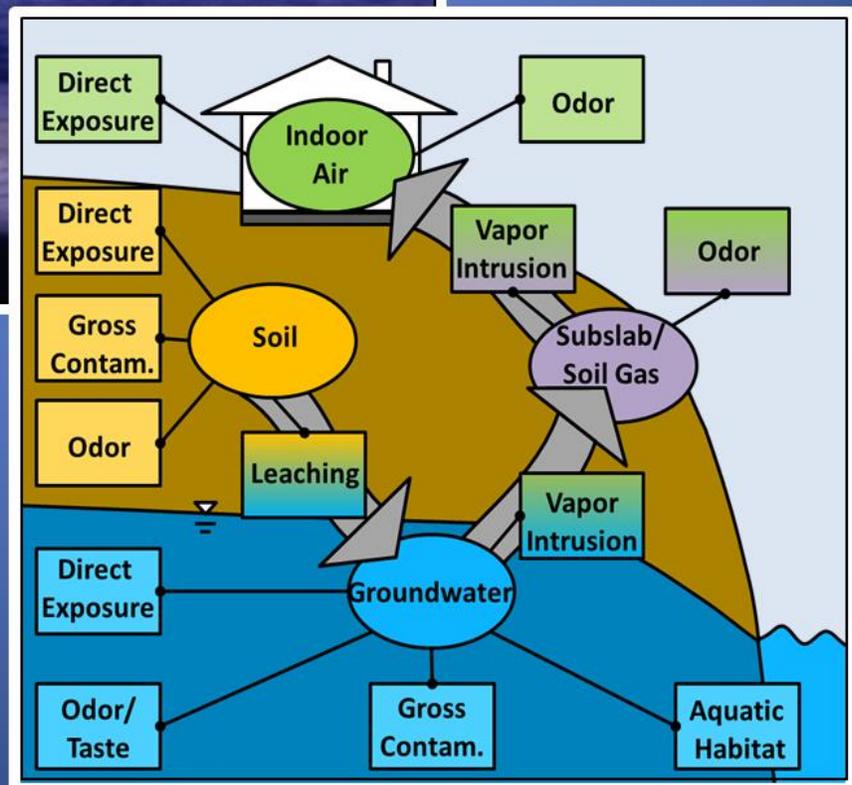
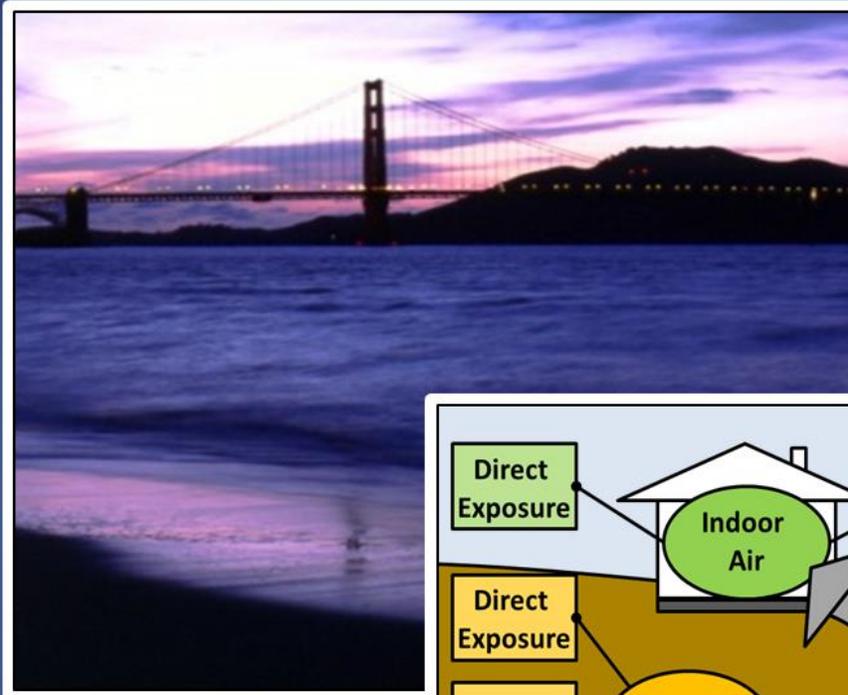


# User's Guide: Derivation and Application of Environmental Screening Levels (ESLs)

INTERIM FINAL 2016



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**DISCLAIMER**

This *User's Guide: Derivation and Application of Environmental Screening Levels* (2016) is a technical report prepared by staff of the California Regional Water Quality Board, San Francisco Bay Region (Regional Water Board staff). This User's Guide is not intended to establish policy or regulation. The Environmental Screening Levels (ESLs) presented in this User's Guide and the accompanying tables (Excel spreadsheets) are specifically not intended to serve as:

- a stand-alone decision making tool,
- guidance for the preparation of baseline environmental assessments,
- a rule to determine if a waste is hazardous under the state or federal regulations, or
- a rule to determine when the release of hazardous chemicals must be reported to the overseeing regulatory agency.

Also, in general, the ESLs are not used at sites that are subject to the *Low-Threat Underground Storage Tank Closure Policy* (State Water Board 2012b). They may be used at such sites to screen for constituents not already addressed by the Policy or as part of site-specific risk assessments for the media-specific criteria (e.g., Groundwater; Petroleum Vapor Intrusion to Indoor Air; and Direct Contact and Outdoor Air).

ESLs may not be adequately protective for some sites. For example, they should not be used at sites where physical conditions or exposure scenarios substantially differ from those assumed in development of the ESLs. In addition, the ESLs do not apply to sediment or sensitive ecological habitats (such as wetlands or endangered-species habitats). The need for a detailed human health or ecological risk assessment should be evaluated on a site-by-site basis for areas where significant concerns may exist.

Use of the ESLs by dischargers or regulators is optional. Dischargers seeking to use the ESLs at their sites should discuss this with the overseeing regulatory agency. The presence of a chemical at concentrations in excess of an ESL does not necessarily indicate adverse effects on human health or the environment, rather that additional evaluation is warranted. Use of the ESLs as cleanup goals should be evaluated in view of the overall site investigation results and the cost/benefit of performing a more site-specific evaluation. Lastly, the ESLs should not be used as criteria to determine when chemical concentrations at a site must be reported to a regulatory agency.

The information presented in this document is not final Board action. Regional Water Board staff reserves the right to change this information at any time without public notice. This document is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation in the State of California. Staff in overseeing regulatory agencies may decide to follow the information provided herein or act at a variance with the information, based on an analysis of site-specific circumstances.

This document will be periodically updated as needed. Regional Water Board staff overseeing work at a specific site should be contacted prior to use of this document in order to ensure that the document is applicable to the site and that the user has the most up-to-date version available. This document is not copyrighted. Copies may be freely made and distributed. Reference to the ESLs without adequate review of the User's Guide could result in misinterpretation and misuse of the ESLs.

# Executive Summary

The purpose of this document is to explain how the Environmental Screening Levels (ESLs) were derived and how they should (and should not) be used. The ESLs have four elements: (1) Microsoft Excel Workbook (all tables); (2) Summary ESL Tables (PDF); (3) User’s Guide; and (4) Frequently Asked Questions (FAQs).

The ESLs allow dischargers and regulators in our region to quickly focus on the most significant problems at contaminated sites. This can streamline the investigation and cleanup process. We have established ESLs for over 100 commonly-found contaminants, and the ESLs address a range of media and concerns commonly found at contaminated sites. Concerns addressed by the ESLs include:

Medium	Human Health	Drinking Water Resources (Current or Potential)	Aquatic Receptors (Discharges to Surface Water)	Source Control	Nuisance and Odors
Groundwater	Yes	Yes	Yes	Yes	Yes
Soil/ Soil Gas	Yes	Yes	Yes	Yes	Yes
Indoor Air	Yes	--	--	--	Yes

ESL users should be aware of site-specific circumstances before applying ESLs to any given site. This includes an understanding of current/future land use type, media affected by contamination, and site-specific factors (collectively, the conceptual site model). If used correctly, ESLs are considered to be protective for typical bay area sites. Under most circumstances, and within the limitations described in the disclaimer, the presence of a chemical in soil, soil gas, or groundwater at concentrations below the corresponding ESL can be assumed to not pose a significant threat to human health, water resources, or the environment. Additional evaluation will generally be necessary at sites where a chemical is present at concentrations above the corresponding ESL. The ESLs may be especially useful at sites where the preparation of a more formal environmental assessment may not be warranted or feasible due to time and cost constraints. The ESLs are “evergreen,” and are updated periodically. Users should use the current version of the ESLs that is posted at the Regional Water Board web site and identify the version for the record in all relevant communications.

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- F – Technical Resource Document: Fraction Approach to Develop ESLs for TPH Mixtures
- G – Technical Resource Document: Site-Specific Evaluation Approach for Petroleum Degradates

# 1 Introduction and Background

The Environmental Screening Levels (ESLs) are groundwater, soil, soil gas, and indoor air concentrations developed by San Francisco Bay Regional Water Quality Control Board (Regional Water Board) staff for over 100 chemicals that can be directly compared to environmental sample data collected at contaminated sites. The ESLs consist of the following:

1. ESL Workbook (Microsoft Excel 2010 Workbook);
2. Summary ESL Tables (PDF);
3. User’s Guide; and
4. Frequently Asked Questions (FAQs)

In addition, Table 1-1 lists associated, stand-alone technical resource documents that address specific topics that should be used in conjunction with the ESLs.

<b>Table 1-1 – Regional Water Board Technical Resource Documents for Use with the ESLs</b>	
<b>Year</b>	<b>Title</b>
1996	Supplemental Instructions to State Water Board December 8, 1995, Interim Guidance on Required Cleanup at Low Risk Fuel Sites
2006	Draft Technical Resource Document – Characterization and Reuse of Petroleum Hydrocarbon Impacted Soil as Inert Waste
2009	Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites
2014	Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region (TCE Framework)
2016a	Technical Resource Document: Default Subslab Soil Gas and Soil Gas to Indoor Air Attenuation Factors in the ESLs
2016b	Technical Resource Document: Fraction Approach to Develop ESLs for TPH Mixtures
2016c	Technical Resource Document: Site-Specific Evaluation Approach for Petroleum Degradates

The following are key aspects of the ESLs:

**The ESLs are intended to be a tool to screen or evaluate the threats posed by contamination at a site.**

Sites that are adequately characterized with data all below the ESLs, most likely do not pose a chemical threat. In some rare instances, there could be an exception resulting from cumulative risk where a large number of chemicals are detected, but the concentrations are just below the respective ESL (evaluation of cumulative risk is discussed in Chapter 3). For a site where chemical concentrations exceed the ESLs, the site may pose a chemical threat and require further investigation or evaluation to better assess the threat.

**The ESLs are intended to be conservative, but reasonable.**

The purpose of screening levels is to enable users to distinguish which sites pose a significant threat relatively quickly. In developing screening levels, there needs to be a balance between conservativeness and reasonableness so that low risk sites are screened out and sites with a significant threat are screened in. When developing screening levels from models, such as those used for human health risk criteria, if the most conservative value is used for every input parameter, the resulting screening level often will be overly conservative. This can cause sites that pose no significant threat to be screened in, requiring the expenditure of resources (time and money) by all stakeholders (regulatory, discharger, and others) to further assess the site. This is inefficient and problematic in that it diverts resources from sites with significant threats.

**The ESLs are a communication tool amongst the various stakeholders.**

Screening levels help dischargers, technical consultants, and stakeholders understand Regional Water Board staff expectations and approaches to evaluating contaminated sites. The ESLs are not default cleanup goals. Cleanup goals typically are chemical concentrations for a specific site that are agreed-upon through evaluation and discussions between the overseeing regulatory agency and dischargers considering site-specific conditions. For many sites, ESLs are selected as cleanup goals, but only after going through the process of evaluation and adoption. For initial site cleanup orders, the Regional Water Board typically uses the ESLs as preliminary cleanup goals until site-specific cleanup goals have been developed, often required by an order.

### **The ESLs save time and money.**

Preparation of quantitative environmental risk assessments for multiple pathways at contaminated sites requires a greater level of expertise and frequently requires a multi-disciplinary team (toxicologists or risk assessors, chemists, engineers, environmental scientists, and geologists). The costs for small businesses and property owners with limited financial resources can be cost-prohibitive. A Tier 2 risk evaluation can be developed relatively quickly with the ESLs.

### **The ESLs are a prioritization tool.**

Regional Water Board staff is required to prioritize our oversight of cases to maximize our protection of human health and the environment. The ESLs serve as an aid in assessing overall threat (pathways and threat level) allowing us to understand whether threats to human health or the environment are controlled. Then we can prioritize the investigation and cleanup needed to eliminate or control the threats posed by a site.

## **1.1 San Francisco Bay Basin Water Quality Control Plan (Basin Plan)**

The ESLs were ultimately developed to help the Regional Water Board staff regulate quality in the Region. By law, the Regional Water Board is required to develop, adopt (after public hearing), and implement a Water Quality Control Plan (Basin Plan) for the region (San Francisco Bay Region). The Basin Plan is the master policy document that contains descriptions of the legal, technical, and programmatic bases of water quality regulation in the region. The plan includes:

- A statement of beneficial water uses to be protected;
- The water quality objectives needed to protect the designated beneficial water uses; and
- The strategies and time schedules for achieving the water quality objectives.

The San Francisco Bay Region is 4,603 square miles, roughly the size of the State of Connecticut, and characterized by its dominant feature, 1,100 square miles of the 1,600 square mile San Francisco Bay Estuary (Estuary), the largest estuary on the west coast of the United States, where fresh waters from California's Central

Valley mix with the saline waters of the Pacific Ocean (Regional Water Board 2013).

Because of its highly dynamic and complex environmental conditions, the Bay system supports an extraordinarily diverse and productive ecosystem. Within each section of the Bay, there are deepwater areas adjacent to large expanses of very shallow water. Salinity levels range from hypersaline to fresh water, and water temperature varies throughout the Bay system. These factors greatly increase the number of species that can live in the Estuary and enhance its biological stability.

Groundwater is an important component of the hydrologic system in the Region. Groundwater provides excellent natural storage, distribution, and treatment systems. Groundwater also supplies high quality water for drinking, irrigation, and industrial processing and service. As an important source of freshwater replenishment, groundwater may also discharge to surface streams, wetlands, and San Francisco Bay. A variety of historical and ongoing industrial, urban, and agricultural activities and their associated discharges degrade groundwater quality. These adverse impacts on groundwater quality often have long-term effects that are costly to remediate. Consequently, as additional discharges are identified, source removal, pollution containment, and cleanup must be undertaken as quickly as possible. Activities that may potentially pollute groundwater must be managed to ensure that groundwater quality is protected.

The following sections introduce those components of the Basin Plan that guide the development of the ESLs, including the beneficial uses of surface water and groundwater, the environmental concerns in the Basin Plan, and the overarching approach to site investigation and cleanup presented in the Basin Plan for the various cleanup programs.

### **1.1.1 Beneficial Uses of Surface Water and Groundwater**

State policy for water quality control in California is directed toward achieving the highest water quality consistent with maximum benefit to the people of the state. Aquatic ecosystems and underground aquifers provide many different benefits to the people of the state. Beneficial uses define the resources, services, and qualities of the aquatic systems that should be protected by the Regional Water Board from pollution and nuisance that may occur as a result of waste discharges in the region. Beneficial uses of waters of the State serve as a basis for establishing water quality objectives and discharge prohibitions to attain these goals.

The beneficial uses drive two key water quality considerations in the ESLs:

1. **All Groundwater is Considered Suitable or Potentially Suitable for Municipal or Domestic Water Supply unless Designated Otherwise by the Regional Water Board** – The Basin Plan recognizes that site-specific factors, such as low yield or poor water quality, may render groundwater unsuitable for potential drinking water purposes (“non-potable” groundwater). These factors are described in State Water Resources Control Board (State Water Board) Resolution No. 88-63, Adoption of Policy Entitled “Sources of Drinking Water” (State Water Board 1988). In the ESL workbook, the Tier 2 ESLs include a toggle allowing the users to determine alternate screening criteria in these situations. A conclusion that groundwater is “non-potable” at a particular site must be based on site-specific data and must be approved by the overseeing regulatory agency.
2. **All Groundwater is Assumed to Ultimately Discharge to Surface Water and Potentially Affect Aquatic Organisms and Habitats** – This assumption can be overly conservative for sites far from surface water bodies. For such sites, an attenuation factor could be developed and applied to the aquatic ESLs for an individual site, although this would require concurrence from the overseeing regulatory agency (see Chapter 5 for further information). A conclusion that groundwater does not discharge to surface water should be based on site-specific data or information and should be agreed upon by the overseeing regulatory agency.

Soil and groundwater ESLs have therefore been developed to protect both drinking water resources and aquatic habitats.

### **1.1.2 Environmental Concerns in the Basin Plan**

Each ESL addresses the environmental concerns stated or implied in the Basin Plan. These concerns are presented in Table 1-2.

<b>Table 1-2 – Environmental Concerns Stated or Implied in the Basin Plan</b>					
Medium	Human Health Risk	Drinking Water Resources (Current or Potential)	Aquatic Receptors (Discharges to Surface Water)	Source Control	Odor Nuisance
Groundwater	Yes	Yes	Yes	Yes	Yes
Soil/ Soil Gas	Yes	Yes	Yes	Yes	Yes

### **1.1.3 Investigation and Cleanup of Discharges**

State Water Board Resolution No. 92-49, "Policies and Procedures for Investigation, Cleanup and Abatement of Discharges Under Water Code Section 13304" (Resolution 92-49; State Water Board 1992) contains the policies and procedures that all Water Boards shall follow to oversee and regulate investigations and cleanup and abatement activities resulting from all types of discharge or threat of discharge subject to Water Code Section 13304.

Resolution 92-49 outlines the basic elements of site investigations and cleanup of discharges. The five basic components of site investigation are:

- Preliminary site assessment to confirm the discharge/ identify the discharger; identify affected or threatened waters of the state and their beneficial uses; and develop preliminary information on the nature and horizontal and vertical extent of the discharge;
- Soil and water investigation to determine the source, nature, and extent of the discharge with sufficient detail to provide the basis for decisions regarding subsequent cleanup, if any are determined by the Regional Water Board to be necessary;
- Proposal and selection of cleanup action to evaluate feasible and effective cleanup and abatement actions and to develop preferred cleanup and abatement alternatives;
- Implementation of cleanup and abatement action to implement the selected alternative and to monitor in order to verify progress; and
- Monitoring to confirm short- and long-term effectiveness of cleanup and abatement.

Minimum cleanup and abatement methods include:

- Source removal and/or isolation;
- In-place treatment of soil or water, including bioremediation, aeration, and fixation;
- Excavation or extraction of soil, water, or gas for on-site or off-site treatment techniques including bioremediation; thermal destruction; aeration; sorption; precipitation, flocculation and sedimentation; filtration; fixation; and evaporation; and,
- Excavation or extraction

In addition, the Basin Plan recognizes that a deed restriction (land use covenant), which typically incorporates a risk management plan, may be required to facilitate the remediation of past environmental contamination and to protect human health and the environment by reducing the risk of exposure to residual hazardous materials. Water Code Section 13307.1 requires that deed restrictions be mandated for certain sites that are not cleaned up to “unrestricted use,” and that the restrictions be recorded and run with the land to prohibit sensitive uses such as homes, schools, or day care facilities.

## **1.2 Comparison of ESLs to Other Screening Levels and Criteria**

### **1.2.1 Other Screening Levels**

The ESLs address a greater range of media and concerns than do other commonly-used screening levels, and reflect the broader scope of environmental concerns outlined in the Basin Plan. Differences and similarities between the ESLs and other screening levels or other regulatory criteria are summarized in Table 1-3.

<b>Table 1-3 – Environmental Concerns in the ESLs versus Other Screening Levels</b>			
<b>Environmental Concern</b>	<b>ESLs</b>	<b>USEPA RSLs/VISLs</b>	<b>CalEPA CHHSLs</b>
<b>Groundwater</b>			
Direct Exposure (Ingestion, Inhalation, Dermal)	Yes	Yes/RSLs	Yes
Vapor Intrusion (Direct Exposure: Inhalation)	Yes	Yes/VISLs	no
Discharge to Surface Water (Aquatic Receptors)	Yes	no	no
Gross Contamination	Yes	no	no
Taste and Odor Nuisance	Yes	no	no
<b>Soil</b>			
Direct Exposure (Ingestion, Inhalation, Dermal)	Yes	Yes/RSLs	Yes
Leaching to Groundwater	Yes	Yes/RSLs	no
Gross Contamination	Yes	no	no
Odor Nuisance	Yes	no	no
<b>Soil Gas</b>			
Vapor Intrusion (Direct Exposure: Inhalation)	Yes	Yes/VISLs	Yes
Odor Nuisance	Yes	no	no
<b>Indoor Air</b>			
Direct Exposure (Inhalation)	Yes	Yes/RSLs and VISLs	Yes
Odor Nuisance	Yes	no	no

### **USEPA RSLs/VISLs**

The United States Environmental Protection Agency (USEPA) publishes Regional Screening Levels (RSLs; formerly known as Preliminary Remediation Goals or PRGs; USEPA 2015) about twice per year. The RSLs include generic tables of criteria and an online calculator that address human health concerns associated with direct exposure to chemicals. The direct exposure ESLs are calculated using the standard equations used for the RSLs, however some toxicity values and exposure factors inputs are different (see Chapter 3). Unlike the ESLs, RSLs do not address ecological, gross contamination, or odor nuisance

concerns. The USEPA also has a Vapor Intrusion Screening Level calculator (VISL; USEPA 2014) that calculates groundwater and soil gas (subslab and deeper or exterior soil gas) vapor intrusion screening levels using USEPA default attenuation factors.

### **CalEPA CHHSLs**

In 2004-2005, the Office of Environmental Health Hazard Assessment (OEHHA) developed the California Human Health Screening Levels (CHHSLs), which are concentrations of more than 50 contaminants commonly detected in soil, indoor air, and soil gas considered to be below thresholds of concern for risks to human health. The CHHSLs are listed in *Use of California Human Health Screening Levels in Evaluation of Contaminated Properties* (CalEPA 2005). The basis of their derivation is presented in *Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (OEHHA 2005). The CHHSLs do not address potential groundwater or surface water protection concerns and address only a portion of the human health concerns addressed by the ESLs. Because the CHHSLs do not address the full scope of potential environmental concerns, they should not be used as a stand-alone tool to evaluate contaminated sites. It is important to understand that for many chemicals, the need for remedial action may be based on environmental concerns other than direct exposures. In addition, DTSC no longer recommends the use of CHHSLs for screening-level human health risk evaluations because they are not routinely reviewed and revised as new scientific information becomes available (DTSC 2015).

## **1.2.2 Hazardous Waste Regulations and OSHA Standards**

The ESLs are not criteria to be used for determining how or where to dispose of waste soils or waters. California Code of Regulations Title 22, Section 66699 (Persistent and Bioaccumulative Toxic Waste) includes criteria that are used for classifying waste material for disposal in a Class I, II, or III landfill. These are the California Total Threshold Limit Concentrations (TTLC) criteria and Soluble Threshold Limit Concentration (STLC) criteria, which are used to compare laboratory analytical data from solid waste materials and solid waste materials subjected to the California Waste Extraction Test, respectively.

These criteria should not, in most cases, be used to screen soil and groundwater data or set cleanup goals. The criteria, developed in the 1980s, are only loosely based on human health and environmental considerations. Rather, these criteria define safe concentrations in a landfill where low pH conditions are likely to

exist that can increase mobilization of metals and other constituents. STLC values generally reflect drinking water or surface water goals of the time, and some are clearly out of date. TTLC values were derived by simply multiplying the STLC value by 10 for organic chemicals or 100 for metals. It is not anticipated that the TTLC and STLC values will be revised in the near future. In most cases, TTLC values exceed the most conservative (Tier 1) ESLs. However, in certain instances TTLC values may be less than risk-based ESLs.

### **1.2.3 OSHA Standards: Permissible Exposure Limits**

The National Institute for Occupational Safety and Health (NIOSH) is the Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury, including exposure to hazardous chemicals in air (NIOSH 2007). NIOSH develops and periodically revises Recommended Exposure Limits (RELs) for hazardous substances in the workplace. The RELs are used to promulgate Permissible Exposure Limits (PELs) under the Occupational Safety and Health Act (OSHA).

OSHA PELs are derived for an occupational setting, where the:

1. Chemical in question is used in the industrial process;
2. Workers and others who might be exposed to the chemical have knowledge of the chemical's presence;
3. Workers receive appropriate health and safety training; and
4. Workers may be provided with protective gear to minimize exposures.

The OSHA PELs are derived for adult, healthy workers and are not intended to protect children, pregnant women, the elderly, or people with compromised immune systems. OSHA recognizes that many of its PELs are outdated and inadequate for ensuring protection of worker health and is presently evaluating how to update them (United States Department of Labor – Occupational Safety & Health Administration 2016).

The question of applicability OSHA PELs versus ESLs typically arises when results of indoor air sampling indicate the presence of the same VOCs as detected in groundwater, soil, or soil gas at or near the site. In such a situation, whether such worker safety criteria or ESLs are applicable depends on the source of the VOCs detected in indoor air. If the source is from the business operation, the appropriate worker safety criteria apply. If the source is the subsurface, the ESLs apply. Distinguishing between sources can be challenging, but there are

various techniques that can be employed (e.g., comparison of chemical ratios in subsurface and indoor air samples, compound-specific isotopes, use of portable instruments such as gas chromatographs with mass spectrometry detector GC-MS, and continuous analyzers that are in development). More information on these techniques and references are presented in the *Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (TCE Framework; Regional Water Board 2014). As discussed in the TCE Framework, the Regional Water Board follows a stepwise approach in vapor intrusion investigations that starts with subsurface sampling first to determine whether there is a subsurface source of VOCs before moving to indoor air sampling.

DTSC and US EPA have taken similar positions on the use of PELs. The DTSC Vapor Intrusion Guidance (VIG; DTSC 2011) indicates that Occupational Safety and Health Act (OSHA) PELs are not appropriate exposure endpoints in occupational settings for indoor air degraded by subsurface contamination and includes a detailed discussion of the use of the PELs (VIG Appendix F). USEPA (2015) also does not recommend use of the PELs for purposes of assessing human health risk posed to workers.

Other aspects pertinent to the applicability of the PELs for a specific site include:

- OSHA PELs are not appropriate for health risk evaluations for commercial settings where the chemical is not currently being used as part of a regulated, industrial process. This includes sites affected by the migration of offsite releases.
- According to State Water Resources Control Board Resolution No. 92-49, Policies and Procedures for Investigation and Cleanup and Abatement of Discharges under Water Code Section 13304, the Regional Water Boards must set cleanup goals that protect the full range of people who might be exposed to contaminants in soil and groundwater, including sensitive receptors. This goes beyond adult, healthy workers for which OSHA limits are intended. OSHA limits are not intended to evaluate risks posed by involuntary exposures to the general public, where site residents and occupants generally do not expect to be exposed to chemicals from a vapor intrusion pathway, do not receive training on such exposure, and have no protective gear to minimize exposures. USEPA Region 9 (2014) has developed accelerated response action levels (ARALs) and urgent response action levels (URALs) for trichloroethene (TCE) in indoor air for the protection of women of child-bearing age in residential as well as commercial settings. Based on the acute nature of the potential effects of

exposure to TCE actions should be taken to reduce exposure to TCE exceeding the ARALs or URALs in weeks or days. This is discussed further in Chapter 4 and the TCE Framework. The ESLs provide a conservative screening level based on long term cancer risk, but do not inherently address the issue of acceptable response time.

### 1.3 Site Closure Evaluations: Use of the ESLs

While the protection of public health, safety, and the environment is our top priority in the Regional Water Board's site cleanup programs, moving sites towards and achieving regulatory site closure (aka no further action or NFA) is fundamentally important. The ESLs are a tool that can assist in that process. However, as previously stated, the ESLs are not default cleanup goals. Cleanup goals typically are chemical concentrations for a specific site that are agreed-upon through evaluation and discussions between the regulatory agency and discharger considering site-specific conditions. A discharger, for instance, may prefer to conduct a site-specific risk assessment to assist in developing cleanup goals. Similarly, a regulator may conclude that the ESLs do not address a key concern for a given site, such as backyard gardening, which requires a site-specific assessment.

Regional Water Board staff uses either of two approaches for evaluating sites for regulatory closure or no further action:

1. Low-Threat Underground Storage Tank Closure Policy (UST Policy; State Water Board 2012a) – The UST Policy must be applied to petroleum UST sites and can be suitable for other petroleum release sites depending on site/release attributes. The UST Policy includes narrative and media-specific criteria. In general, the ESLs are not used at sites that are subject to the Low-Threat Underground Storage Tank Closure Policy (State Water Board 2012). They may be used at such sites to screen for constituents not already addressed by the Policy or as part of site-specific risk assessments for the media-specific criteria (e.g., Groundwater; Petroleum Vapor Intrusion to Indoor Air; and Direct Contact and Outdoor Air).
2. Closure Criteria for Non-UST Sites – The narrative criteria that the Regional Water Board uses for non-UST sites were originally developed for evaluating the low-threat closure of chlorinated solvent sites (Regional Water Board 2009). However, the criteria are versatile and can be applied to releases of any chemical or mixture. The ESLs are the numeric screening criteria that can be combined with the narrative criteria for site evaluations.

### 1.3.1 Low-Threat Underground Storage Tank Case Closure Policy

The principal purpose of the *Low-Threat Underground Storage Tank Case Closure Policy* (UST Policy; State Water Board 2012a) is to increase the efficiency of the cleanup process for petroleum Underground Storage Tank (UST) sites and to facilitate closure at UST sites that do not appear to be a long-term threat to human health, the environment, or the waters of the state. However, a number of sites contaminated with petroleum hydrocarbons will fail one or more of the Policy’s general criteria (shown below) or will not be a good candidate for closure under the UST Policy. For these sites, use of the ESLs may be appropriate. Table 1-4 presents the eight general criteria that must be met in order for a site to become eligible for low-threat closure. These criteria are versatile and can be considered for application to non-UST petroleum releases.

Table 1-4 – Low-Threat UST Closure Policy General Criteria	
ID	Narrative Criterion
a	The unauthorized release is located within the service area of a public water system
b	The unauthorized release consists only of petroleum
c	The unauthorized (“primary”) release from the UST system has been
d	Free product has been removed to the maximum extent practicable
e	A conceptual site model that assesses the nature, extent, and mobility of the release has been developed
f	Secondary source has been removed to the extent practicable
g	Soil or groundwater has been tested for methyl tertiary butyl ether (MTBE) and results reported in accordance with Health and Safety Code
h	Nuisance as defined by Water Code Section 13050 does not exist at the site

The UST Policy’s underlying conceptual model is that of a corner gasoline station where the sources of the petroleum release are the USTs. The UST Policy includes two types of criteria: general (narrative) and media-specific. The three media-specific criteria include: 1) groundwater; 2) vapor intrusion; and 3) soil direct contact and outdoor air inhalation. The technical basis of these criteria is presented in technical justification documents that are included in Appendix A

of the Leaking Underground Fuel Tank Guidance Manual (State Water Board 2015).

### 1.3.2 Closure Criteria for Non-UST Sites

In 2009, the Regional Water Board’s Groundwater Committee developed an *Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites* (Regional Water Board 2009). The tool presents nine narrative criteria that must be met to show that the negative effect of the remaining contamination on the environment, human and/or ecological receptors and present or future drinking water resources is minimal. The criteria fall into three groups: (1) site characterization, (2) source control and mitigation and (3) demonstration that future land and water use is not adversely affected. The criteria are presented in Table 1-5. Although the document title includes chlorinated solvents, these criteria are versatile and can be applied to releases of other chemicals and mixtures. The ESLs can be used in conjunction with these narrative criteria for site evaluations.

<b>Table 1-5 – Regional Water Board Closure Criteria for Non-UST Sites</b>	
No.	Narrative Criterion
1	Develop a complete Conceptual Site Model (CSM) 1a) Pollutant sources are identified and evaluated 1b) The site is adequately characterized 1c) Exposure pathways, receptors, and potential risks, threats, and other environmental concerns are identified and assessed
2	Control sources and mitigate risks and threats 2a) Pollutant sources are remediated to the extent feasible 2b) Unacceptable risks to human health, ecological health, and sensitive receptors, considering current and future land and water uses, are mitigated 2c) Unacceptable threats to groundwater and surface water resources, considering existing and potential beneficial uses, are mitigated
3	Demonstrate that residual pollution in all media will not adversely affect present and anticipated land and water uses 3a) Groundwater plumes are decreasing 3b) Cleanup standards can be met in a reasonable timeframe 3c) Risk management measures are appropriate, documented, and do not require ongoing, active Regional Water Board oversight

## 2 Step-by-Step Guide: ESL Workbook

The ESLs are intended to be used in a tiered approach as outlined in Figure 2-1 and further describe throughout this section.

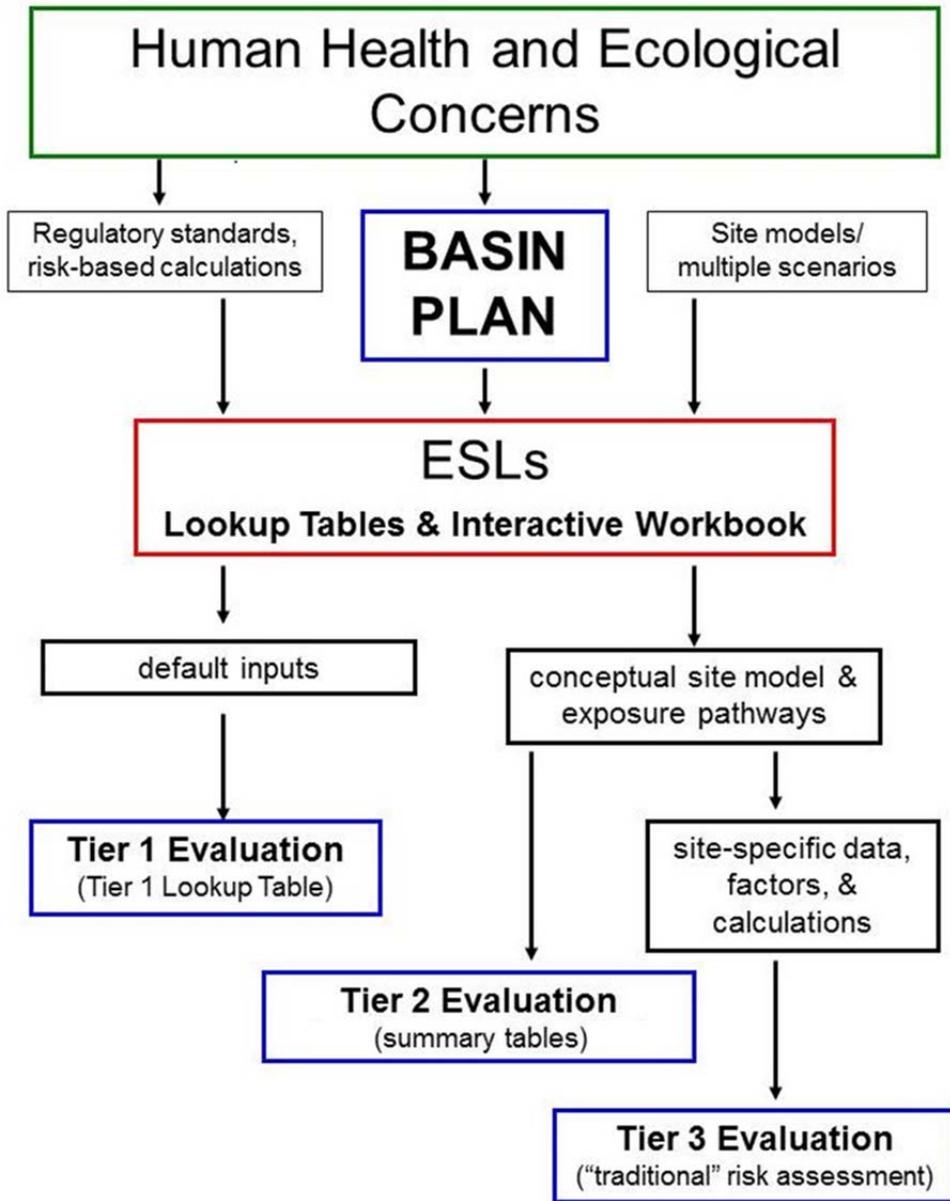


Figure 2-1 – Tiered Process for Selecting Screening Levels

## 2.1 Conceptual Site Model

It is important to gather sufficient information about a contaminated site to ensure data are representative of site conditions, so that ESLs can be used effectively. This means there needs to be enough data to determine the critical features present at the site, so that relevant analytical chemistry data from site samples can be compared to ESL values. In addition, there needs to be a clear understanding of whether specific site features are consistent with assumptions used to derive ESL values. Therefore, a concise summary of what is currently known and how it relates to the goals for the site should be generated (USEPA 1996; see p. 4 and p. 15-20). The summary of this site information is referred to as the Conceptual Site Model (CSM). The CSM compiles various site data and the interpretation of that data to provide a coherent understanding of the contamination so there is a clear path toward adequate site cleanup. Table 2-1 lists information for inclusion in a CSM.

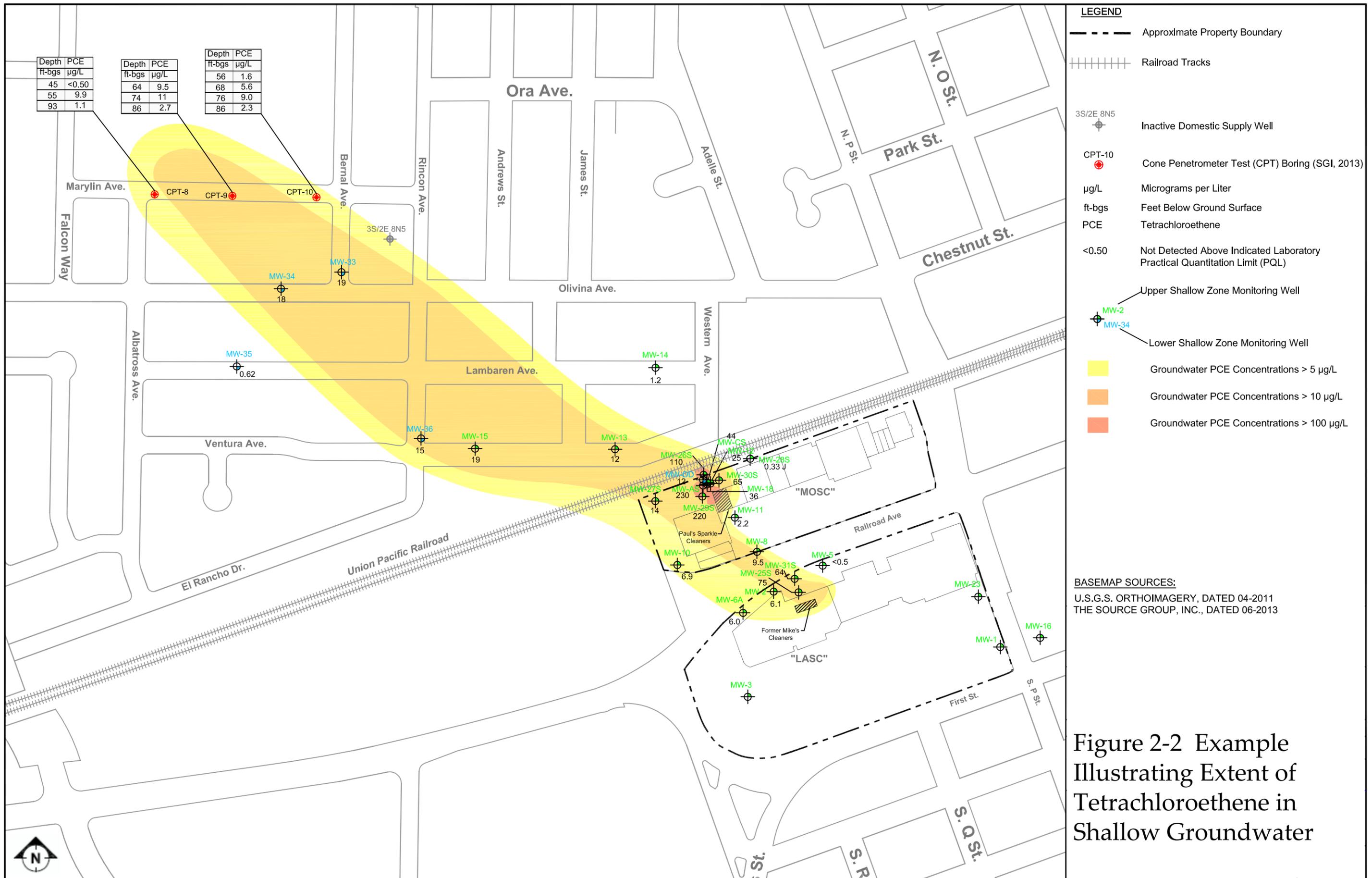
Table 2-1 – Information for a Conceptual Site Model	
Site Data	
Local and Regional Geology Hydrogeology Site Activity and Use History Current and Future Site Use	Nearby Land and Groundwater Use Analytical Chemistry Data Monitoring Data
Interpretation of Site Data	
Contaminant Type(s) and Source(s) Affected Media Type(s) Contaminant Amount Lateral/Vertical Contamination Extent	Degradability of Contamination Mobility of Contamination Receptors and Exposure Pathways

The level of detail in a CSM will vary based on the type of evaluation being conducted and complexity of the project. However, all CSMs should include three basic elements described below:

1. **A description of the nature and extent of contaminants at the site.** ESLs should only be used once there is a relatively clear picture of the contamination type(s) and location(s) at a site. This is often portrayed as a diagram that shows known or suspected sources of contaminants and concentrations of known contaminants (including maps of site with isoconcentration contours for soil and groundwater, such as Figure 2-2).

Cross sections showing the delineation of the vertical extent of contamination should be included (e.g., Figure 2-3). A calculation of residual contaminant mass in each media can also be helpful. It is also helpful to include a summary of the site history, including operations at the site that are known or suspected to have caused the release.

2. **A description of how contaminants are moving or changing in space and time.** This should address whether the extent of known contamination is growing, migrating, or attenuating and should include a discussion of geology and hydrogeology. For new sites, this section may be brief, but for older and more complex sites, this section should summarize relevant site-specific issues such as preferential pathways (natural and man-made), vertical groundwater gradients, and evidence of biodegradation. If biodegradation is occurring at a site, the degradation byproducts should be discussed. Boring logs, well logs, maps of subsurface utilities and other figures, as appropriate, may be used to support this evaluation. Plots of chemical concentration versus distance or time may be useful to illustrate contaminant migration or attenuation. If remediation has been conducted at the site, the effectiveness of the remediation should be evaluated.
3. **An evaluation of the potential receptors and exposure pathways.** This is often shown as a chart indicating which media are impacted and the exposure pathways from each medium to potential receptors. For initial screening at the Tier 1 level, default receptors are assumed (see Section 2.3 and Figure 2-4). For more detailed evaluations, a site specific description of the actual receptors – both human and environmental - should be included and the presence of sensitive receptors such as schools or day care centers highlighted (e.g., Figure 2-5). Exposure pathways and receptors which may be present at the site but are not considered by the ESLs should be noted, such as consumption of backyard produce grown in contaminated soil or ingestion of contaminated surface water by endangered species.



Depth ft-bgs	PCE µg/L
45	<0.50
55	9.9
93	1.1

Depth ft-bgs	PCE µg/L
64	9.5
74	11
86	2.7

Depth ft-bgs	PCE µg/L
56	1.6
68	5.6
76	9.0
86	2.3

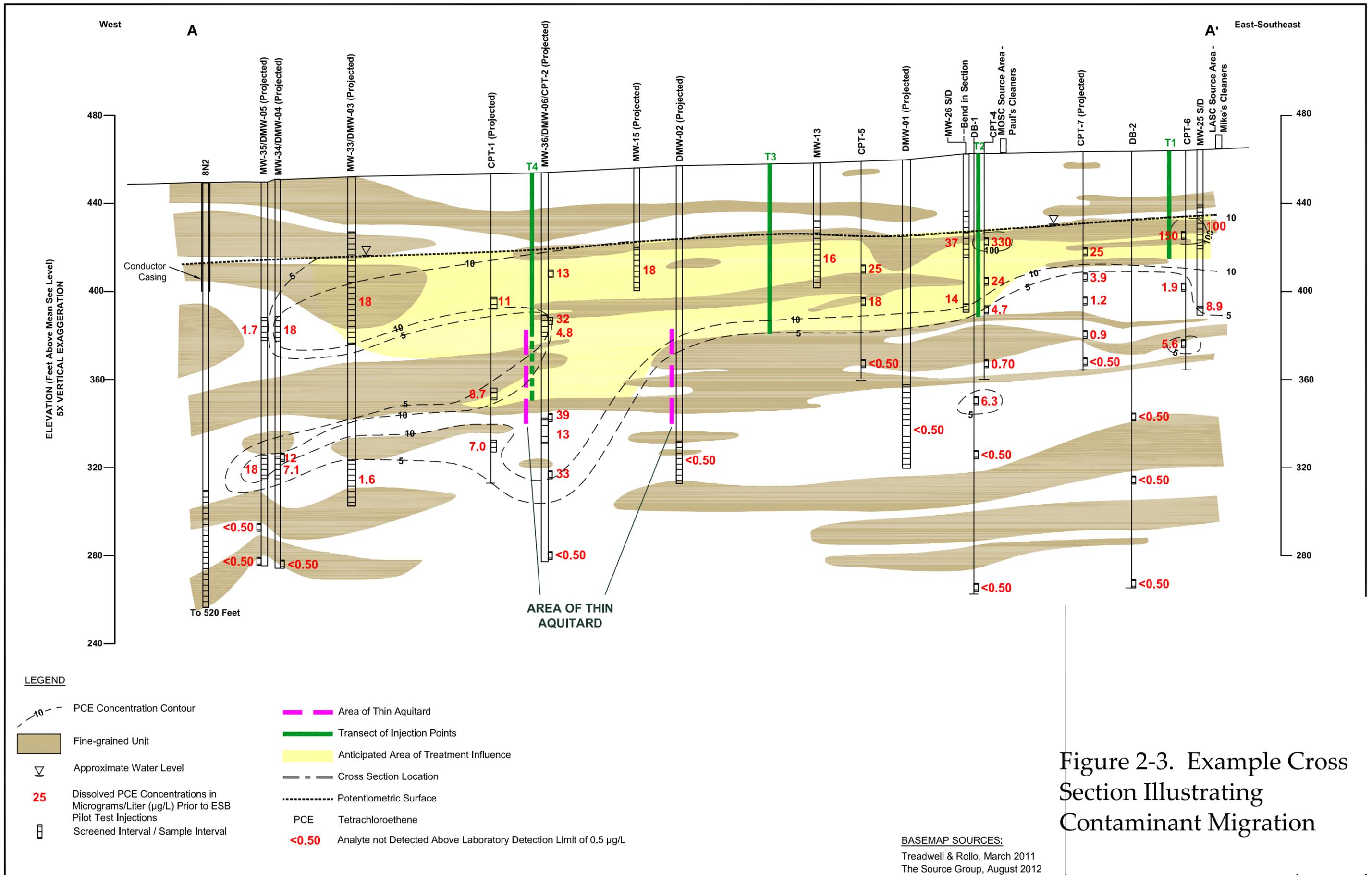
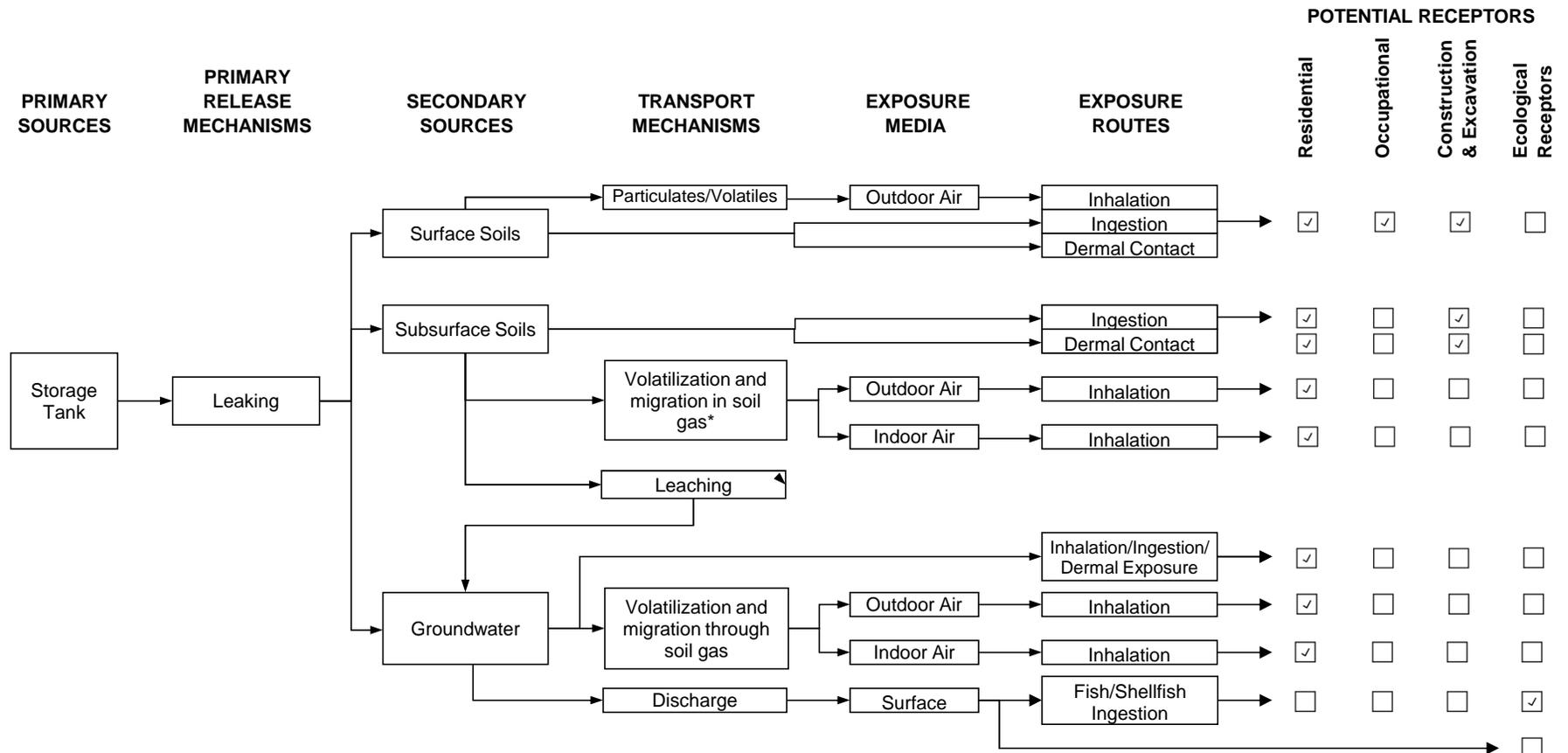


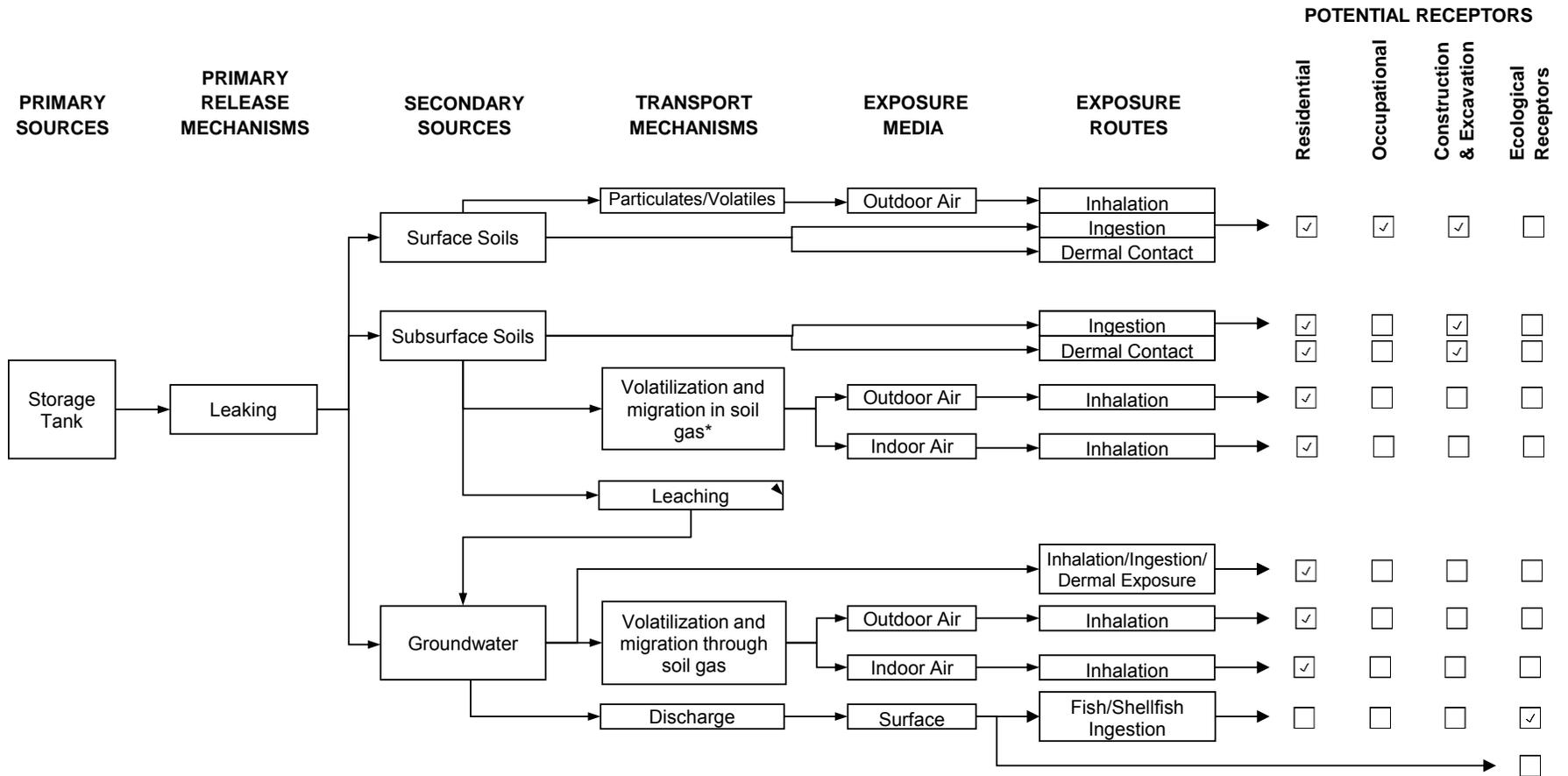
Figure 2-3. Example Cross Section Illustrating Contaminant Migration

Figure 2-4. Default Evaluation of Receptors and Exposure Pathways Used in a Tier 1 Assessment



\* The ESLs do not include soil to indoor air screening levels. Soil gas must be sampled to evaluate this transport pathway.

Figure 2-4. Default evaluation of receptors and exposure pathways used in a Tier 1 assessment



\* The ESLs do not model volatilization of contaminant mass in subsurface soils. Soil gas must be sampled to evaluate this transport pathway.

## 2.2 ESL Workbook Content

The ESL Workbook is a Microsoft Excel file that includes multiple worksheets that were used to calculate and summarize all the ESL for groundwater, soil, subslab/soil gas, and indoor air. Each worksheet is color coded and appears in the workbook in following order:

- **White Tabs** - Index of Tables
- **Dark Blue Tabs** - Summary tables showing all possible ESLs for each media type and those selected as the Tier 1 screening value.
- **Red Tabs** - Interactive Tool that allows users to input site-specific information that will generate Tier 2 (T2) screening levels for a selected chemical and specific site scenario. The tool includes separate worksheets:
  - Table T2-1: Input page for: 1) chemical selection and entry of site-specific information (1<sup>st</sup> yellow box); and 2) specific site contamination concentrations (2<sup>nd</sup> yellow box). The output T2 ESLs are also given (gray box).
  - Table T2-2: Details on which ESL were considered for the output T2 ESLs.
  - Table T2-3: Specific media and pathway concerns for the input site contamination concentrations.
- **Light Blue Tabs** – Calculation tables that show which parameters are used to calculate the ESLs for **Groundwater (GW)**:
  - Table GW-1: Direct Exposure Human Health Risk Level Calculation
  - Table GW-2: Aquatic Ecotoxicity Level Calculation
  - Table GW-3: GW Vapor Intrusion Human Health Risk Level Calculation
  - Table GW-4: Gross Contamination Level Calculation
  - Table GW-5: Taste and Odor Nuisance Level Calculation
- **Yellow Tabs** – Calculation tables that show which parameters are used to calculate the ESLs for **Soil (S)**:
  - Table S-1: Direct Exposure Human Health Risk Level Calculation
  - Table S-2: Leaching to Groundwater Level Calculation
  - Table S-3: Gross Contamination Level Calculation
  - Table S-4: Odor Nuisance Level Calculation

- **Green Tabs** – Calculation tables that show which parameters are used to calculate the ESLs for **Subslab/Soil Gas (SG)**:
  - Table SG-1: Vapor Intrusion Human Health Risk Level Calculation
  - Table SG-2: Vapor Intrusion Odor Nuisance Level Calculation
- **Purple Tabs** – Calculation tables that show which parameters are used to calculate the ESLs for **Indoor Air (IA)**:
  - Table IA-1: Direct Exposure Human Health Risk Level Calculation
  - Table IA-2: Odor Nuisance Level Calculation
- **Tan Tabs** - Lookup Tables compiling the **Input Parameters/Constants (IP)**:
  - Table IP-1: Physical-Chemical Parameters
  - Table IP-2: Toxicity Values
  - Table IP-3: Direct Exposure Model Factors
  - Table IP-4: Maximum Contamination Levels (MCL) and other Drinking water Levels
  - Table IP-5: CalEPA Ecotoxicity Aquatic Habitat Goals
  - Table IP-6: USEPA and Other Ecotoxicity Aquatic Habitat Goals
  - Table IP-7: Seafood Ingestion Risk from Bioaccumulation

## 2.3 Tier 1 ESLs – Default Conservative Site Scenario

Tier 1 ESL are based on conservative default Conceptual Site Model (CSM) scenario conditions listed in Table 2-2. This scenario is designed to protect sites with unrestricted land and water use, shallow soil contamination, shallow ground water, and permeable soil (see Section 2.4 for more information about these and other specific site criteria and how they should be applied).

The Tier 1 ESL Workbook Summary Table gives screening levels for groundwater, soil, subslab/soil gas, and indoor air. By comparing sample data to these Tier 1 ESLs, decisions can be made regarding the need for additional site investigation, remedial action or a more detailed risk assessment. Since a Tier 1 evaluation uses default exposure scenarios, it is most useful for screening out sites where the concentration of a single contaminant is below its ESL for a given medium or concentrations of a limited number of contaminants are well below their respective ESLs. Exceedance of a Tier 1 ESL typically indicates the need for a Tier 2 assessment.

Table 2-2 – Tier 1 ESL Conceptual Site Model	
Site Scenario Criteria	Tier 1 ESL Selection
Land Use	Residential
Groundwater Use	Drinking Water Resource
MCL Priority over Risk Based Levels	Yes
Groundwater Depth	Shallow ( $\leq 10$ ft bgs)
Soil Type for Vapor Intrusion	Sand Scenario
Soil Exposure Depth	Shallow ( $\leq 10$ ft bgs)

## 2.4 Tier 2 ESLs – Site Specific ESL Choice and Use of Interactive Tool

Tier 2 ESL are selected by refining the default CSM to identify relevant pathways, receptors, and concerns specific to an individual site. This is an intermediate approach that is a relatively rapid and cost-effective option for preparing more quantitative site-specific risk assessments. The following sections give a step-by-step description of how to choose the correct Tier 2 ESLs for a specific site. These steps will also help with the selection of appropriate site specific input criteria for the ESL Workbook Interactive Tool Input Table T2-1.

### Step 1: Check ESL Applicability and Updates

Check with the overseeing regulatory agency to determine if the ESLs can be applied to the subject site. Ensure that the most up-to-date version of the ESLs is being used.

## Step 2: Identify Chemicals of Potential Concern

An appropriate ESL assessment must be based on the results of adequate site investigation.

- Determine the extent of chemicals in groundwater, soil, and subslab/soil gas and areas of potential environmental concern at the site and offsite, as required.
- Identify maximum concentrations of chemicals present in the media of concern.
- Soil data should be reported on a dry-weight basis.

The ESLs are intended as a screening tool for sites with low levels of contaminants, and are tabulated for one chemical and one medium (water, soil or indoor air) only. When multiple chemicals are present or receptors are exposed to more than one contaminated medium, the applicability of the ESLs **should be carefully evaluated**. If multiple contaminants are present and one or more of the concentrations approach the respective ESLs, the cumulative risk (and hazard) must be evaluated **as described in** Section 3.2.2.

## Step 3: Land Use Selection

ESLs for soil, subslab/soil gas, and indoor air are selected based on the present and anticipated future use of the site. Land uses are categorized based on the assumed magnitude of potential human exposure (see Section 3). Two options are available in the workbook:

- **Residential Land Use** category is intended for sites where unrestricted future land-use is sought. This includes sites to be used for residences, hospitals, day-care centers and other sensitive purposes (DTSC 2002). ESLs listed under this category incorporate assumptions regarding long-term, frequent exposure of children and adults in a residential setting. Screening levels for residential land use are considered to be appropriate for unrestricted use of a property.
- **Commercial or Industrial Use** assumes that only working-age adults will be present at the site on a regular basis. Direct-exposure assumptions incorporated into the soil ESLs for commercial or industrial land use assume shorter, less frequent exposure for receptors compared to assumptions used for residential land use receptors (e.g., less exposure time per day). For

evaluation of commercial/industrial properties, it is recommended that site data be compared to ESLs for both unrestricted/residential and commercial/industrial land use.

Land use should be selected with respect to the current and foreseeable future use of the site in question. Reference to adopted General Plan maps, zoning maps, and local redevelopment plans is an integral part of this process. Discussions with local planners may help identify reasonably foreseeable changes to land use. Use of the lookup tables for sites with other land uses should be discussed with and approved by the overseeing regulatory agency.

**Implied Land Use Restriction** is terminology the Regional Water Board staff uses to refer to a situation where the current land use or zoning is commercial/industrial, and the site data are only evaluated against commercial/industrial ESLs (i.e., no future residential use scenario is evaluated). This raises the question whether a land use covenant is warranted as a measure of protection for remaining contamination that exceeds residential ESLs. Therefore, we recommend that a residential reuse scenario be evaluated unless residential use is prohibited via a land use covenant or other robust means. Such an evaluation aids staff in assessing whether a land use covenant is warranted. Note that DTSC typically requires a future residential use scenario for both screening level and baseline risk assessments at active as well as closing/closed facilities (DTSC 2015).

#### **Step 4: Groundwater Use Selection**

The beneficial uses of groundwater for a particular basin or area are presented in the Basin Plan. As described in Section 1.1.1, groundwater beneath the site should initially be treated as a current or potential source of drinking water. For more site specific analysis the actual, likely use of groundwater can be determined based on the locations of existing municipal or domestic supply wells and measured quality of the groundwater and the hydrogeologic nature of the soil or bedrock containing the groundwater. State Water Board Resolution 88-63 provides criteria that can be used to determine if groundwater is likely to be used as drinking water (State Water Board 1988).

**Implied Groundwater Use Restriction** is terminology the Regional Water Board staff uses to refer to a situation where the beneficial use of groundwater includes potable uses, but the site data are compared against non-drinking water ESLs because groundwater is not potable or the groundwater is not currently used and

is unlikely to be used in the future (e.g., municipal water system). In these cases a deed restriction may be required to ensure that groundwater will not be used in the future. Further, because groundwater is not static, the potential for contaminant migration needs to be considered.

### **Step 5: MCL Priority vs Risk-Based Screening Levels Selection**

The Basin Plan directs that the lower of the primary and secondary Maximum Contaminant Levels (MCLs) be used as an upper bound when setting cleanup goals for groundwater designated for use as a domestic or municipal supply (see Section 1.1). MCLs are drinking water standards adopted by the California State Water Resources Control Board, Division of Drinking Water (DDR)<sup>1</sup> pursuant to the California Safe Drinking Water Act. Primary MCLs are derived from health-based criteria, but they also include technologic and economic considerations based on the feasibility of achieving and monitoring for these concentrations in drinking water. The balancing of health effects with technologic and economic considerations may not always be appropriate for protection of the quality of all surface water or groundwater resources.

### **Step 6: Groundwater Depth Selection**

Depth to groundwater is an important factor in assessing the potential for vapor intrusion resulting from contaminated groundwater. The groundwater depth and soil type (Step 7) are used in selecting the appropriate groundwater vapor intrusion model scenario (see Section 4.2). The selected groundwater vapor intrusion model scenario effectively determines the amount of contaminant attenuation (reduction in concentration) that occurs during transport from groundwater to indoor air (GW-IA). Groundwater depth is the primary determinant and soil type is a secondary determinant. Depth of groundwater should be determined from the shallowest measured depth to first groundwater

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<sup>1</sup> The California Drinking Water Program was transferred from the California Department of Public Health in July 2014.

at a site (e.g., seasonal high water table). If groundwater is less than 10 feet bgs (Shallow), the most conservative GW-IA attenuation factor (Shallow Sand Scenario; see Chapter 4) is used regardless of soil type.<sup>2</sup> When groundwater is 10 feet bgs or more (Deep), the site-specific soil type is employed in the selection of the groundwater vapor intrusion scenarios, as described in Step 7.

### **Step 7: Soil Type Selection**

The soil type is a secondary determinant in selecting the appropriate groundwater vapor intrusion scenario (Chapter 4.2). The soil types in the vadose should be determined based on lithological information gathered at the site (e.g., boring logs, geotechnical testing, and cross sections). This information is used to determine the groundwater vapor intrusion model scenario and associated amount of contaminant attenuation that is expected to occur at a site. Two different soil-specific groundwater vapor intrusion scenarios were developed for sites with deep groundwater. See the previous step for the shallow groundwater scenario. The first scenario (Deep Sand) assumes all sand and should be used for sites where coarse-grained soils (sands or gravels) are predominant. The second scenario (Fine-Coarse) assumes a continuous, fine-grained soil at the water table and coarse-grained soil beneath the building. This scenario could also be used for sites with predominantly fine-grained soils or layers. Section 4.2 provides a discussion regarding the basis of these scenarios.

### **Step 8: Soil Exposure Depth Selection**

The ESLs employ two soil contamination depth options for soil direct contact considerations (Table 2-3):

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<sup>2</sup> Natural (e.g., conduits created by sand lenses, fractures, or desiccation cracks), manmade (e.g., utility lines or associated backfill) and building-specific (e.g., below-ground elevator components) preferential pathways responsible for minimal attenuation of contaminant vapors are more likely to be present and affect vapor transport in the upper 10 feet of soil.

- **Shallow Soil Contamination (at or above 10 feet bgs):** There is potential for residents, commercial/industrial workers, and construction workers to be exposed to contaminated soil at or above 10 feet bgs. This means that, for most screening evaluations, two potentially exposed receptors need to be considered: 1) residential or commercial/industrial; and 2) construction workers.
- **Deep Soil Contamination (below 10 feet bgs):** There is potential for construction workers to be exposed to contaminated soil below 10 feet bgs. Regular exposure to contaminated soil at that depth by residents or commercial/industrial workers is unlikely, unless the overlying soil were removed, which is rare.

If chemicals are detected in shallow and deep soil, it is appropriate to evaluate depth exposure interval.

<b>Table 2-3 – Soil Direct Exposure Depth Intervals</b>			
Soil Depth	Scenario: Residential	Scenario: Commercial/Industrial	Scenario: Construction Worker
	Land Use: Residential	Land Use: Commercial/Industrial	Land Use: Any
	Receptor: Resident	Receptor: Indoor/Outdoor Worker	Receptor: Construction Worker
Shallow (≤10 feet bgs)	Yes	Yes	Yes
Deep (>10 feet bgs)	No	No	Yes

### Step 9: Final ESL Determination Process

The Interactive Tool uses the site-specific scenario parameters chosen by the user in ESL Workbook Table T2-1, to identify the specific ESLs appropriate for each medium. All screening levels considered for the specified contaminant are shown in the ESL Workbook Table T2-2. The following figures illustrate the considerations used in the determination of the final screening level for each medium: Figure 2-6 (Groundwater), Figure 2-7 (Soil), Figure 2-8 (Subslab/Soil Gas), and Figure 2-9 (Indoor Air).

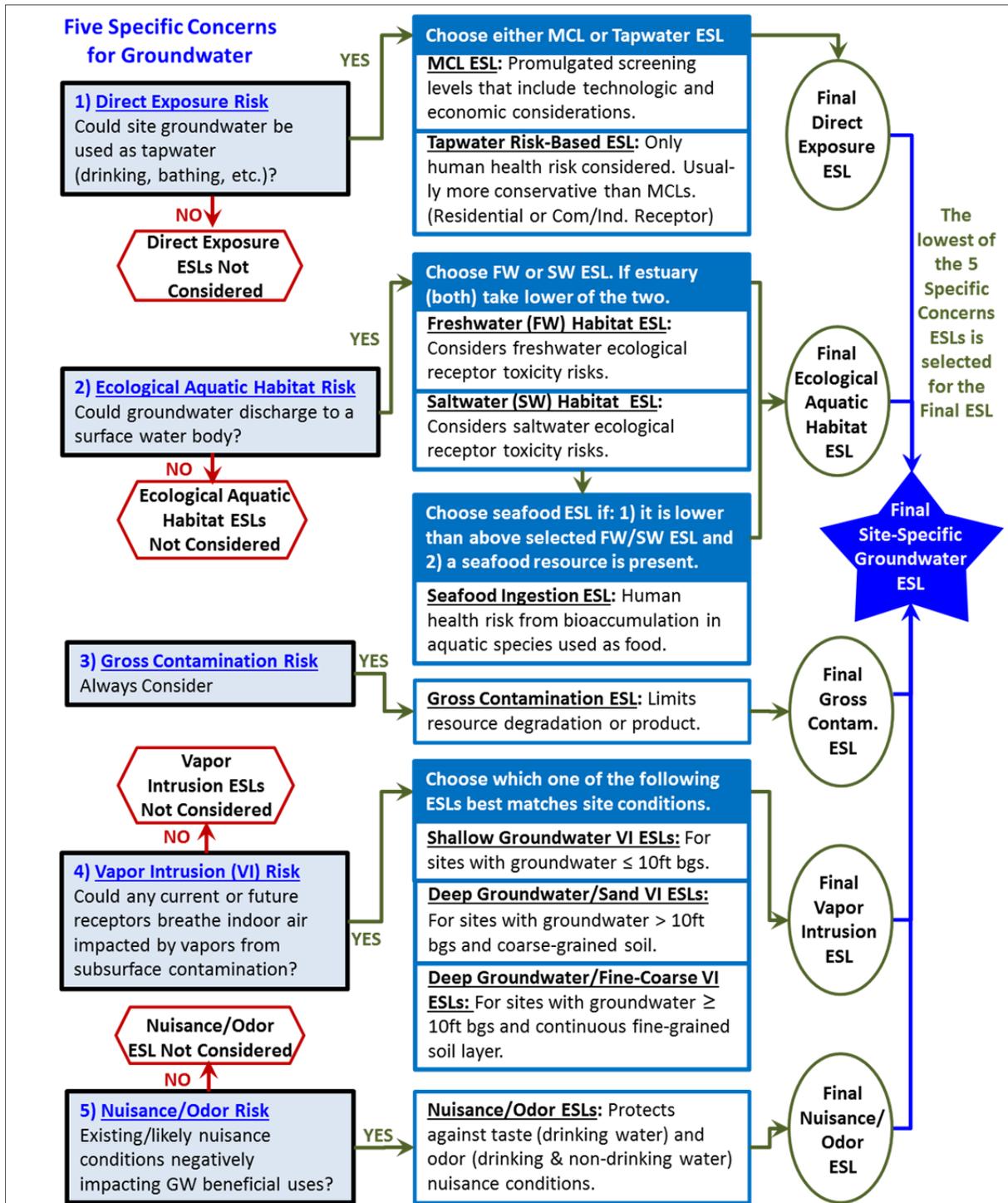


Figure 2-6 – Final Site-Specific Groundwater ESL Determination

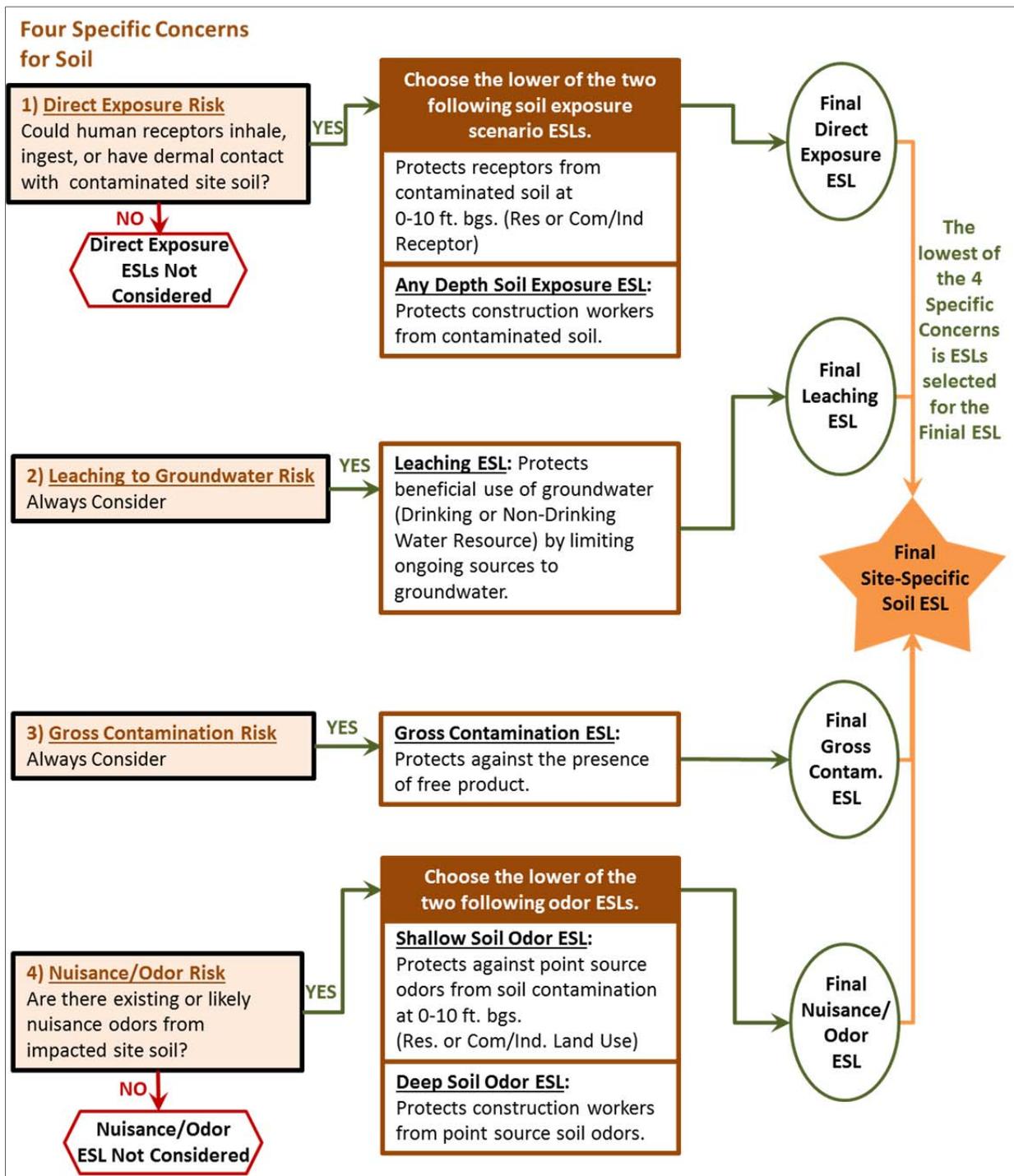


Figure 2-7 – Final Site-Specific Soil ESL Determination

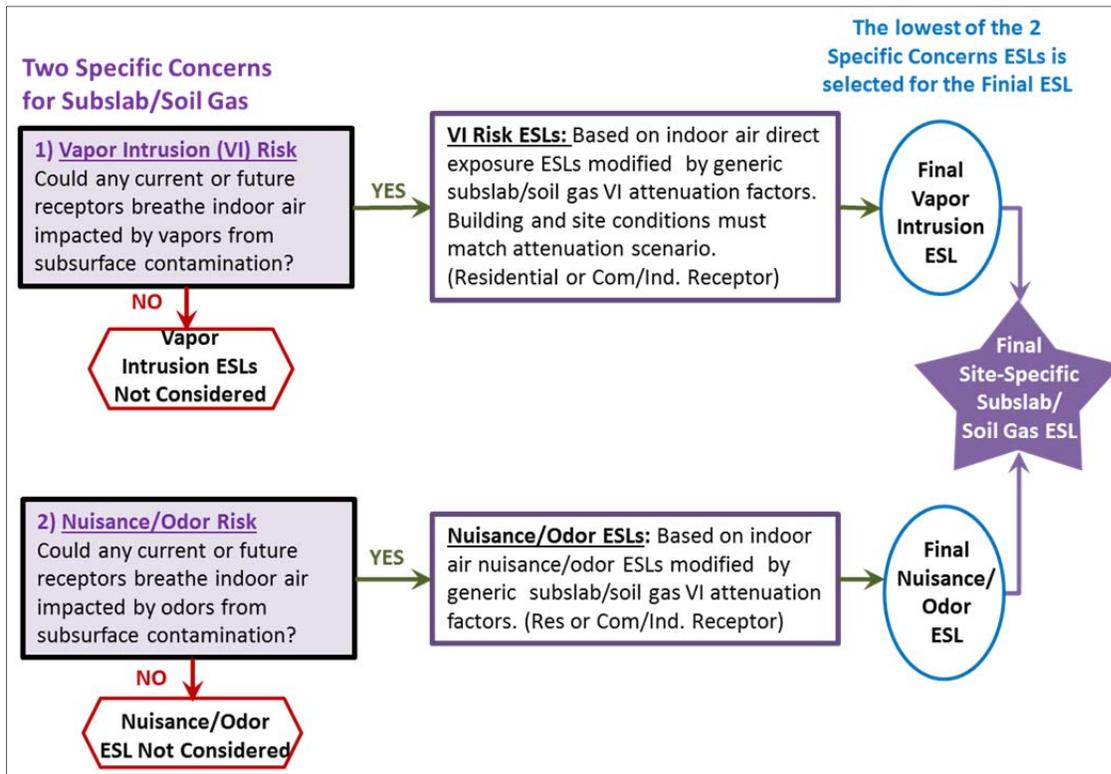


Figure 2-8 – Final Site-Specific Subslab/ Soil Gas ESL Determination

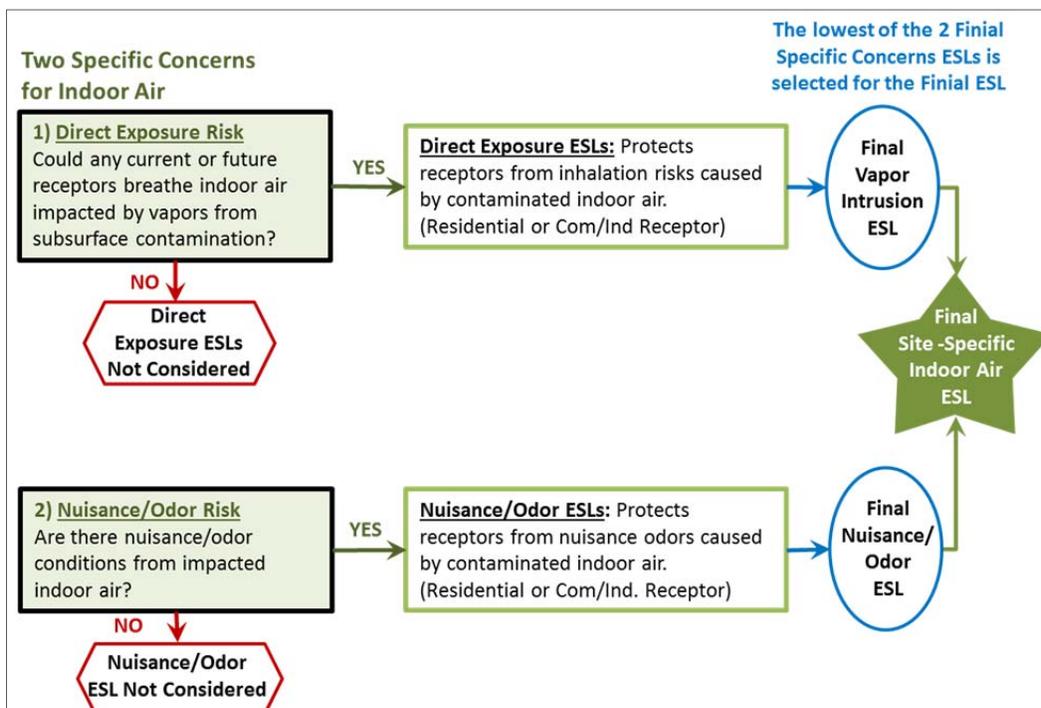


Figure 2-9 – Final Site-Specific Indoor Air ESL Determination

## **Step 10: Compare Site Data to ESLs**

The maximum-detected concentrations of a specific chemical can be input into the Interactive Tool in ESL Workbook Table T2-1 of the Workbook and the specific concerns posed by those concentration levels will be identified in ESL Workbook Table T2-3.

**Note:** Initial screening typically is performed using maximum-detected concentrations. The use of statistical methods (e.g., 95 percent upper confidence limit of the arithmetic mean or UCL) to estimate more site-specific exposure point concentrations (EPCs) and evaluate environmental risks is common for Tier 2 and Tier 3 risk evaluations. The UCL is commonly used as the EPC for soil where the data are averaged over the area/volume to which receptors could be chronically exposed. Guidance for the estimation of exposure point concentrations, use of non-detect data, and other issues is provided in the following documents: 1) Preliminary Endangerment Assessment Guidance Manual (DTSC 2015), 2) Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (USEPA 2002c), and 3) ProUCL Version 5.0.00 User Guide and Technical Guide (USEPA 2013c). As discussed in these documents, care should be exercised when determining the area and depth over which the data are averaged. For soil contaminants in an anticipated residential development, concentrations should not be averaged over an area greater than the area of the existing or anticipated residential lot. Soil leaching to groundwater data generally should not be averaged. For vapor intrusion concerns, groundwater concentrations should not be averaged over an area greater than the floor space area of existing or anticipated buildings.

## **Step 11: Compare Site Data to Background Levels**

If information on the background concentrations of the chemicals of interest at the site is available, compare the background concentrations to the selected ESLs. As discussed in Section 10.2, if site-specific background concentrations of chemicals of concern are greater than risk-based ESLs, the background concentrations may be substituted. This should be pointed out in the appropriate report. For example, arsenic concentrations in site soils typically exceed risk-based screening levels by one or more orders of magnitude, and there is available information on background levels of arsenic in undifferentiated urbanized

flatland soils in the Bay Area. Thus, that value can be substituted for the risk-based ESL. This is further discussed in Section 10.5.3.

## **Step 12: Evaluate the Need for Additional Investigation, Assessment, or Remediation**

Based on a comparison of available site data to the ESLs, evaluate the need for additional action at the site. Additional actions may include additional site investigation, preparation of a site-specific risk assessment, source remediation, or mitigation (to protect a threatened receptor).

### **Example of Interactive Tool Use: Tetrachloroethene**

Tetrachloroethene (PCE) is selected as the contaminant and the specific site scenario options are chosen from the drop down menus in the first yellow box within the Interactive Tool ESL Workbook Table T2-1 (Tier-2 Site-Specific Inputs), as shown in Figure 2-6. For this example site, there is soil and groundwater data which is also entered in the second yellow box (optional step). The final grey box shows the media specific Tier 2 ESLs for the contaminant given the selected site scenario information. Figure 2-7 shows the Interactive ESL Workbook Tool Table T2-2 (ESL Details) for this example. From this table it becomes clear which screening levels are driving the final ESL for each media:

- **Groundwater:** Vapor Intrusion to Indoor Air (ESL = 3 µg/L)
- **Soil:** Leaching to Groundwater (ESL = 0.42 mg/kg)
- **Soil Gas:** Vapor Intrusion to Indoor Air (ESL = 240 µg/m<sup>3</sup>)
- **Indoor Air:** Direct Exposure (ESL = 0.48 µg/m<sup>3</sup>)

The site diagram shown in the Interactive Tool ESL Workbook Table T2-3 (Specific Concerns) can be used to get a better idea of potential threats caused by specific chemical concentrations measured at a site, shown in Figure 2-8 for this example. This diagram uses the concentration inputs from ESL Workbook Table T2-1. The final ESLs for groundwater, soil, subslab/soil gas, and indoor air are shown within circles. Each circle is connected to boxes that show the different ESLs considered for that media type. Red X's will appear next to all ESLs that are exceeded by the input site concentration data and provides a visual for specific site consideration that could be potentially affected at this site. As seen in Figure

2-8, the site specific concerns soil and groundwater concentrations given for this example are:

**Soil:**

- 1) Human health risk from direct exposure to contaminated soil
- 2) Leaching to groundwater

**Groundwater:**

- 1) Groundwater vapor intrusion to indoor air
- 2) Discharge to surface aquatic habitats

Figure 2-8 also shows that both groundwater and soil PCE concentrations at the site are below levels where gross contamination or odor would be a concern.

Tier 2 Scenario Toggles	
Contaminant:	Tetrachloroethene
Land Use:	Residential
Groundwater Use:	Nondrinking Water Resource
MCL Priority over Risk-Based Levels:	No
Groundwater Depth for GW VI: (Shallow ≤ 10ft bgs < Deep)	Shallow Groundwater
Soil Type for GW VI:	Sand Scenario
Soil Depth for Direct Exposure: (Shallow ≤ 10ft bgs < Deep)	Shallow Soil
Enter site data (Optional)	
Soil Concentration (mg/kg) - dry weight:	5.00
Groundwater Concentration (µg/L):	100.00
Subslab/ Soil Gas Concentration (µg/m <sup>3</sup> ):	
Indoor Air Concentration (µg/m <sup>3</sup> ):	
Output Tier 2 ESLs:	
Soil (mg/kg):	4.2E-01
Groundwater (µg/L):	3.0E+00
Subslab/ Soil Gas (µg/m <sup>3</sup> ):	2.4E+02
Indoor Air (µg/m <sup>3</sup> ):	4.8E-01

**Figure 2-10 – Interactive Tool ESL Workbook Site Specific Inputs Table T2-1 based on the example scenario described herein**

Selected Site Scenario	
<b>Selected Chemical:</b>	<b>Tetrachloroethene</b>
Land Use:	Commercial or Industrial
Groundwater Use:	Nondrinking Water Resource
MCL Priority vs Risk-Based:	No
Groundwater Depth for GW VI:	Shallow Groundwater
Soil Type for GW VI:	Sand Scenario
Soil Type for Direct Exposure:	Shallow Soil

Groundwater Screening Levels (µg/L)		
Table W-1	Drinking Water MCL: 5.0E+00 Drinking Water Exposure Risk: 6.0E-02 Nondrinking Water Exposure Risk: --	
	<b>Groundwater Direct Exposure Level: --</b>	
Table W-2	Freshwater Ecotoxicity: 1.2E+02 Saltwater Ecotoxicity: 2.3E+02 Bioaccumulation for Seafood Ingestion Concerns: 8.9E+00	
	<b>Ecological Aquatic Habitat Goal Level: 8.9E+00</b>	
Table W-3	Residential - Shallow Groundwater - Sand: 3.0E+00 Residential - Shallow Groundwater - Fine-Coarse: 3.0E+00 Com/Ind - Shallow Groundwater - Sand: 2.6E+01 Com/Ind - Shallow Groundwater - Fine-Coarse: 2.6E+01 Residential - Deep Groundwater - Sand: 3.7E+00 Residential - Deep Groundwater - Fine-Coarse: 5.1E+01 Com/Ind - Deep Groundwater - Sand: 3.2E+01 Com/Ind - Deep Groundwater - Fine-Coarse: 8.8E+02	
	<b>Groundwater Vapor Intrusion Level: 3.0E+00</b>	
	<b>Table W-4</b>	
	<b>Groundwater Gross Contamination Level: 5.0E+04</b>	
	Table W-5	Drinking Water Nuisance/Odor Value: 1.7E+02 Nondrinking Nuisance/Odor Value: 3.0E+03
		<b>Groundwater Nuisance/Odor Level: 3.0E+03</b>
	<b>Final Groundwater ESL: 3.0E+00</b>	

Soil Screening Levels (mg/kg)	
Table S-1	Residential Exposure Risk: 6.2E-01 Commercial or Industrial Exposure Risk: 2.8E+00 Construction Worker Exposure Risk: 3.4E+01
	<b>Soil Direct Exposure Level: 6.2E-01</b>
	Drinking Water Resource: 4.2E-01 Nondrinking Water Resource: 4.2E-01
Table S-2	<b>Soil Leaching Level: 4.2E-01</b>
Table S-3	<b>Soil Gross Contamination Level: 2.3E+02</b>
Table S-4	Residential - Shallow Soil Exposure: 5.0E+02 Commercial/Industrial - Shallow Soil Exposure: 1.0E+03 Any Land Use - Deep Soil Exposure: 1.0E+03
	<b>Soil Nuisance/Odor Level: 5.0E+02</b>
<b>Final Soil ESL 4.2E-01</b>	

Subslab/Soil Gas Screening Levels (µg/m <sup>3</sup> )	
Table SG-1	Residential Exposure Risk: 2.4E+02 Commercial or Industrial Exposure Risk: 2.1E+03
	<b>Subslab/Soil Gas Vapor Intrusion Level: 2.4E+02</b>
Table SG-2	Residential Nuisance/Odor: 1.6E+07 Commercial/Industrial Nuisance/Odor: 3.2E+07
	<b>Subslab/Soil Gas Nuisance/Odor Level: 1.6E+07</b>
<b>Final Subslab/Soil Gas ESL: 2.4E+02</b>	

Indoor Air Screening Levels (µg/m <sup>3</sup> )	
Table IA-1	Residential Exposure Risk: 4.8E-01 Commercial or Industrial Exposure Risk: 2.1E+00
	<b>Indoor Air Direct Exposure Level: 4.8E-01</b>
Table IA-2	<b>Indoor Air Nuisance/Odor Level: 3.2E+04</b>
<b>Final Indoor Air ESL: 4.8E-01</b>	

Figure 2-11 – Interactive Tool ESL Workbook Details Table T2-2 for PCE ESLs based on the example scenario described herein

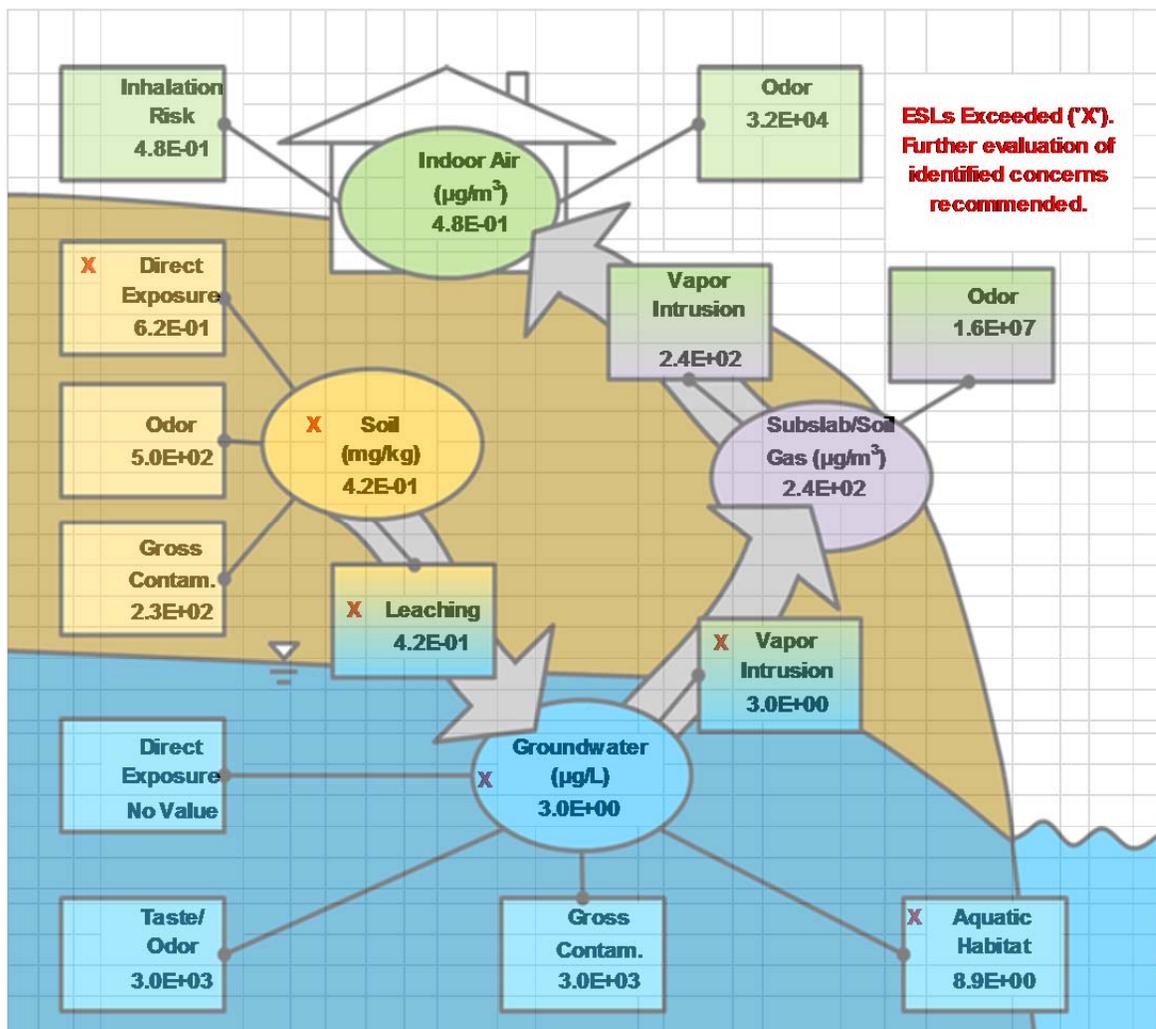


Figure 2-12 – Interactive Tool ESL Workbook Specific Concerns Table T2-3 based on the example scenario described herein

## 2.5 Tier 3 - Risk Assessment Derived Screening Levels

**Tier 3 Screening Levels** are based on alternate models and modeling input assumptions developed by conducting a complete site risk assessment that quantitatively evaluates the risk posed to human and/or ecological receptors by the contaminated media. Consideration of the methodologies and potential environmental concerns discussed in this document is still encouraged for the development of Tier 3 screening levels. See Appendix A for other resources that can be used during the development of Tier 3 risk-based screening levels.

# **3 Methods: Direct Exposure Human Health Risk Screening Levels for All Media**

## **3.1 Default Exposure Scenarios: Receptors and Pathways**

The ESLs take into account human health risk from direct exposure to contaminated groundwater, soil, and indoor air. The three general receptors considered for such direct exposure are:

### **Residents**

Both adults and children are considered residents and are the primary receptors for a Residential Land Use site. Children often exhibit behavior such as greater hand-to-mouth soil contact that can result in greater exposure to soils than those associated with a typical adult. In addition, children have a lower body weight relative to the predicted intake of both water and soil which results in more conservative risk-based concentrations for children compared to an adult-only assumption. Therefore, children are the primary receptors considered for groundwater and soil ESLs for noncancer endpoints at sites with a Residential Land Use.

### **Commercial or Industrial Workers**

Primary receptors considered for sites with a Commercial or Industrial Land Use are commercial/industrial workers. The commercial/industrial scenario represents a variety of workers, from those who spend most of their workday indoors to those who frequently work outdoors, but not workers involved in excavation activities. A commercial/industrial worker is assumed to be an adult who will have eight hours of exposure during the course of a work day as a full-time employee of a company operating on-site. The screening levels for this receptor are expected to protect other reasonably anticipated indoor and outdoor workers at a commercial/industrial facility as well as visitors.

## Construction Workers

Construction could occur at any site, so construction/trench workers are considered for both Residential and Commercial Land Use scenarios. The activities for this receptor typically involve substantial exposures to surface and subsurface soil<sup>3</sup> during excavation, maintenance and building construction projects. Contact with contamination in soil via incidental ingestion, dermal contact, and inhalation due to volatilization and fugitive dust are the main routes of exposure. Therefore only direct contact soil ESLs consider construction/trench worker receptors. A construction worker is assumed to be exposed to contaminated soil during the work day for the duration of a single on-site construction project, lasting one year. If multiple construction projects are anticipated, it is assumed that different workers will be employed for each project. Even though work durations are typically of shorter due to the short-term nature of construction projects, chronic toxicity information was used when developing screening levels for a construction worker receptor. This approach is more conservative than using subchronic toxicity values since it combines relatively short exposure duration with a chronic toxicity value.

Each receptor described above has a varying level of exposure to the different media types through three general exposure pathways: inhalation, ingestion, and dermal contact. Table 3-1 shows which exposure pathways are used to calculate the risk-based screening levels for each media.

Exposure Pathway	Tapwater (Groundwater)	Soil	Indoor Air
Ingestion	Yes	Yes	No
Inhalation	Yes	Yes	Yes
Dermal	Yes	Yes	No

---

<sup>3</sup> Surface soil is considered to be 0 to 0.5 feet bgs and subsurface soil is soil beneath 0.5 feet bgs (DTSC 2015).

## 3.2 Calculation of Health Risk-Based Exposure Screening Levels

The human health direct exposure ESLs for groundwater, soil, and indoor air are calculated using standard equations taken directly from the USEPA RSLs (2015).<sup>4</sup> These equations combine certain exposure assumptions with chemical specific toxicity values to calculate contaminant levels with a one-in-a-million ( $10^{-6}$ ) cancer target risk or a noncancer target hazard quotient (HQ) of 1. Since the levels of carcinogenic or noncarcinogenic effects caused by a given chemical are not related, both must be considered. Therefore, the final direct exposure ESL is the lower of the cancer vs noncancer risk screening level.

### 3.2.1 Toxicity Values

There are four main types of toxicity values (determined using laboratory experiments) that are used for assessing potential adverse effects to humans in the ESL calculations:

#### Carcinogenic Effects

- Cancer Slope Factor (SF<sub>0</sub>): Oral and dermal exposure
- Inhalation Unit Risk (IUR): Inhalation exposure

#### Noncarcinogenic Effects

- Oral Reference Dose (RfD<sub>0</sub>): Oral and dermal exposure
- Reference Concentration (RfC): inhalation exposure

Input Parameters Table IP-3 in the ESL Excel workbook shows all the toxicity values for each chemical used to calculate the direct exposure ESLs. Since many different laboratory experiments have been done to determine the toxicity of each chemical, a single chemical may have several different toxicity values listed in different reference sources. Therefore, in order to select which reference source to use, we developed the following hierarchy for toxicity value selection.

---

<sup>4</sup> The ESLs do not employ the mutagenic equations.

### **Toxicity Value Hierarchy**

Toxicity value reference sources are presented in Table 3-2. The final toxicity values were selected in the listed order, with the exception being that, if the values in the CalEPA Office of Environmental Health Hazard Assessment (OEHHA) Toxicity Criteria Database are more conservative than the Tier 1 through 3 values, then the OEHHA values are used. In general, priority is given to toxicity values that come from publications that are peer-reviewed, readily available to the public, and are transparent about the methods and assumptions used to develop the values.

<b>Table 3-2 – Toxicity Value Hierarchy</b>	
<b>Tier</b>	<b>Source</b>
1	USEPA Integrated Risk Information System (IRIS)
2	USEPA Provisional Peer Reviewed Toxicity Values (PPRTVs)
3	Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs)
4	OEHHA Toxicity Criteria Database
5	USEPA PPRTV screening toxicity values (in PPRTV appendices)
6	USEPA Health Effects Assessment Summary Table
7	Other sources (e.g., State of New Jersey cancer slope factor for chromium VI)

**Note:**  
For instances where the toxicity values in the OEHHA Toxicity Criteria Database are more protective than Tier 1 or 2 toxicity values, then the OEHHA toxicity values are prioritized.

### **Route Extrapolation**

**Oral to Dermal:** Experiments to determine the toxicity values: SF<sub>o</sub> and RfD<sub>o</sub> are designed to specifically test for oral exposure, however these toxicity values can be used to derive dermal exposure toxicity values. The main difference between oral and dermal exposure is where the chemical is absorbed, either through the internal gastrointestinal (GI) tract or through the external skin, respectively. The oral toxicity values only account for toxicity from the fraction of an oral chemical dose that is absorbed through the GI tract (GIABS) and not the total exposure

amount. Therefore, oral toxicity values must first be adjusted to consider the total exposure amount and then they can be further adjusted to account for dermal absorption using the following factors to predict the amount of chemical (in either contaminated soil or water) that will be dermally absorbed:

- Contaminated Soil
  - **ABS<sub>a</sub>**: Fraction of a chemical dose in soil absorbed through the skin
- Contaminated Water
  - **FA**: Fraction of a dermal chemical dose in water absorbed through the skin
  - **B**: Ratio of a chemical's (in water) dermal permeability coefficients for outer (stratum corneum) relative to inner (viable epidermis) layers of the skin.
  - **K<sub>p</sub>**: Dermal permeability coefficient of a chemical in water through the outer skin layer (stratum corneum).
  - **τ<sub>event</sub>**: time a chemical in water takes to absorb through the skin (aka lag time)
  - **t\***: time to reach a steady state absorption rate of a chemical in water through the skin

These absorption values are also listed in the Input Parameters Table IP-2 in the ESL Workbook and are used to calculate dermal exposure risk levels.

**Oral to Inhalation**: The oral toxicity values can also be used to derive inhalation exposure toxicity values. This method is not as universally accepted as the oral to dermal route extrapolation, so the ESLs do not use extrapolated inhalation toxicity values as a rule (also see the USEPA RSL Frequent Questions). One exception is cis-1,2-dichloroethene which is prevalent throughout our region at sites contaminated with chlorinated solvents.

### 3.2.2 Exposure Factors

The input parameters Table IP-3 in the ESL Workbook give list all exposure factors considered in the calculation of the ESLs. Table 3-3 shows which specific exposure factors are used for each media depending on the land use of a site. Differences in exposure factors used for carcinogenic (C) vs noncarcinogenic (NC) risk calculations are also noted in the table.

Most of the carcinogenic risk levels for the residential ESLs are calculated using age adjusted factors that consider both child and adult exposure over a 26-year period typical for residential scenarios. The ESLs do not currently include multiple age-adjustment factors for the early years (0 – 16 years of age). Equations that can account for multiple developmental stages can be found in the calculations for mutagens in the RSLs.

**Table 3-3 – Exposure Factor Selection**

Table 3-3 – Exposure Factor Selection									
		Residential Land Use				Commercial or Industrial Land Use			
		Tapwater	Soil		Indoor Air	Tapwater	Soil		Indoor Air
			Shallow Exposure	Deep Exposure			Shallow Exposure	Deep Exposure	
Body Weight (BW)		NC: Child C: Age Adj.	NC: Child C: Age Adj.	Adult	--	NC: Child C: Age Adj.	Adult	Adult	--
Surface Area (SA) Exposed Skin	Soil	--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
	Water	NC: Child C: Age Adj.	--	--	--	NC: Child C: Age Adj.	--	--	--
Soil to Skin Adherence Factor (AF)		--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
Ingestion Rate (IR)	Soil	--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
	Water	NC: Child C: Age Adj.	--	--	--	NC: Child C: Age Adj.	--	--	--
Exposure Time (ET)	per day, all media	--	Resident	Worker	Resident	--	Worker	Worker	Worker
	per water event	NC: Child C: Age Adj.	--	--	--	NC: Child C: Age Adj.	--	--	--
Exposure Frequency (EF)		Resident	Resident	Const. Worker	Resident	Resident	Com/Ind Worker	Const. Worker	Com/Ind Worker
Exposure Duration (ED)		NC: Child C: Age Adj.	NC: Child C: Age Adj.	Const. Worker	Age Adj.	NC: Child C: Age Adj.	Com/Ind Worker	Const. Worker	Com/Ind Worker

### 3.2.3 Equations for Health Risk-Based Screening Levels Considering a Single Chemical

#### Noncarcinogenic Risk-Based Goals

- **Ingestion Noncarcinogenic Risk-Based Goals:**

Tapwater Ingestion

$$C_{\text{water}} = \frac{\text{THQ} \times \text{ED}_c \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right) \times \text{BW}_c \times \left( \frac{1000 \mu\text{g}}{1 \text{ mg}} \right)}{\text{EF}_r \times \text{ED}_c \times \left( \frac{1}{\text{RfD}_o} \right) \times \text{IRW}_c}$$

Soil Ingestion

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{ED}_c \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right) \times \text{BW}_c}{\text{EF}_r \times \text{ED}_c \times \left( \frac{1}{\text{RfD}_o} \right) \times \text{IRS}_c \times \left( \frac{10^{-6} \text{ kg}}{\text{mg}} \right)}$$

- **Inhalation Noncarcinogenic Risk-Based Goals:**

Tapwater Vapor Inhalation

$$C_{\text{water}} = \frac{\text{THQ} \times \text{ED}_c \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right) \times \left( \frac{1000 \mu\text{g}}{1 \text{ mg}} \right)}{\text{EF}_r \times \text{ED}_c \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \times \left( \frac{1}{\text{RfC}} \right) \times \text{K}}$$

Soil Gas and Particulate Inhalation

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{ED}_c \times \left( \frac{365 \text{ days}}{\text{year}} \right)}{\text{EF}_r \times \text{ED}_c \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hrs}} \right) \times \left( \frac{1}{\text{RfC}} \right) \times \left( \frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Indoor Air Inhalation

$$C_{\text{air}} = \frac{\text{THQ} \times \text{ED}_r \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right) \times \left( \frac{1000 \mu\text{g}}{1 \text{ mg}} \right)}{\text{EF}_r \times \text{ED}_r \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \times \left( \frac{1}{\text{RfC}} \right)}$$

- **Dermal Noncarcinogenic Risk Based Goals**

Tapwater Dermal Exposure

- Inorganic Chemicals

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{K_p \times ET_{\text{wc}}}$$

- Organic Chemicals

If  $ET_{\text{wc}} \leq t^*$  then, 
$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{2 \times FA \times K_p \times \sqrt{\frac{6\tau \times ET_{\text{wc}}}{\pi}}}$$

If  $ET_{\text{wc}} > t^*$  then, 
$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{FA \times K_p \times \left[ \frac{ET_{\text{wc}}}{(1+B)} + \left( 2\tau \times \frac{(1+3B+3B^2)}{(1+B)^2} \right) \right]}$$

Soil Dermal Exposure

$$C_{\text{water}} = \frac{THQ \times ED_c \times 365 \frac{\text{days}}{\text{year}} \times BW_c}{EF_r \times ED_c \times \left( \frac{1}{RfD_o \times GIABS} \right) \times SA_{sc} \times AF_c \times ABS_d \times \frac{10^{-6} \text{kg}}{\text{mg}}}$$

## Carcinogenic Risk based Goals

- **Ingestion Carcinogenic Risk-Based Goals**

Tapwater Ingestion

$$C_{\text{water}} = \frac{\text{TR} \times \text{LT} \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right) \times \left( \frac{1000 \mu\text{g}}{1 \text{ mg}} \right)}{\text{CSF}_0 \times \text{IFW}_{\text{adj}}}$$

Soil Ingestion

$$C_{\text{soil}} = \frac{\text{TR} \times \text{LT} \times \left( \frac{365 \text{ days}}{\text{year}} \right)}{\text{CSF}_0 \times \text{IFS}_{\text{adj}} \times \left( \frac{10^{-6} \text{ kg}}{\text{mg}} \right)}$$

- **Inhalation Carcinogenic Risk-Based Goals**

Tapwater Vapor Inhalation

$$C_{\text{water}} = \frac{\text{TR} \times \text{LT} \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right)}{\text{EF}_r \times \text{ED}_r \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \times \text{IUR} \times \text{K}}$$

Soil Gas and Particulate Inhalation

$$C_{\text{soil}} = \frac{\text{TR} \times \text{LT} \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right)}{\text{EF}_r \times \text{ED}_r \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \times \text{IUR} \times \left( \frac{1000 \mu\text{g}}{\text{mg}} \right) \times \left( \frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Indoor Air Inhalation

$$C_{\text{air}} = \frac{\text{TR} \times \text{LT} \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right)}{\text{EF}_r \times \text{ED}_r \times \text{ET}_r \times \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \times \text{IUR}}$$

- **Dermal Carcinogenic Risk-Based Goals**

Tapwater Dermal Exposure

➤ Inorganic Chemicals

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{K_p \times ET_{\text{wmadj}}}$$

➤ Organic Chemicals

If  $ET_{\text{wmadj}} \leq t^*$  then, 
$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{2 \times FA \times K_p \times \sqrt{\frac{6\tau \times ET_{\text{wmadj}}}{\pi}}}$$

If  $ET_{\text{wmadj}} > t^*$  then, 
$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{FA \times K_p \times \left[ \frac{ET_{\text{wmadj}}}{(1+B)} + \left( 2\tau \times \frac{(1+3B+3B^2)}{(1+B)^2} \right) \right]}$$

Soil Dermal Exposure

$$C_{\text{soil}} = \frac{TR \times LT \times \left( \frac{365 \text{ days}}{1 \text{ year}} \right)}{\left( \frac{CSFo}{GIABS} \right) \times DFS_{\text{adj}} \times ABS_d \times \left( \frac{10^{-6} \text{ kg}}{\text{mg}} \right)}$$

**Total Cancer or Noncancer Risk: All Pathways**

Final Screening = 
$$\frac{1}{\left( \frac{1}{\text{Ingestion SL}} \right) + \left( \frac{1}{\text{DermalContact SL}} \right) + \left( \frac{1}{\text{Inhalation SL}} \right)}$$

### 3.2.4 Cumulative Risk Considering Multiple Chemicals

Risks posed by direct exposure to multiple chemicals with similar health effects are considered to be additive or cumulative. For example, the total risk of cancer posed by the presence of two carcinogenic chemicals in soil is the sum of the risk posed by each individual chemical. The same is true for chemicals that cause the same type of noncarcinogenic health effect. Ideally, noncarcinogens are grouped according to their mechanism of action, but more commonly they are grouped according to target organ.

At sites where more than one contaminant is present at concentrations greater than their respective ESLs, cumulative cancer risk and noncarcinogenic hazard can be readily calculated as follows:

For cancer risk estimates, divide the site-specific concentration by the ESL that is designated as being based on a cancer endpoint (“ca” or “c”). Sum the ratios for each chemical and multiply the total by  $10^{-6}$  (equation 15 below).

$$\text{Risk} = \left[ \left( \frac{\text{Conc}_a}{\text{ESL}_a} \right) + \left( \frac{\text{Conc}_b}{\text{ESL}_b} \right) + \left( \frac{\text{Conc}_c}{\text{ESL}_c} \right) + \dots + \left( \frac{\text{Conc}_i}{\text{ESL}_i} \right) \right] \times 10^{-6}$$

(equation 15)

For non-cancer hazard estimates, divide the site-specific concentration by the ESL that is designated as based on a non-cancer endpoint “nc” and sum the ratios. While the individual ratio is referred to as a hazard quotient (HQ), the cumulative ratio represents a noncarcinogenic hazard index (HI) (equation 16 below).

$$\text{HI} = \left[ \left( \frac{\text{Conc}_a}{\text{ESL}_a} \right) + \left( \frac{\text{Conc}_b}{\text{ESL}_b} \right) + \left( \frac{\text{Conc}_c}{\text{ESL}_c} \right) + \dots + \left( \frac{\text{Conc}_i}{\text{ESL}_i} \right) \right]$$

(equation 16)

A hazard index of 1 or less is generally considered to be without potential adverse health effects. A hazard index greater than 1 suggests further evaluation is necessary.

- **Additional Consideration for Assessing Cumulative Risk and Hazard**

Calculating cumulative risk and hazard across pathways and media is typically part of a Tier 3 evaluation. In particular, segregation of hazard indices by effect and mechanism of action can be complex and time-consuming because it is necessary to identify all of the major effects and target organs for each chemical and then to classify the chemicals according to target organ(s) or mechanism of

action. This analysis is not simple and should be performed under the oversight of a toxicologist. If the segregation is not carefully done, an underestimate of true hazard could result.

### **3.2.5 Groundwater Specific Exposure Considerations**

Exposure pathways for groundwater are only considered in the ESLs when groundwater is being used as tapwater for common domestic activities such as drinking, bathing/showering, cooking, dishwashing/laundry, and flushing the toilet. The tapwater SLs are conservative enough that most receptors should also be protected from incidental contact with contaminated groundwater in the environment. However, the ESLs designated for groundwater that is not a potential source of drinking water (aka tapwater), do not consider risk from direct water contact for any receptors. This could be a problem if recreation or digging activities are expected to occur at a site that would expose receptors (mostly likely construction workers or residents) to contaminated groundwater.

## **3.3 Other Human Health Risk Criteria**

While the direct exposure soil and indoor air ESLs are solely based on the human health risk-based equations described above, the groundwater ESLs also take into account other regulatory health-based criteria (OEHHA Public Health Goals, Division of Drinking Water Notification Levels, and Division of Drinking Water Public Health Archived Advisory Levels for drinking water). The “Other Health-Based Criteria” value considered in ESL Table W-1, is chosen according to the hierarchy in Table 3-4.

Table 3-4 – Hierarchy for Other Health-Based Criteria for Drinking Water	
Tier	Source
1	OEHHA Public Health Goals
2	Division of Drinking Water <sup>1</sup> Notification Levels
3	Division of Drinking Water Public Health Archived Advisory Levels

**Note:**  
1 - In July 2014, California’s Drinking Water Program was transferred from the California Department of Public Health (CDPH) to the State Water Resources Control Board’s Division of Drinking Water (DDW).

The final health risk-based ESL for groundwater is the lower of the calculated health risk-based levels and the selected “other health-based criteria level.

### 3.4 Exceptions

#### 3.4.1 MCL Priority

California MCLs can be used in place of the health risk-based levels to represent the Basin Plan water quality objectives. MCLs are drinking water standards adopted by the California State Water Resources Control Board, Division of Drinking Water (DDR)<sup>5</sup> pursuant to the California Safe Drinking Water Act. Primary MCLs are derived from health-based criteria, but they also include technologic and economic considerations based on the feasibility of achieving and monitoring for these concentrations in drinking water. The Tier 1 ESLs, (also called MCL Priority) use the most conservative of California primary or secondary MCLs for all chemicals with established MCLs to represent the Basin

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<sup>5</sup> The California Drinking Water Program was transferred from the California Department of Public Health in July 2014.

Plan water quality objectives. For chemicals with no established MCL, the final health-risk based ESL is used.

### 3.4.2 Lead

The risk-based screening levels for soil direct-exposure to lead are 80 mg/kg for residential land use and 320 mg/kg for commercial/industrial land use. They are the same values used for the lead CHHSLs. These levels were calculated using a blood lead model developed by OEHHA (OEHHA 2007) and the DTSC LeadSpread Model (DTSC 2011a) rather than the standard USEPA algorithms. The toxic endpoint used for the blood lead model is based on the relationship between blood-lead levels and cognitive ability; where an increase of 1 microgram per deciliter ( $\mu\text{g}/\text{dL}$ ) in blood lead is calculated as having no more than a 2.5 percent probability of decreasing intelligence quotient by more than 1 point in a child or fetus at the 90th percentile of the blood lead distribution in the general population. The LeadSpread Model was used to estimate the concentration in soil that would lead to a 1  $\mu\text{g}/\text{dL}$  increase in blood lead for people exposed to that soil to calculate the CHHSL for lead in soil (OEHHA 2009). The residential CHHSL of 80 mg/kg is based on exposure to a child resident. The commercial/industrial CHHSL of 320 mg/kg is based on exposure to a pregnant adult worker. The evaluation of lead is discussed in *HERO Human Health Risk Note 3, Issue: DTSC-modified Screening Levels (DTSC-SLs)* (DTSC 2016).

### 3.4.3 Short-Term Exposure Levels: Trichloroethene

The ESLs present screening levels for cancer and non-cancer risks from *chronic* (long term) exposure to chemicals since such levels are generally lower than those for short-term exposure risks. However, for TCE, there is a new concern for adverse effects to developing fetuses from low doses over short exposure periods. On September 28, 2011, the USEPA Integrated Risk Information System (IRIS) published new toxicity criteria for TCE (USEPA 2011b). The most significant changes included a substantial reduction in the values for noncancer inhalation toxicity factors and a change in the noncancer toxicity endpoints (adverse effects on specific parts or functions of the human body).

Adverse noncancer health effects documented for TCE include hepatic, renal, neurological, immunological, reproductive and developmental damage. IRIS selected rodent studies showing adverse effects on the kidneys, the immune system and the developing fetus for the 2011 oral reference dose (RfD). The 2011

inhalation reference concentration (RfC) is based on oral studies. The first two endpoints (kidney and immune system) are chronic (long-term) effects whereas the third (fetal heart malformation) is a developmental effect, which is necessarily the result of a short-term exposure, in this case three weeks during the first trimester of pregnancy. Developmental toxicity has been linked to inhalation of TCE vapors as well as ingestion of TCE-contaminated drinking water with more substantial evidence for the latter.

On July 9, 2014, USEPA Region 9 issued a memorandum entitled *EPA Region 9 Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion* (USEPA 2014d). DTSC also has adopted the response action levels as discussed in *HERO Human Health Risk Assessment Note 5, Issue: Health-Based Indoor Air Screening Criteria for Trichloroethylene (TCE)* (DTSC 2014). The *Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (TCE Framework; Regional Water Board 2014) should be consulted for the integration of these response action levels into our vapor intrusion investigation protocols. In the TCE Framework we have also developed “Trigger Levels” for groundwater and subslab/soil gas concentration that would trigger immediate sampling of indoor air. In the ESL Workbook, when TCE is selected in ESL Table T2-1, the TCE Action Levels and Trigger Levels are shown to the right of the table in red. These levels are also presented in Chapter 4.

The USEPA Region 9 response action levels only address the recent changes regarding the inhalation pathway for TCE. Because fetal heart malformation risk could increase in pregnant women exposed to TCE from contaminated drinking water, exceedance of the noncancer, ingestion ESL for TCE in drinking water (10 µg/L; ESL Table GW-1), warrants more immediate action. The investigation and cleanup of TCE-contaminated groundwater for protection of drinking water resources remains a priority for the Regional Water Board and groundwater cleanup should not be delayed. When TCE is selected in ESL Table T2-1, this drinking water TCE Action Level is also shown to the right of the table in red.

### **3.4.4 Chemical Mixtures**

The ESLs include health-risk-based screening levels for several chemical mixtures or groups. Relevant details regarding the derivation or use of the screening levels are presented in Chapter 9.

### **3.5 Site-Specific Evaluations**

Site-specific evaluations can include quantitative risk assessments (Tier 3) evaluations, development of alternative exposure scenarios (e.g., trespasser), or the relatively minor modification of screening levels by use of non-default exposure factors or fate and transport considerations. Consultation with the overseeing regulatory agency is recommended prior to development of such evaluations.

## 4 Methods: Vapor Intrusion Risk Screening Levels for Groundwater and Subslab/Soil Gas

The vapor intrusion (VI) ESLs account for potential human health risk from direct exposure to contaminated indoor air, where the volatile contamination originates from a subsurface source. The two general receptors considered for such direct exposure are residents and indoor commercial/industrial workers. The groundwater VI ESLs were developed using attenuation factors (AFs) calculated with a hybrid model-empirical approach. The subslab soil gas and deeper or exterior soil gas (subslab/ soil gas) were developed using a model approach that is a component of the Johnson and Ettinger Model (JEM; Johnson and Ettinger 1991). These AFs are primarily intended for existing slab-on-grade buildings, but can also be used for future buildings.

The VI ESLs should be used in conjunction with other VI guidance (Section 4.1.3) and USEPA indoor air response action levels or Regional Water Board trigger levels when dealing with trichloroethene (TCE) contamination (Section 4.3). In addition, alternative approaches including the use of site-specific VI models or tracer testing to estimate site- or building-specific AFs may be necessary at some sites (Section 4.4).

### 4.1 Background

The field of vapor intrusion continues to shift due to continuing scientific research, improvements in guidance, and technology advances. Several contemporary issues are addressed by Siegel (2009) and Kram (2015).

#### 4.1.1 Conceptual Model for Vapor Intrusion into Buildings

There are four components to the transport of contaminated subsurface soil gases into buildings: 1) partitioning from the VOC source (groundwater or soil) into the vapor phase; 2) primarily diffusive vapor transport in the subsurface from the VOC source toward the building; 3) vapor entry via advection into the building; and 4) mixing with air inside a building (indoor air). Further details are provided in *Technical Resource Document: Default Subslab Soil Gas and Soil Gas to*

*Indoor Air Attenuation Factors in the Environmental Screening Levels* (Regional Water Board 2016a; Appendix B).

Near source areas, the VOC vapor source can be vadose zone soil as well as groundwater. However, away from source areas, the VOC vapor source is typically groundwater. For a vadose zone soil VOC source, VOC vapors diffuse upward and concentrations will be reduced (attenuated) due to the nature of diffusion (driven by concentration gradients between the source and discharge location such as a building crack or the atmosphere for bare soil) and subsurface characteristics (e.g., moisture content, soil type). For a groundwater VOC source, diffusion first occurs through the capillary fringe, which has high moisture content and low air content. Consequently, groundwater VOC sources are subject to much greater attenuation than vadose zone soil VOC sources, potentially up to three orders of magnitude (McCarthy and Johnson 1993). Furthermore, the thicker the capillary fringe, which is controlled by grain size (fine-grained soils such as silts and clays have thicker capillary fringes than coarse-grained soils such as sands and gravels), the greater the overall resistance to vapor transport.

#### **4.1.2 CVOC Vapor Intrusion versus Petroleum Vapor Intrusion**

At most sites, chlorinated volatile organic compounds (CVOC) and petroleum hydrocarbons are the main contaminants that pose VI threats. In contrast to CVOCs, petroleum hydrocarbons biodegrade readily under aerobic (oxygenated) subsurface conditions due to microorganisms normally present in soil. Aerobic biodegradation typically reduces the contamination and limits subsurface migration of petroleum vapors in the vadose zone. Such biodegradation has been found to be particularly effective at UST sites such as gas stations (State Water Board 2012a and 2012b). A discussion of the differences between CVOC and petroleum vapor intrusion (PVI)<sup>6</sup> is provided in *Petroleum Hydrocarbons and Chlorinated Solvents Differ in their Potential for Vapor Intrusion* (USEPA 2012b). As a

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<sup>6</sup> USEPA (2015b) defines petroleum vapor intrusion (PVI) as the intrusion of vapors from subsurface petroleum hydrocarbons and non-petroleum hydrocarbon fuel additives into overlying or nearby buildings and structures.

result of these differences, USEPA provides separate guidance documents for CVOC vapor intrusion and PVI:

- *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Source to Indoor Air* (OSWER VI Guide; USEPA 2015a); and
- *Technical Guide for Addressing Petroleum Vapor Intrusion At Leaking Underground Storage Tank Sites* (OUST PVI Guide; USEPA 2015b).

Since the VI ESLs do not account for biodegradation, the ESLs may be overly conservative for petroleum-only release sites. The UST Policy includes PVI scenarios and screening levels for a subset of petroleum compounds.

At some petroleum release sites additional attenuation may not be occurring at a measurable rate due to geochemical conditions and/or mass of contamination (size of release). An analysis of the most appropriate VI approach (CVOC versus PVI) for petroleum release sites can be necessary once there is sufficient subsurface information to understand site conditions. The OUST PVI Guide identifies the following types of petroleum-contaminated sites that USEPA considers not to be comparable to UST sites: “refineries, petrochemical plants, terminals, aboveground storage tank farms, pipelines, and large scale fueling and storage operations at federal facilities), or sites with releases of non-petroleum chemicals including comingled plumes of petroleum and chlorinated solvents regardless of the source.” For these types of petroleum sites, USEPA recommends addressing them using the OSWER VI Guide (USEPA 2015a; USEPA 2015b).

#### **4.1.3 Approaches to Evaluating Vapor Intrusion**

As a consequence of the differences between CVOC VI and PVI and the potential for unique conditions at some number of sites, there are several options to evaluating vapor intrusion. Table 4-1 lists these along with relevant guidance documents.

Table 4-1 – Vapor Intrusion Approaches		
Type of Release	Regional Water Board	Other Relevant Guidance
CVOC (non-petroleum)	TCE Framework	<ul style="list-style-type: none"> <li>OSWER VI Guide</li> <li>DTSC VIG</li> </ul>
Petroleum UST or Similar Petroleum Release Sites	UST Policy VI Criteria	<ul style="list-style-type: none"> <li>Technical Justification for Vapor Intrusion Media-Specific Criteria (State Water Board 2012a)</li> <li>OUST PVI Guide</li> </ul>
Petroleum – Large Release Sites	TCE Framework	<ul style="list-style-type: none"> <li>OSWER VI Guide</li> <li>DTSC VIG</li> </ul>

## 4.2 Attenuation Factors for Vapor Intrusion

Vapor attenuation refers to the reduction in volatile chemical concentrations during vapor transport from the subsurface to indoor air. The AF is a measure of this reduction. The equation for the subslab/ soil gas AF is:

$$AF_{SS\text{ or }SG} = \frac{C_{IA}}{C_{SS\text{ or }SG}} \quad (\text{Equation 4-1})$$

where:  $C_{IA}$  is the mean indoor air concentration (typically  $\mu\text{g}/\text{m}^3$ )  
 $C_{SS\text{ or }SG}$  is the mean subslab or soil gas concentration (typically  $\mu\text{g}/\text{m}^3$ )

Therefore the AF is an inverse measurement of the concentration reduction (attenuation) that occurs as during subsurface transport to indoor air. For instance, an AF of 0.002 corresponds to a 500-times reduction in concentration:  $AF = 1/\text{concentration reduction} = 1/500 = 0.002$ . Larger AFs correspond to less attenuation leading to greater potential for VI impacts, and smaller AFs correspond to more attenuation with lower potential VI impacts.

The AF for groundwater to indoor air is slightly different because the groundwater concentration unit is in  $\mu\text{g}/\text{L}$ . It has to be converted to a vapor concentration ( $\mu\text{g}/\text{m}^3$ ). USEPA (2014) presents the equation as:

$$AF_{GW} = \frac{C_{IA}}{C_{GW} \times H \times \left(\frac{1,000\text{L}}{\text{m}^3}\right)} \quad (\text{Equation 4-2})$$

where:  $C_{IA}$  is the mean indoor air concentration

$C_{GW}$  is the mean groundwater concentration ( $\mu\text{g/L}$ )  
 $H$  is the dimensionless Henry's Law Constant at a specified  
groundwater temperature  
 $L$  is liters  
 $\text{m}^3$  is cubic meters

Conversion of the groundwater concentration to an equivalent vapor equation assumes there is complete equilibrium between groundwater and soil gas. Typically, this is not the case due to the capillary fringe described in Section 4.1.1. Therefore, the use of an equilibrium groundwater concentration as a screening level is usually conservative.

#### 4.2.1 Development of Soil Gas Attenuation Factors

A subslab soil gas AF was derived using a model we define as the climate-adjusted vapor flux approach. This is essentially the vapor-entry-to-building component of the Johnson and Ettinger Model (JEM; Johnson and Ettinger 1991) programmed using Microsoft Excel by USEPA (2004a). This subslab soil gas AF is used to calculate a generic soil gas ESL for both subslab soil gas (subslab) and for non-subslab soil gas (i.e., soil gas samples collected well below the slab or where there are no overlying structures). Table 4-2 lists our subslab/soil gas AFs.

The background and technical justification for this model are presented in the *Technical Resource Document: Default Subslab Soil Gas and Soil Gas to Indoor Air Attenuation Factors in the Environmental Screening Levels* (Regional Water Board 2016a; Appendix B).

<b>Table 4-2 – Subslab and Soil Gas Attenuation Factors for Concrete Slab-on-Grade Buildings</b>		
Land/Building Use	Subslab and Soil Gas Attenuation Factor	Concentration Reduction
Residential	0.002	500
Commercial/Industrial	0.001	1,000

**Note:** For other building foundations (e.g., basements), the overseeing regulatory agency should be consulted. For buildings with crawl spaces, the Regional Water Board employs an AF of 1.0 as discussed in the TCE Framework (Regional Water Board 2014).

## 4.2.2 Development of Groundwater Attenuation Factors

Derivation of the groundwater AF consisted of:

1. Development of appropriate scenarios based on depth to groundwater and soil layer design; and
2. Calculation of chemical-specific groundwater AF using the appropriate version of the JEM.

The model versions used include the one-layer or screening version of the groundwater JEM (GW-SCR) modified by DTSC-HERO (2014), and the three-layer or advanced version of the groundwater JEM (GW-ADV; USEPA 2004a). The latter has been updated to be consistent with ESL toxicity values and the physical and chemical constants that DTSC-HERO adapted from the USEPA RSLs in the GW-SCR model. Appendix C includes a copy of model runs for PCE and a table of input parameters for each groundwater VI scenario in Table 4-3 for both a residential building and a commercial/industrial building.

Table 4-3 – Groundwater Vapor Intrusion Scenarios for Existing Residential and Commercial/Industrial Buildings		
Depth to Groundwater (feet bgs)	Coarse-Grained Soil (sand or gravel)	Fine-Grained Soil (silt or clay)
Shallow (≤10 feet bgs)	Shallow Sand Scenario <sup>1</sup>	
Deep (>10 feet bgs)	Deep Sand Scenario <sup>2</sup>	Fine-Coarse Scenario <sup>3</sup>

**Notes:**

**1 – Shallow Sand Scenario** (GW-SCR JEM) – Use if first groundwater is shallow (≤10 feet bgs) and predominantly coarse-grained soils or if high likelihood of preferential pathways (manmade or natural). This scenario is the default Tier 1 scenario.

**2 – Deep Sand Scenario** (GW-SCR JEM) – Use if first groundwater is deep (>10 feet bgs) and predominantly coarse-grained soils and lower likelihood of preferential pathways.

**3 – Fine-Coarse Scenario** (GW-ADV JEM) – Use if first groundwater is deep (>10 feet bgs) and there is a continuous fine-grained soil layer(s) at the water table with a low likelihood of preferential pathways. This scenario can also be used for sites with predominantly fine-grained soils or layers if consistent with the CSM. This scenario was developed using a hybrid model/empirical approach described in the text.

The Sand Scenarios (shallow and deep groundwater) are applied in cases of predominantly coarse soils or where the likelihood of manmade or natural preferential pathways is high. The Sand Scenario screening levels are developed using the JEM (DTSC-HERO December 2014 GW-SCR version) with sand as the only soil type and a 5-foot depth to groundwater (shallow) or 10-foot depth to groundwater (deep). Regional Water Board staff considers that preferential

pathways<sup>7</sup> responsible for minimal attenuation of contaminant vapors are more likely to be present and affect vapor transport in the upper 10 feet of soil. As the user will observe, the additional 5 feet of sand in the Deep Sand scenario does not provide much additional attenuation.

The Fine-Coarse Scenario is appropriate if groundwater is deep (>10 feet bgs) and there is a continuous fine-grained soil layer(s)<sup>8</sup> at the water table with a low likelihood of preferential pathways. This scenario can also be used for sites with predominantly fine-grained soils or layers if consistent with the CSM. This scenario was developed using a hybrid model-empirical approach between 1999 and 2005. The process of developing the fine-coarse scenario was iterative over several years. This process involved the identification of input parameters sufficiently representative of the general site conditions found in the San Francisco Bay region while also resulting in calculated values that are consistent with empirical data collected from sites in the region.

#### **4.2.3 Site-Specific Attenuation Factors for Vapor Intrusion**

Site-specific vapor intrusion models are typically used to evaluate the potential for site conditions to have greater attenuation (smaller AFs) than provided by using the ESLs. These models can be used for sites with existing or future buildings. The model most commonly used is the JEM. Regional Water Board staff developed recommendations for use of the JEM to ensure consistency and facilitate review of modeling reports. The recommendations are included in Appendix D. The TCE Framework discusses how Regional Water Board staff evaluates and weighs the results of models in the multiple lines of evidence approach.

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<sup>7</sup> Preferential pathway types include: natural (conduits created by sand lenses, fractures, or desiccation cracks), manmade (utility lines or associated backfill), or building-specific (below-ground features or significant openings).

<sup>8</sup> The presence of a continuous fine-grained layer (e.g., wet clay) can act as a significant barrier to vertical vapor migration, but the effect dissipates quickly at distances close to the clay layer's termination point (Bozkurt et al. 2009).

Alternatives to models include tracer testing to derive building-specific AFs and site-specific AFs developed from empirical data (McHugh et al. 2004; McHugh et al. 2007; McHugh et al. 2008; King et al. 2010; DTSC 2011; USEPA 2015). As discussed in the *Technical Resource Document: Default Subslab Soil Gas and Soil Gas to Indoor Air Attenuation Factors in the Environmental Screening Levels* (Regional Water Board 2016a; Appendix B), Regional Water Board does not accept building-specific attenuation factors based on a single pair of subslab and indoor air samples due to the spatial variability previously discussed. Rather, per McHugh et al. (2007), all data should be used to develop a single attenuation factor for a building.

### **4.3 TCE Vapor Intrusion Trigger Levels for Indoor Air Sampling**

As discussed in Chapter 3, USEPA Region 9 developed ARALs and URALs, which are TCE indoor air response action levels for both residential and commercial exposure scenarios intended to protect women of reproductive age. In the TCE Framework, the Regional Water Board calculated concentrations for TCE in soil gas and groundwater to prioritize indoor air sampling due to concerns regarding potential TCE short-term effects. These values do not supplant the appropriate ESLs for evaluating the potential for chronic effects. Rather they are a prioritization tool for indoor air sampling. Most VI site investigations follow the stepwise approach, starting with the collection of soil, soil gas and groundwater data and then moving towards subslab soil gas and indoor air sampling later in the process. The Trigger Levels are intended to prioritize indoor air sampling when the potential threat level may be high enough to exceed the ARALs. The Trigger Levels are based on the noncancer hazard; that is, the target concentrations are the indoor air ARALs (2  $\mu\text{g}/\text{m}^3$  and 8  $\mu\text{g}/\text{m}^3$  for residential and commercial/ industrial exposure scenarios, respectively). The USEPA response action levels and Regional Water Board Trigger Levels are listed on Table 4-4.

**Table 4-4 – TCE ESLs, Action Levels for Indoor Air (Response), and Groundwater and Soil Gas Trigger Levels (Sample Indoor Air)**

Medium	Residential				Commercial/Industrial			
	Cancer Risk ESL	Noncancer Hazard ESL	Lowest ESL	Trigger and Action Levels	Cancer Risk ESL	Noncancer Hazard ESL	Lowest ESL	Trigger and Action Levels
Indoor Air (IA) (µg/m <sup>3</sup> )	0.68	2.1	0.68	2.0 Accelerated Response <sup>1</sup>	3.0	8.8	3.0	8.0 Urgent Response <sup>1</sup>
Subslab/ Soil Gas* (µg/m <sup>3</sup> )	300	1,100	300	1,000 Sample IA	3,000	8,800	3,000	8,000 Sample IA
Shallow GW (µg/L) Sand Scenario <sup>2</sup>	5.6	17	5.6	17 Sample IA	49	140	49	140 Sample IA
Deep GW (µg/L) Sand Scenario <sup>3</sup>	6.9	21	6.9	21 Sample IA	60	180	60	180 Sample IA
Deep GW (µg/L) Fine-Coarse Scenario <sup>4</sup>	170	520	170	520 Sample IA	1,500	4,400	1,500	4,400 Sample IA

**Notes:**

- 1 – Response Action Levels – The Accelerated Response Action Levels (ARALs) and Urgent Response Action Levels (URALs) are USEPA-specified concentrations in indoor air that prompt immediate response actions to reduce exposure (for information on response actions and timing of responses see the Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region; Regional Water Board October 2014).
  - 2 – Shallow Sand Scenario – Use if first groundwater is shallow (≤10 feet bgs) and predominantly coarse-grained soils or if high likelihood of preferential pathways (manmade or natural). This scenario is the default Tier 1 scenario.
  - 3 – Deep Sand Scenario – Use if first groundwater is deep (>10 feet bgs) and predominantly coarse-grained soils and lower likelihood of preferential pathways.
  - 4 – Fine-Coarse Scenario – Use if first groundwater is deep (>10 feet bgs) and there is a continuous fine-grained soil layer(s) at the water table with a low likelihood of preferential pathways. This scenario can also be used for sites with predominantly fine-grained soils or layers if consistent with the CSM.
- \* – ESLs and Trigger Levels for soil gas vary slightly due to different exposure factors with the USEPA ARALs/URALs and the ESLs.

## 5 Methods: Ecotoxicity Aquatic Habitat Screening Levels for Groundwater

The default conceptual site model for the Tier 1 ESLs assumes that groundwater could discharge into a body of surface water and impact aquatic habitats; either through downgradient migration of groundwater through porous soils or due preferential pathways (e.g., discharge via a storm drain). Therefore groundwater ecological toxicity screening levels are based on criteria for surface water receptors and bioaccumulation toxicity data for human ingestion of seafood from contaminated surface water habitats. The implied point of compliance is near the edge of the surface water body where chemicals in groundwater begin to discharge or intermix with surface water. This approach does not consider dilution or attenuation of groundwater upon discharge to surface water because benthic organisms may be exposed to the full concentration of chemicals in groundwater prior to mixing with surface water.

The criteria are presented in ESL Tables IP-5 (California levels), IP-6 (USEPA levels) and IP-7 (California Toxics Rule seafood ingestion bioaccumulation levels). The lower of the seafood ingestion ESL and the freshwater and saltwater aquatic receptor toxicity ESLs (described below) is used as the final ecological aquatic habitat ESL.

### 5.1 Aquatic Receptor Toxicity Criteria

Toxicity criteria for both freshwater and saltwater receptors are considered for the final ecological aquatic habitat ESL. The lower of the two screening levels should be used when the habitat is influenced by both freshwater and saltwater sources, as is the case for estuarine habitats found in the San Francisco Bay Area. The **primary sources** of data for surface water toxicity criteria, specific to California, listed in ESL Table IP-5 are:

- the Basin Plan (Regional Water Board 2013);
- the California Toxics Rule (USEPA 2000); and,
- *A Compilation of Water Quality Goals* (State Water Board 2015).

**Other sources** listed in ESL Table IP-6 include the following:

- USEPA *Ecotox Thresholds* (USEPA 1996a);
- USEPA National Recommended Water Quality Criteria (USEPA 2002a);

- U.S. Department of Energy (USDOE) *Preliminary Remediation Goals for Ecological Endpoints* (USDOE 1997); and,
- Ontario Ministry of Environment and Energy (MOEE) *Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria* (MOEE 1996).

For each chemical, a final chronic and acute toxicity level for both freshwater and saltwater receptors is selected in the workbook calculation ESL Table GW-2. The chronic level is the lower of the Basin Plan objective versus a “Chronic Goal” level which is selected using the hierarchy, shown in Table 5-1. If no chronic level is available, 10% of an acute level is used instead.

Table 5-1 – Aquatic Receptor Toxicity Value Hierarchy	
Tier	Chronic Source
1	CTR CCC
2	USEPA CCC
3	Lowest of: a) USEPA AWQC; b) FCV Threshold Value (or the Tier II value cited in the Ecotox Thresholds if no AWQC or FCV); or 3) 50 percent USEPA Chronic LOEL
4	USDOE Chronic PRG
5	50 percent MOEE Chronic AWQC or LOEL
Tier	Acute Source
1	CTR CMC
2	USEPA CMC (or Acute LOEL if no CMC)
3	Other aquatic water quality criteria (LC50)
<b>Abbreviations:</b> AWQC – USEPA Ambient water quality criteria CCC – Criterion Continuous Concentration CMC – Criterion maximum concentration CTR – California Toxics Rule (USEPA 2000) Ecotox – USEPA Ecotox Thresholds (USEPA 1996a) FCV – Final chronic value LC50 – Lethal concentration that kills 50% of the population. LOEL – Low observed effects level USDOE – US Department of Energy PRG – USDOE Preliminary Remediation Goal (USDOE 1997) MOEE – Ontario Ministry of Environment and Energy	

## 5.2 Exceptions

- Barium – The USEPA Ecotox goal for barium (3.9 µg/L; USEPA 1996a) was excluded as a screening level in ESL Table IP-6 and not included in the lookup table for groundwater due to low confidence in the goal.
- Chemical-specific USDOE Preliminary Remediation Goals (USDOE 1997) are used in place of USEPA chronic LOELs when the LOEL was developed for a general group of compounds rather than a specific chemical.
- Selenium – The surface water goals for selenium in ESL Table IP-6 are from the California Toxics Rule as promulgated in 40 Code of Federal Regulations Part 131: *Water Quality Standards, Establishment of Numerical Criteria for Priority Toxic Pollutants for the State of California* (USEPA 2000). However, goals for selenium are based on total recoverable, rather than dissolved, concentrations

## 5.3 Site-Specific Evaluations

For sites where groundwater concentrations exceed the ecological aquatic habitat ESLs, site-specific evaluations for groundwater discharge to surface water and impact to aquatic habitats can be performed. In general a multiple lines-of-evidence approach becomes necessary the closer the site is to a surface water body and becomes increasingly subject to surface water influence. Similarly, proximity to surface water can necessitate implementation of near-shore hydrogeologic investigations. Options for site-specific evaluations include:

- Evaluation of background concentrations of metals in groundwater – Background concentrations of barium, boron, copper, lead, mercury, selenium, thallium, and zinc have been reported in excess of the groundwater aquatic habitat ESLs in the Bay Area and may be excluded from further consideration depending on site-specific conditions.
- Fate and transport modeling (e.g., development of dilution-attenuation factors).
- Site-specific, chronic aquatic toxicity testing using appropriate species, lethal and sublethal endpoints, and contaminated site groundwater. Similar to the Regional Water Board's National Pollutant Discharge Elimination System (NPDES) permits, it may be considered important to

include a sensitive species (e.g., *Americamysis bahia*) in the testing program. In addition, consideration should be given to testing of the early life stage as well as the full life-cycle.

- Near-shoreline hydrogeologic investigations – These typically are performed in conjunction with modeling (validation) and consist of identifying groundwater discharge zones, sampling or monitoring groundwater/sediment porewater in those zones, and estimating mass discharge (Chadwick and Hawkins 2008, Washington Department of Ecology 2009). The default point of compliance for groundwater is the area outside the influence of the water body (i.e., where the chemistry reflects contaminated groundwater rather than surface water). These investigations can also be targeted to understand the presence of the hyporheic zone and its attenuation potential (Landmeyer et al. 2010).

The hyporheic zone, where present, is the saturated sediment zone beneath and adjacent to a surface water body where the surface water readily exchanges. It's an important area of biogeochemical cycling of nutrients, and provides habitat and refugia for a range of organisms. Landmeyer et al. (2010) studied the attenuation (concentration reduction) of oxygenates in four different hyporheic zones and found that attenuation was primarily the result of physical processes such as dilution and dispersion. There was a small contribution in attenuation by biodegradation. While some contaminant degradation may be enhanced within this zone, there is also potential for contaminant accumulation due to organic-rich sediments resulting in toxicity to benthic organisms, which form the base of the food chain. The hyporheic zone can be damaged by the construction of shoreline improvements (e.g., seawalls) or filling (Environment Agency 2009). It is not appropriate to assume contaminant degradation will occur to a sufficient degree within the hyporheic zone to avoid benthic organism toxicity and contaminant discharge without site-specific evidence.

## 6 Methods: Leaching to Groundwater Screening Levels for Soil

Soil screening levels for protection of groundwater are intended to address potential leaching of chemicals from vadose-zone soils and subsequent migration to groundwater. The soil screening levels are back-calculated based on target groundwater screening levels for each groundwater use:

- Drinking Water: Tier 1 Groundwater ESLs
- Nondrinking Water: Lowest of the ecological aquatic habitat screening level, gross contamination water screening level, groundwater vapor intrusion screening level and non-drinking water odor nuisance screening level.

The groundwater vapor intrusion screening level input for ESL Table S-2 is selected solely from the default shallow groundwater/any soil type residential scenario. For the deep groundwater with fine-coarse soil type or different land use, a manual calculation of the Soil Leaching to Groundwater ESL would be necessary. Instructions for the manual calculation are included in Appendix B.

Leaching-based screening levels were generated only for chemicals considered to be significantly soluble and mobile in groundwater under normal, ambient conditions (pH 5.0 to 9.0 and normal redox conditions). Leaching-based soil screening levels were not developed for metals. Leaching of metals from soil is highly dependent on the species of the metal present and the geochemical nature of the soil. At sites where physical-chemical conditions may promote enhanced leaching of metals and other chemicals from soils or waste piles, the use of laboratory-based leaching tests is recommended.

### 6.1 Calculation of Soil Leaching Screening Levels

Computer applications, SESOIL and AT123D, were combined to develop an algorithm (eq. 9a) to model leaching of chemicals from the vadose zone and subsequent migration of the leachate to groundwater, respectively. This algorithm was originally developed by the state of Oregon (Anderson 1992), slightly modified for use by the Massachusetts DEP (MADEP 1994) and then incorporated into the MOEE lookup table guidance (MOEE 1996).

$$C_{\text{soil}} = \text{DAF} \times C_{\text{gw}} \times 0.001 \text{ mg}/\mu\text{g} \quad (\text{equation 9a})$$

$$\text{DAF} = (6207 \times H) + (0.166 \times K_{\text{oc}}) \quad (\text{equation 9b})$$

where:

$C_{\text{soil}}$	=	leaching based soil concentration (mg/kg);
DAF	=	SESOIL-based dilution-attenuation factor;
$C_{\text{gw}}$	=	target groundwater screening level ( $\mu\text{g}/\text{L}$ ).
H	=	Henry's Law Constant ( $\text{atm}\cdot\text{m}^3/\text{mol}$ );
$K_{\text{oc}}$	=	organic carbon partition coefficient ( $\text{cm}^3/\text{g}$ );

The final soil leaching screening levels were calculated using the above empirical equation. However, for highly sorptive chemicals the screening levels were set to the chemicals' theoretical soil saturation. Highly sorptive chemicals are identified if both of the following chemical specific criteria are true:

- Calculated  $C_{\text{soil}} > 0.001$
- $K_{\text{oc}} > 30,000 \text{ cm}^3/\text{g}$

The  $K_{\text{oc}}$  threshold of  $30,000 \text{ cm}^3/\text{g}$  for designating chemicals as highly sorptive is based on modeling carried out by the Hawai'i Department of Health (HDOH 1995). HDOH used the SESOIL model with input values for annual rainfall (400 cm/year or 158 inches/year), infiltration rate (144 cm/year or 57 inches/year), and permeable soil overlying fractured bedrock. These input values are much larger than are expected in California, and therefore use of this threshold  $K_{\text{oc}}$  value for determination of highly sorptive chemicals in California is conservative.

### 6.1.1 Specific Model Calculation Inputs

SESOIL models the generation and downward migration of leachate in the vadose zone. The AT123D application models the mixing of leachate with groundwater immediately below the contaminated area. A more detailed discussion of the derivation and application of the SESOIL/AT123D algorithm as modified by the Massachusetts DEP and adopted for use by the MOEE is provided in MOEE (1996) and MADEP (1994). The algorithm is based on a three-meter thick vadose zone characterized by one meter of contaminated soil between two one-meter thick layers of clean soil (Table 6-1). The lower layer immediately overlies groundwater. All vadose-zone soil is conservatively assumed to be very permeable sand that freely allows the migration of leachate to groundwater. The organic carbon content of the soil is assumed to be

0.1 percent. Mixing with groundwater is modeled over a 10-meter by 10-meter area. Use of a thicker sequence of contaminated soil would not significantly alter the results of the model given the assumed 1-meter depth to groundwater.

<b>Table 6-1 – Soil Leaching to Groundwater Model Design</b>	
Soil Depth	Modeled Soil Type
0 to 1 meter bgs	Clean Sand
1 to 2 meters bgs	Contaminated Sand
2 to 3 meters bgs	Clean Sand
3 meters bgs	Water Table

Annual rainfall is assumed to be 1,100 mm (approximately 43 inches). A total of 720 mm (28 inches) of the total rainfall is assumed to infiltrate the ground surface and reach groundwater (conservative for most portions of the San Francisco Bay Area where a Mediterranean climate is prevalent). Biodegradation during migration of leachate to groundwater is not considered. The model does allow for resorption and re-volatilization of chemicals from the leachate during migration based on the physical-chemical properties of the chemical and the assumed soil properties. Groundwater is assumed to flow at a moderate rate of approximately 73 meters (240 feet) per year. The concentration of a chemical in leachate is assumed to be further reduced upon mixing of the leachate with groundwater using a dilution factor of approximately 3.

For moderately volatile and sorptive chemicals, screening levels developed using the SESOIL-derived algorithm are similar to screening levels generated using the full SESOIL application under a scenario where contaminated soil is within a few meters of groundwater (HDOH 1995). Comparison to screening levels developed using SESOIL suggests that the simplified algorithm may be conservative in the following cases:

- Leaching of highly volatile chemicals;
- Leaching of highly sorptive chemicals;
- Leaching of highly biodegradable chemicals;
- Sites where the depth to groundwater is greater than 10 meters below the bottom of the contaminated soil.

As the distance between the base of contaminated soil and groundwater increases, there is additional time and area for chemicals to volatilize out of the leachate, resorb to soil particles or degrade by naturally occurring biological processes. Site-specific evaluation of the potential for leaching of chemicals from soil may be warranted in such cases (including more rigorous modeling, laboratory leaching tests, and groundwater monitoring).

Although these soil leaching screening levels could be applied to saturated soil, there should be a reasoned analysis of potential limitations. For instance, laboratory analysis of soil samples collected beneath the water table will detect both contaminants sorbed to the soil matrix as well as dissolved in groundwater. Away from source areas, saturated zone soil samples may be detecting the groundwater plume. Application of these screening levels to that situation may not be helpful.

## **6.2 Exceptions**

### **6.2.1 Pentachlorophenol and Bis(2-ethylhexyl)phthalate**

Pentachlorophenol and bis(2-ethylhexyl)phthalate (aka di(2-ethylhexyl)phthalate or DEHP) are significantly more soluble than other highly sorptive chemicals. Leaching-based screening levels for these chemicals were developed using only the SESOIL algorithm described above.

### **6.2.2 Polychlorinated Biphenyls (PCBs)**

Based on our experience, the majority of PCB mixture releases identified in the Bay Area have been Aroclor mixtures 1242, 1254, or 1260. The default  $K_{oc}$  of 33,000  $\text{cm}^3/\text{g}$  presented in ESL Table S-2 was considered to be adequately conservative for this range and used in the leaching model. For less chlorinated PCB mixtures, a site-specific evaluation of potential leaching concerns and possible vapor emission concerns is required.

### **6.2.3 Perchlorate**

A leaching-based soil screening level was developed for perchlorate ( $\text{ClO}_4^-$ ). Perchlorate is a salt, and is not sorptive, volatile or biodegradable under normal conditions. Use of the SESOIL/AT123D algorithm was therefore not considered

appropriate. As an alternative, the simple, chemical partitioning model presented in the USEPA Soil Screening Level Guidance document (USEPA 1996b) was used:

$$C_{\text{soil}} = C_{\text{water}} \times \left( (K_{\text{oc}} \times f_{\text{oc}}) + \left( \frac{\theta_w + (\theta_a \times H')}{\rho_b} \right) \right) \times \text{DAF} \quad (\text{Equation 10a})$$

where:

$C_{\text{soil}}$	=	soil screening level for leaching concerns (mg/kg);
$C_{\text{water}}$	=	target dissolved-phase concentration of chemical (mg/L);
$K_{\text{oc}}$	=	sorption coefficient;
$f_{\text{oc}}$	=	fraction organic carbon in soil;
$\theta_w$	=	water-filled porosity;
$\theta_a$	=	air-filled porosity;
$H'$	=	dimensionless Henry's Law constant;
$\rho_b$	=	soil bulk density (g/cm <sup>3</sup> );
DAF	=	dilution/attenuation Factor

This model can be used to back-calculate the total soil concentration of a chemical based on a target dissolved-phase concentration of the chemical in the soil (i.e., concentration in leachate). For perchlorate,  $K_{\text{oc}}$  and  $H'$  are presumed to be zero and the equation reduces to:

$$C_{\text{soil}} = C_{\text{water}} \times \left( \frac{\theta_w}{\rho_b} \right) \times \text{DAF} \quad (\text{Equation 10b})$$

The default water-filled porosity in the models is 0.15 and the default soil bulk density is 1.5.

### 6.3 Site-Specific Evaluations

For sites where groundwater is relatively shallow, the most direct approach to evaluating soil leaching to groundwater is to conduct a groundwater investigation. However, if the depth to groundwater is deep, site-specific evaluations might include fate and transport modeling and/or simulated leaching tests performed in a laboratory.

Site-specific evaluations of soil contaminant leachability can include groundwater sampling or column leaching tests.

For instance, DAFs that address mixing of contaminants leached from soil with groundwater can be calculated using equations provided in the USEPA *Soil Screening Guidance: Technical Background Document* (USEPA 1996b) or other sources. For the Bay Area, simple leachate/groundwater mixing DAFs for shallow aquifers would typically fall in the range of 5 for silty soils to 20 for sandy soils, assuming a 2 meter thick shallow aquifer, 30 percent effective porosity, infiltration rate of 8 centimeters per year (3 inches/year or approximately 15 percent of total, average rainfall), and hydraulic conductivities of 2 meters per day and 15 meters per day, respectively. Potentially less conservative DAFs that also address adsorption, volatilization and other factors can be calculated using more rigorous models (e.g., SESOIL). Consultation with the overseeing regulatory is recommended before implementing such an evaluation.

For laboratory leaching tests, the more common approaches include the Synthetic Precipitation Leachate Procedure (USEPA Method 1312) or the California Waste Extraction Test modified with an alternative extractant such as deionized water, rainwater (pH adjusted and buffered), or groundwater.

# 7 Methods: Gross Contamination Screening Levels for Groundwater and Soil

Gross contamination screening levels are intended to restrict the presence of potential non-aqueous phase liquid (NAPL; aka “free product”) and limit the overall degradation of both groundwater and soil quality.

## 7.1 Media Specific Gross Contamination Approach

The gross contamination screening levels were determined for each media as follows:

- **Groundwater:** one-half the solubility of a chemical and a maximum of 50,000  $\mu\text{g/L}$  for any chemical based on general resource degradation concerns (ESL Table GW-4, after MADEP 1994).
- **Soil:** The theoretical saturation level of a chemical in soil ( $C_{\text{sat}}$ ; ESL Table S-3) is used as the gross contamination soil ESL, except for the TPH mixtures (see below).  $C_{\text{sat}}$  corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil pore air have been reached (USEPA 1996). Above this concentration, the soil contaminant may be present as NAPL. The primary intent of  $C_{\text{sat}}$  is for calculating the volatilization factor employed in the algorithm for inhalation of volatiles exposure pathway for soil direct contact screening levels. At  $C_{\text{sat}}$ , the emission flux from soil to air for a chemical reaches a plateau. Volatile emissions will not increase above this level no matter how much more chemical is added to the soil.

## 7.2 Exception: Total Petroleum Hydrocarbon Mixtures

Our values for TPH-mixture solubility are based on Shiu et al. (1990). The value for TPH-diesel is used as a surrogate for TPH-Stoddard solvent.

For complex mixtures of chemicals such as TPH,  $C_{\text{sat}}$  significantly underestimates the concentration where there is mobile or migrating NAPL because it does not consider effective solubility or vapor pressure (Brost and DeVaul 2000). For TPH

mixtures in soil, **residual saturation ( $S_r$ )** is more useful as a gross contamination screening level because it represents the concentration above which NAPL in soil may be mobile or migrating (i.e., free product).

In and near the actual release locations (i.e., source areas), some proportion of migrating or mobile NAPL (free product) becomes adsorbed in soil pores through which it travels. This is referred to as **residual NAPL**, and it is bound and immobile in soil because of capillary forces. It also can be referred to as discontinuous NAPL (USEPA 1995). Eventually, after the leak or release has stopped, the migrating or mobile NAPL becomes depleted and what remains is relatively immobile residual NAPL held by capillary tension in soil pore spaces. Residual NAPL in soil poses a risk in its immediate vicinity (USEPA 1999), and it can sustain groundwater plumes through dissolution and vapor plumes through volatilization.

Residual saturation is dependent on many factors related to the characteristics of the mixture (e.g., viscosity, density) and soils (e.g., pore sizes) (USEPA 1995). In finer-grained soils, residual saturation is higher because there is greater surface area for capillary forces to hold NAPL in place. Brost and DeVaul (2000) provide a discussion of residual saturation and provide values for TPH gasoline, TPH diesel, and TPH motor oil based on a range of soil textures. For the gross contamination soil ESLs for TPH mixtures, the lowest (most conservative) values of  $S_r$  are used: 1,000 mg/kg (TPH gasoline); 2,300 mg/kg (TPH Stoddard solvent and TPH diesel; note the TPH diesel value is used as a surrogate for TPH Stoddard solvent); and 5,100 mg/kg (TPH motor oil). Site-specific evaluations of residual saturation can be conducted (USEPA 1996).

# 8 Methods: Taste and Odor Nuisance Screening Levels for All Media

## 8.1 Groundwater Taste and Odor Nuisance Levels

The Basin Plan defines the beneficial uses of municipal and domestic water supply to include protection against unpleasant odors and tastes.

### 8.1.1 Groundwater: Drinking Water Resource

ESL Table GW-5 presents nuisance – taste and odor levels for groundwater which also apply to surface water. These screening levels are for groundwater (or surface water) that is considered to be a current or potential source of drinking water and are based on the chemical’s taste and odor threshold which were selected using the hierarchy presented in Table 8-1.

Table 8-1 – Hierarchy of Taste and Odor Thresholds for Groundwater and Surface Water	
Tier	Source
1	Division of Drinking Water <sup>1</sup> Secondary MCLs;
2	USEPA Secondary MCLs
3	Division of Drinking Water Taste and Odor Action Levels
4	Taste and odor levels developed by Amoores and Hautala (as presented in <i>A Compilation of Water Quality Goals</i> (State Water Board 2016))
5	Odor thresholds presented in Massachusetts DEP (MADEP 1994) and Ontario MOEE (MOEE 1996) guidance documents
<p><b>Note:</b>            1 – In July 2014, California’s Drinking Water Program was transferred from the California Department of Public Health (CDPH) to the State Water Resources Control Board’s Division of Drinking Water (DDW).</p>	

### 8.1.2 Groundwater: Non-Drinking Water Resources

Screening levels for groundwater (and surface water) resources that are not considered to be a current or potential source of drinking water are based on nuisance odor threshold values (Table IP-1). Nuisance odor thresholds are intended to reflect the concentration at which a chemical in water poses unacceptable odor problems. Thresholds presented in the MADEP and MOEE guidance documents were used as the primary sources of data. Taste and odor levels developed by Amoores and Hautala (in State Water Board 2016) were referred to for chemicals that lack odor thresholds in the MOEE guidance. It is apparent that similar sources were used to develop both the MOEE and the Amoores and Hautala databases.

## 8.2 Soil Odor Nuisance Levels

Odor nuisance levels for soil are presented in Table S-4. A chemical's potential to cause nuisance odors is dictated by both the chemical's volatility and the potency of its odor. A chemical's vapor pressure (in Torr, at 20-30 degrees Celsius) can be used to assess its relative volatility and its odor recognition threshold can be used to assess the relative potency of the chemical's odor. Dividing a chemical's vapor pressure by its 50th percentile odor-recognition thresholds (the level at which half of the population can detect the odor) as published in the ATSDR Toxicological Profiles<sup>9</sup> and other references (MOEE 1996; MADEP 1994; U.S. Department of Health and Human Services 2001) produces an "Odor Index" value that gives a relative ranking of a chemical's potential to cause nuisance odors. This relative ranking of chemicals allowed the assignment of Land Use specific upper limit soil contamination levels depending on the Odor Index and vapor pressure values of a chemical using the criteria shown in Table 8-2. These upper limit levels were used as the final nuisance-odor soil ESLs.

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<sup>9</sup> <http://www.atsdr.cdc.gov/toxprofiles/index.asp>

<b>Table 8-2 – Criteria for Assignment of Odor Upper Limit Levels for Soil</b>		
Land Use	Odor and Volatilization Criteria	Upper Limit Level (mg/kg)
<b>Shallow Soil</b>		
Residential	Odor Index $\geq 100$ OR Vapor Pressure $\geq 1$ Torr	100
	$0.1 \leq$ Odor Index $< 100$	500
	Odor Index $\leq 0.1$	1,000
Commercial/ Industrial	Odor Index $\geq 100$ OR Vapor Pressure $\geq 1$ Torr	500
	$0.1 \leq$ Odor Index $< 100$	1,000
	Odor Index $\leq 0.1$	2,500
<b>Deep Soil</b>		
Any Land Use, Deep Soil Exposure Scenario	Odor Index $\geq 100$ OR Vapor Pressure $\geq 1$ Torr	500
	$0.1 \leq$ Odor Index $< 100$	1,000
	Odor Index $\leq 0.1$	2,500

### 8.3 Indoor Air and Soil Gas Odor Nuisance Levels

Odor-based ESLs for indoor air are also based on the 50 percent odor-recognition thresholds describe for soil screening levels. For soil gas, the 50 percent odor thresholds were divided by an attenuation factor of 0.002 (or 1:500) to calculate a screening level. This attenuation factor is the same as the attenuation factor used for evaluating soil gas vapor intrusion into residential indoor air (Chapter 4).

## 9 Methods: Chemical Mixtures or Groups

The ESL Workbook primarily includes screening levels for individual chemicals, but there are also some screening levels for chemical mixtures or groups of - related compounds. Pertinent details relevant to use of the screening levels for these mixtures are presented in this section because the screening levels are either: (1) derived differently or (2) used differently (e.g., laboratory results may need to be aggregated differently for proper comparison).

### 9.1 Chlordane

Chlordane was used as a pesticide in the United States from 1948 to 1988 (ATSDR 1994). Chlordane is not a single chemical, but is a mixture of many related chemicals, of which about 10 are major components. Some of the major components are trans-chlordane, cis-chlordane,  $\beta$ -chlordene, heptachlor, and trans-nonachlor.

The ESLs for chlordane are based on the technical grade chlordane chemical mixture (CAS 57-74-9). Some laboratory analytical methods will either analyze the chlordane mixture as a whole, or individual chlordane isomers separately (e.g., cis- and trans- isomers in USEPA Method 8080). The chlordane mixture (CAS 57-74-9) result should be used to compare to the chlordane ESL. Note that the ESLs employ the CAS number for chlordane listed in the OEHHA Toxicity Criteria Database (CAS 57-74-9) whereas the RSLs use CAS 12789-03-6, which is the same number used by IRIS.

Weathered chlordane is expected to include its metabolite heptachlor epoxide. There are separate ESLs for heptachlor and heptachlor epoxide.

### 9.2 DDD, DDE, and DDT

Dichlorodiphenyltrichloroethane (DDT) is a pesticide that was once widely used to control insects on agricultural crops and insects that carry diseases like malaria and typhus, but is now used in only a few countries to control malaria (ATSDR 2002). Technical-grade DDT is a mixture of three forms, p,p'-DDT (85%), o,p'-DDT (15%), and o,o'-DDT (trace amounts). Technical grade DDT may also contain dichlorodiphenyldichloroethylene (DDE) and

dichlorodiphenyldichloroethane (DDD) as contaminants. DDD was also used to kill pests, but to a far lesser extent than DDT. Both DDE and DDD are breakdown products of DDT. The ESLs present separate screening levels for DDE and DDD. For comparison to the ESLs, these are treated as individual compounds (i.e., no adjustments are necessary).

### 9.3 Dioxins and Furans

Dioxins are molecules that contain a 6-membered ring with 2 double bonds and 2 oxygen atoms in the ring while furans contain 5-membered ring structures with 2 double bonds and 1 oxygen atom in the ring. The dioxins and furans of greatest environmental concern are chlorinated dibenzo-p-**dioxins** (CDDs) and chlorinated dibenzofurans (CDFs) which include 210 compounds with related chemical structures and physiological effects. These chlorinated chemical mixtures are mainly found in the environment as unintentionally generated byproducts of certain chemical processes; such as the incomplete combustion of materials containing chlorine (e.g., plastic), chemical manufacturing of chlorinated compounds (e.g., herbicides such as pentachlorophenol, wood preservatives, and ethylene dichloride), and natural processes such as forest fires and volcanic eruptions/emissions (USEPA 2010).

The ESLs present a single entry to screen CDDs and CDFs: 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) since it is the most toxic of these compounds. Other specific CDD and CDF molecules have been assigned toxicity equivalence factors (TEF) by the World Health Organization that scales their toxicity to that of 2,3,7,8-TCDD, which has a TEF of 1 (Table 9-1; van den Berg et al. 2006). In practice, each individual CDD or CDF concentration is multiplied by its TEF and the results summed. The summation is called the toxic equivalents (TEQ) or dioxin TEQ. Laboratory analytical reports for dioxin or furan mixtures typically calculate this for each sample. The TEQ summation can then be compared to the ESL for 2,3,7,8-TCDD.

Table 9-1 – World Health Organization Toxic Equivalency Factors for Dioxins and Furans (2005)	
Compound	TEF
Chlorinated dibenzo-p-dioxins	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
Chlorinated dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,6,7,8,9-HpCDF	0.01
OCDF	0.0003
<b>Note:</b> USEPA. 2010. <i>Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds</i> . Office of the Science Advisor, Risk Assessment Forum. December.	

This TEF method can only be used for chemicals where extensive mechanistic information shows that all the toxic effects of concern share a common mode of action so that the scaling factor (TEF) derived for each chemical represents all toxic effects and all exposure conditions. This TEF method assumes actual toxicologic equivalence once the scaling factor is applied. USEPA's chemical mixtures guidelines and guidance documents (USEPA 1986; 2000) include various approaches for evaluating the toxicity of chemical mixtures, but recommends these TEFs for human health risk evaluations of dioxins and furans (USEPA 2010) as well as evaluations of their ecological risks (USEPA 2008b). DTSC also uses these same TEFs. When evaluating appropriate cleanup goals for dioxins, HERO *Human Health Risk Assessment Note 2, Issue: Remedial Goals for*

*Dioxins and Dioxin-like Compounds for Consideration at California Hazardous Waste Sites* (DTSC 2009) should be consulted.

## **9.4 Endosulfan**

The ESLs present screening levels for endosulfan (CAS 115-29-7) which was sold as a mixture of two different forms of the same chemical (referred to as alpha- and beta-endosulfan) (ATSDR 2015). In the environment, endosulfan is present as a mixture of alpha, beta and endosulfan sulfate (degradation product). Laboratory analyses typically analyze samples for the individual components rather than the mixture as a whole. For instance, USEPA Method 8080 includes Endosulfan I (alpha Endosulfan; CAS 959-98-8), Endosulfan II (aka beta Endosulfan; CAS 33213-65-9), and Endosulfan sulfate (CAS 1031-07-8) as separate analytes. The results of each of the three component chemicals should be added together get the total endosulfan mixture concentration for comparison to the endosulfan ESLs.

## **9.5 Polychlorinated Biphenyls (PCBs)**

Polychlorinated biphenyls (PCBs) are a group of synthetic chlorinated organic chemicals that were produced for industrial applications because of their inflammability, chemical stability, and insulating properties (USEPA 1996; ATSDR 2000). Commercial mixtures in the United States were marketed under the Aroclor trade name (Morrison and Murphy 2006). The Aroclor mixtures were coded depending on the molecule size and weight percent of chlorine in the formulation. For instance, in Aroclor 1254, the PCB molecule has 12 carbons, and the mixture consists of 54% chlorine by weight. Manufacture in the United States stopped in 1977 in response to the passage of the Toxic Substances Control Act.

Cancer toxicity studies of PCB mixtures indicate that Aroclor 1254 and Aroclor 1260 have the highest observed potencies (USEPA 1996). The USEPA document *PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures* (USEPA 1996) presents different oral cancer slope factors for different tiers of risk and persistence for certain PCB mixtures. The toxicity values for PCBs in the ESLs correspond to the “high” risk and persistence tier listed in IRIS (accessed January 28, 2016) for CAS 1336-36-3. This ESL can be compared to laboratory analytical results for any Aroclor mixture. Even though some PCBs demonstrate dioxin-like modes of action, USEPA (1996) recommends this mixtures approach

rather than the TEF approach because relatively few PCB congeners are dioxin-like.

## 9.6 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs), also known as polynuclear aromatic hydrocarbons (PNAs), are a class of compounds consisting of two or more fused aromatic rings (Morrison and Murphy 2006). The sources of PAHs are varied and commonly are grouped into petrogenic (e.g., crude oil) or pyrogenic (e.g., incomplete combustion of organic substances such as fuels or wood).

Naphthalene is the simplest PAH and consists of two fused benzene rings. BaP may be the most widely recognized PAH because it was the first chemical carcinogen to be discovered. Hundreds of PAH compounds have been identified, although for most soil and groundwater investigations, only the 16 USEPA Priority Pollutant PAHs are tested. These PAHs: 1) have the most toxicological information; 2) are suspected to be the most harmful; and 3) have been detected at the highest concentrations (thus posing the highest exposure risk) at National Priority List sites (ATSDR 1995d).

The ESL Workbook includes screening levels for the 16 PAHs (USEPA Priority Pollutants) presented in alphabetical order (not grouped). These PAHs are listed in Table 9-2. The PAH compounds are evaluated using one of two approaches:

- Noncarcinogenic PAHs and naphthalene are evaluated by comparison of the laboratory analytical results to their individual screening levels;
- For the carcinogenic PAHs (cPAHs; excluding naphthalene), the laboratory analytical results are aggregated using the TEF methodology specific for cPAHs to calculate a benzo(a)pyrene (BaP) equivalents (BaP<sub>eq</sub>) concentration. The TEFs are listed in Table 9-2. The BaP<sub>eq</sub> concentration is then compared to the BaP screening levels. Individual cPAH compounds have separate ESLs. Their oral cancer slope factors are scaled to BaP using the appropriate TEF. So comparison to the individual screening levels also is possible.

**Table 9-2 – PAHs in the ESLs and Interim Toxic Equivalency Factors for the Carcinogenic PAHs**

PAH Compound	CAS No.	Carcinogenic?	Toxic Equivalence Factor (TEF) <sup>1</sup>
Acenaphthene	83-32-9	No	--
Acenaphthylene	208-96-8	No	--
Anthracene	120-12-7	No	--
Benzo[a]anthracene	56-55-3	Yes	0.1
Benzo[b]fluoranthene	205-99-2	Yes	0.1
Benzo[k]fluoranthene	207-08-9	Yes	0.01
Benzo[g,h,i]perylene	191-24-2	No	--
Benzo[a]pyrene	50-32-8	Yes	1.0 (index compound)
Chrysene	218-01-9	No	0.001
Dibenz[a,h]anthracene	53-70-3	Yes	1.0 <sup>2</sup>
Fluoranthene	206-44-0	No	--
Fluorene	86-73-7	No	--
Indeno[1,2,3-cd]pyrene	193-39-5	Yes	0.1
Naphthalene	91-20-3	Yes	-- <sup>3</sup>
Phenanthrene	85-01-8	No	--
Pyrene	129-00-0	No	--

**Notes:**

- 1 – Except for dibenz[a,h]anthracene, the toxic equivalence factor (TEF) values are from OEHHA (2009), which refers to them as potency equivalency factor (PEF). These values are the same as currently used by the USEPA RSLs, which are sourced from USEPA (1993). Also, as implied by HERO Note 3, DTSC employs these same TEFs.
- 2 – OEHHA (2009) provides an independently developed cancer slope factor for dibenz(a,h)anthracene. However, this value is less conservative than the IRIS value, which is based on a TEF of 1.0. Therefore, consistent with the ESL toxicity value hierarchy (Chapter 3), the IRIS value is used.
- 3 – As indicated by DTSC (2009), naphthalene is considered to be a carcinogenic toxic air contaminant and no TEF is listed because naphthalene is evaluated separately from the other carcinogenic PAHs. It is not included the BaP equivalent value calculation.

Because PAHs are widespread in the environment, ambient PAH concentrations can be encountered a site. The DTSC Advisory entitled *Use of the Northern and Southern California Polynuclear Aromatic Hydrocarbon (PAH) Studies in the Manufactured Gas Plant Site Cleanup Process* (DTSC 2009), although intended for manufactured gas plant (MGP) sites could be consulted regarding how to

evaluate whether PAH concentrations in site soil may be ambient-like.

## 9.7 Total Petroleum Hydrocarbons (TPH)

Total Petroleum Hydrocarbons (TPH) refers to a non-specific laboratory analysis that provides a measure of the concentrations of all organic chemicals with carbon-hydrogen bonds, such as hydrocarbons, present in a sample over a particular boiling point range without identifying individual compounds. Therefore, TPH is a mixture of many chemicals. The amount of TPH detected in environmental samples is a useful indicator of petroleum contamination at a site. This chapter describes the development of ESLs for select TPH mixtures as a tool for evaluating the risk to human health posed by petroleum releases that are particularly appropriate for release sites with significant petroleum mass.

In general, the ESLs are not used at sites that are subject to the *Low-Threat Underground Storage Tank Closure Policy* (State Water Board 2012b). ESLs may be used at such sites to screen for constituents not addressed by the Policy. See Chapter 1 for further information.

### 9.7.1 Risk and Hazard Evaluation for Petroleum Hydrocarbon Releases

Potential adverse effects to humans from exposure to petroleum hydrocarbon releases are evaluated as cancer risk and noncancer hazard through a combination of indicator compounds and the bulk of the petroleum mixture using analytical results for the appropriate TPH mixture(s) such as TPH gasoline. For a given petroleum release, the indicator compounds and TPH mixture(s) appropriate for that release(s) comprise the chemicals of potential concern.

#### **Indicator Compounds**

Indicator compounds consist of the toxicologically characterized chemicals for which regulatory toxicity values are available for either their carcinogenic or noncarcinogenic effects or both. Typical indicator compounds are n-hexane, benzene, toluene, ethylbenzene, xylenes, naphthalene, and benzo[a]pyrene. The monoaromatics benzene, toluene, ethylbenzene and the three xylene isomers are commonly referred to as “BTEX”. Other indicator compounds include additives or blending agents typically used in gasolines, which changed during different time periods (e.g., alkylated lead compounds versus MTBE). Table 9-3 presents examples of potential indicator compounds for different petroleum mixtures.

## TPH Mixtures

TPH mixtures for which ESLs have been developed include three fuel mixtures and one petroleum solvent commonly detected at environmental cleanup sites in urban areas: gasoline (TPH gasoline), Stoddard solvent (TPH Stoddard solvent), diesel (TPH diesel), and motor oil (TPH motor oil). While not very accurate, the TPH screening levels provide a reasonably quantitative way to account for toxic effects of the large number the petroleum chemicals in the mixtures that have not been toxicologically studied.

At recent petroleum release sites, the carcinogenic indicator compounds (benzene, ethylbenzene, and naphthalene) typically drive the risk. However, at many older (weathered) petroleum release sites, the carcinogenic compounds are either no longer present or present at low concentrations due to volatilization, dissolution, or biodegradation. At such sites, the noncancer hazard posed by the remaining petroleum hydrocarbons (TPH) typically is the risk drivers (Brewer et al. 2013). This can include the degradation products, which should be measured as part of the TPH analysis.

<b>Table 9-3 – Example Indicator Compounds for Gasoline, Diesel, and Motor Oil<sup>1</sup></b>			
Petroleum Fuel	Indicator Compounds		
	BTEX <sup>2</sup>	Additives <sup>3</sup>	PAHs <sup>4</sup>
Gasoline	Yes	Yes	no
Diesel	Yes	no	Yes
Motor Oil	no	no	Yes

**Notes:**

1 – This table is not intended to be comprehensive.

2 – BTEX – benzene, toluene, ethylbenzene, and xylenes.

3 – Additives – This is a general listing and is not intended to suggest that all of these compounds are present in a single fuel. For unleaded gasolines (methyl tertiary butyl ether or MTBE; tertiary butyl alcohol or TBA; methyl ethyl ketone or MEK; methyl isobutyl ketone or MIBK; methanol; ethanol). For leaded gasolines (alkylated lead compounds, 1,2-dichloroethane or EDC; or 1,2-dibromoethane or EDC).

4 – PAHs (polycyclic aromatic hydrocarbons), typically 16 priority pollutant PAHs, including naphthalene.

## **Other Chemicals Potentially Associated with Petroleum Releases**

The following are some of the chemicals that can be associated with petroleum releases due to the natural attenuation<sup>10</sup> processes (e.g., arsenic mobilization), association based on site operations (e.g., chlorinated solvents or metals).

- All hydrocarbons: Arsenic – A potential secondary effect of the natural attenuation of hydrocarbons coupled with iron reduction is a release of naturally occurring arsenic to groundwater (Cozzarelli et al. 2015). This can occur where there is petroleum or other readily biodegradable organic carbon (e.g., naturally occurring or in landfills). Arsenic plume migration can be limited by the presence of downgradient oxygenated conditions.
- Stoddard Solvent: Tetrachloroethene (PCE) – At dry cleaner sites that used Stoddard solvent, there can be an association with chlorinated VOCs used for dry cleaning such as PCE or TCE. Also, PCE has been added to many dry-cleaning soaps used with petroleum dry cleaning solvents as a bacterial inhibitor and TCE is often used for pre-treatment of stains (State Coalition for Remediation of Drycleaners 2009).
- Waste Oil: Chlorinated Solvents, Metals, and PCBs – At sites where waste oils were released, such as former automotive service stations, the testing of the soil and groundwater for chlorinated solvents, heavy metals, and PCBs is oftentimes required. Where vapor intrusion is a potential concern, appropriate sampling should be considered. The testing program should be discussed with the overseeing regulatory agency.

### **9.7.2 Fraction Approach for Human Health Risk TPH ESLs**

Evaluating the risk to human health from petroleum hydrocarbon mixtures (TPH) is challenging. Toxicological studies suitable for deriving quantitative criteria either: 1) test the toxicity of the whole petroleum hydrocarbon mixture or 2) test the toxicity of each compound present in the mixture individually.

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<sup>10</sup> Natural attenuation processes include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater (USEPA 1995).

Toxicity data are only available for a small proportion of the individual petroleum compounds. Therefore, current approaches to estimate the risk posed by petroleum mixtures or to develop risk-based screening levels for petroleum-contaminated media consist of dividing the petroleum mixtures into fractions based on size or apparent carbon number and selecting surrogate mixtures or compounds to represent the toxicity of these hydrocarbon fractions or carbon ranges (TPHCWG 1997a, 1997b, 1998a, 1998b, and 1999; MADEP 2003; USEPA 2009; Hawaii DOH 2011; Regional Water Board 2016b). The Regional Water Board's fraction approach used to develop screening levels for TPH mixtures is presented in the *Technical Resource Document: Fraction Approach to Develop ESLs for TPH Mixtures* (Appendix F; Regional Water Board 2016b) and includes development of TPH mixture ESLs for gasoline, Stoddard solvent, diesel, and motor oil.

### 9.7.3 Petroleum Degradates

After release to the environment, petroleum mixtures undergo weathering, a stepwise process that produces many oxygen-containing **intermediate breakdown products**. The presence of a strongly electronegative oxygen atom within the molecular structure increases the polarity and therefore water solubility of these compounds. This polarity facilitates their dissolution into water at much higher concentrations than the parent hydrocarbons. For instance, concentrations as high as 40,000 µg/L extractable TPH (TPH diesel and TPH motor oil) are not uncommon near areas with significant contamination mass in soil (source areas). We call these intermediate breakdown products **petroleum degradates**, which encompasses products from photo-oxidation as well, or **petroleum metabolites** (biodegradation only).<sup>11</sup>

There are naturally-occurring oxygen containing organic compounds with a similar polarity to the petroleum degradates, which we refer to as **biogenic organic compounds (BOCs)**. These are often detected at heavily vegetated sites

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<sup>11</sup> The literature refers to the petroleum breakdown products by various terms: organic acids, naphthenic acids, non-volatile dissolved organic carbon, polar compounds, polar metabolites, polar hydrocarbons, polar nonhydrocarbons, oxyhydrocarbons, and, for the breakdown products of polycyclic aromatic hydrocarbons (PAHs), oxygenated PAHs or OPAHs.

(e.g., marshes). Commonly used analysis methods for TPH will also capture the non-petroleum compounds (e.g., BOCs) thus potentially biasing high the extractable TPH concentrations at sites with heavy vegetation. In some situations, **silica gel cleanup (SGC)** was used to remove the BOCs to enable more accurate quantitation of the petroleum hydrocarbons (Zemo and Synowiec 1995). However, since the petroleum degradates and BOCs have similar polarities, they are both removed by the use of SGC. At most release sites the contribution of BOCs is negligible and application of SGC will cause the analysis to be biased low. We use the term “**polar compound**” to refer to any compound that is polar regardless of whether they are sourced from petroleum.

The petroleum degradates are a natural consequence of petroleum releases yet they remain the least well understood components of such releases (Thorn and Aiken 1998; Booth et al. 2007; Lundstedt et al. 2007). This is largely due to limitations with conventional analytical methods. Polar compounds are not easily extracted and therefore many compounds are not analyzed (TPHCWG 1998a). Conventional methods such as GC-MS are unable to separate the numerous co-eluting compounds into individual peaks or spectra (Frysiner et al. 2002). Instead, the degradate compounds typically manifest as a “hump” in the chromatogram, also known as an **unresolved complex mixture (UCM)**.

Intermediate breakdown products such as aliphatic acids, some of which are toxic, have been found to accumulate during hydrocarbon biodegradation (Atlas 1981). Toxic intermediate breakdown products can also result from photo-oxidation of hydrocarbon mixtures as demonstrated by the 2007 Cosco Busan spill in San Francisco Bay that significantly impacted the Pacific Herring embryos in the shallow intertidal zone (Incardona et al. 2012).

Accounting for petroleum degradates in a risk or toxicological evaluation is complicated. Even less is known about the nature and toxicity of the highly variable mixtures produced during degradation as compared to the parent hydrocarbon mixtures. The toxicological study of these compounds has been held back due to analytical limitations and lack of awareness. Recently, however, recently, there has been an increase in the research directed at chemically characterizing these breakdown products although direct toxicity testing continues to lag behind.

As the result of comments received regarding the December 2013, ESL User’s Guide, Regional Water Board staff began a literature review in 2015 and issued a number of updates during the course of 2015 on a project-need basis. Our current findings are presented in *Technical Resource Document: Site-Specific Evaluation Approach for Petroleum Degradates* (Appendix G; Regional Water Board 2016c).

Our key review findings are:

- Laboratory Analytical Issues –The extractable TPH method appears to be the only viable, cost-effective analytical technique available at this time for analysis of the petroleum degradates. Polar compounds do not extract well in solvents such as hexane or methylene chloride used in extractable TPH analyses, which means these compounds are underestimated via this analysis (TPHCWG 1998a; Bekins et al. 2016). Further, polar compounds in complex mixtures (e.g., petroleum and degradates) present severe difficulties, even for GC-MS, which is ineffective for detecting and quantifying these as individual compounds. Research-level techniques are available that can better detect some of these compounds. However, they have significant drawbacks: 1) no single preparation/analysis method can detect all the compounds; 2) the methods are expensive; 3) laboratory standards for quantification are available for limited numbers of compounds; 4) the methods are not standardized. Detection and quantitation of these compounds in field samples is a developing field.
- Fate and Transport – The degradates are an important component of the conceptual site model for a petroleum release. During the initial phases, in the absence of significant weathering, the groundwater plumes typically are dominated by aromatic hydrocarbons because they are a more soluble class of compounds. However, after biodegradation is underway, the plumes become dominated by the petroleum degradates. At many older (significantly weathered) release sites, the groundwater plumes almost entirely consist of degradates (Table 9-4). These plumes can persist for decades at sites with significant contaminant mass in soil. The molecular composition of degradates mixtures varies based on time, that is degree of weathering as well as spatially with increased transport distance. This implies that toxicity can vary as well, although we are unaware of any comprehensive studies that have coupled advanced chemical characterization techniques with toxicity testing to establish definitive correlations between toxicity and degree of transport and/or stage of weathering for groundwater plumes.
- Human Health Risks – Based on our review of limited studies available, we conclude that the toxicity levels of petroleum degradate mixtures and parent hydrocarbons are comparable. Thus, the petroleum degradates should be measured and evaluated as part of site-specific TPH analysis. The results of the extractable TPH analysis provide a bulk concentration that may only roughly correlate with toxicity of the mixture that is actually present. However, at this time, the only available tool for

quantifying the impacts of residual petroleum contamination is the concentration measurement from the extractable TPH analysis.

- Ecological Risks – The effects of the petroleum degradates in marine environments are relatively well studied. They have demonstrated toxicity to aquatic species. The results of ecological toxicity testing suggest the toxicity varies based on the nature of the mixture, degree of weathering (which roughly correlates with age), and increasing transport distance. While the toxicity in some cases decreases with increased weathering (roughly time), the decrease appears to be neither rapid nor steady. The degradates need to be evaluated on a site-specific basis. We are unaware of definitive correlations between toxicity and degree of transport and/or stage of weathering for groundwater plumes. At sites of heightened ecological concern, ecological toxicity testing should be coupled with chemical (TPH) analysis and incorporated into a multiple lines of evidence approach for evaluating threat potential.
- Use of Silica Gel Cleanup – The use of SGC where the concentrations are to be compared to screening criteria or in risk evaluations is not appropriate. SGC is can be useful for understanding the relative proportions of parent hydrocarbons versus degradates in a sample or to assess potential background concentrations from BOCs. Further information regarding use of SGC is presented in Section 9.7.4.

<b>Table 9-4 – Petroleum-Related Compounds Detected in Extractable TPH Analysis Based on Stage of Weathering</b>		
Stage of Weathering	Constituents Detected in the Extractable TPH Analysis	
	TPH diesel	TPH motor oil
Fresh Release – Early Stage	Hydrocarbons	--
Intermediate Stage	Hydrocarbons + Degradates	Degradates
Weathered – Late Stage	Degradates	Degradates

Based on these findings, we have developed the following recommendations for a **site-specific evaluation approach**:

- **Sites of heightened concern** are those with significant remaining contaminant mass in soil, proximal to receptors (insufficient distance for adequate biodegradation/ attenuation) such as groundwater supply wells or aquatic habitats, and uncertainty in the CSM regarding the nature and extent and fate and transport of the petroleum release in question.
- **The extractable TPH analyses (e.g., TPH diesel and TPH motor oil) should be performed without SGC.** The data for TPH-diesel and TPH-motor oil should be added and compared against the TPH-diesel criterion. This is because: 1) motor oil range hydrocarbons are virtually insoluble and are unlikely to add significantly to the water sample result; and 2) at weathered petroleum sites, sample chromatograms show a single UCM that occurs mostly in the diesel range (C<sub>10</sub> to C<sub>24</sub>) with a smaller portion extending into the motor oil range (C<sub>24</sub> to C<sub>36</sub>). It is preferable to have the laboratory integrate and quantitate the entire UCM against a single standard (e.g., diesel) rather than against two standards (diesel and motor oil). However, the TPH-diesel and TPH-motor oil results for each sample can be added after the laboratory analysis as an approximation.

This approach improves the accuracy of an evaluation of the full, cumulative impacts associated with petroleum releases. While the petroleum degradates should be measured and evaluated as part of site-specific evaluations, Regional Water Board's overall approach to petroleum site cleanup remains the same: adequate investigation and delineation; source control to the extent practicable; groundwater plume remediation (including natural attenuation where appropriate); sufficient monitoring to demonstrate plume stability; and institutional controls (e.g., deed restrictions, risk management plans, etc.) when necessary. Consideration of additional action is mainly driven by heightened concerns at a site, such as the presence of nearby receptors (e.g., supply wells, aquatic receptors) that could be affected by the groundwater plume (of hydrocarbons and/or petroleum degradates).

#### **9.7.4 Laboratory Analysis for Use with TPH ESLs**

##### **TPH Analysis for Groundwater and Soil Samples**

The TPH mixture screening levels are intended for use with routine laboratory TPH analyses where there is minimal overlap in carbon ranges to avoid double-

counting (e.g., TPH-diesel as C<sub>10</sub>-C<sub>24</sub> and TPH-motor oil C<sub>24</sub>-C<sub>36</sub>). Laboratory analysis for TPH in soil or groundwater samples is commonly carried out in general accordance with USEPA Method 8015B Nonhalogenated Organics by Gas Chromatography (USEPA 1996f). A detailed discussion of the preparation and analysis method and its limitations is presented in *Technical Resource Document: Site-Specific Evaluation Approach for Petroleum Degradates* (Appendix G; Regional Water Board 2016c).

As previously discussed, the petroleum degradates often dominate groundwater plumes at weathered petroleum release sites and, currently, the best method to detect both the hydrocarbons and degradates is the TPH method. Table 9-5 presents our recommended TPH analysis approach for petroleum releases.

<b>Table 9-5 – TPH Analysis Approach for Petroleum Releases</b>			
Carbon Range of Petroleum Release	Recommended TPH Analysis and Target Compounds		
	TPH gasoline	TPH diesel	TPH motor oil
Low (C <sub>5</sub> -C <sub>12</sub> )	Yes (HC)	Yes (D) <sup>1</sup>	non-soluble
Medium (C <sub>10</sub> -C <sub>24</sub> )	--	Yes (HC + D)	Yes (D)
High (C <sub>24</sub> -C <sub>36</sub> )			Yes (HC)
Abbreviations: HC – Petroleum hydrocarbons D – Petroleum degradates. The breakdown products typically boil at higher temperatures. For instance, breakdown products of low carbon range releases typically boil in the diesel range, and breakdown products of medium carbon range releases boil in both the later diesel and early motor oil range.			

### **TPH Analysis for Vapor Samples**

At sites where significant contaminant mass remains and/or where other unique conditions prevent adequate aerobic biodegradation (e.g., geochemical conditions, preferential pathways, building susceptibility, significant pressure gradients), TPH vapors can drive risk (Brewer et al. 2013). Laboratory analysis of vapor samples (indoor air and soil gas) for TPH can be performed in accordance

with USEPA Methods such as TO-3, TO-15, or TO-17. Based on Brewer et al. (2013), we recommend the following for the analysis of TPH vapors:

- Low and medium carbon range hydrocarbon mixture releases – TPH vapors quantified from C<sub>5</sub> to C<sub>12</sub> against a gasoline standard in accordance with USEPA Method TO-15 or equivalent.
- Medium carbon range hydrocarbon mixture releases – In addition to the above, we recommend analysis for TPH vapors quantified from C<sub>12</sub> to C<sub>18</sub> against a diesel standard in accordance with USEPA Method TO-17 or equivalent. Note that TO-17 is a sorbent tube sampling method.

### **Use of Silica Gel Cleanup**

The use of SGC is an optional procedure that can be added to extractable TPH analysis, for additional cost. Samples can be analyzed for extractable TPH both with and without SGC to garner information about the relative proportion of hydrocarbons, degradates, and BOCs (if any). This provides information on the degree of weathering and may aid management decisions. However, the use of SGC where the concentrations are to be compared to screening criteria or in risk evaluations is not appropriate. For that particular application, use of silica gel underestimates risk. Table 9-6 presents our recommended analysis approach for distinguishing between hydrocarbons, degradates and BOCs.

Potential interferences to the extractable TPH method from BOCs can be assessed by testing both with SGC (hydrocarbons only) and without SGC (hydrocarbons, degradates, and BOCs) in an area of the site with no known release and with a similar hydrologic and vegetation setting. This can be accomplished by testing upgradient or at downgradient locations. However, at bay margin release sites, testing at a cross-gradient area (the same distance from the bay margin) and outside the petroleum-affected area, may be more representative than testing in an upgradient upland area. Consultation with the overseeing regulatory is recommended before implementing a background testing program.

Other applications for silica gel (e.g., fractionation methods) are discussed in *Technical Resource Document: Fraction Approach to Develop ESLs for TPH Mixtures* (Appendix F; Regional Water Board 2016b).

<b>Table 9-6 – Recommended Approach for Distinguishing Between Hydrocarbons, Degradates, and BOCs</b>	
<b>Laboratory Analysis/Evaluation</b>	<b>Result is a Measurement of:</b>
<b>Step 1 (Measurement of Hydrocarbons, Degradates, and Background BOCs) – Samples collected near source area and downgradient.</b>	
1a – Extractable TPH without SGC	HCs + Degradates + BOCs
1b – Extractable TPH with SGC	HCs
Difference (1a minus 1b)	Degradates + BOCs (typically negligible, if any)
<b>Step 2 (Assessment of Background BOCs) – Samples collected from upgradient or at known unimpacted location with similar setting as release area. [Optional]</b>	
2a – Extractable TPH without SGC	BOCs
2b – Extractable TPH with SGC	HCs (expected to be non-detect if an unimpacted location was selected)
Difference (2a minus 2b)	BOCs
<p><b>Notes and Abbreviations:</b></p> <p>Step 2 is optional but is recommended at heavily vegetated sites.</p> <p>Extractable TPH – TPH diesel (diesel range organics) and TPH motor oil (motor oil range organics). Note that this analysis likely underestimates all polar compound concentrations because these compounds are not readily extracted with hexane or methylene chloride.</p> <p>BOCs – Polar biogenic organic compounds unrelated to petroleum.</p> <p>Degradates – Intermediate breakdown products of petroleum hydrocarbons from biodegradation (metabolites) or photo-oxidation. These are polar compounds and are a more soluble class of compounds than the parent hydrocarbons.</p> <p>HCs – Hydrocarbons.</p> <p>SGC – Silica gel cleanup.</p>	

# 10 Additional Considerations

## 10.1 Laboratory Data Issues

### 10.1.1 Detection Limits and Reporting Limits

Method detection limits<sup>12</sup> and laboratory reporting limits<sup>13</sup> for individual chemicals were not directly considered in development of the ESLs. In some cases, ESLs may be less than typical method detection limits. Examples include the risk-based ESLs for dioxin in soil (2.2E-05 mg/kg residential). An evaluation of data quality objectives early in the investigation will help ensure that specific detection limits are appropriate for the project (USEPA 2006). For some analytes, it may be acceptable to consider the method reporting limit in place of the screening level, with the approval of the overseeing regulatory agency. However, in some situations it may be appropriate to work with the environmental laboratory to ensure that reporting limits are less than the ESLs. For certain chemicals (risk drivers), alternate low-detection-level methods may be appropriate.

### 10.1.2 Soil Data Reporting: Dry Weight Basis

All soil data should be reported on a dry-weight basis. This is in part because soil ingestion rates assumed in direct-exposure models are based on dry-weight studies (USEPA 1997). Soil data are calculated by dividing the mass of the chemical of concern detected in the soil by the total weight of the soil. Note that

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<sup>12</sup> The method detection limit is defined as the minimum concentration that can be measured and reported with 99 percent confidence that the concentration is greater than zero, but the exact concentration cannot be reliably quantified.

<sup>13</sup> The laboratory reporting limit is the lowest amount of an analyte in a sample that can be quantitatively determined with stated, acceptable precision and accuracy. Typically the reporting limit is a multiple of the method detection limit.

the California Total Threshold Limit Concentrations, which are used for waste classification purposes (see Chapter 1), are in wet weight format.

## 10.2 Naturally Occurring Background and Ambient Chemicals

Background refers to constituents or locations that are not influenced by the releases at a site and is usually differentiated as naturally occurring versus anthropogenic (USEPA 1989):

- Naturally Occurring Background – Concentrations of chemicals that are present in the environment and have not been influenced by humans (e.g., arsenic, manganese).
- Ambient (Anthropogenic) – Concentrations of chemicals that are present in the environment due to human-made, non-site sources (e.g., industry, automobiles, stormwater runoff). Examples include dioxins and PAHs.

Concentrations of naturally occurring metals should be considered on a site by site basis. The natural background concentration of a chemical in soil or groundwater can vary substantially between sites, or even between soil types within a single site. For situations where naturally occurring background concentrations exceed the ESLs (see arsenic section in this chapter), it may be appropriate to substitute the background concentration for the ESL. Cleanup to less than background or ambient concentrations is not generally required (USEPA 2002b). For quantitative risk assessments, USEPA recommends that background be carried through the risk assessment because knowledge of background risks can help community members to put chemical risks from site releases in perspective.

Background concentrations typically are evaluated by collecting on-site samples, located upgradient of the suspected release or from another un-impacted location but in a similar setting (soils, vegetation, etc.). Local data collected during other studies may also be suitable. Methods to establish a site-specific background or the use of appropriate regional background studies should be verified with the overseeing regulatory agency before using non risk-based values at a site. Guidance that may be useful for distinguishing concentrations of chemicals in soil and groundwater from background includes:

- *Selecting Inorganic Constituents as Chemicals of Potential Concern at Risk Assessments at Hazardous Waste Sites and Permitted Facilities* (DTSC 1997);

- *Engineering Forum Issue Paper: Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites* (USEPA 1995);
- *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites* (USEPA 2001)

Polycyclic aromatic hydrocarbons (PAHs), discussed elsewhere in this chapter, are an example of a group of compounds that is commonly found in the environment both due to site releases (e.g., crude oil spills) and non-site releases since these can be the result of incomplete combustion of fuels in motor vehicles. Therefore, when investigating releases of mixtures with PAHs at a site, it can be important to understand whether there are ambient concentrations of PAHs. Cleanup of non-site-related contamination is not generally required.

### **10.3 Bioavailability**

For some chemicals, animal studies or models indicate that the bioavailability depending on the form or medium (e.g., dissolved in water versus soil or food). The ESLs do not take into account bioavailability with the exception of cadmium for which IRIS includes separate RfDs depending on the medium (water versus food or soil), which is discussed in the cadmium section of this chapter.

USEPA (2012) has developed recommendations for default relative bioavailability of arsenic in soil. The ESLs do not incorporate relative bioavailability for arsenic or other compounds. This could be considered as part of a Tier 3 evaluation. The overseeing regulatory agency should be consulted before incorporating bioavailability, particularly regarding the appropriateness of using any default relative bioavailability value versus conducting a site-specific evaluation.

### **10.4 Degradation Products**

Considering the degradation of a chemical (“parent compound”) to toxic breakdown products (“daughter products”) is an important aspect of site investigations. Living organisms break down organic molecules in several steps and the intermediates may be relatively toxic. The rates of formation of toxic metabolites and their degradation depend on the nature of the contamination and the site conditions (such as oxygen levels or the nature of resident microbial populations). In most cases, both the parent compound and daughter products are present together. One of the better understood examples is the breakdown of

PCE to TCE to dichloroethene and then to vinyl chloride. Both TCE and vinyl chloride are more toxic than the parent compounds. Parent compounds and their degradation products are often present in combination; therefore, the cumulative risk should be considered as described in Section 3.2.3.

For other chemicals and mixtures, our understanding of the degradation processes and the intermediate breakdown products is still developing. In the case of pesticides, the intermediate breakdown products (termed degradates or metabolites when derived solely from biodegradation) are more prevalent in groundwater than the parent compounds (Kolpin et al. 2000). In the case of petroleum hydrocarbons, the degradates are more polar than the original parent compounds and therefore more soluble (Appendix G). Additionally, the large numbers of different degradates can present severe challenges for measurement and detection using conventional analytical techniques such as GC-MS (Fryzinger and Gaines 2002; Aeppli et al. 2012; McKenna et al. 2013). Consequently, many of these compounds have not been identified and fewer have undergone toxicity testing (Wickliffe et al. 2014).

## **10.5 Chemical Specific Considerations**

### **10.5.1 Chemicals Not Listed In ESLs**

The ESLs include more than 100 chemicals or mixtures, representing those most commonly found at sites where releases of chemicals have occurred. ESLs for additional chemicals or mixtures can be developed if sufficient information is available (toxicity values and physical and chemical constants). The overseeing regulatory agency should be consulted. As an initial step, if ESLs are not presented for a chemical or mixture, the USEPA RSLs could be consulted.

### **10.5.2 Multiple Species of One Chemical**

Some contaminants can be present in the environment in different oxidation states or protonation states (acid/base chemistry) resulting in chemical species with different ionic charges. For example, most metals can be found in the environment in more than one oxidation state, such as chromium III ( $\text{Cr}^{3+}$ ) and chromium VI ( $\text{Cr}^{6+}$ ). The charge of a chemical can change when it partitions between different media or when site conditions change. In these cases, every attempt should be made to determine the concentration of the most toxic species for comparison to risk-based screening levels. In the case of cyanides, the ESLs

are based on the most toxic form, protonated HCN (verses the negatively charged,  $\text{CN}^-$ ). For chromium, chromium VI is the more toxic species with a lower risk-based screening level. However, the MCL for chromium in drinking water is currently 50  $\mu\text{g/L}$  for total chromium, which is well above the risk-based level for chromium VI.

### **10.5.3 Arsenic**

Arsenic concentrations in site soils typically exceed risk-based screening levels (e.g., residential direct contact soil is 0.067 mg/kg) by one or more orders of magnitude. In many situations, this is due to naturally occurring background concentrations although site-specific evaluations are still warranted. Duvergé (2011) conducted a study of regional background concentrations of arsenic in undifferentiated urbanized flatland soils and proposed an upper estimate for background arsenic (99th percentile) of 11 mg/kg. This value can be used, as appropriate, in consultation with the overseeing regulatory agency.

Arsenic can exist in multiple chemical forms which differ in bioavailability. The ESLs do not distinguish between these forms and consider all arsenic fully bioavailable. The ESLs do not employ the USEPA (2012d) recommendations for default relative bioavailability of arsenic in soil. This could be considered as part of a Tier 3 evaluation.

### **10.5.4 Cadmium**

ESL Table IP-2 presents two RfDs for cadmium: one for water and one for soil. This is because the fraction of ingested cadmium that is absorbed appears to vary with the source (e.g., food vs. drinking water) (USEPA IRIS accessed January 19, 2016). The food RfD is used for soil.

## **10.6 Acute Hazards: Methane**

The ESLs do not address acute hazards such as asphyxiation or fire and explosions. Methane is non-toxic and therefore typically not evaluated in chemical risk assessments, which are focused on cancer risks and noncancer hazards. However, methane can act as a simple asphyxiant and is a fire and explosion hazard when present at between 5 and 15 volume percent in air (Lundegard et al. 2000).

Naturally occurring methane is classified based on the predominant process by which it formed: thermogenic (produced by abiotic processes) or biogenic (produced by biological processes) (Lundegard et al. 2000). Thermogenic methane is produced at significant depths by thermal degradation of organic matter such as coal, natural gas, and oil. Biogenic methane is produced under anaerobic, near-surface conditions by microbial degradation of organic matter. Such microbially-produced methane occurs widely in association with organic-rich sediments and materials, including marine, lake, and river sediments; marshes and swamps; glacial drift; and in landfills and sewers. In addition, methane can be generated from the anaerobic biodegradation of hydrocarbons from petroleum releases. (Chaplin et al. 2002; USEPA 2015b).

Methane readily degrades under aerobic conditions, but the process creates an oxygen demand that can increase the typical petroleum vapor intrusion separation distances required for full aerobic biodegradation. It can take years for soil gas methane profiles to be fully established following a significant petroleum release (Chaplin et al. 2002).

The USEPA OSWER VI Guide (USEPA 2015a) and USEPA OUST PVI Guide (USEPA 2015b) address methane and its hazards. The DTSC *Evaluation of Biogenic Methane: A Guidance Prepared for the Evaluation of Biogenic Methane in Constructed Fills and Dairy Sites* also provides helpful information (DTSC 2012). For instance, evaluating the potential explosion hazard posed by methane involves measuring concentration as well as the vapor pressure gradient in soil to assess potential methane formation and flux into a structure.

## 10.7 Sediment

ESLs are not derived for sediment<sup>14</sup> because sediment typically is evaluated based on sediment chemistry, toxicity tests, and condition of the benthic community in a multiple lines of evidence approach. Consequently, the

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<sup>14</sup> Sediment – In the context of environmental site cleanup, sediment refers to granular materials beneath or adjacent to a water body (e.g., rivers, streams, bays) that are saturated continually or periodically by the water body. Typically, sediment samples have greater water content than upland soil.

evaluation of sediment can be challenging. In addition, sediment environments are more dynamic, and sediments can be moved, be buried, or eroded over time. This introduces a temporal component untypical of upland soils.

There are some available sediment criteria, but these should be used with caution without the other lines of evidence. In addition, there is guidance regarding a number of aspects such as ambient concentrations. Table 10-1 provides list of documents with sediment criteria or pertinent information deriving such criteria that may be useful. This list is not comprehensive.

In addition, some sediment toxicity testing has been performed on cleanup sites in the region. At the Presidio, saltwater sediment criteria of 12 mg/kg for TPH gasoline and 144 mg/kg TPH fuel oil (diesel range) were developed based on toxicity tests using amphipods (IT Corporation 1997).

<b>Table 10-1 –Sediment Chemical Criteria or Relevant Guidance</b>	
<b>Year</b>	<b>Title and Author</b>
1995	Incidence of adverse biological effects of chemical concentrations in marine and estuarine sediments. Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. Environmental Management 19(1): 81-97.
1996b	ECO Update: Ecotox Thresholds (USEPA)
1997	Preliminary Remedial Goals for Ecological Endpoints (USDOE)
2000	Draft Staff Report – Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines (Regional Water Board)
2003	Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures (USEPA)
2008	NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1 (Buchman)
2008a	Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Compendium of Tier 2 Values for Nonionic Organics (USEPA)
2012c	Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Procedures for the Determination of the Freely Dissolved Interstitial Water Concentrations of Nonionic Organics (USEPA)
2015	Updated Ambient Concentrations of Toxic Chemicals in San Francisco Bay Sediments (San Francisco Estuary Institute)

## 10.8 Total Maximum Daily Loads (TMDLs)

Total Maximum Daily Loads (TMDLs) can have implications for the investigation, evaluation (screening), remediation, or long-term management of cleanup sites. The Federal Clean Water Act requires states to identify water bodies that do not meet water quality standards and to develop TMDLs to ensure the attainment of water quality standards. TMDLs therefore are surface water body and pollutant specific. TMDLs define how much of a pollutant a water body can receive and still meet water quality standards this is referred to as allocation. They also specify actions to be implemented as solutions. TMDLs adopted for the San Francisco Bay region are listed on the Regional Water Board's website.<sup>15</sup> The following are two examples of TMDLs that can have implications for cleanup sites:

- Mercury (San Francisco Bay) (2008) – The TMDL includes no (zero) allocation for discharge of mercury from cleanup sites. In addition, the Basin Plan Amendment vacated the water column water quality objective and replaced it with a fish tissue objective, which has implications for screening. The ESL team is evaluating this issue.
- PCBs (San Francisco Bay) (2010) – The TMDL established an initial 20-year timeframe for reducing PCBs in fish tissue to safe levels for human consumption, a ten-fold reduction. To achieve this, surface sediment PCB concentrations in San Francisco Bay must be reduced to an average of 1 µg/kg, again, a ten-fold decrease. The Regional Water Board is revising its 2012 fact sheet “Cleaning up PCBs in San Francisco Bay.” As part of that revision, it is expected that staff will be recommending the use of analytical methods capable of achieving lower laboratory reporting limits for near-surface soil samples than may be required for a typical upland cleanup sites to better document residual concentrations of PCBs that could be transported offsite to the Bay (e.g., stormwater runoff). This will help improve management of residual PCBs where present in surface soils. The desired reporting limit is at or close to 0.001 mg/kg (1 µg/kg), which

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<sup>15</sup> [http://www.waterboards.ca.gov/sanfranciscobay/water\\_issues/programs/TMDLs/](http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/)

contrasts with the residential direct contact soil ESL of 0.25 mg/kg or the commercial/industrial direct contact soil ESL of 1 mg/kg for PCBs.

# 11 Acknowledgements

Numerous people have contributed to this and previous updates of the Environmental Screening Levels. The Regional Water Board would like to thank the many individuals who provided comments and suggestions that helped to improve the ESLs. The core team for the February 2016 update included Nicole Fry, Stephen Hill, Cheryl Prowell, and Ross Steenson and was assisted by Marcos de la Cruz in updating the toxicity values. Additional technical expertise was provided by staff from the Regional Water Board and other units of the California Environmental Protection agency. In particular, the team would like to thank former staff Roger Brewer, Elizabeth Allen, and Uta Hellmann-Blumberg for their time in answering questions and participating in technical discussions as well as providing continued toxicology and risk assessment support. The cover photograph courtesy of Cleet Carlton is very much appreciated.

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## 13 Acronyms and Abbreviations

ARAL	USEPA Accelerated Response Action Level (for indoor air sample results)
ATSDR	U.S. Department of Public Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry
AWQC	Aquatic Water Quality Criteria
BaP	Benzo[a]pyrene
BaP	Benzo[a]pyrene equivalents
Basin Plan	San Francisco Bay Basin Water Quality Control Plan
bgs	below ground surface
BOCs	Biogenic organic compounds
BTEX	Benzene, toluene, ethylbenzene and xylenes
C or Ca	Cancer
CAS	Chemical Abstracts Service
C <sub>soil</sub>	Leaching based soil concentration (mg/kg)
C <sub>gw</sub>	Target groundwater screening level (µg/L)
CalEPA	California Environmental Protection Agency (includes the Air Resources Board; Department of Pesticide Regulation; Department of Resources Recycling and Recovery or CalRecycle; Department of Toxic Substances Control; Office of Environmental Health Hazard Assessment; and State Water Resource Control Board and Regional Water Quality Control Boards.
CCC	Criterion for Continuous Concentration
CCM	Criterion for Maximum Concentration
CDPH	California Department of Public Health
CHHSL	CalEPA California Human Health Screening Level
CSM	Conceptual Site Model (sometimes called Site Conceptual Model)
CTR	California Toxics Rule

DAF	Dilution-Attenuation Factor
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDR	California State Water Resources Control Board, Division of Drinking Water
DDT	Dichlorodiphenyltrichloroethane
DEP	[Massachusetts] Department of Environmental Protection
DTSC	California Environmental Protection Agency, Department of Toxic Substances Control
EPA	U.S. Environmental Protection Agency
ESL	Regional Water Board Environmental Screening Level
Estuary	In the context of the ESLs, the lowest of freshwater and saltwater values
FCV	Final Chronic Value
GI	Gastrointestinal (tract)
H	Henry's law constant (atm-m <sup>3</sup> /mol)
H'	dimensionless Henry's law constant
HDOH	Hawai'i Department of Health
HI	Hazard index
HQ	Hazard Quotient
HVAC	Heating, ventilation, and air conditioning
IRIS	USEPA Integrated Risk Information System
IUR	Inhalation unit risk (formerly URF or unit risk factor), representing the carcinogenic inhalation toxicity value of a chemical or mixture.
JEM	Johnson & Ettinger model (Johnson and Ettinger 1991)

K <sub>oc</sub>	Organic carbon partition coefficient (cm <sup>3</sup> /g)
LC50	Lethal concentration (50th percentile)
LOEL	Lowest Observed Effect Level
MADEP	Massachusetts Department of Environmental Protection
MCL	Maximum Contaminant Level
mg/kg	Milligrams per kilogram, or parts per million
MOEE	Ontario Ministry of Environment and Energy
MRLs	ATSDR Minimum Risk Levels
MTBE	Methyl tertiary butyl ether (aka tert-methyl butyl ether)
NAPL	Non aqueous phase liquid (aka free product)
NC	Noncancer
NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollution Discharge Elimination System
OEHHA	California Environmental Protection Agency, Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration (federal)
OSWER	USEPA Office of Solid Waste and Emergency Response
OSWER VI Guide	OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Source to Indoor Air (USEPA 2015a)
OUST	USEPA Office of Underground Storage Tanks
OUST PVI Guide	Technical Guide for Addressing Petroleum Vapor Intrusion At Leaking Underground Storage Tank Sites (USEPA 2015b).
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl

PCE	Tetrachloroethene (aka perchloroethylene)
PEL	Permissible Exposure Limit
PPRTV	USEPA Provisional Peer-Reviewed Toxicity Value
PRG	USEPA Preliminary Remediation Goal (now RSL)
PVI	Petroleum vapor intrusion
RfC	Inhalation Reference Concentration (noncarcinogens)
RfD	Oral Reference Dose (noncarcinogens), also RfD.
Region 2	The region overseen by the San Francisco Bay Regional Water Quality Control Board or the region itself
REL	Recommended Exposure Limit
Regional Water Board	California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board
RSL	USEPA Regional Screening Level (formerly PRG)
SFo	Cancer oral slope factor
SGC	Silica gel cleanup
State Water Board	California Environmental Protection Agency, State Water Resources Control Board
STLC	Soluble Threshold Limit Concentration (for liquids)
Subslab	Subslab soil gas. Soil gas collected immediately beneath a concrete slab.
TBA	Tertiary butyl alcohol
TCE	Trichloroethene
TCE Framework	Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region (Regional Water Board 2014)
TEF	Toxicity equivalence factor
TEQ	Toxic equivalents
TMDL	Total Maximum Daily Load
TPH	Total petroleum hydrocarbons

TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group
TTLC	Total Threshold Limit Concentration (for solids)
UCM	Unresolved complex mixture or chromatogram hump, referring to numerous co-eluting compounds
URAL	USEPA Urgent Response Action Level (for indoor air sample results)
USDHHS	U.S. Department of Health and Human Services
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
UST	Underground Storage Tank
UST Policy	Low-Threat Underground Storage Tank Closure Policy (State Water Board 2012b)
VI	Vapor Intrusion
VIG	DTSC Vapor Intrusion Guidance (DTSC 2011)
VISL	USEPA Vapor Intrusion Screening Level calculator (USEPA 2014)
VOC	Volatile organic compound/chemical
µg/L	Micrograms per liter or parts per billion
µg/m <sup>3</sup>	Micrograms per cubic meter



# **Appendix A**

## **Tier 3 Risk Assessment Information**



# Appendix A: Tier 3 Assessments

For a Tier 3 assessment, alternative models and assumptions are used and fully justified to develop a detailed, comprehensive environmental risk assessment. For human health risk assessments, Tables A-1 and A-2 list relevant guidance from USEPA and DTSC, respectively. These are not endorsements or requirements, but are pertinent to risk assessments submitted to the Regional Water Board.

Regional Water Board staff recommends that, prior to submission of Tier 3 assessments, the overseeing regulatory agency be consulted or a work plan be submitted. This significantly reduces the effort by all parties in moving forward.

<b>Year</b>	<b>Title</b>
1989	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A)
1991a	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)
1991b	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives)
1996b	Soil Screening Guidance: Technical Background Document
2001	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments)
2002	Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites
2002	Role of Background in the CERCLA Cleanup Program
2004	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)
2009	Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)
2011	Exposure Factors Handbook: 2011 Edition
2014	Memorandum: Determining Groundwater Exposure Point Concentrations, Supplemental Guidance. OSWER Directive 9283.1-42
2014	Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors. OSWER Directive 9200.1-120

<b>Table A-2 – Select DTSC Documents Relevant for Human Health Risk Assessments</b>	
<b>Year</b>	<b>Title</b>
1997	Selecting Inorganic Constituents as Chemicals of Potential Concern at Risk Assessments at Hazardous Waste Sites and Permitted Facilities. Final Policy.
2009	Human Health Risk Assessment Note 2 – Interim, Issue: Remedial Goals for Dioxins and Dioxin-like Compounds for Consideration at California Hazardous Waste Sites
2014a	Human Health Risk Assessment Note 5, Issue: Health-Based Indoor Air Screening Criteria for Trichloroethylene (TCE)
2014b	Human Health Risk Assessment Note 1, Issue: Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Hazardous Waste Sites and Permitted Facilities
2016	Human Health Risk Assessment Note 3, Issue: DTSC-Modified Screening Levels (DTSC-SLs)
2015a	Human Health Risk Assessment Note 4, Issue: Screening Level Human Health Risk Assessments
2015b	Preliminary Endangerment Assessment Guidance Manual
2016	Human Health Risk Assessment Note 3, Issue: DTSC-Modified Screening Levels (DTSC-SLs)

# **Appendix B**

**Technical Resource Document: Default Subslab Soil Gas  
and Soil Gas to Indoor Air Attenuation Factors in the ESLs**



San Francisco Bay Regional Water Quality Control Board

# Technical Resource Document: Default Subslab Soil Gas and Soil Gas to Indoor Air Attenuation Factors in the ESLs

February 16, 2016

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## Executive Summary

The purpose of this memorandum is to describe the technical basis for the generic attenuation factors used to develop subslab soil gas and soil gas environmental screening levels (ESLs). Subslab soil gas is vapor within the soil pores directly beneath a concrete slab-on-grade building. Vapor attenuation refers to the reduction in volatile chemical concentrations that occurs during vapor transport from the subsurface to indoor air. The subslab soil gas to indoor air (SSIA) attenuation factor (AF) represents the reduction in volatile chemical concentration during vapor transport from subslab soil gas across a building foundation (concrete slab) to indoor air and is defined as the indoor air concentration divided by the subslab soil gas concentration. The SSIA AF and ESLs is also applied to non-subslab soil gas samples (i.e., soil gas samples collected well below the slab or where there are no overlying structures).

Following the development of the USEPA Vapor Intrusion Database, Water Board staff has been evaluating whether a model or empirical approach is best for developing SSIA AFs that would allow the calculation of subslab soil gas ESLs. Staff has selected a model approach that contains some empirical inputs to generate SSIA AFs that in turn are used to develop residential and commercial/industrial subslab soil gas and soil gas ESLs. The memorandum presents background information on the characteristics of subslab soil gas, previous approaches used in the ESLs for soil gas to indoor air AFs, the conceptual model for soil vapor entry into buildings, an evaluation of the model and empirical approaches for calculating the SSIA AF, the selected approach and prerequisites, and integration of the subslab line of evidence into the multiple lines of evidence approach as discussed in the *Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (Water Board 2014).

## 1. Introduction

Subslab soil gas is vapor within the soil pores directly beneath a concrete slab-on-grade building foundation. Vapor attenuation refers to the reduction in volatile chemical concentrations that occurs during vapor transport from the subsurface to indoor air. The subslab soil gas to indoor air (SSIA) attenuation factor (AF) is the indoor air concentration divided by the subslab soil gas (subslab) concentration as shown in Equation 1a below. It allows for the development of subslab screening levels by relating subslab concentrations to the indoor air screening level as shown in Equation 1b:

$$SSIA\ AF = Indoor\ Air\ Concentration / Subslab\ Soil\ Gas\ Concentration \text{ [Equation 1a]}$$

$$Subslab\ Soil\ Gas\ Screening\ Level = Indoor\ Air\ Screening\ Level / SSIA\ AF \text{ [Equation 1b]}$$

Following the development of the USEPA Vapor Intrusion Database, Water Board staff has been evaluating whether a model or empirical approach is best for developing a SSIA AF that would allow for the calculation of generic subslab soil gas screening levels. This memorandum documents our evaluation and technical justification for the adoption of a model-based approach, which we call the vapor flux (VF) approach. This approach is based on the vapor-entry-to-building component of the Johnson and Ettinger model (JEM Johnson and Ettinger 1991) and includes empirical input values.

The memorandum presents background information on the characteristics of subslab soil gas, previous approaches used in the Water Board's Environmental Screening Levels (ESLs) for soil gas to indoor air (SGIA) AFs, the conceptual model for soil vapor entry into buildings, an evaluation of the model and empirical approaches for calculating the SSIA AF, the selected approach and prerequisites, and integration of the subslab line of evidence into the multiple lines of evidence approach as discussed in the *Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (Water Board 2014).

## 2. Background

### a. Characteristics of Subslab Soil Gas

Subslab concentrations are the result of diffusion from the volatile organic compound (VOC) VOC vapor source, which is typically groundwater except near source areas where the vapor source can be vadose zone soil as well. Subslab concentrations are controlled by the characteristic length ratio of the depth of the foundation divided by the depth of the VOC vapor source (Yao et al. 2012) and the slab capping effect (Shen et al. 2014). In part due to the capping effect, areas of high subslab VOC concentrations do not necessarily correspond to areas of high vapor flow or entry into a building (Pennell et al. 2009).

Numerous vapor intrusion studies indicate that the subslab concentrations can vary laterally by several orders of magnitude (McHugh et al. 2007; Luo et al. 2009; Yao et al. 2013; Brewer et al.

2014). In addition to this spatial variability, there is often temporal variability due to indoor-outdoor pressure reversals that can drive indoor air into the subsurface and dilute subslab concentrations (McHugh et al. 2006). As a result of both spatial and temporal variability, the number of spatially-separated subslab samples as well as the number of samples collected over time from the same sampling point necessary to characterize the mean subslab concentration can be quite large. For instance, McHugh et al. (2007) estimated that it could take up to 10 spatially-separated subslab sample points to estimate the mean subslab concentration to within 50 percent (%) of the true mean. This variability translates to uncertainty in the subslab line of evidence since most investigations lack this level of sampling resolution (see Section 6 for discussion of the subslab line of evidence).

## **b. Soil Gas Attenuation Factors in Prior Versions of the ESLs**

The 2008 and prior versions of the ESLs used either of two model-based approaches for calculating a generic SGIA AF:

- 2001 ESLs – JEM as programmed into Microsoft Excel by USEPA (Johnson 2002);
- 2003, 2005, and 2008 ESLs – the VF approach. The SGIA AF was 0.001 (1/1,000). No distinction was made between AFs for subslab soil gas samples and non-subslab or exterior soil gas samples (i.e., soil gas samples collected well below the slab or where there are no overlying structures) prior to the 2013 ESLs; the SGIA AF applied to all soil gas samples. The majority of the attenuation was treated as taking place as subsurface vapors passed from the soil across a concrete slab-on-grade where the soil was dry sand.

Between 2010 and 2011, Water Board staff considered adoption of an empirical SSIA AF of 0.05 (1/20) developed from a preliminary version of USEPA's Vapor Intrusion Database (VI Database; USEPA 2008). This AF also would have been applied to both subslab and non-subslab soil gas, again the majority of attenuation being the result of transport across a concrete slab-on-grade where the soil was dry sand.

As part of that 2010/2011 effort, Water Board staff solicited input from an outside advisory group. The experts' comments reflected a variety of concerns regarding the VI Database such as: 1) appropriateness of relying on a national database given California's climate as well as the San Francisco Bay area's climate; 2) the inability to adequately distinguish between indoor sources of VOCs versus subsurface sources of VOCs and appropriately exclude data impacted by indoor air sources; and 3) the data filtering process removed data pairs where indoor air sample concentrations were less than paired subsurface vapor concentrations which effectively biased the results towards larger AFs (i.e., less attenuation).

In 2013, Water Board staff updated the ESLs and harmonized the soil gas AFs with the DTSC Vapor Intrusion Guidance (VIG; DTSC 2011). This included adopting a residential SGIA AF of 0.002, which had been developed by OEHHA using the soil-to-indoor-air version of the JEM (OEHHA 2004). OEHHA modeled vapor intrusion to indoor air from a location six inches below a concrete slab (i.e., subslab) immediately above the contamination source. We also reduced in the default residential indoor air exchange rate (AER) from 1.0 change per hour (as it had been

in all previous ESL versions) to 0.5/hour, and the commercial/industrial AER from 2.0/hour to 1.0/hour.

However, based on evaluation of the comments received from the advisory group in 2011 as well as the literature and other information, an empirically-derived subslab AF was not adopted. As stated in the December 2013, ESL Frequently Asked Questions,

a “1:20 attenuation factor between indoor air and subslab may not be appropriate for sites in our region. It is based on EPA’s empirical data for sites across the country, many of which have different conditions than are found in our region (e.g., basements and long/cold winters [indoor heating season] that can emphasize the advective flow component of vapor intrusion). As a practical matter, we think that most sites will exceed subslab screening levels based on the 1:20 attenuation factor, meaning that most sites will need to perform Tier 2 assessments. Therefore, the February 2013 ESLs omit subslab ESLs and the cover memo recommends a Tier 2 (site specific) assessment to derive subslab screening levels, as needed.”

### **3. Conceptual Model for Subsurface Vapor Entry into Buildings**

The following is a summary of our understanding of how subsurface vapors intrude into buildings and are mixed including the driving forces for vapor entry, vapor entry rates, and mixing in buildings and indoor air exchange rates.

#### **a. Driving Forces for Vapor Entry**

There are two components to the transport of contaminated subsurface soil vapor into buildings: 1) vapor transport in the subsurface from the VOC vapor source toward the building; and 2) subsurface vapor entry into the building. After entry, vapors are mixed with indoor air.

These two components are dominated by different processes. Overall, vapor transport in the subsurface is controlled by phase partitioning, diffusion, and advection (USEPA 2012a). However, it is widely accepted that diffusion dominates in the transport of contaminated vapors from the subsurface VOC vapor source (vadose zone soil or groundwater) towards a building and that, near a building, advection dominates and is the process by which soil vapor is transported into the building typically considered to be via cracks or other adventitious openings (Yao et al. 2013; USEPA 2015).

Advective subsurface vapor transport into buildings is driven by the preferential differential between the soil gas pressure and the air pressure inside a building ( $\Delta P$ ). This pressure difference is the result of the stack effect<sup>1</sup> and wind effect<sup>2</sup> (Song et al. 2014). In addition, the

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<sup>1</sup> The stack effect is caused by differences in the temperature of outdoor air, indoor air, and intruding subsurface vapor. As heated indoor air rises and leaves the building through gaps and cracks in the roof and walls, cooler subsurface air is drawn up into the building through the slab. Robinson and Sextro (1997) found that the stack effect was associated with about  $\Delta P = -0.15$  Pascals.

operation of mechanical ventilation or heating systems (e.g., heating, and air-conditioning systems or HVAC, furnaces, fans, etc.) can also result in pressure differences that drive inward or outward flow (Hers et al. 2001). While the typical range of  $\Delta P$  is -10 pascals (Pa) to +10 Pa (Shen et al. 2016), under ambient conditions, sustained  $\Delta P$  values are typically 0 to -5 Pa (Robinson and Sextro 1997), with -5 Pa being used as conservative value for constant building depressurization (USEPA 2004; DTSC 2011; Brewer et al. 2014). Depressurizations greater than the typical range (e.g., -10 Pa) are associated with extreme weather conditions such as storms or high winds (Robinson and Sextro 1997; Holton et al. 2013; and Song et al. 2014). Potentially, it is these pressure fluctuations that can drive periodic fluctuations in indoor air concentrations that have been detected in the few buildings that have been subjected to continuous monitoring.

In addition to advection, there can be a small component of transport from diffusion or atmospheric pressure differences. Robinson and Sextro (1997) studied radon entry into an experimental basement and measured the flux associated with diffusion, atmospheric pressure fluctuations, and sustained indoor-soil gas pressures. For steady indoor-soil gas pressure differences greater than 1.5 Pa, advective flow dominated and contributions from atmospheric pressure fluctuations and molecular diffusion were negligible. This condition typically occurs during the winter heating season or on windy days, which corresponds to a VI active period per Holton et al. (2013). For steady indoor-soil gas pressure differences less than 1.5 Pa, diffusion and atmospheric pressure fluctuations drove soil vapor entry, with the contribution from the atmospheric pressure fluctuations being about 50% greater than diffusion. These conditions commonly occur during the summer when indoor-outdoor temperature differences are small and winds are light, which corresponds to a VI inactive period per Holton et al. (2013).

## **b. Soil Vapor Entry Rates**

The pressure-driven soil vapor entry rate ( $Q_{\text{soil}}$  in the JEM) represents the rate at which subsurface vapors enter the building through concrete slab foundation cracks or walls. It is a critical determinant of the indoor air concentration (Johnson 2002) and controlled by  $\Delta P$ . The range of typical  $Q_{\text{soil}}$  values is 1 to 10 L/min (USEPA 2004; Song et al. 2011; DTSC 2011; Song et al. 2014; and Brewer et al. 2014). A value of 5 L/min is recommended by USEPA (2004) for coarse-grained soil and a default-size home.<sup>3</sup> The corresponding  $\Delta P$  is -4 Pa.

Typically,  $Q_{\text{soil}}$  increases as  $\Delta P$  increases although VOC vapor transport into a building can become limited by the rate at which VOC mass diffuses from the VOC vapor source to the soil below the building (USEPA 2012a; Shen et al. 2016). A study by Fischer et al. (1996) demonstrated this  $Q_{\text{soil}} - \Delta P$  relationship in the course of investigated soil gas transport of petroleum VOCs into a 50 square meter building. Part of the study included measurement of the building ventilation rate ( $Q_{\text{building}}$ ) and  $Q_{\text{soil}}$  using forced depressurization with a fan designed for testing ventilation ducts and sulfur hexafluoride as a tracer gas. The ambient  $Q_{\text{soil}}$  was predicted

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<sup>2</sup> The wind effect is the result of the differential pressure from wind load on a building, higher pressure on the upwind side than the downwind side of the building. Thus, air leaks into the building on the upwind side and leaks out on the downwind side.

<sup>3</sup> Default-size home refers to a residential, slab-on-grade building with 100 square-meter footprint and height of 2.44 meters, which results in an enclosed space volume of 244 cubic meters or 244,000 liters. See USEPA (2004) for further information.

to be in the range of 0.4 L/min and 2.1 L/min based on an estimate of depressurization due to average wind loading ( $\Delta P$  between 1 and 4 Pa). Depressurization was imposed at -10 Pa and -75 Pa and the measured  $Q_{\text{soil}}$  values were 3.5 L/min and 14 L/min, respectively. Note that, if the  $Q_{\text{soil}}$  values were proportionally adjusted to a 100 m<sup>2</sup> footprint (default size house),<sup>4</sup> the scaled  $Q_{\text{soil}}$  values would be 7 L/min (-10 Pa) and 28 L/min (-75 Pa). The authors described the dependence of  $Q_{\text{soil}}$  on building depressurization as approximately linear.

### **c. Mixing in Indoor Air and Indoor Air Exchange Rates**

As soil gas migrates into a building, it is mixed with indoor air, which is exchanged via infiltration/leakage, natural ventilation, and/or mechanical ventilation. The indoor air exchange rate is rarely measured in vapor intrusion studies, but has been studied for other reasons (Brewer et al. 2014). Studies between the 1970s and 1990s indicated that, under natural conditions (no mechanical ventilation), average AERs can be about 0.25/h, which is the same value recommended by USEPA (2004). Subsequent, more detailed studies suggest regional variations based on climate, with a US median value of 0.51/h. The USEPA Exposure Factors Handbook (USEPA 2011) provides a discussion of various studies of AERs as does the Supplement to Brewer et al. (2014). For example, the Yamamoto et al. (2010) study between 2000 and 2001 evaluated AERs for residences in Los Angeles. Results of that study indicated a median AER of 0.87/h overall with seasonal differences of 1.13/h (summer) and 0.61/h (winter).

In models, AER is usually set as a fixed value (Shen et al. 2016): 0.5/h Johnson and Ettinger (1991); 0.25/h (USEPA 2004); 0.5/h (Abreu and Johnson 2006); 0.5/h (DTSC 2011); and 0.25/h (Yao et al. 2011). AER was monitored in a single family home for about 18 months by Holton et al. (2013). The AER varied between about 0.2/h to 1.5/h.

Shen et al. (2016) evaluated transient effects on indoor air concentrations from AER variations using a three-dimensional model, and concluded that when  $Q_{\text{soil}}$  and AER are in phase, which is typical, indoor air concentrations varied about an order of magnitude. Both modeling and field studies have demonstrated that there is a positive correlation between  $Q_{\text{soil}}$  and AER (Cavallo et al. 1992; Song et al. 2014). This is because, as  $Q_{\text{soil}}$  increases, the stack effect increases, which increases  $Q_{\text{building}}$ . The increase in  $Q_{\text{building}}$  acts to offset the  $Q_{\text{soil}}$  increase.

## **4. Evaluation of Approaches for Calculating Generic Attenuation Factors**

There are two approaches for generating SSIA and groundwater to indoor air screening levels: models and, more recently, empirical data (Song et al. 2014). The most common model that has been used to generate generic screening levels is the JEM as programmed into Microsoft Excel by USEPA (Johnson 2002). The empirical approach for generating generic AFs relies on field data compiled into a database (e.g., VI Database; USEPA 2012b).

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<sup>4</sup> See Table 3, footnote 5 of the VIG (DTSC 2011).

## a. Model Approach

### i. USEPA Vapor Intrusion Model

The JEM calculates AFs based on soil, building, as well as chemical-specific factors, and exposure parameter inputs. It is a one-dimensional analytical fate and transport model of vapors into indoor air (USEPA, 2004). The model combines source zone partitioning, vapor transport through the vadose zone, vapor transport across building foundation, and enclosed-spacing mixing to estimate the vapor attenuation factor (called the Infinite Source Indoor Air Coefficient on the INTERCALCS worksheet), which relates the indoor air concentration to the vapor concentration at the source (Johnson 2002). The model's intended use is for screening purposes. It is based on a number of simplifying assumptions, which are discussed in the *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (USEPA 2004).

### ii. Vapor Flux Approach Used in the 2003 through 2008 ESLs

The VF approach for estimating SSIA attenuation is based on the subsurface vapor flow into a building through the foundation and the building ventilation rate. As previously stated, this approach is based on the vapor-entry-to-building component of the Johnson and Ettinger model. The basic equation for the AF with a residential example from the 2003 to 2008 ESLs is presented below:

$$SSIA\ AF = Q_{soil} / (Q_{soil} + Q_{building}) \text{ [Equation 2]}$$

$$SSIA\ AF_{residential} = (5\text{L}/\text{min}) / (5\text{L}/\text{min} + 4,000\ \text{L}/\text{min}) = 0.001\ \text{or}\ 1\text{E}-03. \text{ [Equation 3]}$$

where:

$Q_{soil}$  = Pressure-driven volumetric flow of soil gas into building. The USEPA-recommended default value for  $Q_{soil}$  is 5 L/minute (USEPA 2004; DTSC 2011), based on the default-size home.

$Q_{building}$  = Volumetric flow rate of outdoor air exchanged into the default-size home (volume of 244,000 L) with an AER of 1/hour, which results in 4,000 L/min.

### iii. Climate-Adjusted Vapor Flux Approach

A climate-adjusted VF approach was proposed by Brewer et al. (2014). This paper identifies a number of shortcomings associated with the USEPA Vapor Intrusion Database for deriving a simple generic SSIA AF and presents an updated VF approach as an alternative for deriving or "estimating" generic subslab AFs. The VF equation remains the same as Equation 2 above, but has been updated with regional-climate-adjusted inputs for  $Q_{soil}$  and AER; we call this updated approach the climate-adjusted VF approach.

Brewer et al. (2014) divided the United States into four vapor intrusion risk (VIR) regions based on average building leakage rates and associated AERs and vapor entry rates. The climate-adjusted vapor entry rate is based on the average number of heating and cooling days in four VIR regions and a default AER for each region. Table 1 illustrates the inputs and the SSIA AF for each VIR region.

<b>Table 1 – Summary of Climate-Adjusted, Vapor Flux Subslab to Indoor Air Attenuation Factors (after Brewer et al. 2014)</b>			
<b>VIR Region</b>	<b>Climate-Adjusted Vapor Entry Rate (L/min)</b>	<b>Default AER (1/hour)</b>	<b>SSIA AF</b>
A (Cold)	4.5	0.35	0.0032
B (Warm)	4.0	0.50	0.0020
C (Mediterranean)	3.4	1.0	0.0008
D (Tropical)	2.0	1.0	0.0005

The San Francisco Bay Region straddles VIR B and VIR C in Table 2, suggesting that a SSIA AF between 0.002 (1/500) and 0.0008 (1/1250) would be appropriate.

#### **iv. Review of Model Approaches**

Problems associated with the use of models such as the result of over-simplification. Additional problems can arise from lack of accuracy of inputs. Disadvantages of the vapor flux approach are: (1) that the inputs are not measured during vapor intrusion investigations; and (2) both  $Q_{soil}$  and AER are known to vary, but are represented as conservative averages based on published data. Nevertheless, the model reflects conventional understanding of how vapors intrude into buildings, the resulting SSIA AF is consistent with those reported from a number of field studies of concrete slab-on-grade buildings: 0.002 (King et al. 2010; 0.0002-0.0003 McHugh et al. 2004; 0.0026 McDonald and Wertz (2006); and 0.003 for the northeastern United States (Song et al. 2014).

### **b. Empirical Approach**

#### **i. Description of the USEPA Vapor Intrusion Database**

An empirical approach for generic AFs involves the compilation and evaluation of field data. The VI Database is the best known example of an empirical database. The VI Database was developed using data collected by others during the early years of vapor intrusion investigations (e.g., the most recent data are from 2006). The data are indoor air, subslab soil gas, deep/exterior soil gas, and groundwater and were collected from 913 buildings, 41 sites, and 15 states. The rest of our discussion about the VI Database is focused to derivation of the SSIA AF.

The VI Database contains 1,582 paired subslab soil gas and indoor air measurements. The data were paired considering proximity and temporal concurrency. The spatial proximity criterion for subslab soil gas and indoor air samples was whether the samples were from the same building. The temporal concurrency criterion for subslab soil gas and indoor air samples was whether the samples were collected within 48 hours of each other.

The subslab-indoor air data pairs were initially filtered using three screens, collectively called the Baseline Screens:

- Chlorinated VOCs (CVOCs) in Residences Screen – Excluded non-CVOC data and non-residential buildings thus focusing the remaining dataset to CVOCs and residential buildings. This removed 351 data pairs.
- Subsurface Concentration Screen – Excluded data pairs where the subslab concentration was less than reporting limits. This removed 24 data pairs.
- Data Consistency Screen – Excluded samples where the field notes indicated the presence of indoor sources (background) of CVOCs, the indoor air concentrations were greater than the subslab soil gas concentrations, or AFs for individual chemicals were not consistent with other chemicals reported for the same samples. This removed 440 data pairs.

Following application of the Baseline Screens, 767 data pairs remained. Two additional screens were developed, but these screens are not applied together, rather they are alternatives:

- Indoor Air Screen – Excludes samples with indoor sample concentrations that were less than reporting limits or less than the 90<sup>th</sup> percentile of background levels presented in the USEPA *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion* (USEPA 2011a). This removes 447 data pairs, leaving 320 data pairs total.
- Source Strength Screen – Excludes subslab soil gas samples with concentrations less than 50 times the 90<sup>th</sup> percentile of background levels (USEPA 2011). This removes 336 data pairs, leaving 431 data pairs total.

USEPA evaluated the advantages and disadvantages of employing the indoor air screen versus the source strength screen as the final step. Because the AF distributions that remained after applying the Source Strength Screen were close to lognormal distributions and exhibited less of the bimodal distortion that may have been induced by background contributions, the Source Strength Screen (subslab > 50x background) was selected. Then, USEPA calculated median and 95<sup>th</sup> percentile SSIA AFs of 0.003 (1/300) and 0.03 (1/30), respectively.

The USEPA-recommended generic SSIA AF is 0.03 (1/33; USEPA 2015). This same value is recommended for the non-subslab soil gas. Use of the 95<sup>th</sup> percentile value was intended to account for temporal and spatial variability in indoor air and subsurface vapor concentrations. USEPA (2012b and 2015) points out that the upper-bound value (95<sup>th</sup> percentile) of 0.03 is similar to that derived using a low AER (0.18/h; USEPA 2011) and high soil vapor entry rate (10 L/min) for a residential building volume of 154 cubic meters, resulting in an SSIA AF of 0.02.

## ii. Review and Analysis of Empirically-Derived Subslab Attenuation Factors

The VI Database has been subject to a number of reviews (McHugh et al. 2007; Song et al. 2011; Yao et al. 2013; Song et al. 2014; Brewer et al. 2014; and Yao et al. 2015). Criticisms have largely focused on the SSIA AF. In evaluating an empirical approach for deriving SSIA AFs for possible use in the ESLs we considered the following:

- Climate Variation – Given California’s milder climate, it may not be appropriate to rely on a national database that represents buildings with lower AERs and greater indoor-soil gas under pressurization due to colder weather (heating).
- Challenge of Distinguishing between Indoor and Subsurface Sources of VOCs – It is now well recognized that it is more challenging to distinguish between indoor sources of VOCs versus subsurface sources of VOCs and appropriately exclude data impacted by indoor air sources, but there are techniques that can be employed to distinguish indoor versus subsurface vapor sources (Song et al. 2011; NAVFAC 2013). However, these techniques were developed after the data in the VI Database were collected. Some authors have focused on identifying subslab concentrations where it is possible to reasonably attribute indoor air concentrations to be primarily the result of intruding subsurface vapors. Song et al. (2011) evaluated the VI Database and concluded that subsurface concentrations should be at least 300 times higher than potential background indoor air levels to reduce high bias due to indoor sources of VOCs. Yao et al. (2015) similarly concluded that, for subslab concentrations below  $500 \mu\text{g}/\text{m}^3$ , the source of low-level indoor air VOC concentrations cannot be definitively attributed to subsurface vapor intrusion.
- Mass Balance Problem – As discussed by Song et al. (2011), there is a mass balance problem with the SSIA AF of 0.03 considering  $Q_{\text{soil}}$  and AER. For the default-size home, using reasonable values of  $Q_{\text{soil}}$  (5 L/min) and AER (0.5/hour), the SSIA AF would be 0.0025. To achieve a SSIA AF of 0.03 for the default-size home with the same AER,  $Q_{\text{soil}}$  would have to be 70 L/min, which is not consistent with the conceptual model for soil vapor entry and typical  $\Delta P$  conditions. Coupling a low AER and high  $Q_{\text{soil}}$  value, as done in Section 5.1 of the VI Database report (USEPA 2012b), is implausible based on the physics driving soil vapor entry (Hers et al. 2001; Song et al. 2014; and Brewer et al. 2014).
- Lack of Spatial and Temporal Control in the VI Database – The SSIA AF for a building represents the true or average (mean) attenuation across the slab for an exposure scenario. Most buildings in the VI Database only had one subslab soil gas sample and one indoor air sample (i.e., single data pair) (Brewer et al. 2014). The SSIA AF inferred from a single data pair is subject to a potentially very large error (deviation from the true AF) due to spatial and temporal variability. The statistical evaluation of the VI Database addressed the variability between buildings rather than the variability and error within single data points (Brewer et al. 2014). The use of statistics did not resolve the error resulting from the lack of spatial and temporal control in the VI Database (McHugh et al. 2007; Brewer et al. 2014). Based on an evaluation by McHugh et al. (2007), the use of upper-bound statistics (e.g., 95% UCL) in a dataset with these errors results in an over-estimated and overly conservative AF, as further described below.

McHugh et al. (2007) conducted a study of the spatial and temporal variability at two sites. This work involved three components: 1) a field study to statistically characterize the spatial and temporal variability in indoor air and subsurface media samples; and 2) estimation of the number of samples from each medium necessary to adequately

characterize the mean concentration; and 3) an evaluation of the effects of the spatial and temporal variability on the measured AFs in the VI Database.

Based on the coefficients of variation (CVs)<sup>5</sup> measured for subslab and indoor air at the two study sites, the authors used a Monte Carlo approach to simulate the measurement of AFs. The average subsurface VOC concentration was set as 1,000 times the average indoor concentration, so that the average true AF would be 0.001. The authors generated 5,000 AFs based on simulated measurements from these populations. The Monte Carlo simulation indicated that the variability in VOC concentration resulted in a 95th percentile AF that is 6.2 times higher than the true AF in a database of AFs based on single paired subslab and indoor air measurements. The authors concluded that the 95th percentile subslab AFs selected by the USEPA are likely to be significantly more conservative than would be expected if the impact of spatial variability were better controlled through better characterization of the average subslab and indoor air concentrations.

## 5. Selected Approach for Generic Subslab/ Soil Gas Attenuation Factors in the ESLs

Although Water Board staff typically prefers empirical approaches over model approaches, in this case, we have significant concerns that using USEPA's empirically-derived SSIA AF (0.03 or 1/33) is not technically defensible and is not suitable for screening or prioritizing cases. We consider the climate-adjusted vapor flux approach to be consistent with the conceptual model for contaminated subsurface vapor entry into buildings and more scientifically sound for deriving a SSIA AF. Therefore, we are re-adopting the vapor flux approach, but with climate-adjusted inputs, as the basis for deriving SSIA AFs for concrete slab-on-grade buildings. The residential SSIA AF is 0.002 and the commercial/industrial SSIA AF is 0.001.

The residential and commercial/industrial SSIA AFs are also applied to non-subslab soil gas to generate residential and commercial/industrial subslab/soil gas ESLs. This approach conservatively assumes the only attenuation is the result of an intact concrete slab that limits the amount of vapor transported into the building and then the dilution of those vapors by mixing with indoor air. While there can be additional attenuation as vapors diffuse through the soil from a deeper VOC vapor source (primarily due to soil moisture), there are other factors that can result in less attenuation than otherwise expected through the soil profile:

- The slab capping effect results from the presence of concrete slabs or buildings that limit VOC release to the atmosphere. Soil gas concentration profiles beneath slabs or buildings show less attenuation than in unpaved areas. Cross-sectional illustrations of this effect are provided in *Conceptual Model Scenarios for the Vapor Intrusion Pathway* (USEPA 2012a).

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<sup>5</sup> The coefficient of variation (CV) is a normalized measure of variability that is independent of the measurement scale and can therefore be compared between sample sets. It is calculated for data sets with three or more matched measurements as the standard deviation divided by the sample mean.

- A soil moisture shadow can develop beneath buildings or paved areas that prevents rainwater from infiltrating.
- Further, significant attenuation for coarse-grained soils (sand or gravel) is not usually observed unless there is significant soil moisture (nearly saturated conditions) or the thickness of the vadose zone above the VOC vapor source is great.

For other building foundation types (e.g., basements) or future construction, the overseeing regulatory agency should be consulted. For buildings with crawl spaces, the Water Board employs an AF of 1.0 as discussed in the *Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (Water Board 2014).

### a. Climate-Specific Generic Subslab and Soil Gas Attenuation Factors

The San Francisco Bay region straddles VIR B and VIR C (see Figure 4 of Brewer et al. 2014). We use a residential slab-on-grade building (residential) SSIA AF corresponding to VIR B (0.002 or 1/500). This corresponds numerically to 2013 ESLs SGIA AF (see Section 2b). The residential SSIA AF is derived using a climate-adjusted vapor entry rate of 4 L/min and an AER of 0.5/hour for VIR Region B (Table 1). This is a reasonably conservative assumption that remains protective given the variability in how individual residences are ventilated. Staff may consider use of the lower VIR C AF, provided adequate technical justification is provided (e.g., building-specific tracer study or other supporting lines of evidence). For commercial/industrial slab-on-grade buildings, we will use the SSIA AF of 0.001, which is derived using a climate-adjusted  $Q_{soil}$  of 4 L/min and an AER of 1.0/hour. The residential and commercial/industrial AFs are listed in Table 2. Figure 1 illustrates the calculation of the residential SSIA AF using tetrachloroethene (PCE) as an example.

<b>Table 2 – Attenuation Factors Used for Developing Subslab/ Soil Gas ESLs</b>			
<b>Building Type/Use</b>	<b>Climate-Adjusted <math>Q_{soil}</math> (L/min)</b>	<b>Default AER (1/hour)</b>	<b>AF</b>
Residential Buildings (slab-on-grade)	4.0	0.5	0.002 (1/500)
Commercial/Industrial Buildings (slab-on-grade)	4.0	1.0	0.001 (1/1000)
<b>Note:</b> Use of the AF for subslab data assumes that the foundation is intact without significant conduits to the subsurface (e.g. cracks) or compromised utility connections.			

### b. Prerequisites for Use of the Subslab Attenuation Factor

The intended use of the subslab ESLs and the subslab line of evidence is to aid users in assessing vapor intrusion resulting from vapor flow through porous media and then into the building. Subslab ESLs do not address preferential pathways including those identified by

Pennell et al. (2013) (compromised sanitary sewer connection) or Guo et al. (2015) (land drain in direct connection with groundwater that terminated beneath the slab and did not penetrate the slab). Consequently, it is imperative to gather as much information about the construction, condition, and use of a building and use subslab data (subslab line of evidence) in conjunction with other lines of evidence as discussed in the *Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region* (Water Board 2014).

#### **i. Intact Foundation**

Use of the AF of 0.002 for subslab data assumes that the building foundation is intact without significant conduits to the subsurface (e.g. cracks) or compromised utility connections. Building drawings should be reviewed and the foundation inspected to the extent possible to support use of the AF for subslab samples. Reports should include information on the age of the building, foundation construction, current foundation condition, building use, other characteristics (basement, garage, etc.), presence of conduits to subsurface (drains, sumps, utility connections), and information on the HVAC and interior partitions. This information should be provided in an appropriate report for review by the overseeing regulatory agency.

#### **ii. Properly Collected Subslab Data**

The subslab data should be collected consistent with the methods discussed in the *Advisory – Active Soil Gas Investigations Advisory – Active Soil Gas Investigations* (CalEPA 2015). In addition, sufficient sampling should be performed to address spatial and temporal variability.

Samples should be appropriately located to permit evaluation of relevant exposure of receptors and to determine spatial variability, which can include a combination of targeted and areal or grid-based sampling locations. Targeted sampling can be based on the distribution of source contamination, building occupancy and use, HVAC layout, utility conduits, preferential pathways, and other potential vapor entry points. For areal coverage, some samples should be located near the center of the building (where vapor concentrations are anticipated to be greatest) and others should be located near the edge of the building. McHugh et al. (2007) recommended six spatially-separated subslab samples per building to estimate the mean concentration within 67 percent. Alternatively, high purge volume subslab sampling could be considered to better estimate the mean subslab concentration (McAlary et al. 2010; CalEPA 2015) as another way to address the spatial variability issue.

The Water Board does not accept building-specific attenuation factors based on a single pair of subslab and indoor air samples due to the spatial variability previously discussed. Rather, per McHugh et al. (2007), all available data should be used to develop a single attenuation factor for a building.

Given temporal variability, soil gas (including subslab soil gas) should be monitored over time to determine appropriate exposure point concentrations (USEPA 2015 and DTSC 2011). For instance, consistent with DTSC VIG Appendix G, a final risk determination for a building should not be made without at least two subslab sampling events, at least one should be conducted

during a colder weather period or building under pressurization condition. The latter can be ascertained by coupling indoor-soil gas pressure measurements with the subslab soil gas sampling program (USEPA 2015).

### **c. Development of Site-Specific, Generic SSIA AFs**

The Water Board will consider the development of an alternative SSIA AF based on building design and climate factors discussed in Brewer et al. (2014) on a site-specific basis. Such a proposal should include adequate technical justification and documentation. Consideration should be given to how an alternative SSIA AF can be validated.

## **6. Subslab Line of Evidence and Multiple Lines of Evidence Approach**

Although Water Board staff has selected a subslab AF that is the same as the soil gas AF, staff considers subslab data neither to be a strong line of evidence nor equivalent to the soil gas line of evidence. Rather, subslab data should always be combined with other lines of evidence (Water Board 2014), including other data lines of evidence such as concurrently collected indoor air samples, deeper soil gas and/or groundwater data. We also recommend use of indoor-soil gas pressure measurements because these can help to diagnose whether there is sufficient driving force for subsurface vapor entry at or around the time of sampling (USEPA 2015).

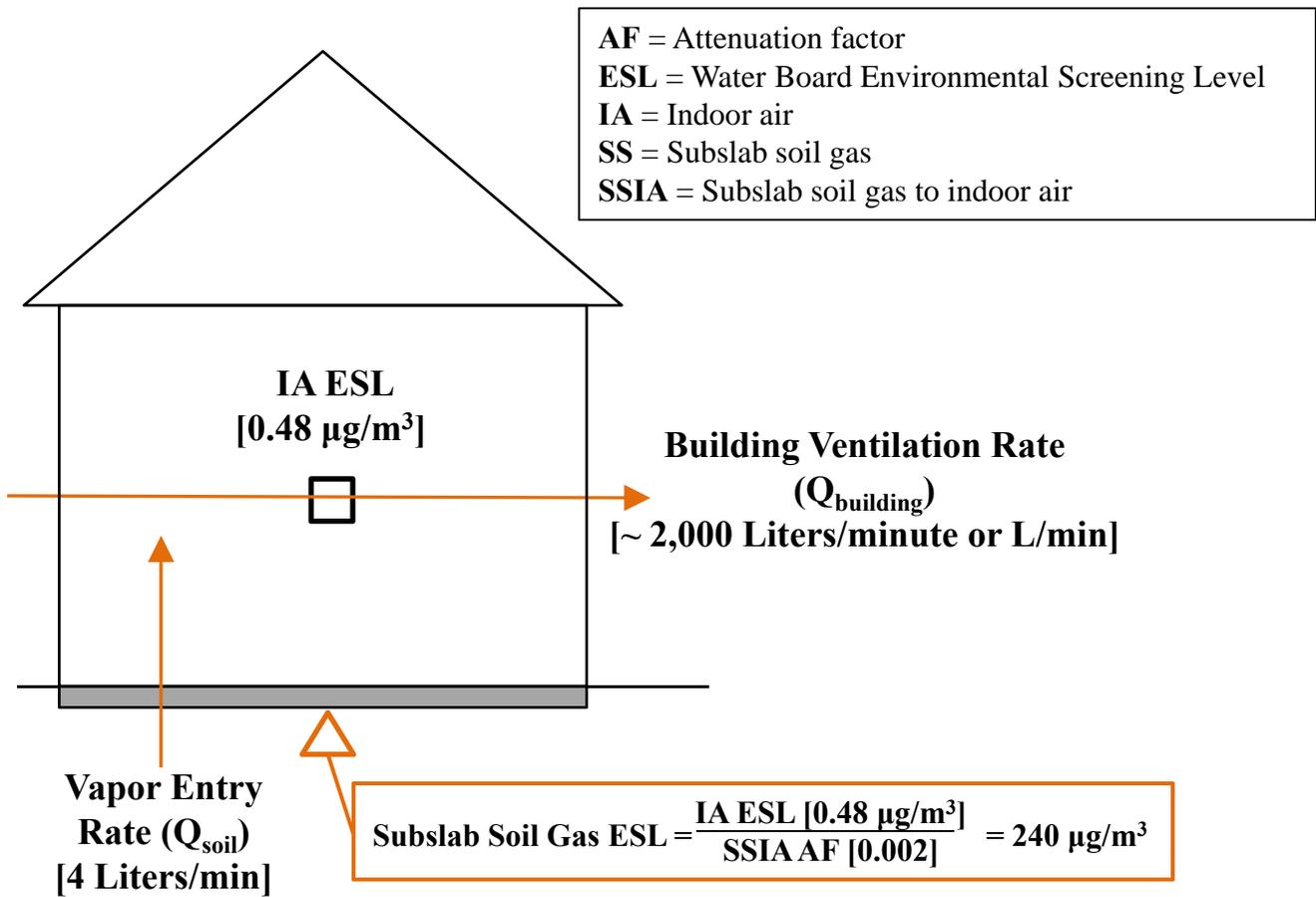
Lines of evidences for vapor intrusion investigations typically are weighted based on proximity to the receptor (building occupant) as well as data representativeness and quality. While subslab data might be more heavily weighted due to proximity to the receptor, that weighting is undermined by the significant concerns regarding data representativeness resulting from spatial and temporal variability. Therefore, unless, the dataset is robust, the subslab line of evidence generally should not be heavily weighted. As stated above, it is important to combine subslab data with other lines of evidence.

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### **VAPOR FLUX MODEL**

**Default building dimensions** = 2.44 meters high by 10 meters long by 10 meters wide.

**Default building volume** = 244 cubic meters or 244,000 liters (L).

**Default Indoor Air Exchange Rate** = 0.5/hour or 122,000 L/hour

**Q<sub>building</sub>** = 122,000 L/hour x (hour/60 min) ~ 2,000 L/min.

**SSIA AF** = Q<sub>soil</sub> / (Q<sub>soil</sub> + Q<sub>building</sub>).

**SSIA AF** = 4 L/min / (2,004 L/min) = 0.002.

**Figure 1 – Generic Subslab Soil Gas to Indoor Air Attenuation Factor Based on the Vapor Flux Model and Using PCE as an Example.**



# Appendix C

## **Model Parameters for Groundwater Vapor Intrusion ESLs**

Tables of Inputs and Copies of Johnson & Ettinger Model Worksheets for Three Soil Layer Designs (Shallow Groundwater, Deep Groundwater Sand, and Deep Groundwater Fine-Coarse)



**Appendix C Table 1**  
**Parameters for Shallow GW Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
<b>Soil/Groundwater and Soil Layer Parameters</b>			
Average Soil/Groundwater Temperature (T)	Celsius	15	From USEPA User's Guide Figure 8.
Depth Below Grade to Bottom of Enclosed Floor ( $L_F$ )	cm	15	DTSC VIG Table 3.
Depth Below Grade to Water Table ( $L_{WT}$ )	cm	152	Shallow GW model-specific.
Thickness of Soil Stratum A ( $h_A$ )	cm	152	Shallow GW model-specific.
Soil Type Used to Estimate Soil Vapor Permeability	na	Sand (S)	USDA SCS soil texture classification. See note (1).
Soil Stratum Directly Above Water Table	na	A	Sand
Stratum A SCS Soil Type	na	Sand (S)	Shallow GW model-specific.
Stratum A Soil Dry Bulk Density ( $\rho_b^A$ )	grams/cm <sup>3</sup>	1.66	Sand default
Stratum A Soil Total Porosity ( $n^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.375	Sand default
Stratum A Soil Water-Filled Porosity ( $\Theta_w^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.054	Sand default
<b>Building Parameters</b>			
Enclosed Space Floor Thickness ( $L_{crack}$ )	cm	15	Same as $L_F$ (DTSC VIG Table 3)
Soil-Bldg Pressure Differential ( $\Delta P$ )	g/cm-s <sup>2</sup>	40	DTSC VIG Table 3.
Enclosed Space Floor Length ( $L_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Floor Width ( $W_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Height ( $H_B$ )	cm	244	Slab-on-grade scenario. USEPA User's Guide, p. 40.
Floor-Wall Seam Crack Width ( $w$ )	cm	0.1	USEPA User's Guide, p. 55.
Indoor Air Exchange Rate (ER)	1/hour	0.5	DTSC VIG Table 3.
Average Vapor Flow Rate into Bldg ( $Q_{soil}$ )	L/min	5	DTSC VIG Table 3.

**Appendix C Table 1**  
**Parameters for Shallow GW Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
<b>Exposure Parameters</b>			
Averaging Time for Carcinogens (AT <sub>C</sub> )	yr	70	DTSC Human Health Note 1 (DTSC, 2014).
Averaging Time for Noncarcinogens (AT <sub>NC</sub> )	yr	26	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Duration (ED)	yr	26	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Frequency (EF)	d/yr	350	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Time (ET)	hours/d	24	DTSC Human Health Note 1 (DTSC, 2014).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL User's Guide
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL User's Guide
<b>Toxicity Factors</b> - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
<b>Chemical Properties</b> - No change to the values used in the VLOOKUP.			

**Abbreviations/Acronyms:**

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

DTSC VIG - Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance) (DTSC, 2011).

g - gram.

L - liter.

min - minute.

s - second.

SCS - Soil Conservation Service; now the Natural Resources Conservation Service (NRCS).

U.S. DA - United States Department of Agriculture.

USEPA - United States Environmental Protection Agency.

USEPA User's Guide - User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (Environmental Quality Management 2004).

## 8. Acronyms and Abbreviations

AER	Air exchange rate for a building
AF	Attenuation factor
CV	Coefficient of variation
CVOC	Chlorinated volatile organic compound/chemical
DTSC	Department of Toxic Substances Control
ESL	Water Board Environmental Screening Level
HVAC	Heating, ventilation, and air conditioning
JEM	Johnson & Ettinger model
L	Liters
NAVFAC	Naval Engineering Facilities Command
OEHHA	Office of Environmental Health Hazard Assessment
Pa	Pascals
$Q_{\text{building}}$	Building ventilation rate
$Q_{\text{soil}}$	Pressure-driven soil gas flow rate into a building
SGIA	Soil gas to indoor air
SSIA	Subslab soil gas to indoor air
Subslab	Subslab soil gas
USEPA	U.S. Environmental Protection Agency
VF	Vapor flux
VI	Vapor intrusion
VI Database	USEPA Vapor Intrusion Database
VIG	DTSC Vapor Intrusion Guidance (DTSC 2011)
VIR	Vapor intrusion region
VOC	Volatile organic compound/chemical
Water Board	San Francisco Bay Regional Water Quality Control Board
$\Delta P$	Pressure differential; difference in soil gas pressure and the air pressure inside a building
$\mu\text{g}/\text{m}^3$	Micrograms per cubic meter

**Appendix C Table 1**  
**Parameters for Shallow GW Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
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yr - year.

**Note:**

(1) USDA SCS - The USDA SCS Soil Texture Classification system employed in the USEPA Vapor Intrusion Model differs from the Unified Soil Classification System (USCS), which is the system commonly used for soil logging in the environmental remediation industry. See the USEPA User's Guide for further information.

**References:**

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**Appendix C Table 2**  
**Parameters for Shallow GW Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
<b>Soil/Groundwater and Soil Layer Parameters</b>			
Average Soil/Groundwater Temperature (T)	Celsius	15	From USEPA User's Guide Figure 8.
Depth Below Grade to Bottom of Enclosed Floor ( $L_F$ )	cm	15	DTSC VIG Table 3.
Depth Below Grade to Water Table ( $L_{WT}$ )	cm	152	Shallow GW model-specific.
Thickness of Soil Stratum A ( $h_A$ )	cm	152	Shallow GW model-specific.
Soil Type Used to Estimate Soil Vapor Permeability	na	Sand (S)	USDA SCS soil texture classification. See note (1).
Soil Stratum Directly Above Water Table	na	A	Sand
Stratum A SCS Soil Type	na	Sand (S)	Shallow GW model-specific.
Stratum A Soil Dry Bulk Density ( $\rho_b^A$ )	grams/cm <sup>3</sup>	1.66	Sand default
Stratum A Soil Total Porosity ( $n^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.375	Sand default
Stratum A Soil Water-Filled Porosity ( $\Theta_w^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.054	Sand default
<b>Building Parameters</b>			
Enclosed Space Floor Thickness ( $L_{crack}$ )	cm	15	Same as $L_F$ (DTSC VIG Table 3)
Soil-Bldg Pressure Differential ( $\Delta P$ )	g/cm-s <sup>2</sup>	40	DTSC VIG Table 3.
Enclosed Space Floor Length ( $L_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Floor Width ( $W_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Height ( $H_B$ )	cm	244	Slab-on-grade scenario. USEPA User's Guide, p. 40.
Floor-Wall Seam Crack Width ( $w$ )	cm	0.1	USEPA User's Guide, p. 55.
Indoor Air Exchange Rate (ER)	1/hour	1.0	DTSC VIG Table 3.
Average Vapor Flow Rate into Bldg ( $Q_{soil}$ )	L/min	5	DTSC VIG Table 3.

**Appendix C Table 2**  
**Parameters for Shallow GW Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
<b>Exposure Parameters</b>			
Averaging Time for Carcinogens (AT <sub>C</sub> )	yr	70	DTSC Human Health Note 1 (DTSC, 2014).
Averaging Time for Noncarcinogens (AT <sub>NC</sub> )	yr	25	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Duration (ED)	yr	25	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Frequency (EF)	d/yr	250	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Time (ET)	hours/d	8	DTSC Human Health Note 1 (DTSC, 2014).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL User's Guide
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL User's Guide
<b>Toxicity Factors</b> - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
<b>Chemical Properties</b> - No change to the values used in the VLOOKUP.			

**Abbreviations/Acronyms:**

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

DTSC VIG - Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance) (DTSC, 2011).

g - gram.

L - liter.

min - minute.

s - second.

SCS - Soil Conservation Service; now the Natural Resources Conservation Service (NRCS).

U.S. DA - United States Department of Agriculture.

USEPA - United States Environmental Protection Agency.

USEPA User's Guide - User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (Environmental Quality Management 2004).

**Appendix C Table 2**  
**Parameters for Shallow GW Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
DTSC Vapor Intrusion Model, GW-SCR, December 2014

Parameter	Units	Value	Notes
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yr - year.

**Note:**

(1) USDA SCS - The USDA SCS Soil Texture Classification system employed in the USEPA Vapor Intrusion Model differs from the Unified Soil Classification System (USCS), which is the system commonly used for soil logging in the environmental remediation industry. See the USEPA User's Guide for further information.

**References:**

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**Appendix C Table 3**  
**Parameters for Fine-Coarse Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
<b>Soil/Groundwater and Soil Layer Parameters</b>			
Average Soil/Groundwater Temperature (T)	Celsius	15	From USEPA User's Guide Figure 8.
Depth Below Grade to Bottom of Enclosed Floor ( $L_F$ )	cm	15	DTSC VIG Table 3.
Depth Below Grade to Water Table ( $L_{WT}$ )	cm	300	Fine-Coarse Mix model-specific.
Thickness of Soil Stratum A ( $h_A$ )	cm	100	Fine-Coarse Mix model-specific.
Thickness of Soil Stratum B ( $h_B$ )	cm	200	Fine-Coarse Mix model-specific.
Soil Type Used to Estimate Soil Vapor Permeability	na	Sand (S)	USDA SCS soil texture classification. See note (1).
Soil Stratum Directly Above Water Table	na	B	Fine-Coarse Mix model-specific. Note that placing a 200-cm-thick Clay Loam at the Water Table results in a model-calculated capillary fringe thickness of ~47 cm that serves as the dominant source of attenuation.
Stratum A SCS Soil Type	na	Sand (S)	Fine-Coarse Mix model-specific.
Stratum A Soil Dry Bulk Density ( $\rho_b^A$ )	grams/cm <sup>3</sup>	1.50	USEPA (1996)
Stratum A Soil Total Porosity ( $n^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.43	USEPA (1996)
Stratum A Soil Water-Filled Porosity ( $\Theta_w^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.15	USEPA (1996)
Stratum B SCS Soil Type	na	Clay Loam (CL)	Fine-Coarse Mix model-specific.
Stratum B Soil Dry Bulk Density ( $\rho_b^B$ )	grams/cm <sup>3</sup>	1.50	USEPA (1996)
Stratum B Soil Total Porosity ( $n^B$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.43	USEPA (1996)
Stratum B Soil Water-Filled Porosity ( $\Theta_w^B$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.30	USEPA (1996)
<b>Building Parameters</b>			
Enclosed Space Floor Thickness ( $L_{crack}$ )	cm	15	Same as $L_F$ (DTSC VIG Table 3)

**Appendix C Table 3**  
**Parameters for Fine-Coarse Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
Soil-Bldg Pressure Differential ( $\Delta P$ )	g/cm-s <sup>2</sup>	40	DTSC VIG Table 3.
Enclosed Space Floor Length ( $L_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Floor Width ( $W_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Height ( $H_B$ )	cm	244	Slab-on-grade scenario. USEPA User's Guide, p. 40.
Floor-Wall Seam Crack Width ( $w$ )	cm	0.1	USEPA User's Guide, p. 55.
Indoor Air Exchange Rate (ER)	1/hour	0.5	DTSC VIG Table 3.
Average Vapor Flow Rate into Bldg ( $Q_{soil}$ )	L/min	5	DTSC VIG Table 3.
<b>Exposure Parameters</b>			
Averaging Time for Carcinogens ( $AT_C$ )	yr	70	DTSC Human Health Note 1 (DTSC, 2014).
Averaging Time for Noncarcinogens ( $AT_{NC}$ )	yr	26	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Duration (ED)	yr	26	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Frequency (EF)	d/yr	350	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Time (ET)	hours/d	24	DTSC Human Health Note 1 (DTSC, 2014).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL User's Guide
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL User's Guide
<b>Toxicity Factors</b> - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
<b>Chemical Properties</b> - No change to the values used in the VLOOKUP.			

**Abbreviations/Acronyms:**

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

**Appendix C Table 3**  
**Parameters for Fine-Coarse Scenario - Residential**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
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DTSC VIG - Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance) (DTSC, 2011).

g - gram.

L - liter.

min - minute.

s - second.

SCS - Soil Conservation Service; now the Natural Resources Conservation Service (NRCS).

U.S. DA - United States Department of Agriculture.

USEPA - United States Environmental Protection Agency.

USEPA User's Guide - User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (Environmental Quality Management 2004).

yr - year.

**Note:**

(1) USDA SCS - The USDA SCS Soil Texture Classification system employed in the USEPA Vapor Intrusion Model differs from the Unified Soil Classification System (USCS), which is the system commonly used for soil logging in the environmental remediation industry. See the USEPA *User's Guide* for further information.

**References:**

DTSC. 2014. Human Health Risk Assessment Health Note 1. Office of Human and Ecological Risk (HERO). September 30

DTSC. 2011. Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance). October.

Environmental Quality Management. 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. Prepared for

U.S. Environmental Protection Agency Office of Emergency and Remedial Response. February 22.

USEPA. 1996. Soil Screening Guidance: Technical Background Document. EPA-540-R95-128. Washington, D.C. Office of Solid Waste and Emergency Response. May.

**Appendix C Table 4**  
**Parameters for Fine-Coarse Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
<b>Soil/Groundwater and Soil Layer Parameters</b>			
Average Soil/Groundwater Temperature (T)	Celsius	15	From USEPA User's Guide Figure 8.
Depth Below Grade to Bottom of Enclosed Floor ( $L_F$ )	cm	15	DTSC VIG Table 3.
Depth Below Grade to Water Table ( $L_{WT}$ )	cm	300	Fine-Coarse Mix model-specific.
Thickness of Soil Stratum A ( $h_A$ )	cm	100	Fine-Coarse Mix model-specific.
Thickness of Soil Stratum B ( $h_B$ )	cm	200	Fine-Coarse Mix model-specific.
Soil Type Used to Estimate Soil Vapor Permeability	na	Sand (S)	USDA SCS soil texture classification. See note (1).
Soil Stratum Directly Above Water Table	na	B	Fine-Coarse Mix model-specific. Note that placing a 200-cm-thick Clay Loam at the Water Table results in a model-calculated capillary fringe thickness of ~47 cm that serves as the dominant source of attenuation.
Stratum A SCS Soil Type	na	Sand (S)	Fine-Coarse Mix model-specific.
Stratum A Soil Dry Bulk Density ( $\rho_b^A$ )	grams/cm <sup>3</sup>	1.50	USEPA (1996)
Stratum A Soil Total Porosity ( $n^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.43	USEPA (1996)
Stratum A Soil Water-Filled Porosity ( $\Theta_w^A$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.15	USEPA (1996)
Stratum B SCS Soil Type	na	Clay Loam (CL)	Fine-Coarse Mix model-specific.
Stratum B Soil Dry Bulk Density ( $\rho_b^B$ )	grams/cm <sup>3</sup>	1.50	USEPA (1996)
Stratum B Soil Total Porosity ( $n^B$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.43	USEPA (1996)
Stratum B Soil Water-Filled Porosity ( $\Theta_w^B$ )	cm <sup>3</sup> /cm <sup>3</sup>	0.30	USEPA (1996)
<b>Building Parameters</b>			
Enclosed Space Floor Thickness ( $L_{crack}$ )	cm	15	Same as $L_F$ (DTSC VIG Table 3)

**Appendix C Table 4**  
**Parameters for Fine-Coarse Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
Soil-Bldg Pressure Differential ( $\Delta P$ )	g/cm-s <sup>2</sup>	40	DTSC VIG Table 3.
Enclosed Space Floor Length ( $L_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Floor Width ( $W_B$ )	cm	1,000	USEPA User's Guide, p. 54.
Enclosed Space Height ( $H_B$ )	cm	244	Slab-on-grade scenario. USEPA User's Guide, p. 40.
Floor-Wall Seam Crack Width ( $w$ )	cm	0.1	USEPA User's Guide, p. 55.
Indoor Air Exchange Rate (ER)	1/hour	1.0	DTSC VIG Table 3.
Average Vapor Flow Rate into Bldg ( $Q_{soil}$ )	L/min	5	DTSC VIG Table 3.
<b>Exposure Parameters</b>			
Averaging Time for Carcinogens ( $AT_C$ )	yr	70	DTSC Human Health Note 1 (DTSC, 2014).
Averaging Time for Noncarcinogens ( $AT_{NC}$ )	yr	25	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Duration (ED)	yr	25	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Frequency (EF)	d/yr	250	DTSC Human Health Note 1 (DTSC, 2014).
Exposure Time (ET)	hours/d	8	DTSC Human Health Note 1 (DTSC, 2014).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL User's Guide
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL User's Guide
<b>Toxicity Factors</b> - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
<b>Chemical Properties</b> - No change to the values used in the VLOOKUP.			

**Abbreviations/Acronyms:**

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

**Appendix C Table 4**  
**Parameters for Fine-Coarse Scenario - Commercial**  
**GW-to-Indoor Air ESLs**  
 USEPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
-----------	-------	-------	-------

DTSC VIG - Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance) (DTSC, 2011).

g - gram.

L - liter.

min - minute.

s - second.

SCS - Soil Conservation Service; now the Natural Resources Conservation Service (NRCS).

U.S. DA - United States Department of Agriculture.

USEPA - United States Environmental Protection Agency.

USEPA User's Guide - User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (Environmental Quality Management 2004).

yr - year.

**Note:**

(1) USDA SCS - The USDA SCS Soil Texture Classification system employed in the USEPA Vapor Intrusion Model differs from the Unified Soil Classification System (USCS), which is the system commonly used for soil logging in the environmental remediation industry. See the USEPA User's Guide for further information.

**References:**

DTSC. 2014. Human Health Risk Assessment Health Note 1. Office of Human and Ecological Risk (HERO). September 30

DTSC. 2011. Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance). October.

Environmental Quality Management. 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. Prepared for

U.S. Environmental Protection Agency Office of Emergency and Remedial Response. February 22.

USEPA. 1996. Soil Screening Guidance: Technical Background Document. EPA-540-R95-128. Washington, D.C. Office of Solid Waste and Emergency Response. May.

## Groundwater to Indoor Air ESL - Shallow Groundwater, Sand Scenario

DATA ENTRY SHEET

Scenario: **Residential**  
Chemical: **Tetrachloroethylene**

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

**OR**

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES

Reset to  
Defaults

<b>ENTER</b>	<b>ENTER</b>	
Chemical CAS No. (numbers only, no dashes)	Initial groundwater conc., $C_w$ ( $\mu\text{g/L}$ )	Chemical
127184		Tetrachloroethylene

Results Summary					Risk-Based Groundwater Concentration	
Soil Gas Conc. ( $C_{\text{source}}$ ) ( $\mu\text{g/m}^3$ )	Attenuation Factor (alpha) (unitless)	Indoor Air Conc. ( $C_{\text{building}}$ ) ( $\mu\text{g/m}^3$ )	Cancer Risk	Noncancer Hazard	Cancer Risk = $10^{-6}$ ( $\mu\text{g/L}$ )	Noncancer HQ = 1 ( $\mu\text{g/L}$ )
4.29E+02	3.7E-04	1.6E-01	NA	NA	3.0E+00	2.3E+02

MESSAGE: Values of  $C_{\text{source}}$  and  $C_{\text{building}}$  (INTERCALCS worksheet) are based on unity and do not represent actual values.

MORE  
↓

<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
Depth below grade to bottom of enclosed space floor, $L_F$ (15 or 200 cm)	Depth below grade to water table, $L_{WT}$ (cm)	SCS soil type directly above water table	Average soil/groundwater temperature, $T_s$ ( $^{\circ}\text{C}$ )	Average vapor flow rate into bldg. (Leave blank to calculate) $Q_{\text{soil}}$ (L/m)
15	152	S	15	5

MORE  
↓

<b>ENTER</b>	<b>OR</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
Vadose zone SCS soil type (used to estimate soil vapor permeability)		User-defined vadose zone soil vapor permeability, $k_v$ ( $\text{cm}^2$ )	Vadose zone SCS soil type <small>Lookup Soil Parameters</small>	Vadose zone soil dry bulk density, $\rho_b^v$ ( $\text{g/cm}^3$ )	Vadose zone soil total porosity, $n^v$ (unitless)	Vadose zone soil water-filled porosity, $\theta_w^v$ ( $\text{cm}^3/\text{cm}^3$ )
S			S	1.66	0.375	0.054

MORE  
↓

Lookup Receptor Parameters

	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Averaging time for carcinogens, $AT_C$ (yrs)	Averaging time for noncarcinogens, $AT_{NC}$ (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Exposure Time ET (hrs/day)	Air Exchange Rate ACH ( $\text{hour}^{-1}$ )
Residential	1.0E-06	1	70	26	26	350	24	0.5
	Used to calculate risk-based groundwater concentration.							

END

CHEMICAL PROPERTIES SHEET

Tetrachloroethylene

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RFC (mg/m <sup>3</sup> )
5.05E-02	9.46E-06	1.77E-02	25	8,288	394.40	620.20	9.49E+01	2.06E+02	5.9E-06	3.5E-02

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: Residential

Chemical: Tetrachloroethylene

Source-building separation, $L_T$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^V$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone effective total fluid saturation, $S_{te}$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Vadose zone soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Vadose zone soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
137	0.321	0.003	1.00E-07	0.998	9.99E-08	17.05	0.375	0.122	0.253	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ ( $\text{atm}\cdot\text{m}^3/\text{mol}$ )	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_v^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )
3.39E+04	1.00E+06	5.00E-03	15	9,502	1.01E-02	4.29E-01	1.77E-04	8.16E-03	3.25E-04	2.04E-03

Diffusion path length, $L_d$ (cm)	Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC ( $\text{mg}/\text{m}^3$ )
137	15	4.29E+02	1.25	8.33E+01	8.16E-03	5.00E+03	7.45E+08	<b>3.73E-04</b>	1.60E-01	5.9E-06	3.5E-02

END

RESULTS SHEET

Scenario: Residential

Chemical: Tetrachloroethylene

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
2.98E+00	2.28E+02	2.98E+00	2.06E+05	2.98E+00

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE SUMMARY BELOW:

MESSAGE: Values of C<sub>source</sub> and C<sub>building</sub> (INTERCALCS worksheet) are based on unity and do not represent actual values.

END

## Groundwater to Indoor Air ESL - Shallow Groundwater, Sand Scenario

DATA ENTRY SHEET

Scenario: **Commercial**  
Chemical: **Trichloroethylene**

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

**OR**

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES

Reset to  
Defaults

**ENTER** Chemical CAS No. (numbers only, no dashes)  
**ENTER** Initial groundwater conc.,  $C_w$  ( $\mu\text{g/L}$ )  
Chemical

79016 **Trichloroethylene**

MESSAGE: See VLOOKUP table comments on chemical properties and/or toxicity criteria for this chemical.

Results Summary					Risk-Based Groundwater Concentration	
Soil Gas Conc. ( $C_{\text{source}}$ ) ( $\mu\text{g}/\text{m}^3$ )	Attenuation Factor (alpha) (unitless)	Indoor Air Conc. ( $C_{\text{building}}$ ) ( $\mu\text{g}/\text{m}^3$ )	Cancer Risk	Noncancer Hazard	Cancer Risk = $10^{-6}$ ( $\mu\text{g}/\text{L}$ )	Noncancer HQ = 1 ( $\mu\text{g}/\text{L}$ )
2.53E+02	2.4E-04	6.1E-02	NA	NA	4.9E+01	1.4E+02

MESSAGE: Values of  $C_{\text{source}}$  and  $C_{\text{building}}$  (INTERCALCS worksheet) are based on unity and do not represent actual values.

MORE  
↓

**ENTER** Depth below grade to bottom of enclosed space floor,  $L_F$  (15 or 200 cm)  
**ENTER** Depth below grade to water table,  $L_{WT}$  (cm)  
**ENTER** SCS soil type directly above water table  
**ENTER** Average soil/groundwater temperature,  $T_s$  ( $^{\circ}\text{C}$ )  
**ENTER** Average vapor flow rate into bldg. (Leave blank to calculate)  
 $Q_{\text{soil}}$  (L/m)

15    152    S    15    5

MORE  
↓

**ENTER** Vadose zone SCS soil type (used to estimate soil vapor permeability)  
**OR**  
**ENTER** User-defined vadose zone soil vapor permeability,  $k_v$  ( $\text{cm}^2$ )  
**ENTER** Vadose zone SCS soil type (Lookup Soil Parameters)  
**ENTER** Vadose zone soil dry bulk density,  $\rho_b^v$  ( $\text{g}/\text{cm}^3$ )  
**ENTER** Vadose zone soil total porosity,  $n^v$  (unitless)  
**ENTER** Vadose zone soil water-filled porosity,  $\theta_w^v$  ( $\text{cm}^3/\text{cm}^3$ )

S          S    1.66    0.375    0.054

MORE  
↓

**ENTER** Target risk for carcinogens, TR (unitless)  
**ENTER** Target hazard quotient for noncarcinogens, THQ (unitless)  
**ENTER** Averaging time for carcinogens,  $AT_C$  (yrs)  
**ENTER** Averaging time for noncarcinogens,  $AT_{NC}$  (yrs)  
**ENTER** Exposure duration, ED (yrs)  
**ENTER** Exposure frequency, EF (days/yr)  
**ENTER** Exposure Time, ET (hrs/day)  
**ENTER** Air Exchange Rate, ACH ( $\text{hour}^{-1}$ )

Lookup Receptor  
Parameters

Commercial

1.0E-06    1    70    25    25    250    8    1  
Used to calculate risk-based groundwater concentration.

END

CHEMICAL PROPERTIES SHEET

Trichloroethylene

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RFC (mg/m <sup>3</sup> )
6.87E-02	1.02E-05	9.85E-03	25	7,505	360.36	544.20	6.07E+01	1.28E+03	4.1E-06	2.0E-03

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: Commercial  
 Chemical: Trichloroethylene

Source-building separation, $L_T$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^V$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone effective total fluid saturation, $S_{te}$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Vadose zone soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Vadose zone soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
137	0.321	0.003	1.00E-07	0.998	9.99E-08	17.05	0.375	0.122	0.253	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ ( $\text{atm}\cdot\text{m}^3/\text{mol}$ )	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_v^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )
6.78E+04	1.00E+06	5.00E-03	15	8,495	5.99E-03	2.53E-01	1.77E-04	1.11E-02	4.43E-04	2.78E-03

Diffusion path length, $L_d$ (cm)	Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC ( $\text{mg}/\text{m}^3$ )
137	15	2.53E+02	1.25	8.33E+01	1.11E-02	5.00E+03	3.32E+06	2.41E-04	6.09E-02	4.1E-06	2.0E-03

END

RESULTS SHEET

Scenario: Commercial

Chemical: Trichloroethylene

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
4.91E+01	1.44E+02	4.91E+01	1.28E+06	4.91E+01

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE SUMMARY BELOW:

MESSAGE: Values of C<sub>source</sub> and C<sub>building</sub> (INTERCALCS worksheet) are based on unity and do not represent actual values.

END

## Groundwater to Indoor Air ESL - Deep Groundwater, Sand Scenario

DATA ENTRY SHEET

Scenario: Residential  
Chemical: Tetrachloroethylene

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES

Reset to Defaults

ENTER	ENTER	
Chemical CAS No. (numbers only, no dashes)	Initial groundwater conc., $C_w$ ( $\mu\text{g/L}$ )	Chemical
127184		Tetrachloroethylene

Results Summary					Risk-Based Groundwater Concentration	
Soil Gas Conc. ( $C_{\text{source}}$ ) ( $\mu\text{g}/\text{m}^3$ )	Attenuation Factor (alpha) (unitless)	Indoor Air Conc. ( $C_{\text{building}}$ ) ( $\mu\text{g}/\text{m}^3$ )	Cancer Risk	Noncancer Hazard	Cancer Risk = $10^{-6}$ ( $\mu\text{g/L}$ )	Noncancer HQ = 1 ( $\mu\text{g/L}$ )
4.29E+02	3.0E-04	1.3E-01	NA	NA	3.7E+00	2.8E+02

MESSAGE: Values of  $C_{\text{source}}$  and  $C_{\text{building}}$  (INTERCALCS worksheet) are based on unity and do not represent actual values.

MORE  
↓

ENTER	ENTER	ENTER	ENTER	
Depth below grade to bottom of enclosed space floor, $L_F$ (15 or 200 cm)	Depth below grade to water table, $L_{WT}$ (cm)	SCS soil type directly above water table	Average soil/groundwater temperature, $T_s$ ( $^{\circ}\text{C}$ )	Average vapor flow rate into bldg. (Leave blank to calculate) $Q_{\text{soil}}$ (L/m)
15	304	S	15	5

MORE  
↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	
Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	User-defined vadose zone soil vapor permeability, $k_v$ ( $\text{cm}^2$ )	Vadose zone SCS soil type <div style="border: 1px solid gray; padding: 2px; font-size: small;">Lookup Soil Parameters</div>	Vadose zone soil dry bulk density, $\rho_b^v$ ( $\text{g}/\text{cm}^3$ )	Vadose zone soil total porosity, $n^v$ (unitless)	Vadose zone soil water-filled porosity, $\theta_w^v$ ( $\text{cm}^3/\text{cm}^3$ )
S			S	1.66	0.375	0.054

MORE  
↓

Lookup Receptor Parameters

	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	
	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Averaging time for carcinogens, $AT_C$ (yrs)	Averaging time for noncarcinogens, $AT_{NC}$ (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Exposure Time ET (hrs/day)	Air Exchange Rate ACH ( $\text{hour}^{-1}$ )
Residential	1.0E-06	1	70	26	26	350	24	0.5
	Used to calculate risk-based groundwater concentration.							

END

CHEMICAL PROPERTIES SHEET

Tetrachloroethylene

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RFC (mg/m <sup>3</sup> )
5.05E-02	9.46E-06	1.77E-02	25	8,288	394.40	620.20	9.49E+01	2.06E+02	5.9E-06	3.5E-02

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: Residential

Chemical: Tetrachloroethylene

Source-building separation, $L_T$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^V$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone effective total fluid saturation, $S_{te}$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Vadose zone soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Vadose zone soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
289	0.321	0.003	1.00E-07	0.998	9.99E-08	17.05	0.375	0.122	0.253	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ ( $\text{atm}\cdot\text{m}^3/\text{mol}$ )	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_v^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )
3.39E+04	1.00E+06	5.00E-03	15	9,502	1.01E-02	4.29E-01	1.77E-04	8.16E-03	3.25E-04	3.37E-03

Diffusion path length, $L_d$ (cm)	Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC ( $\text{mg}/\text{m}^3$ )
289	15	4.29E+02	1.25	8.33E+01	8.16E-03	5.00E+03	7.45E+08	3.02E-04	1.29E-01	5.9E-06	3.5E-02

END

RESULTS SHEET

Scenario: Residential

Chemical: Tetrachloroethylene

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
3.68E+00	2.82E+02	3.68E+00	2.06E+05	3.68E+00

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE SUMMARY BELOW:

MESSAGE: Values of C<sub>source</sub> and C<sub>building</sub> (INTERCALCS worksheet) are based on unity and do not represent actual values.

END

## Groundwater to Indoor Air ESL - Deep Groundwater, Sand Scenario

DATA ENTRY SHEET

Scenario: **Commercial**  
Chemical: **Tetrachloroethylene**

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

**OR**

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES

Reset to Defaults

<b>ENTER</b>	<b>ENTER</b>	
Chemical CAS No. (numbers only, no dashes)	Initial groundwater conc., $C_w$ ( $\mu\text{g/L}$ )	Chemical
127184		Tetrachloroethylene

Results Summary					Risk-Based Groundwater Concentration	
Soil Gas Conc. ( $C_{\text{source}}$ ) ( $\mu\text{g/m}^3$ )	Attenuation Factor (alpha) (unitless)	Indoor Air Conc. ( $C_{\text{building}}$ ) ( $\mu\text{g/m}^3$ )	Cancer Risk	Noncancer Hazard	Cancer Risk = $10^{-6}$ ( $\mu\text{g/L}$ )	Noncancer HQ = 1 ( $\mu\text{g/L}$ )
4.29E+02	1.5E-04	6.5E-02	NA	NA	3.2E+01	2.4E+03

MESSAGE: Values of  $C_{\text{source}}$  and  $C_{\text{building}}$  (INTERCALCS worksheet) are based on unity and do not represent actual values.

MORE  
↓

<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
Depth below grade to bottom of enclosed space floor, $L_F$ (15 or 200 cm)	Depth below grade to water table, $L_{WT}$ (cm)	SCS soil type directly above water table	Average soil/groundwater temperature, $T_s$ ( $^{\circ}\text{C}$ )	Average vapor flow rate into bldg. (Leave blank to calculate) $Q_{\text{soil}}$ (L/m)
15	304	S	15	5

MORE  
↓

<b>ENTER</b>	<b>OR</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
Vadose zone SCS soil type (used to estimate soil vapor permeability)		User-defined vadose zone soil vapor permeability, $k_v$ ( $\text{cm}^2$ )	Vadose zone SCS soil type <small>Lookup Soil Parameters</small>	Vadose zone soil dry bulk density, $\rho_b^v$ ( $\text{g/cm}^3$ )	Vadose zone soil total porosity, $n^v$ (unitless)	Vadose zone soil water-filled porosity, $\theta_w^v$ ( $\text{cm}^3/\text{cm}^3$ )
S			S	1.66	0.375	0.054

MORE  
↓

Lookup Receptor Parameters

<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>	<b>ENTER</b>
Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Averaging time for carcinogens, $AT_C$ (yrs)	Averaging time for noncarcinogens, $AT_{NC}$ (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Exposure Time ET (hrs/day)	Air Exchange Rate ACH ( $\text{hour}^{-1}$ )
1.0E-06	1	70	25	25	250	8	1
Used to calculate risk-based groundwater concentration.							

END

CHEMICAL PROPERTIES SHEET

Tetrachloroethylene

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm·m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RFC (mg/m <sup>3</sup> )
5.05E-02	9.46E-06	1.77E-02	25	8,288	394.40	620.20	9.49E+01	2.06E+02	5.9E-06	3.5E-02

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: Commercial

Chemical: Tetrachloroethylene

Source-building separation, $L_T$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^V$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone effective total fluid saturation, $S_{te}$ ( $\text{cm}^3/\text{cm}^3$ )	Vadose zone soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Vadose zone soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Vadose zone soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
289	0.321	0.003	1.00E-07	0.998	9.99E-08	17.05	0.375	0.122	0.253	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ ( $\text{atm}\cdot\text{m}^3/\text{mol}$ )	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_v^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )
6.78E+04	1.00E+06	5.00E-03	15	9,502	1.01E-02	4.29E-01	1.77E-04	8.16E-03	3.25E-04	3.37E-03

Diffusion path length, $L_d$ (cm)	Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC ( $\text{mg}/\text{m}^3$ )
289	15	4.29E+02	1.25	8.33E+01	8.16E-03	5.00E+03	7.45E+08	1.51E-04	6.47E-02	5.9E-06	3.5E-02

END

RESULTS SHEET

Scenario: Commercial

Chemical: Tetrachloroethylene

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
3.21E+01	2.37E+03	3.21E+01	2.06E+05	3.21E+01

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE SUMMARY BELOW:

MESSAGE: Values of C<sub>source</sub> and C<sub>building</sub> (INTERCALCS worksheet) are based on unity and do not represent actual values.

END

DATA ENTRY SHEET

Re GW-ADV  
on 3.1; 02/04

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES

San Francisco Bay Regional Water Quality Control Board	
Soil Layer Design: Fine-Coarse Scenario	
Exposure Scenario: Residential	
Cancer Risk GW (µg/L):	1.0E+02
Noncancer Hazard GW (µg/L):	7.7E+03
GW ESL (µg/L):	1.0E+02

**ENTER**  
Chemical CAS No.  
(numbers only, no dashes)

127184

**ENTER**  
Initial groundwater conc.,  $C_w$   
(µg/L)

Chemical

**Tetrachloroethylene**

MORE  
↓

<b>ENTER</b> Average soil/groundwater temperature, $T_s$ (°C)	<b>ENTER</b> Depth below grade to bottom of enclosed space floor, $L_f$ (cm)	<b>ENTER</b> Depth below grade to water table, $L_{WT}$ (cm)	<b>ENTER</b> Thickness of soil stratum A, $h_A$ (cm)	<b>ENTER</b> Thickness of soil stratum B, (Enter value or 0) $h_B$ (cm)	<b>ENTER</b> Thickness of soil stratum C, (Enter value or 0) $h_C$ (cm)	<b>ENTER</b> Soil stratum directly above water table, (Enter A, B, or C)	<b>ENTER</b> SCS soil type directly above water table	<b>ENTER</b> Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	<b>ENTER</b> User-defined stratum A soil vapor permeability, $k_v$ (cm <sup>2</sup> )
15	15	300	100	200		B	CL	S		

MORE  
↓

<b>ENTER</b> Stratum A SCS soil type Lookup Soil Parameters	<b>ENTER</b> Stratum A soil dry bulk density, $\rho_b^A$ (g/cm <sup>3</sup> )	<b>ENTER</b> Stratum A soil total porosity, $n^A$ (unitless)	<b>ENTER</b> Stratum A soil water-filled porosity, $\theta_w^A$ (cm <sup>3</sup> /cm <sup>3</sup> )	<b>ENTER</b> Stratum B SCS soil type Lookup Soil Parameters	<b>ENTER</b> Stratum B soil dry bulk density, $\rho_b^B$ (g/cm <sup>3</sup> )	<b>ENTER</b> Stratum B soil total porosity, $n^B$ (unitless)	<b>ENTER</b> Stratum B soil water-filled porosity, $\theta_w^B$ (cm <sup>3</sup> /cm <sup>3</sup> )	<b>ENTER</b> Stratum C SCS soil type Lookup Soil Parameters	<b>ENTER</b> Stratum C soil dry bulk density, $\rho_b^C$ (g/cm <sup>3</sup> )	<b>ENTER</b> Stratum C soil total porosity, $n^C$ (unitless)	<b>ENTER</b> Stratum C soil water-filled porosity, $\theta_w^C$ (cm <sup>3</sup> /cm <sup>3</sup> )
S	1.50	0.430	0.15	CL	1.5	0.43	0.3				

MORE  
↓

<b>ENTER</b> Enclosed space floor thickness, $L_{crack}$ (cm)	<b>ENTER</b> Soil-bldg. floor pressure differential, $\Delta P$ (g/cm-s <sup>2</sup> )	<b>ENTER</b> Enclosed space floor length, $L_B$ (cm)	<b>ENTER</b> Enclosed space floor width, $W_B$ (cm)	<b>ENTER</b> Enclosed space floor height, $H_B$ (cm)	<b>ENTER</b> Floor-wall seam crack width, $w$ (cm)	<b>ENTER</b> Indoor air exchange rate, ER (1/h)	<b>ENTER</b> Average vapor flow rate into bldg. OR Leave blank to calculate $Q_{soil}$ (L/m)
15	40	1000	1000	244	0.1	0.5	5

MORE  
↓

<b>ENTER</b> Averaging time for carcinogens, $AT_C$ (yrs)	<b>ENTER</b> Averaging time for noncarcinogens, $AT_{NC}$ (yrs)	<b>ENTER</b> Exposure duration, ED (yrs)	<b>ENTER</b> Exposure frequency, EF (days/yr)	<b>ENTER</b> Exposure time, ET (hours/day)	<b>ENTER</b> Target risk for carcinogens, TR (unitless)	<b>ENTER</b> Target hazard quotient for noncarcinogens, THQ (unitless)
70	26	26	350	24	1.0E-06	1.0

END

Used to calculate risk-based groundwater concentration.

**CHEMICAL PROPERTIES SHEET**

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm·m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
5.05E-02	9.46E-06	1.77E-02	25	8,288	394.40	620.20	9.49E+01	2.06E+02	5.9E-06	3.5E-02

**END**

**INTERMEDIATE CALCULATIONS SHEET**

Exposure duration, $\tau$ (sec)	Source-building separation, $L_T$ (cm)	Stratum A soil air-filled porosity, $\theta_a^A$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum B soil air-filled porosity, $\theta_a^B$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum C soil air-filled porosity, $\theta_a^C$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum A effective total fluid saturation, $S_{fe}$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum A soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Stratum A soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Stratum A soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
8.20E+08	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ (atm-m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Stratum A effective diffusion coefficient, $D_A^{eff}$ ( $\text{cm}^2/\text{s}$ )	Stratum B effective diffusion coefficient, $D_B^{eff}$ ( $\text{cm}^2/\text{s}$ )	Stratum C effective diffusion coefficient, $D_C^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )	Diffusion path length, $L_d$ (cm)
3.39E+04	1.00E+06	5.00E-03	15	9,502	1.01E-02	4.29E-01	1.77E-04	3.94E-03	3.08E-04	0.00E+00	2.19E-05	1.07E-04	285

Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
15	4.29E+02	1.25	8.33E+01	3.94E-03	5.00E+03	3.81E+27	<b>1.10E-05</b>	4.73E-03	5.9E-06	3.5E-02

**END**

**RESULTS SHEET**

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
1.01E+02	7.71E+03	1.01E+02	2.06E+05	1.01E+02

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

**SCROLL  
DOWN  
TO "END"**

**END**

DATA ENTRY SHEET

GW-ADV  
1; 02/04  
Reset

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES

<b>San Francisco Bay Regional Water Quality Control Board</b>	
<b>Soil Layer Design: Fine-Coarse Scenario</b>	
<b>Exposure Scenario: Commercial</b>	
Cancer Risk GW (µg/L):	8.8E+02
Noncancer Hazard GW (µg/L):	6.5E+04
<b>GW ESL (µg/L):</b>	<b>8.8E+02</b>

**ENTER**  
Chemical CAS No.  
(numbers only, no dashes)

127184

**ENTER**  
Initial groundwater conc.,  $C_w$  (µg/L)

Chemical

**Tetrachloroethylene**

MORE ↓

**ENTER** Average soil/groundwater temperature,  $T_s$  (°C)  
**ENTER** Depth below grade to bottom of enclosed space floor,  $L_f$  (cm)  
**ENTER** Depth below grade to water table,  $L_{WT}$  (cm)

15 15 300

**ENTER** Thickness of soil stratum A,  $h_A$  (cm)  
**ENTER** Thickness of soil stratum B, (Enter value or 0)  $h_B$  (cm)  
**ENTER** Thickness of soil stratum C, (Enter value or 0)  $h_C$  (cm)  
Totals must add up to value of  $L_{WT}$  (cell G28)

100 200

**ENTER** Soil stratum directly above water table, (Enter A, B, or C)  
**ENTER** SCS soil type directly above water table

B CL

**ENTER** Soil stratum A SCS soil type (used to estimate soil vapor permeability)  
**OR**  
**ENTER** User-defined stratum A soil vapor permeability,  $k_v$  (cm<sup>2</sup>)

S

MORE ↓

**ENTER** Stratum A SCS soil type  
Lookup Soil

S

**ENTER** Stratum A soil dry bulk density,  $\rho_b^A$  (g/cm<sup>3</sup>)

1.50

**ENTER** Stratum A soil total porosity,  $n^A$  (unitless)

0.430

**ENTER** Stratum A soil water-filled porosity,  $\theta_w^A$  (cm<sup>3</sup>/cm<sup>3</sup>)

0.15

**ENTER** Stratum B SCS soil type  
Lookup Soil Parameters

CL

**ENTER** Stratum B soil dry bulk density,  $\rho_b^B$  (g/cm<sup>3</sup>)

1.5

**ENTER** Stratum B soil total porosity,  $n^B$  (unitless)

0.43

**ENTER** Stratum B soil water-filled porosity,  $\theta_w^B$  (cm<sup>3</sup>/cm<sup>3</sup>)

0.3

**ENTER** Stratum C SCS soil type  
Lookup Soil

**ENTER** Stratum C soil dry bulk density,  $\rho_b^C$  (g/cm<sup>3</sup>)

**ENTER** Stratum C soil total porosity,  $n^C$  (unitless)

**ENTER** Stratum C soil water-filled porosity,  $\theta_w^C$  (cm<sup>3</sup>/cm<sup>3</sup>)

MORE ↓

**ENTER** Enclosed space floor thickness,  $L_{crack}$  (cm)

15

**ENTER** Soil-bldg. floor pressure differential,  $\Delta P$  (g/cm-s<sup>2</sup>)

40

**ENTER** Enclosed space floor length,  $L_B$  (cm)

1000

**ENTER** Enclosed space floor width,  $W_B$  (cm)

1000

**ENTER** Enclosed space floor height,  $H_B$  (cm)

244

**ENTER** Floor-wall seam crack width,  $w$  (cm)

0.1

**ENTER** Indoor air exchange rate, ER (1/h)

1.0

**ENTER** Average vapor flow rate into bldg. OR Leave blank to calculate  $Q_{soil}$  (L/m)

5

MORE ↓

**ENTER** Averaging time for carcinogens,  $AT_C$  (yrs)

70

**ENTER** Averaging time for noncarcinogens,  $AT_{NC}$  (yrs)

25

**ENTER** Exposure duration, ED (yrs)

25

**ENTER** Exposure frequency, EF (days/yr)

250

**ENTER** Exposure time, ET (hours/day)

8

**ENTER** Target risk for carcinogens, TR (unitless)

1.0E-06

**ENTER** Target hazard quotient for noncarcinogens, THQ (unitless)

1.0

END

Used to calculate risk-based groundwater concentration.

**CHEMICAL PROPERTIES SHEET**

Diffusivity in air, D <sub>a</sub> (cm <sup>2</sup> /s)	Diffusivity in water, D <sub>w</sub> (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm·m <sup>3</sup> /mol)	Henry's law constant reference temperature, T <sub>R</sub> (°C)	Enthalpy of vaporization at the normal boiling point, ΔH <sub>v,b</sub> (cal/mol)	Normal boiling point, T <sub>B</sub> (°K)	Critical temperature, T <sub>C</sub> (°K)	Organic carbon partition coefficient, K <sub>oc</sub> (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
5.05E-02	9.46E-06	1.77E-02	25	8,288	394.40	620.20	9.49E+01	2.06E+02	5.9E-06	3.5E-02

**END**

**INTERMEDIATE CALCULATIONS SHEET**

Exposure duration, $\tau$ (sec)	Source-building separation, $L_T$ (cm)	Stratum A soil air-filled porosity, $\theta_a^A$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum B soil air-filled porosity, $\theta_a^B$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum C soil air-filled porosity, $\theta_a^C$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum A effective total fluid saturation, $S_{fe}$ ( $\text{cm}^3/\text{cm}^3$ )	Stratum A soil intrinsic permeability, $k_i$ ( $\text{cm}^2$ )	Stratum A soil relative air permeability, $k_{rg}$ ( $\text{cm}^2$ )	Stratum A soil effective vapor permeability, $k_v$ ( $\text{cm}^2$ )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ ( $\text{cm}^3/\text{cm}^3$ )	Floor-wall seam perimeter, $X_{crack}$ (cm)
7.88E+08	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	4,000

Bldg. ventilation rate, $Q_{building}$ ( $\text{cm}^3/\text{s}$ )	Area of enclosed space below grade, $A_B$ ( $\text{cm}^2$ )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ (atm-m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Stratum A effective diffusion coefficient, $D_A^{eff}$ ( $\text{cm}^2/\text{s}$ )	Stratum B effective diffusion coefficient, $D_B^{eff}$ ( $\text{cm}^2/\text{s}$ )	Stratum C effective diffusion coefficient, $D_C^{eff}$ ( $\text{cm}^2/\text{s}$ )	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ ( $\text{cm}^2/\text{s}$ )	Total overall effective diffusion coefficient, $D_T^{eff}$ ( $\text{cm}^2/\text{s}$ )	Diffusion path length, $L_d$ (cm)
6.78E+04	1.00E+06	5.00E-03	15	9,502	1.01E-02	4.29E-01	1.77E-04	3.94E-03	3.08E-04	0.00E+00	2.19E-05	1.07E-04	285

Convection path length, $L_p$ (cm)	Source vapor conc., $C_{source}$ ( $\mu\text{g}/\text{m}^3$ )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ ( $\text{cm}^3/\text{s}$ )	Crack effective diffusion coefficient, $D^{crack}$ ( $\text{cm}^2/\text{s}$ )	Area of crack, $A_{crack}$ ( $\text{cm}^2$ )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ ( $\mu\text{g}/\text{m}^3$ )	Unit risk factor, URF ( $\mu\text{g}/\text{m}^3$ ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
15	4.29E+02	1.25	8.33E+01	3.94E-03	5.00E+03	3.81E+27	<b>5.52E-06</b>	2.37E-03	5.9E-06	3.5E-02

**END**

**RESULTS SHEET**

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

INCREMENTAL RISK CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
8.78E+02	6.48E+04	8.78E+02	2.06E+05	8.78E+02

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

**SCROLL  
DOWN  
TO "END"**

**END**

# **Appendix D**

## **Recommendations for Site-Specific Vapor Intrusion Models**



## RECOMMENDATIONS FOR SITE-SPECIFIC VAPOR INTRUSION MODELS<sup>1</sup>

Regional Water Board staff frequently reviews reports in which human health risk due to vapor intrusion from soil gas or groundwater is evaluated using Johnson & Ettinger model (JEM) with site-specific inputs. The readily available and customizable JEM versions typically are used when default attenuation factors or screening levels suggest a potentially significant risk. Several JEM versions programmed into a Microsoft Excel workbook are provided by USEPA (2004) and DTSC (December 2014). The USEPA model versions for soil gas and groundwater include a screening version with one soil layer and an advanced version with three soil layers. The DTSC model versions for soil gas and groundwater are one-layer (screening) versions and incorporate California-specific toxicity factors, updated physical and chemical constants, and other parameters recommended in the DTSC Vapor Intrusion Guidance (VIG; DTSC, 2011), a commercial exposure scenario option, and a Results Summary that includes the attenuation factor (AF). Note that the DTSC soil gas model defaults to an AF of 0.05 (1/20) if  $L_T$  (source-building separation) is less than 40 centimeters.

The content of submitted reports with JEM outputs varies widely, with the result that typically multiple iterations of agency comments and discharger responses are necessary to reach agreement on the appropriateness of model use and model inputs and output. The purpose of this document is to improve consistency of the reports and to facilitate communication, which is expected to increase the efficiency and to expedite the review of reports containing site-specific model runs, resulting in a reduction of the number of iterations (cost and time). It contains a list of items staff typically look for sorted into categories. In addition, this document provides a brief description of the JEM versions and list of key references.

The list below is not intended to be absolute. However, for most reports containing human health risk estimates derived from JEM versions, it will be necessary to address the items below in order for Regional Water Board staff and the discharger to reach agreement.

### RECOMMENDED CONTENT FOR VAPOR INTRUSION MODELING REPORT

#### General Expectations

- Written report that contains a conceptual site model (CSM), a description of the lines of evidence for the vapor intrusion pathway, the JEM version (including any reprogramming to run more than one chemical at a time, etc.), identification of the exposure scenario (e.g., residential versus commercial/industrial), as well as the following items:
- List or table of inputs with clear identification of all non-default inputs and explanations of the latter.
- List or table of key outputs that should include the attenuation factors for all chemicals and model runs.

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<sup>1</sup> Prepared by San Francisco Bay Regional Water Quality Control Board staff Ross Steenson. This is an update to a previous version prepared by Ross Steenson and former staff Dr. Uta Hellmann-Blumberg.

## Recommendations for Site-Specific Vapor Intrusion Models

- Copies of each of the model worksheets (DATAENTER, CHEMPROPS, INTERCALCS, RESULTS, VLOOKUP).
- Include the Excel file of the model to enable Regional Water Board staff to conduct an independent evaluation.

### Conceptual Site Model

#### ***Site geology and hydrogeology***

- Written description of soil types and continuity of strata (layers). Discussion of adequacy of geologic and hydrogeologic characterization.
- Identification and evaluation of preferential pathways – This can include manmade pathways (e.g., utility corridors including backfill material) or natural (e.g., desiccation cracks, macropores, or channels).
- Depth to groundwater (recent and historical ranges).
- Include geologic cross sections and boring logs (with clear identification of the soil classification system) or reference to reports containing the logs.

#### ***Buildings susceptibility<sup>2</sup> (for buildings within 100 feet of a soil vapor or groundwater plume)***

- Physical features include but are not limited to: cracks (holes or gaps), subgrade structures, floor drains, utility vaults or pits, sumps, elevator shafts (and pits for the pistons), basements, crawl spaces, modifications to the original foundation (e.g., repairs), staining or seeps (wet foundations).
- Operational features such as heaters or central heat and air units. Characteristics of the HVAC system operation are important (e.g., zones of mechanical influence, non-uniform over-pressurization). In addition, exhaust fans and furnaces can induce local pressure gradients that encourage vapor intrusion.

#### ***Applicability of model given site conditions***

- Discussion regarding whether model use is applicable and appropriate for the site (see USEPA User's Guide Section 5).

### Specific Model Inputs and Output

#### ***Exposure Point Concentrations***

- Indicate whether the concentrations are based on a one-time sampling event or temporal data (describe the trend).
- Describe the basis of the modeled concentrations (e.g., maximum concentrations, all concentrations, or an average).

---

<sup>2</sup> Building susceptibility refers to building physical or operational features that may allow for vapors to intrude.

## Recommendations for Site-Specific Vapor Intrusion Models

- Discuss whether sufficient numbers of samples have been collected for adequate lateral and vertical characterization and whether the sample locations used for vapor intrusion evaluation are appropriately located relative to the receptor(s).

### **Soil Layers**

- Describe the model soil layers in relation to the site geology and hydrogeology (e.g., is the model being used with soil layers replicating those observed in a single boring are the soil layers generalized, etc.).
- State whether the soils were logged using the USDA Natural Resource Conservation Service (formerly Soil Conservation Service) Soil Texture Classification used in the model. If not, describe how they were converted along with appropriate justification. The USDA Soil Conservation Service Soil Texture Classification system is different than the Unified Soil Classification System typically used for boring logs; discrepancies between the two systems are a common source of errors observed by Regional Board staff.
- State whether the most conservative soil type was used (see EPA User's Guide and DTSC VIG).
- The effective diffusion coefficient is a measure of the vapor flux due to diffusion. The model calculates a total effective diffusion coefficient depending on the soil layer design and soil parameter values. Because of the soil classification issue previously mentioned, it is helpful to understand how selection of soil types in the model affect diffusion coefficients (vapor transport). A ranking of effective diffusion coefficients for each of the 12 soil types in the JEM is included in Table 1 (soil gas) and Table 2 (groundwater). The rankings in Table 1 (soil gas) are driven by the soil type and soil parameter values. The rankings in Table 2 (groundwater) are driven by the above along with how the capillary fringe is modeled for the particular soil type. In the JEM, the capillary fringe is modeled as a separate layer and thus the effective diffusion coefficient in Table 2 is a function of the soil type, soil parameter values, and capillary fringe characteristics.

### **Soil Parameters**

- The most sensitive model parameter is soil moisture (soil water-filled porosity). Discuss whether the soil moisture values are reasonable.
- Site-Specific Soil Data (Geotechnical Laboratory Analyses) – The VIG states that estimating soil physical properties from a visual description of subsurface soil, as annotated onto a boring log, is not an appropriate approach for the selection of model input parameters. The following should be confirmed regarding site-specific geotechnical soil data:
  - Indicate whether three or more geotechnical soil samples were collected from each modeled soil layer and whether the most conservative results have been used as recommended in the DTSC VIG Appendix D.

## Recommendations for Site-Specific Vapor Intrusion Models

- Describe the sample collection methodology and likelihood of sample disturbance.
- Indicate whether the lateral and vertical sample locations were appropriate given the receptors.
- Indicate whether the samples impacted by transient soil moisture (e.g., collected near the surface during the rainy season or after a storm or after irrigation system operation) or within/near the capillary fringe?
- Confirm that the geotechnical laboratory classified the soils using the USDA Soil Conservation Service Soil Texture Classification. If not, consider using the online calculator or the Excel file version (search “USDA soil texture calculator”).

### ***Hydrogeology (Groundwater Model Only)***

- Describe why the basis for the selected depth to groundwater is reasonable given the recent and historical range of fluctuation.
- State why the model assumption of a clean capillary fringe (i.e., devoid of contamination) is valid.

### ***Uncertainty and Sensitivity Analysis***

- Identify parameters that have the most uncertainty in their values.
- Identify the parameters that, when changed (within reasonable variations), result in significant changes in output. Soil moisture (soil water-filled porosity) is the most sensitive parameter (Johnson, 2002) and values should be varied to reflect seasonal changes or other differences (e.g., soils beneath buildings or pavement typically are drier). Other parameters to consider varying include the depth to groundwater and capillary fringe thickness.
- Provide a reasonable range in outcomes and discuss relative to model precision.

## ATTACHMENT

### DESCRIPTION OF THE JOHNSON & ETTINGER MODEL AND MODEL ASSUMPTIONS

The JEM is a one-dimensional analytical fate and transport model of vapors into indoor air (USEPA, 2004). The model calculates an attenuation factor (called the Infinite Source Indoor Air Coefficient on the INTERCALCS worksheet) that relates vapor concentration in indoor air to the vapor concentration at the source. Even under optimal conditions, the JEM is generally considered to have a precision no greater than an order of magnitude (Weaver and Tillman, 2005; DTSC, 2011). The model's intended use is for screening purposes. It is based on a number of simplifying assumptions. The assumptions that should be revisited when applying the model to a site include the following:

- Homogeneous soil layers with isotropic properties.
- Contaminants are homogeneously distributed at the source.
- The vapor source is infinite.
- For the groundwater model, the vapor concentration at the source is calculated based on equilibrium partitioning.
- Vapor is assumed to diffuse directly upward (one-dimensional transport) through uncontaminated soil (including an uncontaminated capillary fringe in the groundwater model) to the base of the building foundation, where advection carries the vapor through cracks and openings in the foundation into the building. Both diffusive and advective transport processes are assumed to be at steady state.
- The model is not valid for the following situations:
  - Presence of NAPL in the subsurface
  - Presence of heterogeneous geological materials (other than the three layers in the advanced version of the model) between the vapor source and building
  - Geologic materials that are fractured, karst, or contain macropores or other preferential pathways
  - Sites where significant lateral flow of vapors occurs (e.g., geologic layers that deflect contaminants from a strictly upward motion and buried pipelines or conduits that form preferential pathways)
  - Shallow groundwater where the building foundation is wetted by groundwater
  - Very small building air exchange rates (<0.25/hour)
  - Building with crawlspace structures or other significant openings to the subsurface (the model is designed for slab on grade and basement situations)
  - Contaminated groundwater with significant fluctuations in water table elevation (in these situations the capillary fringe likely is contaminated)

## Recommendations for Site-Specific Vapor Intrusion Models

Based on our review of peer-reviewed journal articles and other information that provide a level of detail regarding the JEM (Johnson et al. 2002; Hers et al. 2003; Fitzpatrick and Fitzgerald 2002; Weaver and Tillman 2005; Provoost et al. 2010; Yao et al. 2011), the model appears to be generally able to predict indoor air concentrations within an order of magnitude except for preferential pathway situations (Johnson et al. 2002; Hers et al. 2003; Fitzpatrick and Fitzgerald 2002; Weaver and Tillman 2005; Provoost et al. 2010; Yao et al. 2011). In a small percentage of cases, the JEM under predicts. For instance, Yao et al. (2011) identifies concerns that JEM under predicts indoor air concentrations for extreme values of intrinsic permeability such as gravels ( $k = 10^{-10} \text{ m}^2$ ) and clay-like soils ( $10^{-14}$  to  $10^{-13} \text{ m}^2$ ).

## REFERENCES

- DTSC. 2011. Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance). California Environmental Protection Agency, Department of Toxic Substances Control. October.
- Fitzpatrick, N. A.; Fitzgerald, J. J. An Evaluation of Vapor Intrusion into Buildings through a Study of Field Data. *Soil Sed. Contam.* 2002, 11, 603–623.
- Hers, I., R. Zapf-Gilje, P.C. Johnson, and L. Li. 2003. Evaluation of the Johnson and Ettinger Model for Prediction of Indoor Air Quality. *Ground Water Monit. Rem.* 2003, 23, p. 119–133.
- Johnson, P. C. 2002. Identification of Application-Specific Critical Inputs for the 1991 Johnson and Ettinger Vapor Intrusion Algorithm. *Ground Water Monitoring and Remediation*, v. 25, no. 1, p. 63 – 78.
- USEPA. 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. U.S. Environmental Protection Agency Office of Emergency and Remedial Response. February 22.
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- USEPA. 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. U.S. Environmental Protection Agency Office of Emergency and Remedial Response. February 22.
- Weaver, J. W., and F. D. Tillman. 2005. Uncertainty and the Johnson-Ettinger Model for Vapor Intrusion Calculations. United State Environmental Protection Agency Publication No. EPA/600/R-05/110. September 2005.
- Yao, Y., R. Shen, K.G. Pennell, and E.M. Suuberg. 2011. A Comparison of the Johnson-Ettinger Vapor Intrusion Screening Model Predictions with Full Three-Dimensional Model Results. *Environ. Sci. Technol.* 2011, 45 (12), 2227–2235.

SCS Soil Type	SCS Soil Name	Bulk Density (g/cm <sup>3</sup> )	Total Porosity (cm <sup>3</sup> /cm <sup>3</sup> )	Soil Water-Filled Porosity Content (cm <sup>3</sup> /cm <sup>3</sup> )	Total D <sub>eff</sub> (cm <sup>2</sup> /s)	Index Values (Total D <sub>eff</sub> /Lowest D <sub>eff</sub> )	Narrative Ranking of Index Values
C	Clay	1.43	0.459	0.215	2.97E-03	1.68	Low
CL	Clay Loam	1.48	0.442	0.168	4.72E-03	2.67	Moderate
L	Loam	1.59	0.399	0.148	4.32E-03	2.44	Moderate
LS	Loamy Sand	1.62	0.390	0.076	9.54E-03	5.39	High
S	Sand	1.66	0.375	0.054	1.11E-02	6.27	High (Highest)
SC	Sandy Clay	1.63	0.385	0.197	1.77E-03	1.00	Low (Lowest)
SCL	Sandy Clay Loam	1.63	0.384	0.146	3.91E-03	2.21	Moderate
SI	Silt	1.35	0.489	0.167	6.60E-03	3.73	High
SIC	Silty Clay	1.38	0.481	0.216	3.56E-03	2.01	Moderate
SICL	Silty Clay Loam	1.37	0.482	0.198	4.47E-03	2.53	Moderate
SIL	Silt Loam	1.49	0.439	0.180	3.96E-03	2.24	Moderate
SL	Sandy Loam	1.62	0.387	0.103	6.93E-03	3.92	High

Soil Type	Ranked Index Values	Narrative Ranking
Sandy Clay	1.00	Lowest
Clay	1.68	Low
Silty Clay	2.01	Moderate
Sandy Clay Loam	2.21	Moderate
Silt Loam	2.24	Moderate
Loam	2.44	Moderate
Silty Clay Loam	2.53	Moderate
Clay Loam	2.67	Moderate
Silt	3.73	High
Sandy Loam	3.92	High
Loamy Sand	5.39	High
Sand	6.27	Highest

**Table 1 - Ranking of Total Effective Diffusion (D<sub>eff</sub>) Coefficients for Different Soil Types in the SG-SCR Version of the JEM.**

Model Information: HERO SG-SCR Model (December 2014). TCE. Depth to soil gas sample = 152 cm. Residential. Default Parameters.

SCS Soil Type	SCS Soil Name	Bulk Density (g/cm <sup>3</sup> )	Total Porosity (cm <sup>3</sup> /cm <sup>3</sup> )	Soil Water-Filled Porosity (cm <sup>3</sup> /cm <sup>3</sup> )	Capillary Fringe Height (cm)	Total D <sub>eff</sub> (cm <sup>2</sup> /s)	Index Values (Total D <sub>eff</sub> /Lowest D <sub>eff</sub> )	Narrative Ranking of Index Values
C	Clay	1.43	0.459	0.215	81.52	6.54E-05	1.56	Low
CL	Clay Loam	1.48	0.442	0.168	46.88	2.79E-04	6.66	Moderate
L	Loam	1.59	0.399	0.148	37.50	4.07E-04	9.73	Moderate
LS	Loamy Sand	1.62	0.390	0.076	18.75	1.74E-03	41.61	High
S	Sand	1.66	0.375	0.054	17.05	4.54E-03	108.52	Highest
SC	Sandy Clay	1.63	0.385	0.197	30.00	8.78E-05	2.10	Low
SCL	Sandy Clay Loam	1.63	0.384	0.146	25.86	2.82E-04	6.72	Moderate
SI	Silt	1.35	0.489	0.167	163.04	2.99E-04	7.14	Moderate
SIC	Silty Clay	1.38	0.481	0.216	192.31	4.19E-05	1.00	Lowest
SICL	Silty Clay Loam	1.37	0.482	0.198	133.93	1.65E-04	3.95	Low
SIL	Silt Loam	1.49	0.439	0.180	68.18	4.67E-04	11.16	High
SL	Sandy Loam	1.62	0.387	0.103	25.00	6.39E-04	15.27	High

Soil Type	Ranked Index Values	Narrative Ranking
Silty Clay	1.00	Lowest
Clay	1.56	Low
Sandy Clay	2.09	Low
Silty Clay Loam	3.93	Low
Clay Loam	6.64	Moderate
Sandy Clay Loam	6.70	Moderate
Silt	7.12	Moderate
Loam	9.70	Moderate
Silt Loam	11.12	High
Sandy Loam	15.22	High
Loamy Sand	41.47	High
Sand	108.17	Highest

**Table 2 - Ranking of Total Effective Diffusion (D<sub>eff</sub>) Coefficients for Different Soil Types in the GW-SCR Version of the JEM.**  
 Model Information: HERO GW-SCR Model (December 2014). TCE. Depth to groundwater = 300 cm. Residential. Default Parameters.

# Appendix E

## Manual Calculation of Soil Leaching to Groundwater ESL



## MANUAL CALCULATION OF SOIL LEACHING TO GROUNDWATER ESL

**Issue:** As presented in ESL Table S-2, soil leaching to groundwater ESLs are calculated for two target groundwater concentrations: 1) the drinking water resource target that also corresponds to the Tier 1 ESLs and 2) the non-drinking water resource target. The latter is the lowest ESL that addresses three environmental concerns: gross contamination, groundwater vapor intrusion, and nuisance/odor. There may be situations where the user wishes to manually calculate a soil leaching to groundwater ESL for a specified groundwater target that represents a single concern, rather than the lowest of three concerns. The following instructions detail how to accomplish this.

**Resolution:** The resolution process includes manual selection of the target groundwater screening level, calculation the soil leaching to groundwater ESL, and manual review to determine the Final Soil ESL.

**Background on Soil Leaching to Groundwater ESL Calculation:** ESLs for soil leaching to groundwater concerns are presented in summarized in ESL Table S-2. These screening levels are intended to address potential leaching of chemicals from vadose-zone soils and subsequent impact to groundwater. The soil leaching ESLs are back- calculated based on target groundwater screening levels.

The formula for calculating this ESL is presented in the User's Guide. That formula is:

$$C_{\text{soil}} = \text{DAF} \times C_{\text{gw}} \times 0.001 \text{ mg}/\mu\text{g}$$

Where:

$C_{\text{soil}}$  = leaching based soil concentration (mg/kg);

DAF = SESOIL-based dilution/attenuation factor;

$C_{\text{gw}}$  = target groundwater screening level ( $\mu\text{g}/\text{L}$ ).

### Procedure:

1. Select the DAF for the target chemical from ESL Table S-2.
2. Select the target groundwater concentration for the user's specific application.
3. Multiply DAF by  $C_{\text{gw}}$  by 0.001 mg/ $\mu\text{g}$  as indicated above.
4. In the Workbook, review ESL Table T2-3 (Specific Concerns) and re-evaluate the Final Soil ESL with the manually calculated soil leaching to groundwater ESL.



# **Appendix F**

**Technical Resource Document: Fraction Approach to  
Develop ESLs for TPH Mixtures**



San Francisco Bay Regional Water Quality Control Board

# Technical Resource Document: Fraction Approach to Develop ESLs for TPH Mixtures

February 17, 2016

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## Executive Summary

Total petroleum hydrocarbons (TPH) refers to a non-specific laboratory analysis that provides a measure of the concentrations of all hydrocarbons present in a sample over a particular carbon range without identifying individual compounds. TPH is a mixture of many chemicals. The amount of TPH detected in environmental samples is a useful indicator of petroleum contamination at a site.

The Environmental Screening Levels (ESLs) have always included human health-risk-based screening levels for TPH mixtures (Regional Water Board 2000). As part of the May 2013, ESL update, a fraction approach to developing screening levels for TPH mixtures was adopted. Our approach is modeled after the fraction approach used by the Hawai'i Department of Health (HDOH) in *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2011) and based on the fractions, surrogates, toxicity values in the U.S. Environmental Protection Agency (USEPA) *Final Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons* (USEPA 2009c).

The purpose of this memorandum is to describe the technical basis for use of the fraction approach to develop human health-risk-based ESLs as a tool for evaluating risks at petroleum release sites. The presentation includes discussion of petroleum chemistry, fate of released petroleum, background regarding fraction approaches, description of our TPH fractions, toxicity values and surrogates for the fractions, calculation of weighted-average toxicity values and constants, development of screening levels for other mixtures, and fractionation analysis methods and their use in site-specific evaluations.

In general, the ESLs are not used at sites that are subject to the *Low-Threat Underground Storage Tank Case Closure Policy* (State Water Board 2012). They may be used at such sites to screen for constituents not already addressed by the Policy. See the ESL User's Guide for further information.

## 1. Introduction

Total petroleum hydrocarbons (TPH) refers to a non-specific laboratory analysis that provides a measure of the concentrations of all hydrocarbons present in a sample over a particular carbon range without identifying individual compounds. TPH is a mixture of many chemicals. The amount of TPH detected in environmental samples is a useful indicator of petroleum contamination at a site.

The Environmental Screening Levels (ESLs) have always included human health-risk-based screening levels for TPH mixtures (Regional Water Board 2000). As part of the May 2013, ESL update, a fraction approach to developing screening levels for TPH mixtures was adopted. Our approach is modeled after the fraction approach used by the Hawai'i Department of Health (HDOH) in *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2011) and based on the fractions, surrogates, toxicity values in the U.S. Environmental Protection Agency (USEPA) *Final Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons* (Complex Mixtures PPRTV; USEPA 2009c).

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In general, the ESLs are not used at sites that are subject to the Low-Threat Underground Storage Tank Closure Policy (State Water Board 2012). They may be used at such sites to screen for constituents not already addressed by the Policy. See the ESL User's Guide for further information.

## 2. Petroleum Chemistry

Petroleum hydrocarbons are chemicals composed of hydrogen and carbon molecules that originate from crude oil. Most crude oils are complex mixtures contain tens of thousands of compounds, including hydrocarbons and nonhydrocarbons. The latter contain heteroatoms (nitrogen, sulfur, or oxygen atoms; aka NSO) (Stout et al. 2002). Whereas most hydrocarbon compounds are nonpolar or moderately polar (e.g. aromatics), NSO compounds are significantly more polar because nitrogen, sulfur, and oxygen are strongly electronegative. In addition, there are smaller amounts of organometallic compounds and inorganic salts. Crude oils are refined by various techniques to produce different petroleum fuels and products based on boiling point

range (e.g., gasoline, diesel fuel, motor oil, bunker fuel), and much of the NSO (polar) compound content intrinsic to crude oils can be removed in the process.

The hydrocarbons can be divided into two broad families based on molecular structure and chemical bonding patterns:

**Aliphatic hydrocarbons** are nonpolar because electrons are shared fairly evenly. In other words, there is no electron excess (partial negative charge) or deficit (partial positive charge) for the interaction with polar molecules such as water. They can further be divided into several classes including straight-chain, saturated aliphatics (alkanes); branched alkanes (isoalkanes); cyclic alkanes (cycloalkanes); and various unsaturated aliphatics (alkenes and alkynes). Examples of aliphatics include n-hexane (C<sub>6</sub>, straight-chain or linear alkane) and cyclohexane (C<sub>6</sub>, cyclic alkane).

**Aromatic hydrocarbons** are moderately polar because they have “clouds” of loosely attached “delocalized” electrons which facilitate interactions among the aromatics as well as between the aromatics and other polar molecules. Aromatic hydrocarbons consist of one or more unsaturated ring(s) and can have aliphatic attachments. Examples include benzene (C<sub>6</sub>, a single ring aromatic or monoaromatic hydrocarbon), toluene (C<sub>7</sub>, aka methylbenzene) and naphthalene (C<sub>10</sub>), which has a fused, double ring and is the smallest polycyclic aromatic hydrocarbon (PAH).

Aliphatic and aromatic hydrocarbons have physical, chemical and biological properties that are distinct from each other. Table 1 illustrates some of these differences. For instance, n-hexane (C<sub>6</sub> aliphatic) is about 15 times more volatile than benzene (C<sub>6</sub> aromatic) based on vapor pressure. Benzene, however, is about 200-times more solubility in water than n-hexane, which is directly attributable to the polarity of benzene. Therefore, the chemical properties of petroleum mixtures vary with the percent of aliphatic versus aromatic compounds, the size of the molecules, the presence of nonhydrocarbons, the presence of breakdown products, and how the chemicals interact. Table 1 also illustrates the properties of two metabolites of hexane: hexanoic acid and 2-hexanone. As indicated, the metabolites are significantly more soluble than the parent hydrocarbon.

<b>Table 1 – Physico-Chemical Properties of Selected Hydrocarbons and Metabolites</b>					
<b>Chemical</b>	<b>Formula</b>	<b>Boiling Point (°C)</b>	<b>Vapor Pressure (mm Hg)</b>	<b>Solubility (µg/L)</b>	<b>Henry’s Law Constant (atm·m<sup>3</sup>/mol)</b>
Benzene	C <sub>6</sub> H <sub>6</sub>	80	9.48E+01	2.0E+06	5.55E-03
n-Hexane	C <sub>6</sub> H <sub>14</sub>	68.7	1.51E+02	9.5E+03	1.8
2-Hexanone	C <sub>6</sub> H <sub>12</sub> O <sub>1</sub>	127.6	1.36E+01	7.7E+06	9.32E-05
Hexanoic Acid	C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	205.2	4.35E-02	5.8E+06	7.58E-07
<b>Note:</b> Parameter values from USEPA Estimation Programs Interface (EPI) Suite.					

### 3. Fate of Released Petroleum

Although there can be degradation during storage and transmission of petroleum mixtures, the composition of petroleum mixtures tends to change more rapidly due to weathering processes after release to the environment. The definition of weathering overlaps with environmental fate and transport, particularly for petroleum mixtures since the aliphatics and aromatics have different properties. **Environmental fate and transport** refers to the displacement (movement) of the chemicals after release as well as chemical alteration which determine the chemical's fate. Transport processes include partitioning, evaporation or volatilization; dissolution or leaching; adsorption to soil particles; and NAPL flow.

Spills and leaks of petroleum hydrocarbons such as gasoline, diesel, motor oils, petroleum solvents, bunker fuels and crude oils have caused widespread contamination in the environment (USEPA 1999). Generally these contaminants are present both in NAPL form (non-aqueous phase liquid; the bulk liquid petroleum hydrocarbon) and also as dissolved contaminants in the groundwater. In and near the actual release locations (i.e., source areas), some proportion of migrating or mobile NAPL (free product) becomes adsorbed in soil pores through which it travels. This is referred to as **residual NAPL**, and it is bound and immobile in soil because of capillary forces. It also can be referred to as discontinuous NAPL (USEPA 1995). Eventually, after the leak or release has stopped, the migrating or mobile NAPL becomes depleted and what remains is relatively immobile residual NAPL held by capillary tension in soil pore spaces. Residual NAPL in soil poses a risk in its immediate vicinity (USEPA 1999), and it can sustain groundwater plumes through dissolution and vapor plumes through volatilization.

**Weathering** is a general term for a variety of processes that change the nature and composition of chemicals and mixtures released to the environment. The chemical alteration processes include abiotic degradation (e.g., photo-oxidation for surface releases) and microbial biodegradation. Stepwise degradation can ultimately lead to carbon dioxide and water as the final products, although a relatively inert residuum can be formed that cannot be further degraded (Aeppli et al. 2012). Because it requires many different catalytic activities, complete petroleum hydrocarbon break down takes time, particularly for more complex compounds and mixtures. For some cases the Regional Water Board oversees, there remains significant contaminant mass in soil nearly 100 years after release.

**Microbial biodegradation** is a process in which resident soil microbes break the hydrocarbons down either for energy for activity and cell growth or through co-metabolization. There are many factors that influence biodegradation including the composition of the released mixture, nature of the resident microbial population, presence of oxygen or other electron acceptors, nutrient availability (e.g., nitrogen, phosphorus) for activity and cell growth, moisture content, pH, and soil temperature. Biodegradation occurs more rapidly in aerobic conditions but can occur in anaerobic conditions, albeit more slowly (TPHCWG 1998b). Susceptibility to biodegradation for

various hydrocarbons varies. In general, the greater branching correlates to increased resistance to microbial attack (Atlas 1981; Watson et al. 2002; Scott et al. 2005; Booth et al. 2007; Melbye et al. 2009). For example, n-alkanes are considered the most susceptible to biodegradation whereas cycloalkanes are very resistant.

**Intermediate breakdown products** such as aliphatic acids, some of which are toxic, have been found to accumulate during hydrocarbon biodegradation (Atlas 1981). We call these intermediate breakdown products **petroleum degradates**, which encompasses products from photo-oxidation as well, or **petroleum metabolites** (biodegradation only).

## 4. Fraction Approach

### a. Background

The TPH Criteria Working Group (TPHCWG 1997a) estimated the number of individually identified hydrocarbon components of various petroleum fuels and crude oils at approximately 250. Only a relatively small number of these 250 hydrocarbons have been sufficiently studied to understand their toxicity and fate and transport characteristics. Despite this limitation, the TPHCWG (1997a, 1997b, 1998a, 1998b, and 1999) and many states have elected to develop risk-based screening levels for TPH rather than underestimate the potential risks (e.g., MADEP 2003; HDOH 2011, and others). Many of these have adopted a fraction approach for developing TPH screening levels.

USEPA supports a fraction-based approach to risk assessment for petroleum mixtures similar to previous efforts by Massachusetts Department of Environmental Protection (MADEP) and the TPHCWG. The USEPA approach is presented in the Complex Mixtures PPRTV (USEPA 2009c) and is supported by six PPRTV<sup>1</sup> documents, which were also used for our particular fraction approach in the ESLs:

- n-hexane (USEPA 2009f);
- commercial or practical grade hexane (USEPA 2009b);
- midrange aliphatic hydrocarbon streams (USEPA 2009c);
- white mineral oil (USEPA 2009a);
- high-flash aromatic naphtha (USEPA 2009d); and
- fluoranthene (USEPA 2012).

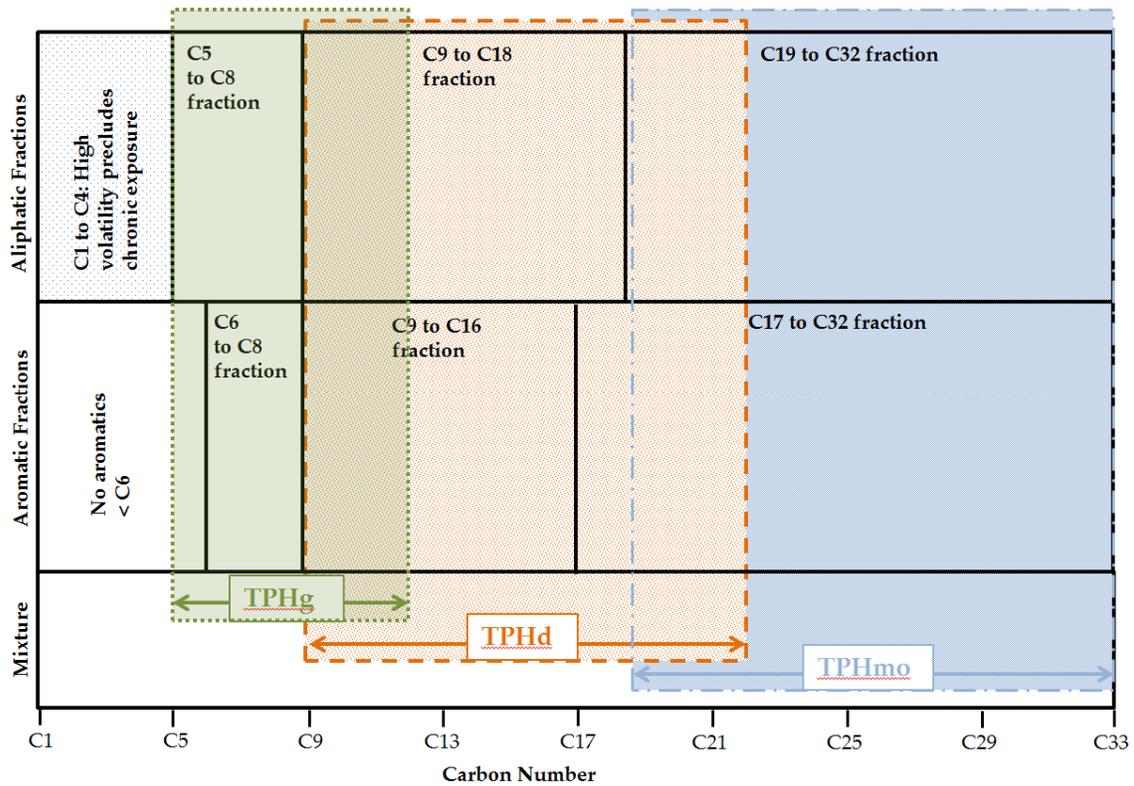
USEPA considers the approach to be reasonable, flexible, and best available methodology for risk assessment of complex mixtures of aliphatic and aromatic hydrocarbons. USEPA scientists evaluated the approach using computational chemistry and statistical methods and found supporting evidence for selecting the fractions (Wang

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<sup>1</sup> The USEPA PPRTVs are Tier 2 toxicity values in the ESL toxicity value hierarchy (see Chapter 3).

et al. 2012). The RSLs also include screening levels for the TPH fractions (USEPA 2015) with some variations from the Complex Mixtures PPRTV.

The health risk-based direct exposure ESLs (e.g., soil direct contact, tapwater, and indoor air) for the different TPH mixtures were calculated by developing weighted-average toxicity values based on the proportion of each USEPA defined TPH fraction present in the specified TPH mixtures, similar to HDOH (2011). Figure 1 illustrates how TPH gasoline, TPH diesel, and TPH motor oil mixtures overlap with the six USEPA TPH fractions. For example, TPHd is composed of four fractions: C<sub>9</sub> to C<sub>18</sub> aliphatics, C<sub>19</sub> to C<sub>32</sub> aliphatics, C<sub>9</sub> to C<sub>16</sub> aromatics, and C<sub>17</sub> to C<sub>32</sub> aromatics.



**Figure 1. Overlay of Three TPH Mixtures (TPH gasoline, TPH diesel, and TPH motor oil) with the Six TPH Fractions**

**b. TPH Fractions Used to Characterize TPH Mixtures**

The TPH fractions are divided by molecular structure into aliphatics and aromatics, and then each structure is subdivided into three carbon ranges (low, medium, and high), for a total of six fractions, as shown in Table 1.

Table 2 – Fractions and Characteristics Defined Based on Molecular Structure and Carbon Range			
Molecular Structure	Carbon Range		
	Low	Medium	High
<b>Aliphatics</b>	C <sub>5</sub> to C <sub>8</sub> Soluble Volatile	C <sub>9</sub> to C <sub>18</sub> Non-soluble Volatile	C <sub>19</sub> to C <sub>32</sub> Non-soluble Non-volatile
<b>Aromatics</b>	C <sub>6</sub> to C <sub>8</sub> Soluble Volatile	C <sub>9</sub> to C <sub>16</sub> Soluble Volatile	C <sub>17</sub> to C <sub>32</sub> Non-soluble Non-volatile

Different petroleum mixtures are made up of varying proportions of each fraction. Previously, only three different TPH fuel mixtures, commonly measured and reported at environmental cleanup sites, were considered for the ESLs: gasoline, diesel, and motor oil. At staff request, screening levels for Stoddard solvent have also been developed. The composition of these four mixtures is described herein, in approximate carbon range order (lower to higher):

- **Gasoline** is a complex mixture of C<sub>4</sub> to C<sub>12</sub> hydrocarbons (TPHCWG 1998b) consisting of about 50 to 80 percent aliphatics (dominantly branched) and about 20 to 50 percent aromatics (ATSDR 1995a). In addition to hydrocarbons, these mixtures commonly include additives and blending agents to boost performance. Finished gasolines typically contain more than 150 separate compounds although as many as 1,000 compounds have been identified in some blends (ATSDR 1995b).
- **Stoddard solvent** is a petroleum distillate widely used as a dry-cleaning solvent and as a general cleaner and degreaser (ATSDR 1995c). It may also be used as paint thinner, as a solvent in some types of photocopier toners and printing inks, and in some adhesives. Stoddard solvent is considered to be a form of mineral spirits, white spirits, and naphtha. However, not all forms of mineral spirits, white spirits, and naphtha are considered to be Stoddard solvent (ATSDR 1995c).
- **Diesel** is a middle distillate mixture of C<sub>8</sub> to C<sub>21</sub> hydrocarbons (TPHCWG 1998b), consisting of about 65 percent aliphatics and 35 percent aromatics (ATSDR 1995b). Some other examples of middle distillates include kerosene, home heating fuel, and jet fuel (e.g., JP4). As discussed in Brewer et al. (2013), vapor-phase compounds associated with diesel are dominated by variable proportions of C<sub>5</sub>-C<sub>8</sub> aliphatics and C<sub>9</sub>-C<sub>12</sub> aliphatics, with only minor amounts of C<sub>9</sub>-C<sub>10</sub> aromatics, even though the C<sub>5</sub>-C<sub>8</sub> aliphatics may comprise a very minor amount of the fuel itself.
- **Motor oil** is a heavy distillate mixture characterized by high molecular weight hydrocarbons with a carbon range of C<sub>18</sub> to C<sub>34+</sub>, consisting of about 80 percent aliphatic and 20 percent aromatics (TPHCWG 1998b).

TPH mixtures can be found at a site as either: NAPL and, for those mixtures that partition, vapor or dissolved in water. Table 2 shows how the composition of each TPH

mixture (percentage of each TPH fraction) changes depending on the phases in which it occurs.

### c. Toxicity Values and Surrogates for the Fractions

Surrogates are used to represent noncarcinogenic toxicity of the TPH fractions. As discussed in the Complex Mixtures PPRTV, USEPA selected surrogates for each fraction in the following order of preference (hierarchy):

1. **Mixtures of similar composition.**
2. **Representative compound in the fraction.** Options include using the most toxic component if the toxicity varies considerably or a component that represents a large proportion of the fraction. In some cases, such as the medium carbon aromatics, compounds with more potent toxicities (naphthalene and 2-methylnaphthalene) can be assessed separately while the remaining fraction mass is assessed using values for a surrogate mixture (high-flash aromatic naphtha).
3. **Components Method.** For fractions where the individual compounds are well characterized and with toxicity values (e.g., low carbon aromatic fraction or BTEX), the components are individually assessed.

For the ESLs, five of the six TPH fractions are used. The low carbon range aromatic fraction is not used because BTEX typically is evaluated by testing for the individual compounds as indicator compounds (components method). Because the TPH fractions are integrated into weighted-average toxicity values and constants to calculate screening levels for TPH mixtures, the partitioning behavior of each fraction in water (solubility) and air (volatile) is taken into consideration as follows:

- **NAPL and Soil** – All TPH fractions adsorbed to soil (as NAPL) are available for direct human exposure during soil contact. No partitioning is required.
- **Water** – Since the main human exposure route for TPH dissolved in water is via tapwater, it is appropriate to employ only the water-soluble fractions in estimating weighted-average toxicity values and constants. The soluble constituents of petroleum hydrocarbon mixtures are largely limited to aromatic hydrocarbon molecules with 14 or fewer carbon atoms ( $C_{14}$  and smaller), and smaller aliphatic hydrocarbon molecules with 6 or fewer carbon items ( $C_6$  and smaller) (Zemo and Synowiec 1995). The soluble fractions are the low carbon range aliphatics, low carbon range aromatics, and medium carbon range aromatics. The fractionally-soluble TPH mixtures for which ESLs are derived include TPH Stoddard solvent and TPH diesel.

**Table 3 – Fraction Composition for TPH Mixtures**

TPH Fraction	TPH gasoline			TPH Stoddard solvent			TPH diesel			TPH motor oil		
	NAPL	Vapor	Water	NAPL	Vapor	Water	NAPL	Vapor	Water	NAPL	Vapor	Water
<b>Aliphatics</b>												
C <sub>5</sub> to C <sub>8</sub>	45%	99%	100%	--	25%	--	--	25%	--	--	--	--
C <sub>9</sub> to C <sub>18</sub>	12%	0.5%	--	86%	75%	--	45%	75%	--	--	--	--
C <sub>19</sub> to C <sub>32</sub>	--	--	--	--	--	--	35%	--	--	75%	--	--
<b>Aromatics</b>												
C <sub>6</sub> to C <sub>8</sub>	N/A <sup>1</sup>	N/A <sup>2</sup>	N/A <sup>3</sup>	--	--	--	--	--	--	--	--	--
C <sub>9</sub> to C <sub>16</sub>	16%	0.5%	--	14%	--	100%	20%	--	100%	--	--	--
C <sub>17</sub> to C <sub>32</sub>	--	--	--	--	--	--	--	--	--	25%	--	--
<b>Notes:</b>												
<b>NAPL (and Soil):</b> TPH fraction compositions: TPH gasoline (Park and San Juan 2000), TPH Stoddard solvent (ATSDR 1995c); TPH diesel (Park and San Juan 2000); and TPH motor oil (TPHCWG 1998b).												
1 – The C <sub>6</sub> to C <sub>8</sub> aromatic fraction can represent about 27% of the gasoline mixture. This fraction is not used for calculation of the TPH gasoline values because the compounds are individually analyzed. Therefore, the percentages of the fractions in TPH gasoline in this table were normalized so the total equals 100% in the final calculations.												
<b>Vapor:</b> TPH fraction compositions for petroleum vapors based on HDOH (2011). Stoddard solvent is expected to partition similarly to diesel, so the diesel vapor composition is used as a surrogate.												
2 – This fraction is not used for calculation of the TPH gasoline values because the compounds are individually analyzed.												
<b>Water-Soluble:</b> TPH water-soluble fraction compositions: Zemo and Synowiec (1995).												
3 – This fraction is not used for calculation of the TPH gasoline values because the compounds are individually analyzed.												

- **Air** – TPH vapors associated with petroleum fuels are dominated by the most volatile carbon range components of the fuel. For gasoline, the vapor-phase compounds associated are typically dominated by C<sub>5</sub>-C<sub>8</sub> aliphatics and BTEX, similar to the fuel itself, with only minor amounts of C<sub>9</sub>-C<sub>12</sub> aliphatics (e.g., Hartman 1998; Brewer et al. 2013). For diesel and other middle distillate mixtures vapor-phase compounds associated also are typically dominated by variable proportions of C<sub>5</sub>-C<sub>8</sub> aliphatics and C<sub>9</sub>-C<sub>12</sub> aliphatics, with only minor amounts of C<sub>9</sub>-C<sub>10</sub> aromatics, even though the C<sub>5</sub>-C<sub>8</sub> aliphatics may comprise a very minor amount of the fuel itself (Brewer et al. 2013).

Table 3 presents the surrogates and the toxicity values for NAPL/Soil (RfD), Vapors (RfC), and Water-Soluble (RfD) TPH fractions.

<b>Table 4 – Surrogates and Toxicity Values for the TPH Fractions</b>			
<b>TPH Fraction</b>	<b>Media Specific Toxicity Values</b>		
	<b>NAPL/Soil RfD (mg/kg-day)</b>	<b>Vapor RfC (µg/m<sup>3</sup>)</b>	<b>Water-Soluble RfD (mg/kg-day)</b>
Aliphatics C <sub>5</sub> to C <sub>8</sub>	3.0E-01	6.0E+02	3.0E-01
	n-Hexane	Commercial hexane	n-Hexane
Aliphatics C <sub>9</sub> to C <sub>18</sub>	1.0E-02	1.0E+02	Non-soluble
	Aliphatic hydrocarbon stream C <sub>9</sub> -C <sub>17</sub>	Aliphatic hydrocarbon stream C <sub>9</sub> -C <sub>17</sub>	
Aliphatics C <sub>19</sub> to C <sub>32</sub>	3.0E+00	Non-volatile	Non-soluble
	White mineral oil		
Aromatics C <sub>6</sub> to C <sub>8</sub>	Not used for TPH. Analyzed as individual compounds.		
Aromatics C <sub>9</sub> to C <sub>16</sub>	3.0E-02	1.0E+02	3.0E-02
	High-flash aromatic naphtha	High-flash aromatic naphtha	High-flash aromatic naphtha
Aromatics C <sub>17</sub> to C <sub>32</sub>	4.0E-02	Non- volatile	Non-soluble
	Fluoranthene		

Source: Fraction, surrogates, and toxicity values from the Complex Mixtures PPRTV.

#### **d. Weighted-Average Toxicity Values and Constants for TPH Mixtures**

The purpose of using the weighted-average toxicity values and constants is to provide a better representation of risk given the composition of the TPH mixtures. The basic formula for calculating weighted-average values employs the harmonic mean, as follows:

$$\text{Weighted Average Value} = \frac{1}{\left(\frac{\% F1}{TV1} + \frac{\% F2}{TV2} + \dots + \frac{\% F6}{TV6}\right)}$$

**FX – Fraction X**

**TVX –Toxicity value for fraction X**

Each TPH fraction's media specific toxicity value (NAPL/soil RfD), water-soluble RfD, and air-volatile RfC; as shown in Table 3) is weighted based on its relative proportion in a particular TPH mixture for a given media (as shown in Table 2). This means that for NAPL/soil RfDs, the fraction weighting is based on weight percent composition in the bulk fuel mixture (NAPL); water-soluble RfDs are calculated only for the fractionally-soluble TPH mixtures (TPH Stoddard solvent and TPH diesel) using the soluble fractions; and for air-volatile RfC, the fraction weighting is based on weight percent composition of the associated petroleum vapors for the TPH mixture. Weighted-average Henry's Law Constant values for the volatile or fractionally volatile TPH mixtures (TPH gasoline, TPH Stoddard solvent, and TPH diesel) were calculated. This is pertinent to inhalation of particulates and vapors (one component of the soil direct contact exposure model).

The weighted-average toxicity values and Henry's Law Constants are listed in ESL Workbook Tables IP-2 and IP-1, respectively.

### **e. Development of Screening Levels for Other TPH Mixtures**

TPH screening levels for other mixtures (e.g., jet fuels) using published composition data and employing the fraction approach provided that there is information on the fraction composition (weighting) and partitioning (solubility and volatility). Crude oils potentially could present a challenge because compositions vary and can span low-, medium-, and high- carbon ranges. TPH crude oil analysis might not provide the resolution to proportion between the fractions. Assuming that such TPH crude oil results can be evaluated against TPH motor oil screening levels could underestimate risk while assuming that TPH crude oil results can be evaluated against TPH diesel screening levels could over-estimate risk.

### **f. Fractionation Methods and Site-Specific Evaluations**

Site-specific evaluations can include development of site-specific screening levels or cleanup goals, provided adequate testing is performed to estimate the current fraction composition of the TPH. This necessitates the use of fractionation methods to determine the composition to enable calculation of weighted-average toxicity values and physical constants, which then can be used in the appropriate health risk-based equations to generate site-specific screening levels or cleanup goals.

Fractionation methods differ for soil and water samples versus vapor samples. MADEP and Washington Department of Ecology (WDOE) have recommended methods that can be evaluated for: 1) soil and water (MADEP 2004a and 2004b; WDOE 1997); and 2) vapor: MADEP (2009).

Fractionation methods employ separation techniques such as silica gel solid-phase extraction/fractionation processes to separate aliphatic and aromatic hydrocarbons. In this application, use of silica gel is not necessarily an issue. Consultation with the overseeing regulatory is recommended before implementing a fractionation testing program.

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## 5. Acronyms and Abbreviations

ATSDR	US Agency for Toxic Substances and Disease Registry
BTEX	Benzene, toluene, ethylbenzene, and xylenes
ESL	Water Board Environmental Screening Level
HDOH	Hawai'i Department of Health
JP4	Jet propellant no. 4 (jet fuel)
MADEP	Massachusetts Department of Environmental Protection
NAPL	Non-aqueous phase liquid
NSO	Nitrogen, sulfur, and oxygen
PAH	Polycyclic aromatic hydrocarbon
PPRTV	USEPA provisional peer-reviewed toxicity values
Regional Water Board	California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board
RfC	Inhalation reference concentration
RfD	Oral reference dose
RSL	USEPA Regional Screening Level
State Water Board	California Environmental Protection Agency, State Water Resources Control Board
TPH	Total petroleum hydrocarbons
USEPA	U.S. Environmental Protection Agency
WDOE	Washington Department of Ecology

# Appendix G

## Technical Resource Document: Site-Specific Evaluation Approach for Petroleum Degradates

- *This document is expected to be finalized in March 2016 –*