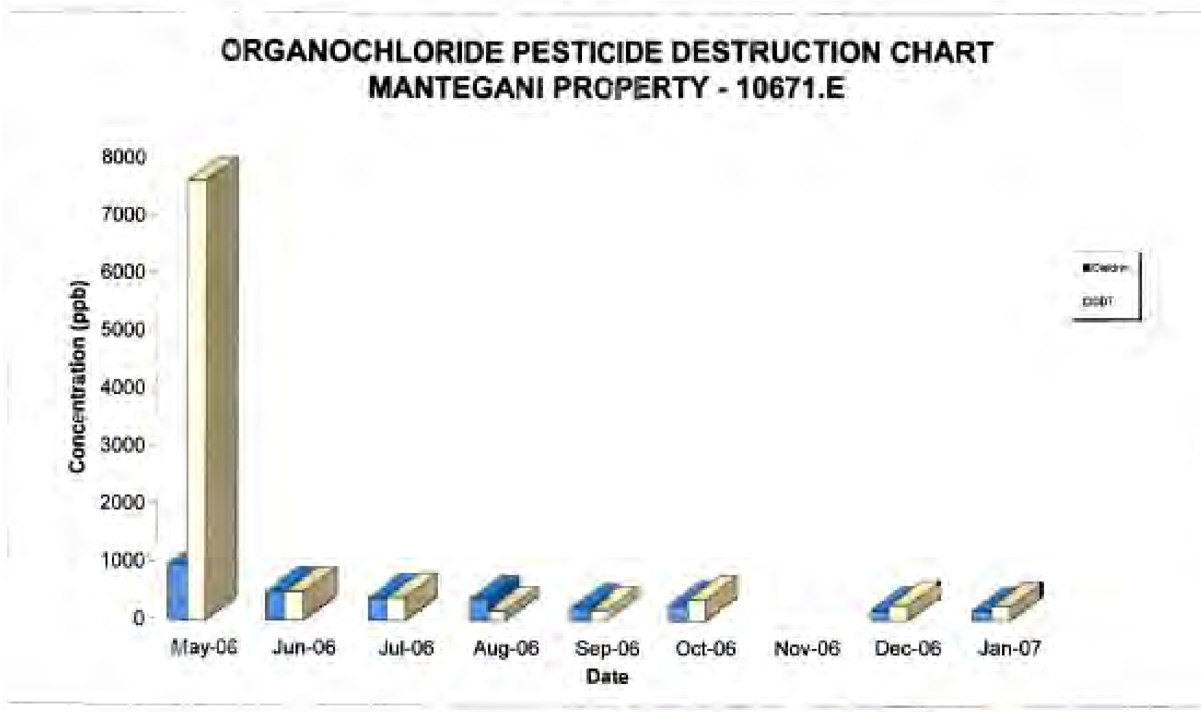


Figure 2. Progress of In situ Bioremediation Technology During Full Scale Operation

Terrasearch, Inc. 2007. Completion Report for Remedial Action, Mantegani Property, 735 Commercial Avenue, South San Francisco, California, January 30.

APPENDIX D

LINK TO ADDITIONAL RESOURCES

The following resources included in the *PT&R Guidance – Remediation of Metals in Soil* are also applicable to cleanup of sites with OCPs in soil.

Appendix A1	Conceptual Site Model
Appendix A2	Characterization Phase Workplan
Appendix A3	Annotated Outline for Site Characterization Report
Appendix C2	Remedial Action Plan Sample
Appendix C3	Removal Action Workplan Sample
Appendix C4	Scope of Work for Corrective Measures Study
Appendix C5	Scope of Work for Interim Measures
Appendix C6	Example for Statement of Basis
Appendix C7	Example for Bridging Memorandum
Appendix D1	Excavation, Disposal, and Restoration Plan Sample
Appendix D2	Transportation Plan
Appendix D3	Soil Confirmation Sampling Plan
Appendix D5	Annotated Outline for Excavation Completion Report
Appendix E1	Annotated Outline for Containment/Capping Design and Implementation Plan
Appendix E2	Operation and Maintenance Plan Sample
Appendix E3	Annotated Outline for Containment/Capping Completion Report
Appendix F1	Fact Sheet Sample
Appendix F2	Public Participation Sample Documents

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

Note: The appendix references refer to the location within *PT&R Guidance – Remediation of Metals in Soil* (DTSC, 2008b).

APPENDIX E

ADDITIONAL INFORMATION ABOUT TOXAPHENE

Toxaphene is a complex mixture of compounds and is estimated to contain about 800 congeners, including chlorinated bornane and chlorinated camphene compounds. Although banned for most uses in the United States since 1982, and all uses since 1990 (USEPA, 2005), toxaphene persists for years in the environment, undergoing environmental degradation or 'weathering' processes. The degradation / weathering processes produce various mixtures of toxaphene congeners which may differ from the parent compound.

Because these complex metabolized or weathered mixtures may differ from the parent compound in terms of composition and/or ratios of individual components (Lamb and Neal, 2008), there is a level of toxicological uncertainty as to the nature of the compound. Studies on weathered toxaphene congeners from soil showed that mutagenicity was less than that of the parent compound. Conversely, studies of metabolites from fish livers seem to imply that toxicity is similar to that of the parent compound and in some cases there may be some capacity for potentiation of specific toxaphene metabolites. (Young *et a*l., 2009).

For the purposes of characterizing toxaphene in soil, currently the USEPA Method 8081 (or equivalent) is recommended. The method quantifies toxaphene congeners by comparing chromatographic peaks from a technical toxaphene standard to those of the sample. However, the weathered or metabolic derivatives may not have the same composition or ratios of individual components as the parent compound, so results are relative 'estimates' of the original mixture.

USEPA is currently evaluating a proposed SW-846 method (Method 8276) to measure toxaphene and toxaphene congeners using gas chromatography / negative ion mass spectrometry (GC/NIMS). According to a presentation at the 2009 State and Federal Laboratories Conference (Sivertsen, 2009), the method is expected to be uploaded as a SW-846 determinative method for public use and comment in the near future.

REFERENCES

Lamb IV, J.C., B.H. Neal, and J.I. Good. 2008. Risk Assessment of Toxaphene and its Breakdown Products: Time for a Change? *Critical Reviews in Toxicology*, 38:805-815.

Sivertsen, S.K. 2009. A New SW-846 Method for the Analysis of Toxaphene and Toxaphene Congeners Using Gas Chromatography / Negative Ion Mass Spectrometry: Method Status. Presentation at the 2009 Region 4 State and EPA Environmental Laboratories Conference in Athens Georgia, October 6-7, 2009. www.epa.gov/Region4/sesd/training/statelabs/2009conference/Method-8276-for-Toxaphene-Congeners.pdf

USEPA. 2005. Ombudsman Report: More Information Is Needed On Toxaphene Degradation Products. Office of Inspector General. Report No 2008-00007. December 16.

USEPA. 2008. Method 8081B: Organochlorine Pesticides by Gas Chromatography. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. www.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/8081b.pdf

Young, J.C., A.D. Freeman, R.M. Bruce, D. Williams, and K. Maruya. 2009. Comparing the mutagenicity of toxaphene after aging in anoxic soils and accumulating in fish. Ecotoxicology and Environmental Safety. 72(1):162-72.