



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

INTERIM FINAL 2025

**San Francisco Bay
Regional Water Quality Control Board
1515 Clay Street, Suite 1400
Oakland, CA 94612**

Environmental Screening Levels User's Guide

Contact Information

For Comments and Questions, Please Contact:

ESL Email (RB2-ESLs@waterboards.ca.gov)

-or-

Nicole Fry, PhD

San Francisco Bay Regional Water Quality Control Board
1515 Clay Street, Suite 1400
Oakland, CA 94612
Phone: 1-510-622-2307

Document Prepared by:

Nicole Fry, PhD, Research Scientist III, Chemical

Angus Chan, PE, Senior Water Resource Control Engineer

Document Approved by:

Ross Steenson, CHG, Assistant Executive Officer

Acknowledgements

Numerous people have contributed to this and previous editions of the Environmental Screening Levels. The Regional Water Board would like to thank the many contributors and those who have provided comments and suggestions. The cover photograph courtesy of John Karachewski is very much appreciated. The photo was taken over 10 years ago at sunrise on Ring Mountain in the Marin Headlands above Kirby Cove (lower left), Golden Gate National Recreation Area. Mount Diablo sneaks into the upper left corner as the isolated pyramid shaped peak.

Disclaimer

This *User's Guide: Compilation and Application of Environmental Screening Levels* is a technical report prepared by staff of the California Regional Water Quality Board, San Francisco Bay Region (Regional Water Board staff). Although this User's Guide is not intended to establish policy or regulation, it is consistent with existing policies and 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) a stand-alone, decision-making tool; (b) guidance for the preparation of baseline environmental risk assessments; (c) a rule to determine if a waste is hazardous under State or federal regulations; or (d) a rule to determine when the release of hazardous chemicals must be reported to the overseeing regulatory agency.

In general, the ESLs are not used at sites that are subject to the *Low-Threat Underground Storage Tank Closure Policy* (LTCP; State Water Board 2012b). Specifically, the LTCP does not use the ESLs to screen contaminants at petroleum-contaminated sites. Instead the LTCP provides closure levels for carcinogens and general (narrative) criteria. ESLs may be used at sites with “unique attributes” to screen for constituents not already addressed by the LTCP.

ESLs may not be adequately protective for certain 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, thereby posing a risk to human or ecological receptors. 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 exceeding an ESL does not necessarily indicate adverse effects on human health or the environment, but rather that additional evaluation is warranted. ESLs are not default cleanup goals. Cleanup goals or levels are dictated by State Water Resources Control Board Resolution No. 92-49 (Resolution 92-49). Use of the ESLs as cleanup goals must be consistent with Resolution 92-49 and should be evaluated in view of the overall site investigation findings and the cost/benefit of performing a more site-specific evaluation (e.g., feasibility study).

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 any administrative or judicial proceeding in the State of California. Regional Water Board staff may or may not decide to use the information compiled herein, based on an analysis of site-specific circumstances.

This document will be periodically updated as needed to compile the latest technical information. Regional Water Board staff overseeing work at a specific site should be contacted prior to use of this document to ensure user has the most up-to-date version. Copies of this document may be freely made and distributed. Reference to the ESLs without adequate review of the User’s Guide could result in misinterpretation and misuse.

Executive Summary

The purpose of the User's Guide is to explain how the Environmental Screening Levels (ESLs) were compiled and how they should (and should not) be used. The ESLs are composed of three elements: (1) Microsoft Excel Workbook (all tables); (2) Summary ESL Tables (PDF); and (3) User's Guide. The Frequently Asked Questions, previously a fourth element, are now included as Appendix B of the User's Guide.

The ESLs allow dischargers and regulators to quickly focus on the most significant problems at contaminated sites. This review 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 are listed in the following Table:

Table of Concerns Addressed by ESLs

Medium	Human Health	Drinking Water Resource (Current or Potential)	Aquatic Receptors (Discharge to Surface Water)	Terrestrial Receptors (Direct Contact)	Source Control	Nuisance and Odors
Ground-water	Yes	Yes	Yes	--	Yes	Yes
Soil/ Soil Gas	Yes	Yes	Yes	Yes	Yes	Yes
Indoor Air	Yes	--	--	--	--	Yes

Users of this guide should be aware of site-specific circumstances before applying ESLs. This includes an understanding of current/future land use type, media affected by contamination, and site-specific factors (collectively, the Conceptual Site Model or "CSM"). If used correctly, ESLs are protective for *typical* Bay Area sites. Under most instances, and within the limitations described in the disclaimer, it's unlikely the presence of a chemical in soil, soil gas, or groundwater at concentrations below the corresponding ESL will 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 review the current version of the ESLs that is posted at the Regional Water Board website and identify the version for the record in all relevant communications.

Table of Contents

Contact Information.....	ii
Acknowledgements.....	ii
Disclaimer.....	ii
Executive Summary.....	iv
Table of Contents.....	v
List of Figures.....	xv
List of Tables.....	xvi
ESL User's Guide.....	1-1
1. Introduction and Background.....	1-1
1.1. San Francisco Bay Basin Water Quality Control Plan (Basin Plan).....	1-1
1.2. History of the ESLs.....	1-4
1.3. Intended Use of the ESLs.....	1-5
1.4. Comparison of ESLs to Other Screening Levels and Criteria.....	1-6
1.5. Site Closure Evaluations: Use of the ESLs.....	1-10
1.6. Other Technical Documents.....	1-13
2. Step-by-Step Guide: ESL Workbook.....	2-1
2.1. Conceptual Site Model.....	2-1
2.2. ESL Workbook Content.....	2-8
2.3. Tier 1 ESLs – Default Conceptual Site Model.....	2-9
2.4. Tier 2 ESLs – Selecting Site-Specific ESLs and Use of Interactive Tool	2-10
2.5. Tier 3 – Develop Site Specific Screening Levels.....	2-19
3. Methods: Direct Exposure Human Health Risk Screening Levels for All Media	3-1
3.1. Groundwater Direct Exposure ESLs.....	3-2
3.2. Soil Direct Exposure ESLs.....	3-3
3.3. Indoor Air Direct Exposure ESLs.....	3-4
3.4. Calculation of Human Health Direct Exposure Screening Levels.....	3-4
3.5. Addressing Cumulative Risk and Hazard.....	3-15
3.6. Exceptions: Human Health Screening Levels for Chemical Mixtures.....	3-17
3.7. Site-Specific Evaluations.....	3-25
4. Methods: Petroleum Mixture Screening Levels.....	4-1
4.1. Background.....	4-2

4.2. Approach to Evaluating Human Health Risks Posed by Petroleum Releases	4-6
4.3. Calculation of ESLs for Petroleum Hydrocarbon Mixtures	4-14
4.4. Calculation of ESLs for Petroleum Fractions	4-17
4.5. Calculation of Groundwater ESLs for Petroleum HOPs	4-17
4.6. Laboratory Analytical Methods for Use with the Petroleum Mixture ESLs	4-20
4.7. Site-Specific Human Health Risk Evaluations for Petroleum Mixtures	4-31
5. Methods: Vapor Intrusion Risk Screening Levels for Groundwater and Subslab/Soil Gas	5-1
5.1. Calculation of Soil Gas and Groundwater VI ESLs	5-2
5.2. Chemical-Specific Exceptions	5-5
5.3. Site-Specific Evaluations	5-6
6. Methods: Short-Term Exposure Levels	6-1
6.1. Trichloroethene Short-Term Exposure Levels	6-1
6.2. Elemental Mercury Short-Term Exposure Levels	6-3
7. Methods: Aquatic Habitat Screening Levels for Groundwater	7-1
7.1. Aquatic Receptor Toxicity Criteria	7-2
7.2. Hierarchy for Aquatic Receptor Toxicity Criteria	7-3
7.3. Chemical-Specific Exceptions	7-4
7.4. Site-Specific Evaluations	7-7
8. Methods: Terrestrial Habitat Screening Levels for Soil	8-1
8.1. Background and Basis for Screening Levels	8-1
8.2. Exceptions	8-3
8.3. Site-Specific Evaluations	8-4
9. Methods: Leaching to Groundwater Screening Levels for Soil	9-1
9.1. Leaching Model	9-1
9.2. Calculation of Soil Leaching Screening Levels	9-4
9.3. Exceptions	9-5
9.4. Site-Specific Evaluations	9-6
10. Methods: Gross Contamination Screening Levels for Groundwater and Soil	10-1
10.1. Calculation of Gross Contamination Screening Levels	10-1
10.2. Exceptions	10-2
10.3. Site-Specific Evaluations	10-2

11. Methods: Taste and Odor Nuisance Screening Levels for All Media.....	11-1
11.1. Background.....	11-1
11.2. Groundwater Taste and Odor Nuisance Thresholds.....	11-2
11.3. Soil Odor Nuisance Thresholds.....	11-3
11.4. Indoor Air and Soil Gas Odor Nuisance Thresholds.....	11-5
11.5. Exceptions.....	11-5
11.6. Site-Specific Evaluations.....	11-5
12. Additional Considerations.....	12-1
12.1. Multiple Chemical Species.....	12-1
12.2. Chemicals Without ESLs.....	12-1
12.3. Chemical Degradation and Generation of Transformation Products.....	12-2
12.4. Naturally Occurring Background and Ambient Chemicals.....	12-3
12.5. Sediment Screening Levels.....	12-5
12.6. Laboratory Data Issues.....	12-6
12.7. Physical Hazards.....	12-7
12.8. Total Maximum Daily Loads (TMDLs)	12-8
13. References.....	13-1
14. Acronyms and Abbreviations.....	14-1
15. Appendix A: Equations for Direct Exposure Screening Levels.....	15-1
15.1. Noncarcinogenic Risk-Based Screening Levels.....	15-2
15.2. Carcinogenic Risk-Based Screening Levels.....	15-4
15.3. Total Cancer or Noncancer Screening Levels for All Exposure Pathways....	15-5
16. Appendix B: ESL Frequently Asked Questions (FAQs).....	16-1
16.1. GENERAL QUESTIONS.....	16-2
16.2. APPLICATION OR USE QUESTIONS.....	16-3
16.3. HUMAN HEALTH EXPOSURE QUESTIONS.....	16-6
16.4. ECOTOXICITY QUESTIONS.....	16-10
16.5. CHEMICAL-SPECIFIC QUESTIONS.....	16-11

List of Figures

Figure 2-1: Tiered Process for Selecting Screening Levels.....	2-1
Figure 2-2: Example Illustrating Horizontal Extent of Tetrachloroethene in Shallow Groundwater.....	2-4
Figure 2-3: Example Cross Section Illustrating Contaminant Distribution.....	2-5
Figure 2-4: Default Evaluation of Receptors and Exposure Pathways Used in a Tier 1 Assessment.....	2-6
Figure 2-5: Example of a Site-Specific Evaluation of Receptors and Exposure Pathways.....	2-7
Figure 2-6: Final Site-Specific Groundwater ESL Determination.....	2-15
Figure 2-7: Final Site-Specific Soil ESL Determination.....	2-16
Figure 2-8: Final Site-Specific Subslab/ Soil Gas ESL Determination.....	2-17
Figure 2-9: Final Site-Specific Indoor Air ESL Determination.....	2-17
Figure 2-10: ESL Workbook Interactive Tool Tier 2 ESL Input and Output Table T2-1 for Example Scenario.....	2-20
Figure 2-11: Interactive ESL Workbook Tool Table T2-2 for the Example Scenario....	2-21
Figure 2-12: Interactive ESL Workbook Tool Specific Concerns Table T2-3 for the Example Scenario.....	2-22
Figure 4-1: Example of Basic Petroleum Chromatogram Review for HOPs.....	4-24
Figure 4-2: Example NOCs Chromatogram.....	4-25
Figure 4-3: Conceptual Plume Map Showing How to Estimate Petroleum HOPs Concentrations.....	4-27
Figure 4-4: Illustration of the Key Shortcoming with the TPH-diesel (also “diesel-range organics” or “DRO”) Analysis for Measuring Petroleum HOPs Concentrations.....	4-28
Figure 4-5: Example Carbon Ranges for Bulk TPH and TPH Fractionation Laboratory Analyses.....	4-34
Figure 5-1: Conventional Conceptual Model for Vapor Intrusion.....	5-1
Figure 7-1: Bay Margin Groundwater Discharge Conceptual Model.....	7-1
Figure 9 1: Conceptual Model for Soil Leaching ESLs.....	9-2

List of Tables

Table of Concerns Addressed by ESLs.....	iv
Table 1-1: Environmental Concerns Stated or Implied in the Basin Plan and Addressed by ESLs.....	1-3
Table 1-2: Environmental Concerns for ESLs versus Other Screening Levels.....	1-8
Table 1-3: Low-Threat UST Case Closure Policy (LTCP) General Criteria.....	1-11
Table 1-4: Regional Water Board Closure Considerations for Non-UST Sites.....	1-12
Table 1-5: Technical Resource Documents for Use with the ESLs.....	1-13
Table 2-1: Information for a Conceptual Site Model.....	2-2
Table 2-2: Tier 1 ESL Conceptual Site Model.....	2-10
Table 3-1: Human Health Direct Exposure Scenarios in the ESLs.....	3-1
Table 3-2: Soil Human Health Direct Exposure Scenarios.....	3-3
Table 3-3: Human Health Toxicity Value Hierarchy.....	3-9
Table 3-4: Exposure Factor Selection.....	3-12
Table 3-5: Mutagens.....	3-2
Table 3-6: World Health Organization Toxic Equivalency Factors for Dioxins and Furans (2005).....	3-9
Table 3-7: PAHs in the ESLs and Relative Potency Factors for the Carcinogenic PAHs	3-11
Table 4-1: Physical-Chemical Properties of Selected Hydrocarbons and Hydrocarbon Oxidation Products.....	4-3
Table 4-2: Potential Individual Chemicals of Concern for Different Petroleum Mixtures	4-9
Table 4-3: ESL Petroleum Hydrocarbon Fractions, Partitioning Characteristics, and Toxicity Surrogates.....	4-12
Table 4-4: Chemicals of Potential Concern for Petroleum Risk Evaluations.....	4-13
Table 4-5: Bulk TPH Laboratory Analysis for Soil and Groundwater Samples.....	4-30
Table 7-1: Hierarchy for Aquatic Receptor Direct Water Exposure Toxicity Criteria...	7-4
Table 11-1: Hierarchy of Taste and Odor Thresholds for Groundwater.....	11-3
Table 11-2: Criteria for Assignment of Odor Upper Limit Levels for Soil.....	11-4
Table 12-1: Publications Regarding Naturally Occurring Background Levels.....	12-4
Table 12-2: Sediment Chemical Criteria or Relevant Guidance.....	12-5

ESL User's Guide

1. Introduction and Background

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

- Cover Memo;
- ESL Workbook (Microsoft Excel Workbook) and Summary ESL Tables (PDF); and
- User's Guide, including Frequency Asked Questions (FAQs)

The following sections provide the basis for the ESLs, history and use, comparison to other screening levels, the Regional Water Board's approach to site closure evaluations, and other technical documents for use in conjunction with the ESLs.

1.1. San Francisco Bay Basin Water Quality Control Plan (Basin Plan)

The ESLs were ultimately compiled to help the Regional Water Board staff protect water 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 (Regional Water Board 2024) 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 Estuary is the largest 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 2024).

Because of its highly dynamic and complex environmental conditions, the Bay supports an extraordinarily diverse and productive ecosystem. Within each section of the Bay, there are deep water 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 have degraded groundwater quality. Adverse impacts on groundwater quality often have long-term effects that are costly to remediate. Consequently, as new additional discharges are identified, investigation, source control, pollution containment, and cleanup should be undertaken as quickly as possible. Activities that may potentially pollute groundwater should be managed to ensure the short- and long-term protection of groundwater quality.

The following sections introduce certain components of the Basin Plan that guide the compilation 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 direct and indirect different benefits. 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 conditions following unpermitted 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 protect water quality.

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

- **All Groundwater is Considered Suitable or Potentially Suitable for Municipal or Domestic Water Supply unless Designated Otherwise by the Regional Water Board** – All groundwater in the Region is considered a potential source of drinking water 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 as a potential drinking water source (“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, with concurrence from the overseeing regulatory agency. A conclusion that groundwater is non-potable does not mean other concerns can be ignored (e.g., vapor intrusion, groundwater discharge to surface water, nuisance odor).

- 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 and where the extent of groundwater contamination is defined and is demonstrated to be stable (e.g., not migrating). Chapter 7 provides information regarding options for site-specific evaluations. A conclusion that groundwater does not discharge to surface water should be based on site-specific data or information accepted by the overseeing regulatory agency. Although modeling can assist with evaluating this pathway, it should not be used exclusively to conclude whether groundwater will discharge to surface water.

Soil and groundwater ESLs have therefore been compiled 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 1-1.

Table 1-1: Environmental Concerns Stated or Implied in the Basin Plan and Addressed by ESLs

Medium	Human Health	Drinking Water Resource	Aquatic Receptors (Discharge to Surface Water)	Terrestrial Receptors (Direct Contact)	Source Control	Nuisance Taste and Odor
Ground-water	Yes	Yes	Yes	--	Yes	Yes
Soil/ Soil Gas	Yes	Yes	Yes	Yes	Yes	Yes
Indoor Air	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 for all Water Boards to follow when overseeing and regulating investigations and cleanup and abatement activities resulting from all types of discharges or threat of discharge subject to Water Code section 13304.

Resolution 92-49 outlines the basic elements of site investigations and cleanup of discharges and identifies minimum cleanup and abatement methods. Section III.G of Resolution 92-49 states that Regional Water Boards shall “ensure that dischargers are required to clean up and abate the effects of discharges in a manner that promotes attainment of either background water quality, or the best water quality which is reasonable if background levels of water quality cannot be restored, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible.” Any such alternative cleanup level shall: (1) be consistent with the maximum benefit to the people of the state, (2) not unreasonably affect present and anticipated beneficial use of such water, and (3) not result in water quality less than that prescribed in water quality control plans and policies adopted by the State and Regional Water Boards.

In addition, the Basin Plan recognizes 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 deed restrictions for certain sites not cleaned up to allow “unrestricted use.” Furthermore, deed restrictions must be recorded and “run” with the land.

1.2. History of the ESLs

The San Francisco Bay Regional Water Board Control Board first published risk-based screening levels (RBSLs) in September 2000. Screening levels were compiled for 100 commonly encountered chemicals at sites with impacted soil and groundwater. The RBSLs were intended to expedite risk assessments and evaluations of the need for additional work, particularly for small- to medium-sized sites. Following peer review of the 2001 RBSLs by the University of California, the scope was broadened beyond human health risk to include ecological risk (aquatic and terrestrial receptors), concerns for nuisance and potential presence of separate-phase liquid (gross contamination). This effort culminated in 2003 with the renamed Environmental Screening Levels (ESLs) that added screening levels for surface water, indoor air, and soil gas. Regional Water Board staff continues to maintain and update the ESLs, with updates generally about every two to three years. After first publication, major updates have been published as follows: December 2001; July 2003; February 2005; May

2008; 2013 (February and December); February 2016 (three revisions); and January 2019 (two revisions).

1.3. Intended Use of the ESLs

1.3.1. Evaluate the Chemical Threats Posed by Contamination

Sites that are adequately characterized with chemical concentration data 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 present at a site, but individual chemical 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 further investigation or evaluation should be considered to better assess the threat. The ESLs do not address hazards such as asphyxiation or explosions. The ESLs should not be used as the sole basis for determining whether fill soil is clean because the ESLs do not address all exposure pathways (e.g., transport of pollutants in dissolved or particulate phases via surface water). The ESL Frequently Asked Questions (Appendix B) provide additional information regarding clean fill soil and marginally contaminated soil.

1.3.2. Conservative, but Reasonable Screening Levels

The main purpose of screening levels is to quickly enable users to distinguish which sites pose a significant threat. In developing screening levels, there should be a balance between conservativeness and reasonableness so that low risk sites are screened out and sites with a significant threat are screened in and given greater attention. 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 may be overly conservative. This approach 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 contamination. This approach is inefficient and problematic because it diverts resources from sites with significant threats.

1.3.3. Communication Tool

Screening levels help dischargers, technical consultants, and other 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 a risk and feasibility evaluation and discussions between the overseeing regulatory agency and the discharger considering site-specific conditions, consistent with applicable laws and regulations. For many sites, ESLs

are selected as cleanup goals, but only after going through the regulatory evaluation process.

1.3.4. Time and Money Saver

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 to prepare a comprehensive risk assessment can be substantial, and potentially prohibitive, for small businesses and property owners with limited financial resources. A “Tier 2” risk evaluation can be developed relatively quickly with the ESLs.

1.3.5. Prioritization Tool

Regional Water Board staff prioritizes the oversight of cases to maximize our protection of human health and the environment. The ESLs serve as an aid in assessing the overall threat (pathways and threat level) at any given site, allowing us to understand whether threats to human health or the environment are adequately controlled. We can then prioritize the investigation and cleanup needed to eliminate or control the threats posed by the contamination at a site.

1.4. Comparison of ESLs to Other Screening Levels and Criteria

1.4.1. Other Screening Levels

The ESLs address a greater range of media and concerns than other commonly used screening levels and reflect the broader scope of environmental concerns outlined in the Basin Plan (Table 1-2).

USEPA RSLs/VISLs

The United States Environmental Protection Agency (USEPA) publishes Regional Screening Levels (RSLs; formerly known as Preliminary Remediation Goals or PRGs; USEPA 2024b) 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 2024c) that calculates groundwater and soil gas (subslab and deeper or exterior soil gas) vapor intrusion screening levels using USEPA recommended attenuation factors (USEPA 2015a).

CalEPA CHHSLs

In 2004 to 2005, the Office of Environmental Health Hazard Assessment (OEHHA) developed the California Human Health Screening Levels (CHHSLs) for more than 50 contaminants commonly detected in soil, soil gas, and indoor air. CHHSLs are set at an excess lifetime cancer risk of one-in-a-million, 1×10^{-6} and a hazard quotient of 1.0 for noncancer hazard (CalEPA 2005). The basis of derivation is presented in *Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (OEHHA 2004a). The CHHSLs do not address potential groundwater or surface water protection concerns and focus on only a portion of the human health concerns addressed by the ESLs.

The CHHSLs should not be used as a stand-alone tool to evaluate contaminated sites because the CHHSLs do not cover the full scope of potential environmental concerns. It is important to understand that for many chemicals, the need for remedial action may be based on environmental concerns and not direct exposures.

DTSC-Modified Screening Levels

The California Department of Toxic Substances Control (DTSC) endorses the RSL soil, tapwater, and air values for chemicals listed in the RSLs except where California toxicity criteria values are required per the Toxicity Criteria for Human Health Risk Assessments, Screening Levels, and Remediation Goal ("California Toxicity Criteria Rule", discussed in Section 3.4.6) or DTSC recommends more stringent criteria in Human Health Risk Assessment Note 10 (DTSC 2025c). For chemicals meeting these exceptions, DTSC publishes DTSC-modified screening levels (DTSC-SLs) in Human Health Risk Assessment Note 3 (DTSC 2025b) for soil, tapwater, and air, as needed. Human Health Risk Assessment Note 3 is periodically updated.

Table 1-2: Environmental Concerns for ESLs versus Other Screening Levels

Media	Environmental Concern	ESLs	USEPA RSLs and VISLs	CalEPA CHHSLs
Groundwater	Direct Exposure (Ingestion, Inhalation, Dermal)	Yes	Yes/RSLs	Yes
Groundwater	Vapor Intrusion (Direct Exposure: Inhalation)	Yes	Yes/VISLs	--
Groundwater	Discharge to Surface Water (Aquatic Receptors)	Yes	--	--
Groundwater	Gross Contamination	Yes	--	--
Groundwater	Taste and Odor Nuisance	Yes	--	--
Soil	Direct Exposure (Ingestion, Inhalation, Dermal)	Yes	Yes/RSLs	Yes
Soil	Terrestrial Habitat	Yes	--	--
Soil	Leaching to Groundwater	Yes	Yes/RSLs	--
Soil	Gross Contamination	Yes	--	--
Soil	Odor Nuisance	Yes	--	--
Soil Gas	Vapor Intrusion (Direct Exposure: Inhalation)	Yes	Yes/VISLs	Yes
Soil Gas	Odor Nuisance	Yes	--	--
Indoor Air	Direct Exposure (Inhalation)	Yes	Yes/RSLs and VISLs	Yes
Indoor Air	Odor Nuisance	Yes	--	--

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

mobilization of metals and other constituents. STLC values generally reflect drinking water or surface water goals of the time. TTLC values were derived by simply multiplying the STLC value by 10 for organic chemicals or 100 for metals. It is unlikely that the TTLC and STLC values will be revised in the near future. In most cases, TTLC values exceed the most conservative ESLs. However, in certain instances TTLC values may be lower than risk-based ESLs.

1.4.3. 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:

- Chemical in question is used in the industrial process;
- Workers and others who might be exposed to the chemical have knowledge of the chemical's presence;
- Workers receive appropriate health and safety training; and
- 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 the results of indoor air sampling indicate the presence of the same VOCs detected in groundwater, soil, or soil gas at or near the site. In such a situation, whether worker safety criteria or ESLs are appropriate depends on the source of the VOCs detected in indoor air. If the source is clearly from the business operation, the appropriate worker safety criteria apply. If the source is the subsurface contamination, then ESLs are more appropriate. 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 monitoring. Information on some of these techniques are mentioned in the Vapor Intrusion Mitigation Guidance, Attachment 2 (Regional Water Board 2022) and

the Final Draft Supplemental Guidance: Screening and Evaluating Vapor Intrusion (DTSC and State Water Board 2023).

DTSC and USEPA have taken similar positions on the use of PELs. The DTSC Vapor Intrusion Guidance (VIG; DTSC 2011b) indicates Occupational Safety and Health Act (OSHA) PELs are inappropriate exposure endpoints in work-related occupational settings for indoor air degraded by subsurface contamination and includes a detailed discussion of the use of the PELs (VIG Appendix C). USEPA (2015a) 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 the 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.

1.5. 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 (i.e., No Further Action or NFA) is fundamentally important, as well. The ESLs are a tool to aid in evaluating cases eligible for closure. 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, consistent with Resolution 92-49. 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, for which a site-specific assessment would typically be recommended.

Regional Water Board staff uses either of two approaches for evaluating sites for regulatory closure or No Further Action: The Low-Threat Underground Storage

Tank Closure Policy (LTCP; State Water Board 2012b) or Closure for Non-UST Sites as discussed below.

1.5.1. Low-Threat Underground Storage Tank Case Closure Policy

The main purpose of the LTCP is to improve the efficiency and consistency of the cleanup process for petroleum Underground Storage Tank (UST) sites. The LTCP facilitates closure for those UST sites that do not pose a threat to human health, the environment, or the waters of the State. Table 1-3 presents the eight general criteria that must be satisfied in order for a site to become eligible for low-threat closure.

Table 1-3: Low-Threat UST Case Closure Policy (LTCP) 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 stopped
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 Section 25296.15
h	Nuisance as defined by Water Code Section 13050 does not exist at the site

The LTCP does not use the ESLs to screen contaminants at petroleum-contaminated sites. Instead the LTCP provides closure levels for petroleum carcinogens (benzene, ethylbenzene, methyl tertiary butyl ether or MTBE, naphthalene, and benzo[a]pyrene equivalents) and general (narrative) criteria (e.g., removal of the secondary source to the extent practicable). ESLs may be used at sites with “unique attributes” to screen for constituents not already addressed by the LTCP.

The LTCP’s underlying CSM is that of a corner gasoline station where the sources of the petroleum release are the UST system. The LTCP 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 scientific rationale behind the criteria is presented in

technical justification documents, now included in Appendix A of the *Leaking Underground Fuel Tank Guidance Manual* (State Water Board 2015).

1.5.2. Closure 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 considerations to demonstrate remaining contamination will have a minimal impact on the environment, human and/or ecological receptors, and present or future drinking water resources. They 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 (Table 1-4). Although the document title includes chlorinated solvents, the nine considerations are versatile and can be applied to releases of other chemicals and mixtures. As of May 2025, this tool is in the process of being revised to clearly indicate its applicability to all low threat sites. The ESLs or site-specific criteria can be used in conjunction with these narrative considerations for site evaluations.

Table 1-4: Regional Water Board Closure Considerations for Non-UST Sites

No.	Narrative Considerations
1	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	Sources controlled and risks and threats mitigated 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	Residual pollution in all media will not adversely affect present and anticipated land and water uses 3a) Groundwater and soil vapor 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

1.6. Other Technical Documents

From time to time, Regional Water Board staff publishes technical memoranda on key topics. In addition, Table 1-5 lists associated, stand-alone technical resource documents for specific topics that can be utilized in conjunction with the ESLs.

Table 1-5: Technical Resource Documents for Use with the ESLs

Year	Title
1996	Supplemental Instructions to the State Water Board December 8, 1995, Interim Guidance on Required Cleanup at Low Risk Fuel Sites (Regional Water Board 1996)
2009	Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites (Regional Water Board 2009)
2022	Technical Resource Document: Vapor Intrusion Mitigation Guidance (Regional Water Board 2022)
2023	Final Draft Supplemental Guidance: Screening and Evaluating Vapor Intrusion (DTSC and State Water Board 2023)

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.

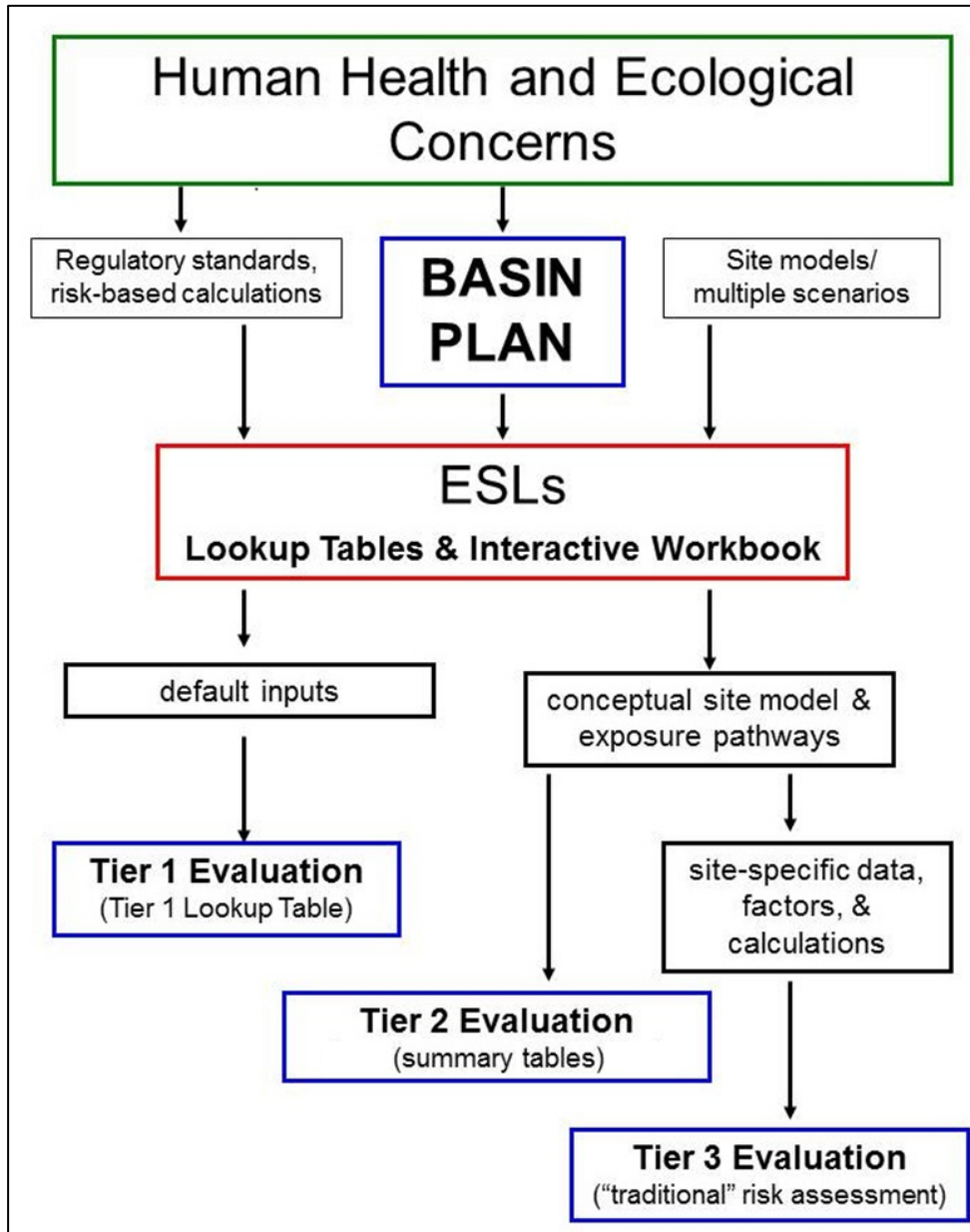


Figure 2-1: Tiered Process for Selecting Screening Levels

2.1. Conceptual Site Model

To use ESLs effectively, data should be evaluated within the context of the specific contaminated site. A conceptual site model (CSM) is a common way to provide this context. A CSM is a concise summary of what is currently known

about site conditions and how investigation data relates to the goals for the site (USEPA 1996c; p. 4 and p. 15 through 20). A complete CSM describes the nature and extent of contamination, how contamination is moving in space and time, and what receptors are likely to be impacted. A good CSM is detailed enough to understand whether site characteristics are consistent with the assumptions used to derive ESL values. The CSM is updated as new information and data is obtained (USEPA 2011c). Table 2-1 lists information for inclusion in a CSM.

Table 2-1: Information for a Conceptual Site Model

Site Data	Interpretation of Site Data
Local and Regional Geology	Contaminant Type(s) and Source(s)
Hydrogeology	Affected Media Type(s)
Site Activity and Use History	Contaminant Amount
Current and Future Site Use	Lateral/Vertical Contamination Extent
Nearby Land and Groundwater Use	Degradability of Contamination
Analytical Chemistry Data	Mobility of Contamination
Biological Testing Data	Receptors and Exposure Pathways
Monitoring Data (temporal data)	

The level of detail in each CSM will vary based on the type of evaluation being conducted, severity of the contamination, and complexity of the contaminant distribution. However, all CSMs include the three basic elements described below:

- 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 distribution(s) at a site. This is often portrayed as a diagram depicting known or suspected sources of contaminants and concentrations of known contaminants (including isoconcentration contour maps for soil and groundwater, such as Figure 2-2). Hydrogeologic cross sections showing the delineation of the vertical extent of contamination should be prepared (e.g., Figure 2-3). A calculation of residual contaminant mass in each media can also be helpful. A summary of the site history, including operations at the site that are known or suspected to have caused the release(s), is especially valuable.
- A description of how contaminants are moving or changing in space and time.** This evaluation should address whether the extent of known contamination is growing, migrating, or attenuating and should include an accurate discussion of geology and hydrogeology. It is critical that available geologic and topographic maps along with aerial photos be reviewed and interpreted. For new sites, this section could be brief, but for older and more complex situations, 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 risk associated with transformation products should be discussed as well as the apparent rate of biodegradation. Boring logs, well logs, maps of subsurface utilities and other figures, as appropriate, should be created 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, the effectiveness of the remediation should be evaluated.

- **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 hospitals, schools, day care centers, wetlands, or endangered species highlighted (e.g., Figure 2-5). Exposure pathways and receptors that may be present at the site but are not considered by the ESLs should be identified and the need for a site-specific risk assessment evaluated. Examples of exposures not considered in the ESLs include:
 - Consumption of backyard produce grown in contaminated soil;
 - Contact with contaminants transported via surface water (e.g., stormwater runoff, streamflow) in the form of contaminated sediments, suspended contaminated solids, or dissolved contaminants; or
 - Ingestion of contaminated surface water by endangered species.

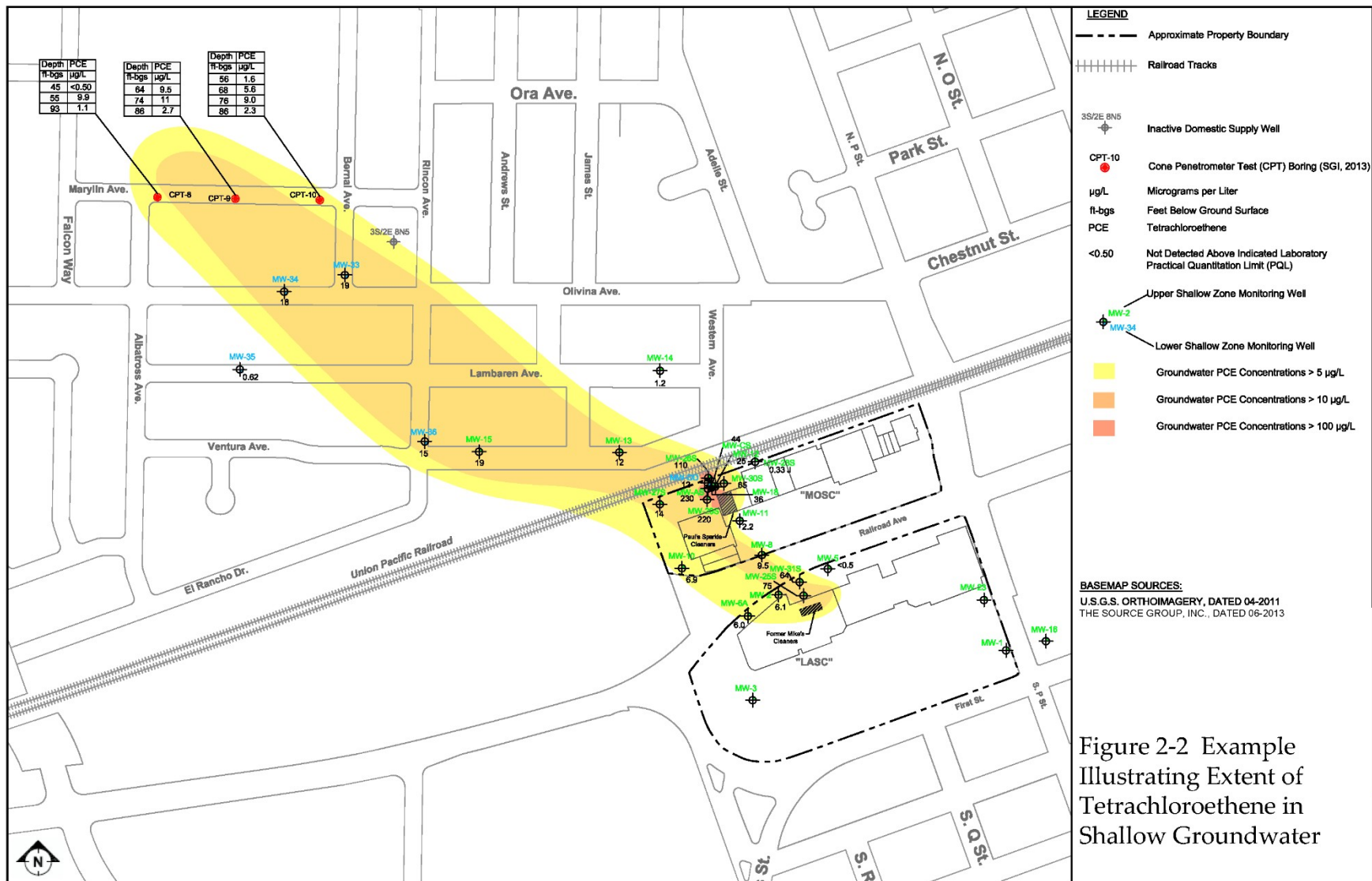


Figure 2-2: Example Illustrating Horizontal Extent of Tetrachloroethene in Shallow Groundwater



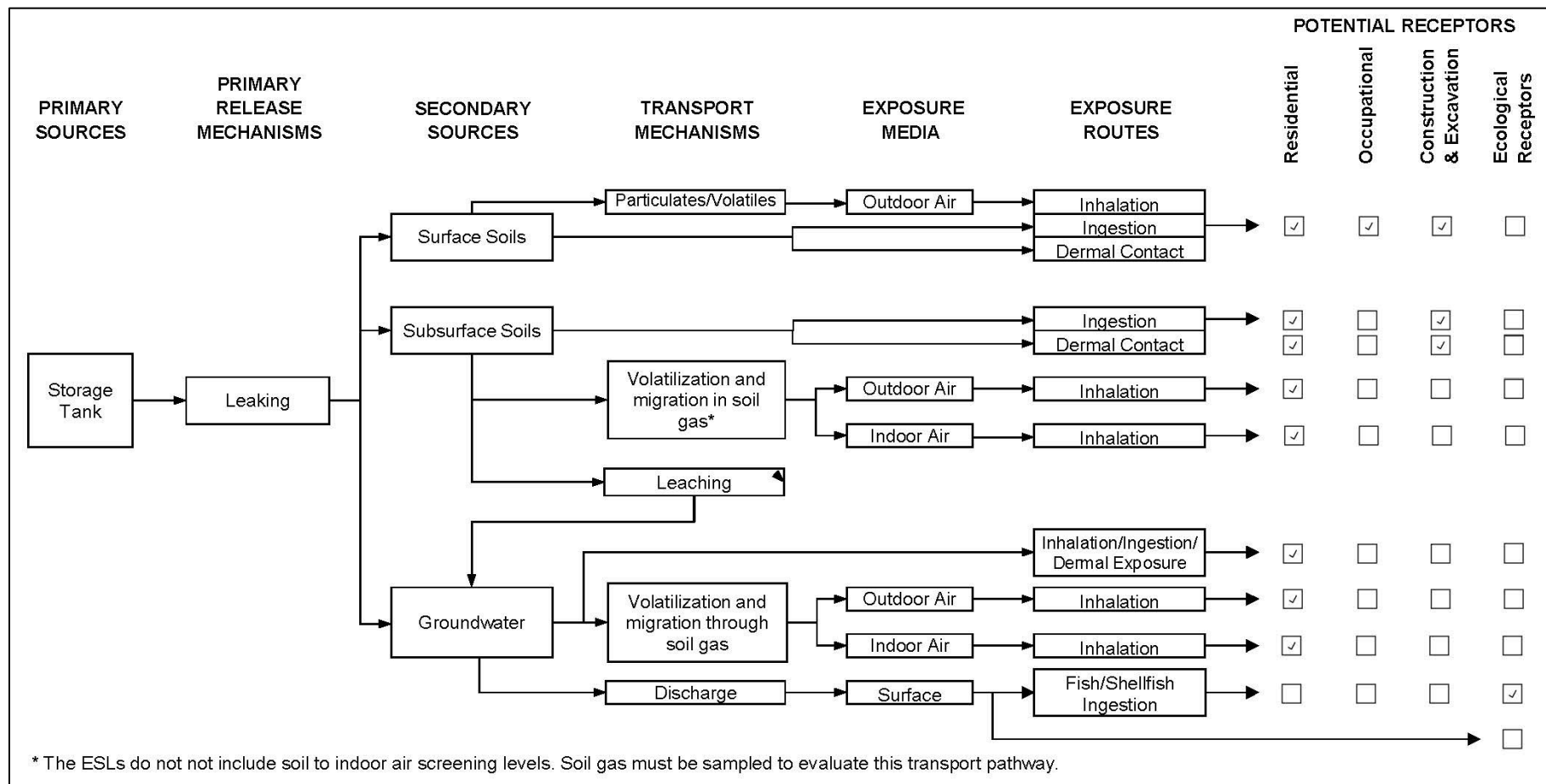


Figure 2-4: Default Evaluation of Receptors and Exposure Pathways Used in a Tier 1 Assessment

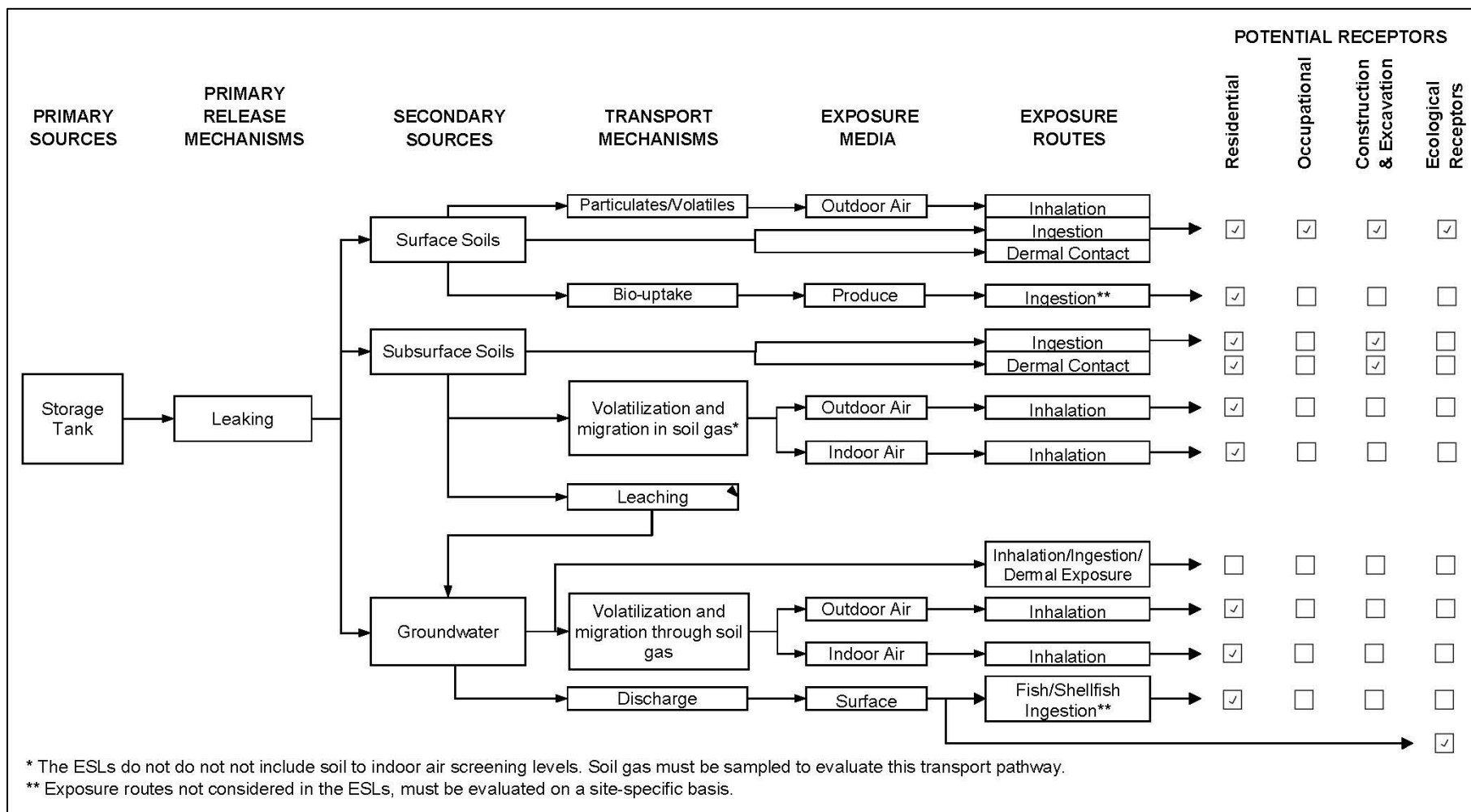


Figure 2-5: Example of a Site-Specific Evaluation of Receptors and Exposure Pathways

2.2. ESL Workbook Content

The ESL Workbook is a Microsoft Excel file that includes multiple worksheets used to calculate and summarize all the ESLs for groundwater, soil, subslab/soil gas, and indoor air. Each worksheet is color coded and appears in the workbook in the 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)** – Allows users to input site-specific information to generate Tier 2 (T2) screening levels and cumulative risk values for a selected chemical and specific site scenario. The tool includes three separate worksheets:
 - **Table T2-1 (Site-Specific ESLs)** – Input page for chemical(s) selection and entry of site-specific information in the yellow boxes and the site-specific T2 ESL outputs are provided in the gray boxes.
 - **Table T2-2 (Cumulative Risk Calculator)** – Input site-specific contaminant concentrations to obtain output of the calculated cumulative cancer risk and noncancer hazard index.
 - **Table T2-3 (Site-Specific Concerns)** – Output visual CSM with media and pathway concerns for the input site-specific contaminant concentrations.
- **Light Blue Tabs (Groundwater)** – Calculation tables showing the parameters used to calculate the ESLs for groundwater (GW):
 - **Table GW-1** – Direct Exposure Human Health Risk Level Calculation
 - **Table GW-2** – Aquatic Habitat Level Calculation
 - **Table GW-3** – GW Vapor Intrusion Risk Level Calculation
 - **Table GW-4** – Gross Contamination Level Calculation
 - **Table GW-5** – Taste and Odor Nuisance Level Calculation
- **Yellow Tabs (Soil)** – Calculation tables showing the parameters used to calculate the ESLs for soil (S):
 - **Table S-1** – Direct Exposure Human Health Risk Level Calculation
 - **Table S-2** – Terrestrial Habitat Level Calculation
 - **Table S-3** – Leaching to Groundwater Level Calculation
 - **Table S-4** – Gross Contamination Level Calculation
 - **Table S-5** – Odor Nuisance Level Calculation

- **Purple Tabs (Subslab/Soil Gas)** – Calculation tables showing the parameters 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
- **Green Tabs (Indoor Air)** – Calculation tables showing the parameters used to calculate the ESLs for indoor air (IA):
 - **Table IA-1** – Indoor Air Direct Exposure Risk Level Calculation
 - **Table IA-2** – Indoor Air Odor Nuisance Level Calculation
- **Tan Tabs (Input Parameters/Constants)** – Lookup tables compiling the input parameters and constants (IP):
 - **Table IP-1** – Physical-Chemical Values
 - **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 Aquatic Habitat Goals
 - **Table IP-6** – USEPA and Other Aquatic Habitat Goals
 - **Table IP-7** – Seafood Ingestion Aquatic Habitat Goals (Risk from Bioaccumulation)
 - **Table IP-8** – Soil Terrestrial Habitat Goals
 - **Table IP-9** – Petroleum Fractions

2.3. Tier 1 ESLs – Default Conceptual Site Model

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

The Tier 1 ESL Workbook Summary Table presents 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 employs 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 where 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
Vegetation Level	Substantial
Groundwater Use	Drinking Water Resource
MCL Priority over Risk Based Levels	Yes
Discharge to Surface Water	Saltwater & Freshwater
Groundwater VI Attenuation Factor	0.001
Soil Gas VI Attenuation Factor	0.03
Soil Contamination Depth	Shallow (≤ 10 ft bgs)

2.4. Tier 2 ESLs – Selecting Site-Specific ESLs and Use of Interactive Tool

Tier 2 ESLs are selected by refining the default CSM to identify relevant pathways, receptors, and concerns specific to an individual site. For sites where the exposure scenarios and concerns are addressed in the ESLs, this intermediate approach is a relatively rapid and cost-effective option for developing site-specific screening levels in lieu of proceeding to a Tier 3 quantitative risk assessment. The following sections give a step-by-step description of how to select the correct Tier 2 ESL(s) for a specific site. These steps will aid in the selection of appropriate site-specific input criteria for the ESL Workbook Interactive Tool Input Table T2-1.

2.4.1. 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. If the answer is yes, ensure the most up-to-date version of the ESLs is being used.

2.4.2. Step 2: Identify Chemicals of Potential Concern

An appropriate risk evaluation should be based on the results of an adequate site investigation.

- Characterize the distribution and extent of chemicals of potential environmental concern identified in the CSM in groundwater, soil, subsurface/soil gas, and indoor air within areas located both on- and off-site.
- Identify maximum concentrations of chemicals present in the media of concern.

2.4.3. Step 3: Land Use Selection

The selected ESLs for soil, slab/soil gas, and indoor air are based on the present use and anticipated future use of the site. Land uses are categorized based on the assumed magnitude of potential human exposure (see Section 3.4.2).

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

Two options are available in the workbook:

- **Residential Land Use** should be used to evaluate sites for unrestricted future land-use. This includes sites to be used for residential developments, 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 generally are considered to be appropriate for long-term use of a property, though there can be situations where short-term, more intensive exposures to soil can drive risk (e.g., construction worker soil ESL for nickel).
- **Commercial or Industrial Land Use** assumes that only working-age adults will be present at the site on a regular basis. For example, 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). However, 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 to avoid the potential requirements for unneeded institutional controls, such as a deed restriction that prohibits residential land use, which are generally not needed if residential ESLs are exceeded.

An “**Implied Land Use Restriction**” is a situation where: (1) the current land use or zoning is commercial/industrial; (2) there is low or no likelihood that the land use will change in the future; and (3) the site data are only evaluated against commercial/industrial ESLs. This situation raises the question regarding whether a land use covenant is warranted as a measure of protection for remaining contamination that exceeds residential ESLs. California Water Code section 13307.1(c) gives the Regional Water Board the Authority to determine when a deed restriction is required, with a few exceptions.

2.4.4. Step 4: Vegetation Level Selection

Terrestrial Habitat ESLs were compiled for either “Significantly Vegetated Areas” or “Minimally Vegetated Areas”. These ESLs can be applied to either the residential or commercial/ industrial scenarios depending on the site-specific vegetation level. Several factors should be considered when determining the vegetation level of a given site, such as:

- the level of urbanization in surrounding areas;
- the percentage of the site that is covered by vegetation; and
- if there is any observed animal habitat.

For example, a suburban residence with over 50% of the property is covered by vegetation could be considered a substantially vegetated area. On the other hand, almost all high-density urban scenarios could be considered minimally vegetated areas. Most commercial/industrial sites will most likely be considered minimally vegetated areas.

2.4.5. Step 5: 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 a more site-specific analysis, the actual (likely) use of groundwater can be determined based on the locations of existing municipal or domestic supply wells, 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).

When Groundwater Use is set to nondrinking water resource, the resulting groundwater ESLs do not consider risk from direct exposure to groundwater used as tapwater (ingestion, inhalation, or dermal contact).

An “**Implied Groundwater Use Restriction**” is 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 situations, a deed restriction may be required to ensure that groundwater will not be used in the future. Further, because groundwater contamination plumes are not static, the potential for contaminant migration should be adequately assessed as well as the potential for vapor intrusion.

2.4.6. Step 6: MCL Priority versus Risk-Based Screening Levels Selection

Choosing MCL Priority changes how the final ESL for groundwater direct exposure is selected. If MCL Priority is not chosen, the final ESL for groundwater direct exposure is the lowest of the three types of direct exposure criteria (Section 3.1.1): tapwater ESLs, MCLs, or other drinking water levels (e.g., OEHHA public health goals). If MCL Priority is chosen and a chemical has an MCL, the MCL is selected as the final ESL for groundwater direct exposure. The Tier 1 ESLs use the MCL Priority value to assess the groundwater direct exposure risk.

According to the Basin Plan, the lower of the primary and secondary Maximum Contaminant Levels (MCLs) for selected chemicals must be used as an upper bound when setting cleanup goals for groundwater designated for domestic or municipal supply use (see Section 1.1.1). MCLs are drinking water standards adopted by the California State Water Resources Control Board, Division of Drinking Water (DDW)¹ pursuant to the California Safe Drinking Water Act. Primary MCLs are derived from health-based criteria considering technologic and economic constraints and the feasibility of achieving and monitoring the concentrations in drinking water.

2.4.7. Step 7: Discharge to Surface Water Type Selection

The likelihood of a groundwater plume discharging into a nearby surface water body should be considered when selecting groundwater ESLs. If enough information is present to show that a groundwater plume extent is defined, stable, not likely to migrate further, and not discharging to surface water, then the “No Discharge Expected” can be selected in the site-specific input ESL Workbook Table 2-1 (Tier 2 Site Specific ESLs). When a groundwater plume is currently discharging, could discharge in the future, or discharge status is uncertain, in ESL Workbook Table 2-1 select the type of surface water habitat that could be affected: freshwater, saltwater, or both (in the case of estuaries).

2.4.8. Step 8: Soil Exposure Depth Selection

The ESLs employ two contamination depth options for soil direct exposure considerations (see Table 3-1):

- **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 level evaluations, two potentially exposed

¹ The California Drinking Water Program was transferred from the California Department of Public Health to the State Water Resources Control Board, Division of Drinking Water in July 2014.

receptor populations need to be considered: 1) residents or commercial/industrial workers; and 2) construction workers.

- **Deep Soil Contamination (below 10 feet bgs):** Construction workers may also 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 was removed.

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

2.4.9. Step 9: Final ESL Determination Process

The Interactive Tool uses the site-specific scenario parameters selected by the user in ESL Workbook Table T2-1, to identify the site-specific ESLs appropriate for each medium. Figures 2-6 through 2-9 illustrate the considerations used in the determining the final screening level for groundwater, soil, subslab/soil gas, and indoor air, respectively.

2.4.10. Step 10: Compare Site Data to ESLs

The concentrations of up to five contaminants detected at a site can be entered into the Interactive Tool in the ESL Workbook Table T2-2 to calculate the cumulative cancer risk and hazard index. The specific concerns posed by those chemicals and concentrations will be identified in ESL Workbook Table T2-3.

Initial screening is typically performed using maximum-detected concentrations as the exposure point concentrations (EPCs). Tier 2 or Tier 3 risk evaluations may employ the use of statistical methods (e.g., 95 percent upper confidence limit of the arithmetic mean, or UCL) to estimate EPCs for specific exposure areas.

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. Information for the estimation of EPCs use of non-detect data, and other related 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 2002g), and (3) the most current version of ProUCL. 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, ideally, soil gas and groundwater concentrations should not be averaged over an area greater than the floor space area of existing or anticipated buildings.

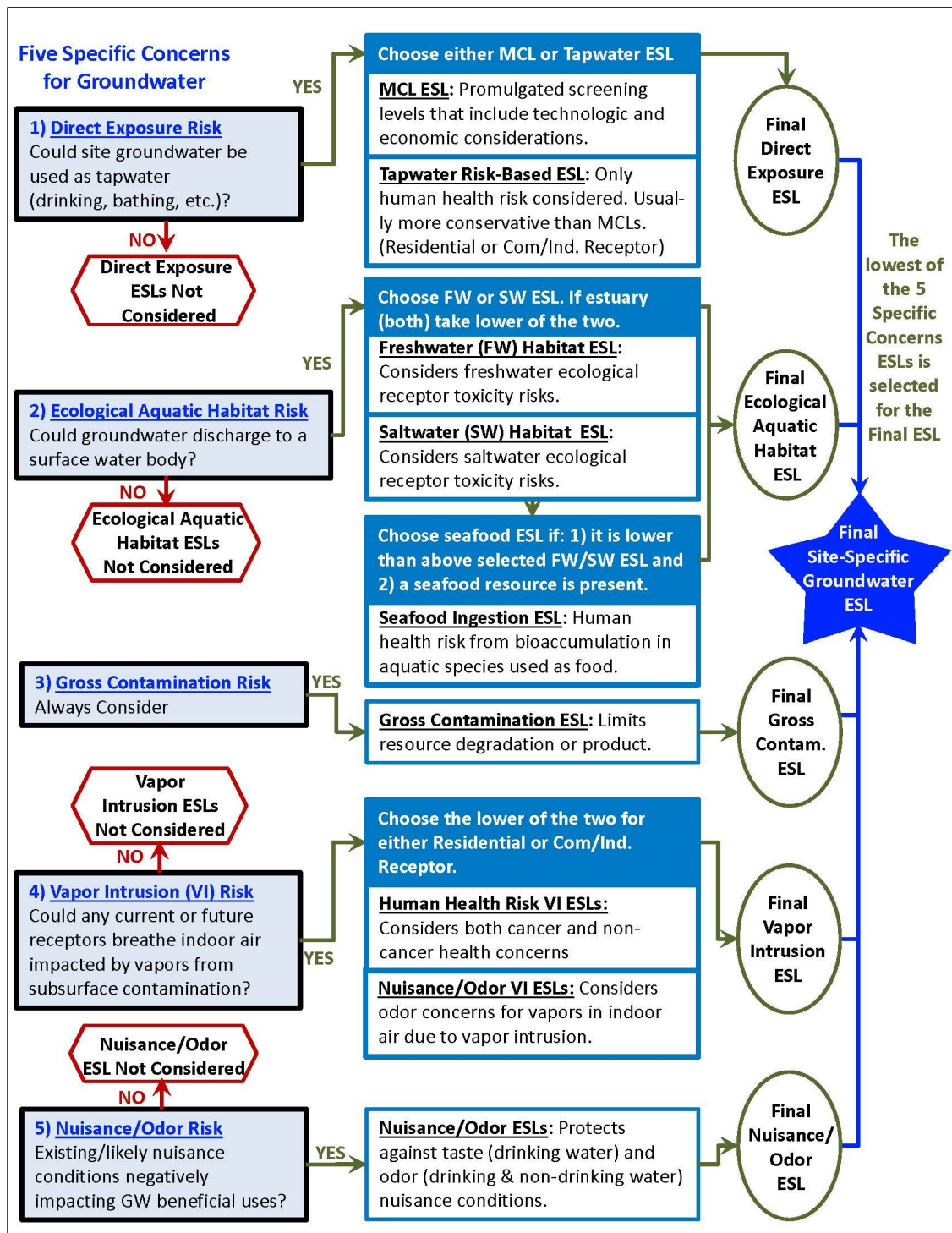


Figure 2-6: Final Site-Specific Groundwater ESL Determination

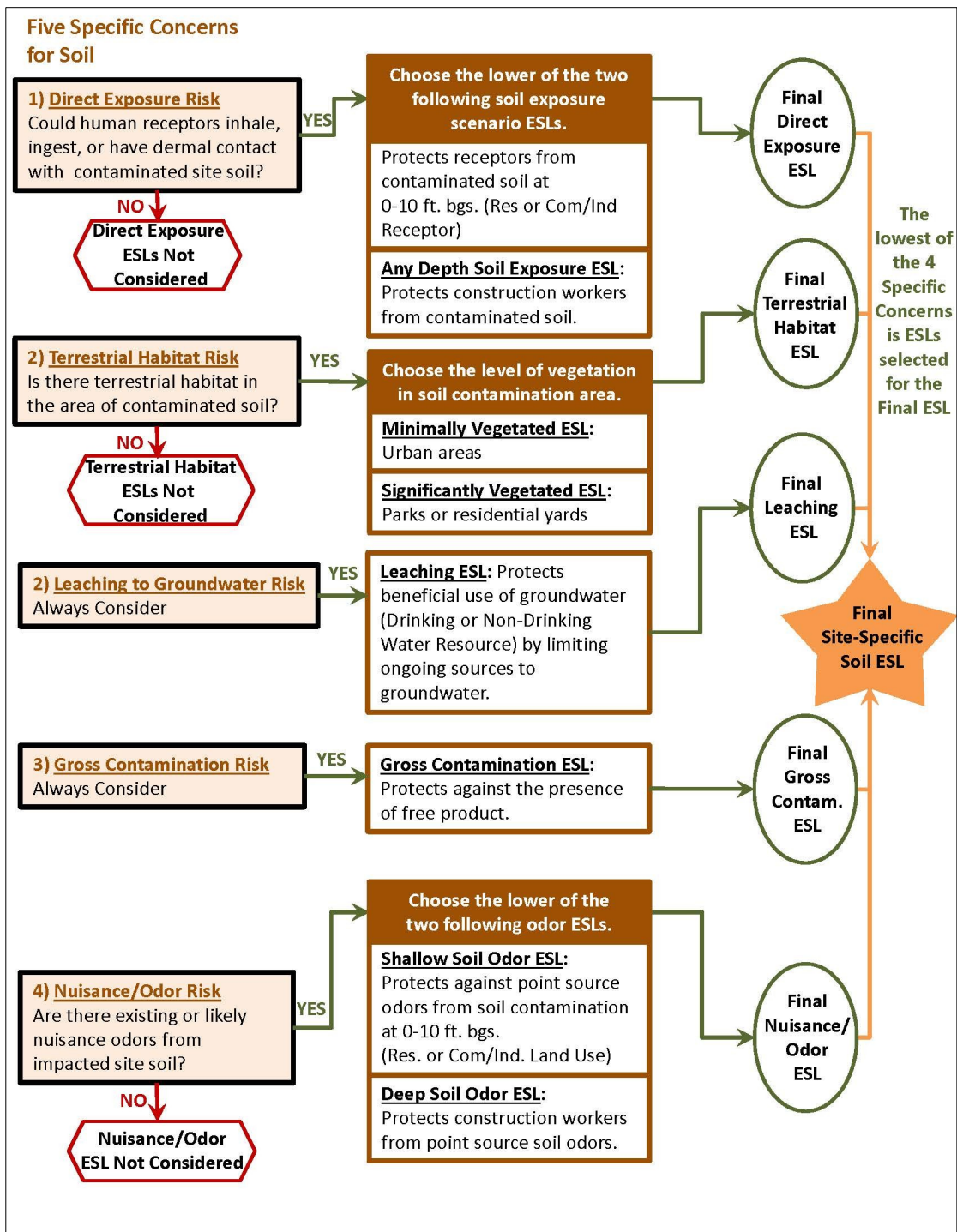


Figure 2-7: Final Site-Specific Soil ESL Determination

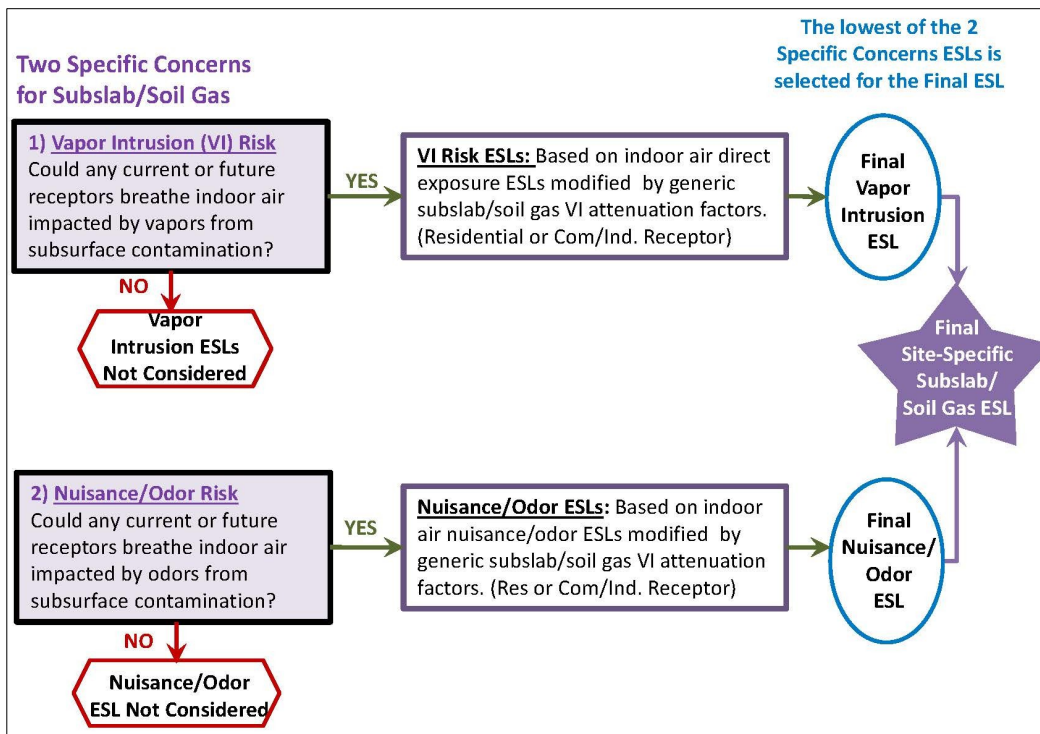


Figure 2-8: Final Site-Specific Subslab/ Soil Gas ESL Determination

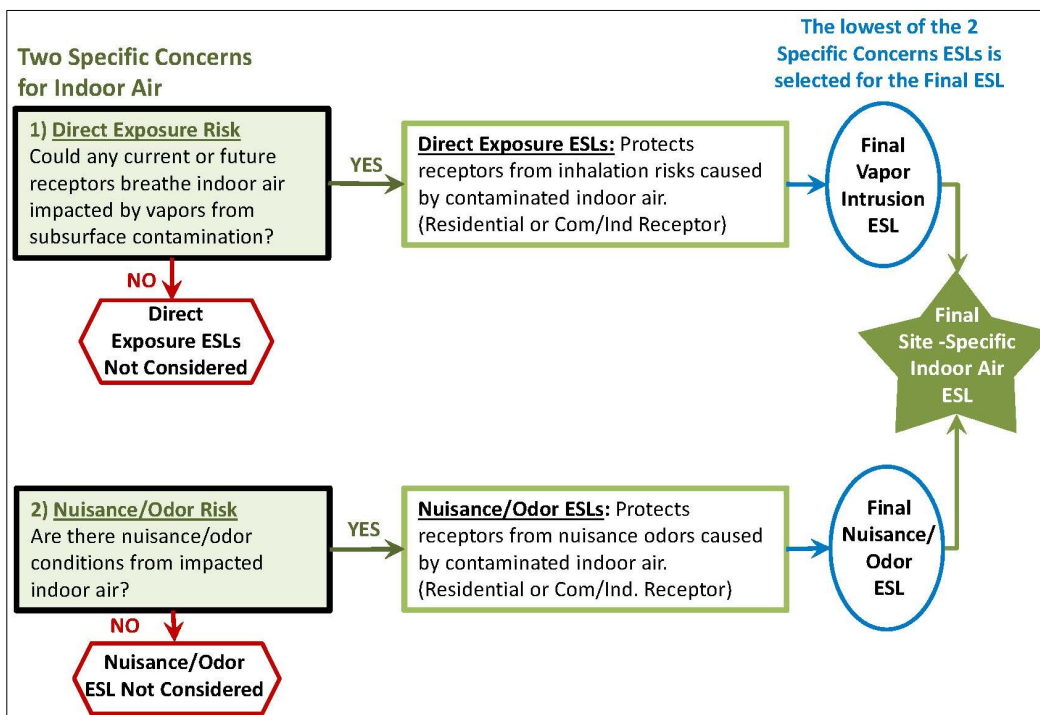


Figure 2-9: Final Site-Specific Indoor Air ESL Determination

2.4.11. Step 11: Compare Site Data to Background/Ambient Levels

If background sampling analysis or applicable published background studies can be used to determine the naturally occurring background or ambient concentrations of chemicals of concern at a site, compare them with the site's selected ESLs. If the site-specific background or ambient concentrations are greater than the risk-based ESLs, the background concentrations may be used to screen sites for excess risk posed by site contamination. This should only be done in consultation with the overseeing regulatory agency. Risk from background or ambient levels of chemicals of concern should still be documented in the screening analysis report, so those risks can be considered for risk communication and risk management decisions. Further information is provided in Section 12.4.

2.4.12. Step 12: Evaluate the Need for Additional Investigation, Assessment, or Remediation

Based on a comparison of available site data to the ESLs, the user should evaluate the need for additional action at the site. Additional action should be evaluated when the cumulative cancer risk is greater than 1×10^{-6} or the noncancer hazard index is equal to or greater than 1 at a site. Additional actions may include, but are not limited to further investigation, institutional controls, monitoring, preparation or revision of a site-specific risk assessment, source remediation, or mitigation (to protect a threatened receptor until cleanup levels are attained). Information about the calculation of cumulative cancer risk and noncancer hazard are provided in Section 3.5.

2.4.13. Example of Interactive Tool Use: Dry Cleaner Release of Tetrachloroethene and Stoddard Solvent

The site-specific scenario options are chosen from the drop-down menu in the first yellow box and the top five contaminants for the site are selected in the second yellow box of Table T2-1 in the Interactive Tool of the ESL Workbook, as shown in Figure 2-10. The gray box shows the output media specific Tier 2 ESLs for the five contaminants given the selected site scenario information. The basis for the selected ESL is shown to the right of each Tier 2 ESL.

For this example, available soil, groundwater, subslab/soil gas, and indoor air data were entered in the yellow box of Interactive ESL Workbook Tool Table T2-2, as shown in Figure 2-11. The default screening soil gas attenuation factor 0.03 was also entered. In the purple box, the cancer risk and noncancer hazard for each contaminant concentration is calculated for the soil exposure pathway, tapwater exposure pathway, and indoor air exposure via the vapor intrusion pathway. Risk and hazard for the vapor intrusion pathway are further split into current (primarily based on indoor air data) and future (primarily based on subs lab/ soil gas data) exposure scenarios (see section 3.5.1 for more information).

The cumulative risk and hazards, considering all five contaminants, are shown for each media in the black box.

The Specific Concerns diagram shown in the Interactive ESL Workbook Tool Table T2-3 can be used to get a better idea of potential threats caused by specific contaminant concentrations measured at a site, shown in Figure 2-12 for this example. This diagram uses the site-specific scenario inputs and chemical input for “Contaminant 1” in Table T2-1 and the “Contaminant 1” concentration inputs from Table T2-2. Each media type (groundwater, soil, subslab/soil gas, and indoor air) is shown within a circle. Each circle is connected to a box for each of 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. The “red X visual” highlights specific media needing further evaluation and potentially response actions. As seen in Figure 2-12, the site-specific concerns for the site-specific concentration data for this example are:

- Soil: Leaching to groundwater
- Groundwater: Human health risk from vapor intrusion to indoor air
- Subslab/ Soil Gas: Human health risk from vapor intrusion to indoor air
- Indoor Air: Human health risk from direct exposure

Figure 2-12 also shows that both groundwater and soil concentrations are below levels where gross contamination or odor (nuisance) would be a concern. The soil contaminant concentrations do not pose a soil exposure risk to human or ecological receptors. No risk to human health from tapwater exposure is shown since this is a nondrinking water resource and no risk to aquatic habitats is shown since no groundwater discharge to surface water is expected at the site.

2.5. Tier 3 – Develop Site Specific Screening Levels

Tier 3 Screening Levels typically are developed by either modifying Tier 2 ESLs or developing screening levels for an exposure scenario not considered in the ESLs. Tier 2 ESLs can be modified to adjust exposure factor values to those considered more representative for a particular site, given adequate justification. Alternatively, different exposure scenarios can be developed with adequately justified algorithms, models, or inputs. Two examples of alternative exposure scenarios are consumption of garden produce and recreational swimmer exposure.

In lieu of Tier 3 screening levels, a site-specific risk assessment can be developed.

January 2019
(Rev. 1)

Table T2-1: Tier 2 ESLs
Site-Specific Input and Output
Click in cell and use pull-down boxes to make selection.

Tier 2 Scenario Toggles

Land Use:

Commercial or Industrial

Vegetation Level:

Minimal

Groundwater Use:

Nondrinking Water Resource

MCL Priority over Risk-Based:

Yes


Discharge to Surface Water:

No Discharge Expected


Soil Contamination Depth:


(Shallow ≤ 10ft bgs < Deep)

Shallow & Deep Soil



Environmental Screening Levels
San Francisco Bay Regional Water Quality Control Board


GAVIN NEWSOM
GOVERNOR


JARED BLUMENFELD
SECRETARY FOR
ENVIRONMENTAL PROTECTION

Select Site Contaminants:

Contaminant 1

Tetrachloroethene

Contaminant 2

Trichloroethene

Contaminant 3

cis-1,2-Dichloroethene

Contaminant 4

Vinyl chloride

Contaminant 5

Petroleum - Stoddard Solvent

Note:
Groundwater **depth** is no longer a toggle for evaluating vapor intrusion. See the notes in Workbook Table GW-3 and the User's Guide Chapter 5 for further information.

Figure 2-10: ESL Workbook Interactive Tool Tier 2 ESL Input and Output Table T2-1 for Example Scenario



Environmental Screening Levels San Francisco Bay Regional Water Quality Control Board

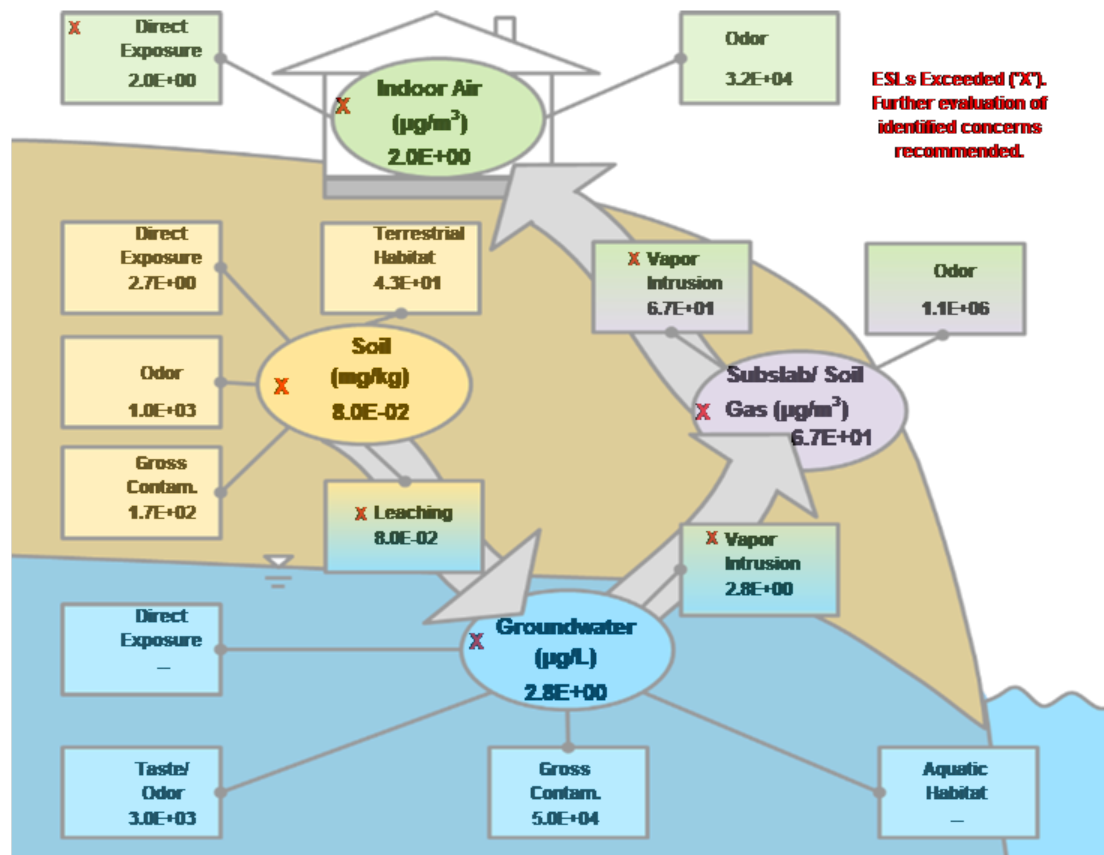


January 2019 (Rev. 1)		Table T2-2: Tier 2 – Site-Specific Cumulative Risk and Hazard Calculator					Selected Site Scenario (from T2-1)
Enter Site Data (Leave blank when no data exists)							Land Use: Commercial or Industrial Vegetation Level: Minimal Groundwater Use: Nondrinking Water Resource MCL Priority vs Risk-Based: Yes Discharge to Surface Water: No Discharge Expected Soil Contamination Depth: Shallow & Deep Soil
Contaminant inputs from T2-1:	Contaminant 1 Tetrachloroethene	Contaminant 2 Trichloroethene	Contaminant 3 cis-1,2-Dichloroethene	Contaminant 4 Vinyl chloride	Contaminant 5 Petroleum - Stoddard Solvent		
Soil Concentration (mg/kg) - dry weight:	0.50	0.30			3,000.00		
Groundwater Concentration (µg/L):	100.00	40.00	60.00	5.00	500.00		
Subslab/ Soil Gas Concentration (µg/m³):	50,000	1,000	100	100	400,000		
Indoor Air Concentration (µg/m³):	10.00	0.50					
Soil Gas VI Attenuation Factor (Use 0.03 for Screening):						0.0300	
Cancer Risk:							
Soil Exposure Risk:	1.9E-07	4.9E-08	--	--	--		Cumulative Risk 2.4E-07
Tapwater Exposure Risk:	--	--	--	--	--		--
Current* Vapor Intrusion Exposure Risk: Basis:	5.0E-06 Indoor Air	1.7E-07 Indoor Air	-- Subslab/Soil Gas VI	1.9E-05 Subslab/Soil Gas VI	-- Subslab/Soil Gas VI		5.1E-06 Indoor Air
Future** Vapor Intrusion Exposure Risk: Basis:	7.5E-04 Subslab/Soil Gas VI	1.0E-05 Subslab/Soil Gas VI	-- Subslab/Soil Gas VI	1.9E-05 Subslab/Soil Gas VI	-- Subslab/Soil Gas VI		7.8E-04 Subslab/Soil Gas VI
Noncancer Hazard:							
Soil Exposure Hazard:	1.4E-03	1.7E-02	--	--	2.7E+00		Cumulative Hazard 2.7E+00
Tap Water Exposure Hazard:	--	--	--	--	--		--
Current* Vapor Intrusion Exposure Hazard: Basis:	5.7E-02 Indoor Air	5.7E-02 Indoor Air	8.6E-02 Subslab/Soil Gas VI	6.8E-03 Subslab/Soil Gas VI	8.7E+00 Subslab/Soil Gas VI		1.1E-01 Indoor Air
Future** Vapor Intrusion Exposure Hazard: Basis:	8.6E+00 Subslab/Soil Gas VI	3.4E+00 Subslab/Soil Gas VI	8.6E-02 Subslab/Soil Gas VI	6.8E-03 Subslab/Soil Gas VI	8.7E+00 Subslab/Soil Gas VI		2.1E+01 Subslab/Soil Gas VI
Notes: Cumulative cancer risk and noncancer hazard are not automatically calculated across pathways because exposure via multiple pathways typically is not simultaneous. This may be performed separately as part of a site-specific evaluation. See the User's Guide Section 3.3 (Addressing Cumulative Risk and Hazard). * Current (VI exposure to current occupants of existing buildings) – Primarily based on indoor air data. See User's Guide Chapter 5 for further information. In the absence of indoor air data, subslab/soil gas or groundwater data is used to predict current indoor air concentrations. Subslab/soil gas data is given priority over groundwater data for current exposure calculations. The cumulative risk calculation follows the same hierarchy. ** Future (VI exposure to future occupants of existing or future buildings) – Primarily based on subslab/soil gas data. See User's Guide Chapter 5 for further information. In the absence of subslab/soil gas data, groundwater data is used to predict future indoor air concentrations. The cumulative risk calculation follows the same hierarchy.							

Figure 2-11: Interactive ESL Workbook Tool Table T2-2 for the Example Scenario

January 2019
(Rev. 1)

Table T2-3: Diagram of Specific Concerns for:
Tetrachloroethene
Based on "Contaminant 1" inputs in Tables T2-1 and T2-2



Selected Site Scenario (Table T2-1):

Land Use: Commercial or Industrial
Vegetation Level: Minimal
Groundwater Use: Nondrinking Water Resource
MCL Priority over Risk-Based: Yes
Discharge to Surface Water: No Discharge Expected
Soil Contamination Depth: Shallow & Deep Soil

Site Concentration Inputs (Table T2-2):

Soil (mg/kg): 0.50
Groundwater ($\mu\text{g}/\text{L}$): 100.00
Soil Gas ($\mu\text{g}/\text{m}^3$): 50,000
Indoor Air ($\mu\text{g}/\text{m}^3$): 10.00

Figure 2-12: Interactive ESL Workbook Tool Specific Concerns Table T2-3 for the Example Scenario

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

The ESLs consider potential adverse effects to human health from chronic direct exposure to contaminated groundwater, soil, and indoor air. Direct exposure (or direct contact) refers to exposure via one or a combination of the three exposure routes (ingestion, inhalation, and dermal contact). Direct exposure human health risk ESLs are presented in three ESL Workbook tables where the exposure point is groundwater (Workbook Table GW-1), soil (Workbook Table S-1), and indoor air (Workbook Table IA-1). Table 3-1 identifies the human health direct exposure scenarios in the ESLs, including the receptors, exposure routes, and media.

Table 3-1: Human Health Direct Exposure Scenarios in the ESLs

Medium/ Workbook Table	Resident Exposure Routes	Commercial/ Industrial Worker Exposure Routes	Construction Worker Exposure Routes
Groundwater (Table GW-1 Tapwater Columns)	Ingestion Inhalation Dermal	--	-- ¹
Shallow Soil (≤10 ft bgs) (Table S-1)	Ingestion Inhalation Dermal	Ingestion Inhalation Dermal	Ingestion Inhalation Dermal
Deep Soil (>10 ft bgs) (Table S-1)	--	--	Ingestion Inhalation Dermal
Indoor Air (Table IA-1)	Inhalation	Inhalation	--

Table 3-1 Note 1: See Frequently Asked Questions regarding construction worker exposures to groundwater.

This chapter presents the following:

- background on risk assessment and management;
- calculation of the human health direct exposure ESLs for the different media (groundwater, soil, and indoor air)
- evaluation of cumulative risk and hazard;
- risk assessment for the chemical mixtures included in the ESLs including methodology and/or application;
- consideration of chemical transformation and generation of degradation products; and
- general information on site-specific evaluations.

3.1. Groundwater Direct Exposure ESLs

The ESLs consider potential adverse effects to humans through exposure to groundwater used as tapwater for common domestic activities, such as drinking, bathing/showering, cooking, dishwashing/laundry, and flushing the toilet. ESL Workbook Table GW-1 presents these ESLs.

The application of these ESLs to a cleanup site implies that the tapwater source is from a well located onsite with the well screened across the zone of groundwater contamination. Consideration of this exposure pathway should always be included when the designated beneficial uses of the groundwater include drinking water.

3.1.1. Direct Exposure Health Risk Criteria

ESL Workbook Table GW-1 includes screening levels from three sources as described below:

- Tapwater Screening Levels – These values are calculated in ESL Workbook Table GW-1 using the USEPA RSL resident tapwater equations for all three exposure routes (ingestion, inhalation, and dermal exposure per Table 3-1).
- Maximum Contaminant Levels (MCLs) – These values are compiled in ESL Workbook Table IP-4. MCLs are drinking water standards adopted by the California State Water Resources Control Board, Division of Drinking Water (DDW) 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 detecting and monitoring for these concentrations in drinking water. The compiled values include both the Primary and Secondary MCLs. The Primary MCL values are the lowest of the Federal or California Primary MCLs and constitute the Primary MCLs applicable for California. Certain per- and polyfluoroalkyl substances (PFAS) have MCLs based on the calculation of cumulative hazard associated with exposure to multiple PFAS (see section 3.6.6).
- Other Drinking Water Levels – These values are compiled in ESL Workbook Table IP-4 and include Public Health Goals developed by the Office of Environment Health Hazard Assessment (OEHHA), Notification Levels by DDW, or Public Health Archived Advisory Levels by DDW.

3.1.2. Hierarchy for Direct Exposure Health Risk Criteria

ESL Workbook Table GW-1 determines the Groundwater Direct Exposure ESLs from the compiled criteria as described herein. First, for each chemical, the MCL Screening Levels for cancer risk and noncancer hazard are selected using the lower of the Primary or Secondary MCL from USEPA and California. Second, the Other Drinking Water Criteria for cancer risk and noncancer hazard are selected

using the more stringent of the other criteria. Third, the Final Human Health Screening Levels for cancer risk and noncancer hazard are determined using the lowest of the calculated Tapwater Screening Levels and Other Drinking Water Criteria.

The groundwater Tier 1 ESLs do not consider the Tapwater ESLs for chemicals with established primary or secondary MCLs (also called MCL Priority) to reflect the Basin Plan water quality objectives. Therefore, the Tier 1 ESLs for groundwater are not necessarily the lowest or most stringent possible direct exposure-based value.

3.2. Soil Direct Exposure ESLs

The ESLs consider potential adverse effects to humans through direct exposure to soil via intrusive activities such as landscaping or digging. Direct exposure for soil includes incidental ingestion, inhalation of particulates and vapors, and dermal contact. A chemical is considered volatile if either: (1) the vapor pressure is greater than 1 millimeter of mercury or (2) the Henry's Law Constant is greater than 1×10^{-5} atmospheres-cubic meter/mole (USEPA 2015a). ESL Workbook Table S-1 presents these ESLs for three exposure scenarios based on land use. The soil direct exposure ESLs are based on dry weight. Soil exposure scenarios depend on the land use, receptor, and depth of contamination as follows and per Table 3-2:

- Shallow Soil Contamination (at or above 10 feet bgs) – Residents, commercial/industrial workers, and construction workers may be exposed to contaminated soil at or above 10 feet bgs. Most evaluations should consider two potentially exposed receptor populations: 1) residents or commercial/industrial workers; and 2) construction workers.
- Deep Soil Contamination (below 10 feet bgs) – Construction workers may also 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 soils were permanently removed.

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

Table 3-2: Soil Human Health Direct Exposure Scenarios

Soil Depth	Land Use: Residential, Receptor: Resident	Land Use: Commercial/ Industrial, Receptor: Worker	Land Use: Any, Receptor: Construction Worker
Shallow	Yes	Yes	Yes
Deep	--	--	Yes

3.3. Indoor Air Direct Exposure ESLs

The ESLs consider potential adverse effects to humans through inhalation of vapors. ESL Workbook Table IA-1 presents indoor air ESLs for volatile chemicals for two exposure scenarios based on land use: residential and commercial/industrial. A chemical is considered volatile if either: (1) the vapor pressure is greater than 1 millimeter of mercury or (2) the Henry's Law Constant is greater than 1×10^{-5} atmospheres-cubic meter/mole (USEPA 2015a).

3.4. Calculation of Human Health Direct Exposure Screening Levels

The human health direct exposure ESLs for groundwater, soil, and indoor air are calculated for specific exposure scenarios using methodologies and equations developed by USEPA with numerous inputs including target risk, physical and chemical properties, toxicity values, and exposure parameters (e.g., liters of water consumed per day). The equations used in the ESLs are listed in Appendix A. The equations combine exposure assumptions with chemical-specific toxicity values to calculate contaminant levels with a one-in-a-million (1×10^{-6}) cancer target risk or a noncancer target hazard quotient (HQ) of 1. Since the levels of carcinogenic and noncarcinogenic effects caused by a given chemical are not related, both should be considered. To be conservative, the final direct exposure ESL is the lower of the cancer versus noncancer risk screening level.

3.4.1. Background: Use of Screening Levels for Risk Assessment

Risk assessment is the characterization of potentially adverse human health or environmental impacts resulting from exposure to contamination. The document entitled "Use of Risk Assessment in Management of Contaminated Sites" (ITRC 2008) provides detailed background regarding the development of risk assessment for use at environmental cleanup sites. The risk assessment paradigm largely was set forth by the National Research Council (NRC 1983). Most of the methodology has been developed by the USEPA in response to passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 1980), as amended by the Superfund Amendments and Reauthorization Act (SARA; 1986), commonly called Superfund. Both federal statutes CERCLA and the Resource Conservation and Recovery Act (RCRA; 1976), as amended by the Hazardous and Solid Waste Amendments (1984) require risk assessment to determine whether remedial or corrective actions are necessary. Under California law, remedial or corrective actions can be required based on nuisance, as well as risk.

The methodologies for health-risk-based screening levels have been derived by USEPA in numerous guidance documents as part of the Superfund program, most notably Risk Assessment Guidance for Superfund (RAGS), Volume I, Parts

A through E. The aspects of those documents relevant to the ESLs are described as follows, in chronological order:

- RAGS, Vol. I: Human Health Evaluation Manual, Part A, Interim Final (RAGS Part A; USEPA 1989) – This document describes cancer risk and noncancer (systemic) hazard and provides a detailed discussion on how a baseline risk assessment should be conducted. The baseline risk assessment assumes no response action has taken place and unrestricted land use. This type of risk assessment is called a forward risk assessment (ITRC 2008). It starts with a concentration of a chemical in environmental media (exposure concentration), defines exposure assumptions, calculates dose, identifies toxicity values, and estimates a cancer risk or noncancer hazard,
- RAGS, Vol. I: Human Health Evaluation Manual, Part B (Development of Preliminary Remediation Goals), Interim Final (USEPA 1991c) – This document presents the methodologies and equations used to calculate risk-based preliminary remediation goals (PRGs) for individual chemicals in soil, groundwater, and ambient air. The contemporary terminology for PRG is “risk-based screening level” or even “screening level.” This type of risk assessment is called a backward risk assessment. It begins with the selection of a target cancer risk or noncancer hazard, identifies a potential chemical in environmental media, defines the exposure assumptions, calculates a factor representing dose, identifies toxicity values, and determines the concentration of a chemical in environmental media that is protective of human health based on the acceptable cancer risk or hazard quotient,
- Soil Screening Guidance (USEPA 1996b and 1996c) – This guidance document provides a tiered framework for developing risk-based, site-specific soil screening levels (SSLs) for residential use.
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA 2002h) – This guidance document is a companion to the preceding 1996 guidance. It primarily includes methods for developing non-residential SSLs and updated residential SSL equations considering combined exposures (ingestion and dermal absorption).
- RAGS, Vol. I: Human Health Evaluation Manual, Part E (Supplemental Guidance for Dermal Risk Assessment) (RAGS Part E; USEPA 2004b) – This document provides a number of updates regarding dermal risk assessment methodology. These include, but are not limited to, updated dermal exposure assessment equations for the water pathway (e.g., tapwater dermal contact), dermal absorption values for soil, and updated soil adherence values.
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (RAGS Part F; USEPA 2009a) – This document provides a

new approach to human health inhalation toxicity values. In the old approach from RAGS Part A, the inhalation exposure estimate was derived based on a chronic, daily air intake. The inhalation toxicity values were the inhalation cancer slope factor (CSF_i) and the inhalation reference dose (RfD_i). The new RAGS Part F methodology uses the USEPA IRIS toxicity values derived as concentrations (inhalation unit risk for cancer endpoints and reference concentrations for noncancer effects). In addition, the document indicates that performing simple route-to-route extrapolations may not be appropriate because the hazard can be misrepresented without consideration of toxicokinetic differences between the routes.

- Regional Screening Levels. User's Guide (USEPA 2024b) – This document presents the screening level equations, key assumptions, and frequent questions.

More background information on human health risk assessment and discussion of important issues is provided in the following: (1) Examination of Risk-Based Screening Values and Approaches of Selected States (ITRC 2005); (2) Use of Risk Assessment in Management of Contaminated Sites (ITRC 2008); and (3) Decision Making at Contaminated Sites – Issues and Options in Human Health Risk Assessment (ITRC 2015).

3.4.2. Exposure Scenarios: Land Use, Receptors, and Pathways

The default exposure scenarios for each of the three media (groundwater, soil, and indoor air) are shown in Table 3-1 and described in Sections 3.1, 3.2., and 3.3, respectively. Each scenario is developed based on one or more of these three general receptors considering land use (residential or commercial/industrial):

- Residents – Both adults and children are considered residents and are the primary receptors for a residential land use site. Children often exhibit different behaviors than adults, such as greater hand-to-mouth soil contact that can result in increased exposure to contaminated soils. 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 direct exposure ESLs for noncancer endpoints at sites with 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 workday as a full-time employee of a company operating onsite. 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 include intensive exposures to surface and subsurface soil during excavation, maintenance, and building construction projects. A construction worker is assumed to be exposed to contaminated soil during the workday for the duration of a single on-site construction project, lasting one year. This exposure scenario is based on dust generated by traffic (20 cars and 10 trucks per day that weigh 2 and 20 tons respectively) on unpaved roads and assumes 60 days is the mean number of days with 0.01 inches or more of annual precipitation. Even though work durations may be shorter than assumed in this scenario, chronic toxicity information was used when developing screening levels for the 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 routes: ingestion, inhalation, and dermal contact. Table 3-1 shows which exposure routes are used to calculate the risk-based screening levels for each media.

3.4.3. Screening Level Equations

The human health direct exposure ESLs for groundwater, soil, and indoor air are calculated using standard equations adopted directly from the USEPA RSLs (2018b). Lead is the one exception with soil direct exposure screening levels calculated using blood lead models (see Section 3.4.8).

3.4.4. Inputs: Target Cancer Risk and Noncancer Hazard

The target cancer risk is 1×10^{-6} and the target noncancer hazard index is unity (or 1), based on the California Code of Regulations, Title 22, Division 4.5, sections 68400.5, 69020-69022 (“Toxicity Criteria for Human Health Risk Assessment”), effective September 4, 2018.

3.4.5. Inputs: Physical/Chemical Constants

For some risk-based screening level calculations, physical or chemical constants are needed (e.g., diffusivity in air for the volatilization factor equation for soil inhalation exposure). The physical and chemical constants (e.g., Henry’s Law Constant) for the chemicals are primarily obtained from the USEPA RSLs

Chemical Specific Parameters table. Physical/chemical constant values are tabulated in ESL Workbook Table IP-1.

Inputs for some PFAS, not provided in the USEPA RSLs, were selected from the ITRC PFAS Guidance Table 4. Priority was given to values from studies with the following criteria, listed in order of preference:

- Experimentally determined,
- Field work,
- Experimental temperature was reported and close to room temperature (e.g., 20 degrees Celsius), and
- More recent work.

The following reference values were used for the specified PFAS inputs for Perfluoropentanoic acid (PFPeA), Perfluoroheptanoic acid (PFHpA), Perfluorononanoic acid (PFNA), and Perfluorohexane sulfonic acid (PFHxS):

- Vapor Pressure: PFPeA = Kwan, 2001; PFHpA = Steele et al., 2002b; PFHxS = Kim et al., 2015
- Solubility: PFPeA = Kim et al., 2015; PFHpA = Kaiser et al., 2006;
- Henry's Law: PFPeA = Kwan, 2001; PFHpA = 3M Company, 2021; PFNA = Arp, Niederer and Goss, 2006; PFHxS = Wang et al., 2011
- Organic Carbon Partitioning Coefficient ((K_{oc}): PFPeA and PFHpA = Weber et al., 2017.

3.4.6. Inputs: Toxicity Values

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

- Two for carcinogenic effects
 - Cancer Slope Factor (SF): Oral and dermal exposure
 - Inhalation Unit Risk (IUR): Inhalation exposure
- Two for noncarcinogenic effects
 - Oral Reference Dose (RfD): Oral and dermal exposure
 - Reference Concentration (RfC): inhalation exposure

ESL Excel Workbook Table IP-2 lists the toxicity values and sources for each chemical used to calculate the direct exposure ESLs. Since different laboratory experiments have determined the toxicity of each chemical, a single chemical may have several different toxicity values listed in different reference sources. In general, priority is given to toxicity values from peer-reviewed publications and

articles that are readily available to the public and transparent about the methods and assumptions used to develop the values. Table 3-3 presents the ESL hierarchy for selecting toxicity values. This hierarchy is consistent with the California Code of Regulations, Title 22, Division 4.5, sections 68400.5, 69020-69022 (California Toxics Rule), effective September 4, 2018.

Table 3-3: Human Health Toxicity Value Hierarchy

Tier	Source
1	OEHHA values required by the California Toxics Rule.
2	USEPA Integrated Risk Information System (IRIS), except where in conflict with the May 26, 2021 USEPA Memorandum, <i>Recommendations on the Use of Chronic or Subchronic Noncancer Values for Superfund Human Health Risk Assessments</i> .
3	The most protective values considering other available sources (e.g., USEPA Provisional Peer-Reviewed Toxicity Values (PPRTVs), ATSDR, etc.)

Route to Route Extrapolated Toxicity Values

Route to route extrapolation refers to the use or modification of toxicity values derived based on exposures administered via one exposure route to a different exposure route. The two common applications of this extrapolation are described below.

Oral to Dermal Route Extrapolation

Experiments to determine the toxicity values SF and RfD are designed to specifically test for oral exposure. Dermal toxicity values have not been developed. The oral 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 absorbed through the GI tract (GIABS) and not the total exposure amount. Therefore, oral toxicity values should first be adjusted to consider the total exposure amount, and then they can be further adjusted using the following factors to predict the amount of chemical (in either contaminated soil or water) that will be dermally absorbed:

- Contaminated Soil
 - **ABS_d**: 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_p:** Dermal permeability coefficient of a chemical in water through the outer skin layer (stratum corneum).
- **τ_{event}:** time a chemical in water takes to absorb through the skin (also 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 Excel Workbook Table IP-2. Further information on evaluating dermal exposures is presented in RAGS Part E.

Oral to Inhalation Route Extrapolation

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 (see RAGS Part F), so the ESLs typically do not use extrapolated inhalation toxicity values (also see the USEPA RSL Frequent Questions). Two exceptions are cis- and trans-1,2-dichloroethene which are prevalent at sites contaminated with chlorinated solvents (discussed below).

Toxicity Values for Cadmium

ESL Workbook 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 versus drinking water) (USEPA IRIS accessed January 19, 2016). The food RfD is used for soil.

Toxicity Values for Dichloroethene

Cis- and trans-1,2-dichloroethene are prevalent throughout our region at sites contaminated with chlorinated solvents. Both currently lack inhalation toxicity values from the sources in the toxicity value hierarchy. To provide a tool for evaluating inhalation exposures, an RfC was extrapolated for each compound from the corresponding RfD available in the USEPA IRIS. This route extrapolation is also performed in DTSC HHRA Note 3 (DTSC 2025b).

Toxicity Values for Petroleum Mixtures

ESLs are provided for six petroleum-related mixtures: five hydrocarbon mixtures (gasoline, Stoddard solvent, jet fuel, diesel, and motor oil) and petroleum hydrocarbon oxidation products (HOPs). Due to the complexities associated with chemical mixtures and particularly petroleum mixtures, the derivation of petroleum mixture health risk-based ESLs is presented in a separate chapter (Chapter 4).

Toxicity Values for Vanadium

The RfD for vanadium is based on the RfD used in the RSLs. Although there is no RfD specifically available for vanadium through IRIS, there is a PPRTV with an oral RfD (7.0E-04 mg/kg-day). However, confidence in the primary study that was used is low (USEPA 2009h). The RSLs employ an RfD based on the oral RfD toxicity value for vanadium pentoxide by factoring out the molecular weight of the oxide ion. Vanadium pentoxide has a molecular weight of 181.88. The two atoms of vanadium contribute 56% of the molecular weight. Vanadium pentoxide's oral RfD of 9.0E-03 mg/kg-day multiplied by 56% yields a vanadium oral RfD of 5.0E-03 mg/kg-day.

3.4.7. Inputs: Exposure Factors

In the context of the ESLs, exposure factors are factors related to receptor behavior and characteristics that help determine the receptor's exposure to a contaminant. These can include, among the many factors, the amount of particulates incidentally ingested during intrusive soil work, the surface area of skin exposed during such work considering assumptions about the clothing being worn, and the duration of the exposure. ESL Workbook Table IP-3 lists all exposure factors considered in the calculation of the ESLs. Sources for these values include the following:

- The Exposure Factors Handbook (USEPA 2011a)
- Update of Standard Default Exposure Factors (USEPA 2014a); and
- 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 (DTSC 2025a)

Table 3-4 lists specific exposure factors used for each media depending on the land use. The table also differentiates the exposure factors used for carcinogenic (C) versus noncarcinogenic (NC) risk calculations.

Table 3-4: Exposure Factor Selection

	Res Receptor Tapwater (from Ground-water) Exposure	Res Receptor Shallow Soil Exposure	Res Receptor Deep Soil Exposure	Res Receptor Indoor Air Exposure	Com/Ind Receptor Tapwater (from Ground-water) Exposure	Com/Ind Receptor Shallow Soil Exposure	Com/Ind Receptor Deep Soil Exposure	Com/Ind Receptor Indoor Air Exposure
Body Weight (BW)	NC: Child C: Age Adj.	NC: Child C: Age Adj.	Adult	--	--	Adult	Adult	--
Soil: Surface Area (SA) Exposed Skin	--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
Water: Surface Area (SA) Exposed Skin	NC: Child C: Age Adj.	--	--	--	--	--	--	--
All Media: Exposure Time (ET) per day	--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
Water Event Exposure Time (ET)	--	NC: Child C: Age Adj.	Const. Worker	--	--	Com/Ind Worker	Const. Worker	--
Soil to Skin Adherence Factor (AF)	NC: Child C: Age Adj.	--	--	--	--	--	--	--
Soil Ingestion Rate (IR)	--	Resident	Worker	Resident	--	Worker	Worker	Worker
Water Ingestion Rate (IR)	NC: Child C: Age Adj.	--	--	--	--	--	--	--
Exposure Frequency (EF)	Resident	Resident	Const. Worker	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.	--	Com/Ind Worker	Const. Worker	Com/Ind Worker

Relative Bioavailability

The USEPA RSL equations for the incidental ingestion of soil particles include a parameter for relative bioavailability (RBA). Absolute bioavailability is the portion of the ingested dose that is absorbed (USEPA 2007c). Relative bioavailability accounts for differences in the bioavailability of a contaminant between the medium of exposure (e.g., soil) and the tested medium from which the toxicity value was derived (e.g., the arsenic SF and RfD are based on drinking water studies).

The ESLs do not account for relative bioavailability with the exceptions of cadmium (described in section 3.4.6) and exposure to lead-contaminated soil (described in section 3.4.8), and ingestion of arsenic-contaminated soil. For arsenic, a relative bioavailability factor of 0.6 is applied for soil ingestion screening levels, as discussed in the USEPA RSL User's Guide. For other chemicals, relative bioavailability could be considered as part of a site-specific evaluation.

Mutagens

The ESLs follow USEPA guidance for adjusting the screening level calculations for carcinogens that cause irreversible damage to DNA through a mutagenic mode of action (USEPA 2005). Such carcinogens are termed "mutagens." Table 3-5 provides a list of mutagens considered in the ESLs. USEPA recommends that default adjustment factors (called age dependent adjustment factors or ADAFs) be used to account for increased potency of exposure to mutagens during early-life when children are still developing. The following generic ADAFs reflect the potential for early-life exposure (to any mutagen) to make a greater contribution to cancers appearing later in life:

- **10-fold ADAF** – Represents an approximation of the weighted geometric mean tumor incidence ratio from juvenile or adult exposures in the repeated dosing studies. This adjustment is applied for the first 2 years of life, when toxicokinetic and toxicodynamic differences between children and adults are greatest.
- **3-fold ADAF** – Represents an intermediate level of adjustment that is applied after 2 years of age through just below 16 years of age. This upper age limit represents middle adolescence following the period of rapid developmental changes in puberty and the conclusion of growth in body height. USEPA selected the 3-fold adjustment because it reflects a midpoint, i.e., approximately half the difference between 1 and 10 on a logarithmic scale ($10^{1/2}$), between the 10-fold adjustment for the first 2 years of life and no adjustment (i.e., 1-fold) for adult exposure.
- **1-fold ADAF** – No adjustment is applied for exposures after turning 16 years of age.

Table 3-5: Mutagens ¹

Chemical	CAS No.
Chromium VI	18540-29-9
1,2-Dibromo-3-chloropropane	96-12-8
Methylene Chloride	75-09-2
Trichloroethene ²	79-01-6
Vinyl Chloride ²	75-01-4
Benz[a]anthracene [PAH]	56-55-3
Benzo[b]fluoranthene [PAH]	205-99-2
Benzo[k]fluoranthene [PAH]	207-08-9
Benzo[a]pyrene [PAH]	50-32-8
Chrysene [PAH]	218-01-9
Dibenz[a,h]anthracene [PAH]	53-70-3
Indeno[1,2,3-cd]pyrene [PAH]	193-39-5

Table 3-5 Notes:

Note 1 – Carcinogens considered by USEPA to act through a mutagenic mode of action causing irreversible damage to DNA.

Note 2 – Mutagen has a chemical-specific risk equation

These generic ADAFs are used only when no chemical-specific data are available to directly assess cancer susceptibility from early-life exposure to a mutagen. The adjustment factors are derived from a weighted geometric mean of the data evaluated and will both over-estimate and under-estimate the potential potency for early-life exposure for chemicals with a mutagenic mode of action for carcinogenesis. For this reason, the guidance emphasizes that chemical-specific data should be used in preference to these default adjustment factors whenever such data are available.

Chemical-specific data are available for TCE and vinyl chloride indicating increased cancer susceptibility from early-life exposure to these mutagens. Chemical-specific intake equations are used for these chemicals, as discussed below.

- TCE – The TCE-specific equation in the RSLs employ combined mutagenic and carcinogenic equations that combine mutagenic concerns for the kidney endpoint along with the default ADAFs and then cancer concerns for the remaining endpoints. There is sufficient evidence to conclude that a mutagenic mode of action is operative for TCE-induced kidney tumors (USEPA 2011b). However, the data are inadequate for complete quantification of early-life susceptibility (i.e., development of

TCE-specific ADAFs) for all of TCE's carcinogenic endpoints (liver and non-Hodgkin lymphoma). The inhalation unit risk and oral slope factor estimates for TCE reflect lifetime cancer risk for all endpoints (kidney, liver, and) and all modes of action.

- Vinyl Chloride – The vinyl chloride-specific equation in the RSLs employs a two-fold adjustment factor for the estimated cancer risk to account for early life exposure (USEPA 2000a).

3.4.8. Exception: Soil Noncancer Screening Levels for Lead

The soil direct exposure noncancer screening levels for lead are calculated using blood lead models rather than the standard USEPA equations and inputs. Blood lead models are used since there is no consensus RfD for lead. (Note – OEHHA Public Health Goal for lead is used for the noncancer groundwater direct exposure ESL). The toxic endpoint used in the models represents the incremental increase in children's blood lead level corresponding to an IQ reduction of up to one point. This is the benchmark incremental change criterion for lead and the value is one microgram per deciliter (1 µg/dL; OEHHA 2007); in the models this is labeled the "blood lead level of concern." Use of this blood lead value complies with the California Toxicity Criteria regulation (see Table 3-3).

[LeadSpread 9.1](#) (DTSC 2024) includes the blood lead models employed to calculate the soil direct contact levels for lead. These blood lead models employ central tendency soil ingestion rates rather than reasonable maximum exposure ingestion rates used in the standard USEPA soil direct exposure equations. Specifically, LeadSpread 9.1 was used to calculate the 90th percentile estimate of the concentration in soil that would lead to a:

- 1 µg/dL increase in blood lead for a child resident assuming a soil ingestion rate of 80 milligrams per day (USEPA 2017b);
- 1.1 µg/dL increase in blood lead for pregnant adult worker (and subsequent 1 µg/dL increase for the fetus) assuming a soil ingestion rate of 30 milligrams per day (USEPA 2017b); and
- A pregnant adult construction worker with a soil ingestion rate of 100 milligrams per day, which reflects more intensive soil contact (USEPA 2016a).

3.5. Addressing Cumulative Risk and Hazard

Risks posed by direct exposure to multiple chemicals are considered as 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 noncarcinogenic health effect.

At sites where more than one contaminant is present, cumulative cancer risk and noncarcinogenic hazard should be evaluated. The following example is provided:

For cancer risk estimates, divide the site-specific concentration by the ESL designated as being based on a cancer endpoint. Sum the ratios for each chemical and multiply the total by 10^{-6} (equation 1).

Equation 1:

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

For noncancer hazard estimates, divide the site-specific concentration by the ESL designated as based on a noncancer endpoint 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 2).

Equation 2:

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

Further evaluation can include segregation of hazard indices by effect and mechanism of action when different endpoints and/or target organs are known for the specific chemicals of concern. Ideally, noncarcinogens are grouped according to their mechanism of action, but more commonly they are grouped according to target organ. If the hazard index exceeds 1 then it is appropriate to re-aggregate the hazard index by adding only the hazard quotients of chemicals that affect the same endpoint or target organ. This consists of identifying all of the major effects and target organs for each chemical and classifying 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.

Calculating cumulative risk and hazard across pathways should not be performed unless a well-developed CSM considering sources, release mechanisms, migration pathways, exposure routes, and receptors indicates such calculations are appropriate. In most cases, exposures via different pathways will not be simultaneous (e.g., outdoor versus indoor exposure pathways).

3.5.1. Workbook Tier 2 Risk and Hazard Calculator

The interactive portion of the Workbook (Tier 2) can be used to calculate cumulative risk and hazard for up to five chemicals (Table T2-2). The cumulative risk and hazard are calculated for three different exposure pathways:

- Soil Exposure – Based on soil data
- Tapwater Exposure – Based on groundwater data
- Vapor Intrusion (VI) Exposure:

- Current (VI exposure to current occupants of existing buildings) – Primarily based on indoor air data. In the absence of indoor air data, subslab/soil gas or groundwater data is used to predict indoor air concentrations. Subslab/soil gas data is prioritized over groundwater data for these calculations given that these data are a direct measure of chemical concentration in the vapor phase.
- Future (VI exposure to future occupants of existing or future buildings) – Primarily based on subslab/soil gas data since current indoor air data might not be representative of vapor intrusion conditions in new construction or existing buildings as they age over time. In the absence of subslab/soil gas data, groundwater data is used to predict future vapor intrusion risk and hazard.

3.6. Exceptions: Human Health Screening Levels for Chemical Mixtures

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).

3.6.1. Background: Assessing Health Risks from Chemical Mixtures

Chemical mixtures are combinations of two or more chemical substances regardless of source (USEPA 1986). They can include highly complex mixtures created from a single source or process (e.g., diesel exhaust), complex mixture of related compounds from a commercial process (e.g., gasoline, pesticide formulations), or unrelated compounds stored or disposed in the same area and released together. Although occasionally a mixture is well characterized, more often than not only some components (chemicals in the mixture) are known, exposure data are uncertain (e.g., analytical methods do not detect all the components), and toxicologic data on the known components are limited.

USEPA provides general guidelines for health risk assessment of chemical mixtures (USEPA 1986, 2000e) The two major approaches are whole mixture versus components. The preferred approach to health risk evaluation of chemical mixtures is to perform the assessment using health effects and exposure data on the whole mixture. The alternative approach based on a mixture's chemical components is only recommended for relatively simple, identified mixtures with a dozen or fewer chemicals. Key elements of these approaches are summarized below:

- 1) Whole Mixture – The evaluation options for whole mixtures (e.g., diesel) depend on data availability for the mixture of concern, a sufficiently similar

mixture, or a group of similar mixtures. “Sufficiently similar” refers to a mixture that is close in composition to the mixture of concern and has identical or at least indistinguishable toxicologic consequences from exposure. Such a determination of sufficient similarity should be accompanied by appropriate analysis (e.g., acceptability of the surrogate and uncertainty). Groups of similar mixtures are identified as having chemically-related structures that act by a similar mode of action.²

- 2) Components – The evaluation options for components depend on the toxicologic characteristics (act similarly or independently) and whether there is data on toxicologic interactions. While the use of the whole mixture approach inherently provides interactions information, this is not the case for the components approach. When adequate interactions information is lacking, dose addition or response addition models are recommended. Further information on dose addition and response addition is as follows:
 - a. Dose addition refers to chemical behavior as a concentration or dilution of every other chemical in the mixture (components act similarly). The biological basis for dose addition is the similarity of chemical components regarding toxicologic behavior, such as toxic mechanism, mode of action, or endpoint. There are three methods based on dose addition:
 - i. Relative potency factor (RPF) – The RPF method employs empirically-derived scaling factors based on the toxicity studies for the effect and exposure conditions of interest. An example is the carcinogenic PAHs (see Section 3.6.7).
 - ii. Toxicity equivalence factor (TEF) – The TEF method is a special case of the RPF method where extensive mechanistic information shows all the toxic effects of concern share a common mode action. An example of the TEF is dioxins and furans discussed in a later section. The scaling factors represent the toxicity of the component relative to the toxicity of one component, the index chemical, typically the best-studied chemical.
 - iii. Hazard index (HI) – The HI method requires only similarity in target organ, and this is routinely used to evaluate the cumulative hazard posed by noncarcinogens. Following these assumptions, the combined toxicity of the individual components can be estimated using the sum of their doses which are scaled for potency relative to another component

² Mode of action – Series of key events and processes starting with interaction of an agent with a cell, and proceeding through operational and anatomical changes causing disease formation (USEPA 2000e).

of the mixture for which adequate dose-response information is available.

- b. Response addition is recommended for mixture components that act on different systems or produce effects that do not influence each other, and thus, can be assumed to act independently. For example, response addition is appropriate for a two-chemical mixture where the body's response to the first chemical is the same regardless of the presence of the second chemical (components act independently). This approach is routinely applied to evaluate risk from exposure to carcinogens.

3.6.2. Chlordane

The ESLs for chlordane are based on the technical grade chlordane chemical mixture (CAS 57-74-9). Chlordane was used as a pesticide in the United States from 1948 to 1988 (ATSDR 1994). Chlordane is a mixture of related chemicals, of which about 10 are major components. Some of the major chemicals are trans-chlordane (gamma-chlordane), cis-chlordane (alpha-chlordane), β -chlordane, heptachlor, and trans-nonachlor. Further information on chlordane composition is provided in the RSL Frequent Questions (USEPA 2024b).

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 8081). The chlordane mixture (CAS 57-74-9) result should be used for comparison to the chlordane ESL. Note that the ESLs employ the CAS number for chlordane listed in the OEHHHA 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.

3.6.3. DDD, DDE, and DDT

The ESLs present separate screening levels for:

- dichlorodiphenyltrichloroethane (DDT),
- dichlorodiphenyldichloroethylene (DDE) and
- dichlorodiphenyldichloroethane (DDD)

DDT is a toxic pesticide that was once widely used to control pests 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 DDE and DD) 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.

3.6.4. Dioxins and Furans

The ESLs present a single entry to screen chlorinated dibenzo-p-dioxins (CDDs) and chlorinated dibenzofurans (CDFs): 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), the most toxic of these compounds. Other specific CDD and CDF molecules (dioxin-like compounds) have been assigned toxicity equivalence factors (TEFs) by the World Health Organization that scales their toxicity to that of 2,3,7,8-TCDD, which has a TEF of 1 (Table 3-6; 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.

Dioxins are molecules that contain a 6-membered ring with two double bonds and two oxygen atoms in the ring, while furans contain 5-membered ring structures with two double bonds and one oxygen atom in the ring. The dioxins and furans of greatest environmental concern are CDDs and 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 like pentachlorophenol, wood preservatives, and ethylene dichloride); and natural processes such as forest fires and volcanic eruptions/emissions (USEPA 2010).

The TEF methodology, a component mixture method, is used to evaluate human health risks posed by mixtures of dioxin-like compounds, using TCDD as the index chemical (USEPA 2010). Dioxin-like compounds are structurally and toxicologically related halogenated aromatic hydrocarbons. The TEFs are to be used for all effects mediated through aryl hydrocarbon receptor binding by the DLCs including cancer and noncancer effects.

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 2017) should be consulted.

Table 3-6: World Health Organization Toxic Equivalency Factors for Dioxins and Furans (2005)

Compound	TEF ¹
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
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

3.6.5. 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 (a degradation product). Laboratory analyses typically evaluate samples for the individual components rather than the mixture as a whole. For instance, USEPA Method 8081 includes Endosulfan I (alpha Endosulfan; CAS 959-98-8), Endosulfan II (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 to obtain the total endosulfan mixture concentration for comparison to the endosulfan ESLs.

3.6.6. Per- and Polyfluoroalkyl Substances (PFAS)

PFAS are a family of man-made substances consisting of thousands of chemicals that have been produced since the mid-1900s. PFAS are commonly found in stain resistant and waterproof textiles, food contact paper, non-stick cookware, certain class B firefighting foams, metal plating operations, and many other industrial and commercial products and processes (ITRC 2023). As of 2025, there are federal MCLs for a few individual PFAS and one PFAS mixture. Compliance with the PFAS mixture MCL can be determined using equation 3 where the non-cancer hazard quotient for each chemical in the mixture is added together (USEPA 2024a).

Equation 3:

$$\text{Hazard Index (HI)} = \frac{[\text{PFBS Conc}]}{2,000 \text{ ppt}} + \frac{[\text{PFHxS Conc}]}{10 \text{ ppt}} + \frac{[\text{PFNA Conc}]}{10 \text{ ppt}} + \frac{[\text{HFPO-DA Conc}]}{10 \text{ ppt}}$$

Specifically, the non-cancer hazard index (HI) should be less than or equal to 1 when site-specific concentrations (conc) of each of the following chemicals found in the PFAS mixture are put into the equation.

- Perfluorobutane sulfonic acid (PFBS)
- Perfluorohexane sulfonic acid (PFHxS)
- Perfluorohexane sulfonic acid (PFHxS)
- Hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as “GenX”)

For example, concentrations of 500 ppt for PFBS and 2.5 ppt for PFHxS, PFNA, and HFPO-DA in a PFAS mixture would equal an HI of 1 and would therefore be equal to the MCL.

3.6.7. Polychlorinated Biphenyls (PCBs)

The ESL Workbook includes a single entry for polychlorinated biphenyls (PCBs), where the toxicity value is based on 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.

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 1996e; ATSDR 2000). Commercial mixtures in the United States were marketed under the Aroclor trade name (Boehm 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.

Manufacturing of Aroclor in the United States stopped in 1977 in response to the passage of the Toxic Substances Control Act (TSCA).

Cancer toxicity studies of PCB mixtures indicate that Aroclor 1254 and Aroclor 1260 have the highest observed potencies (USEPA 1996e). The USEPA document *PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures* (USEPA 1996e) presents different oral cancer slope factors for different tiers of risk and persistence for certain PCB mixtures. Even though some PCBs demonstrate dioxin-like modes of action, USEPA (1996e) recommends this mixtures approach rather than the TEF approach because relatively few PCB congeners are dioxin-like.

3.6.8. Polycyclic Aromatic Hydrocarbons (PAHs)

The ESL Workbook includes screening levels for 13 polycyclic aromatic hydrocarbons (PAHs), listed as a group. These 13 PAHs are identified as priority pollutants by USEPA and are listed in Table 3-7.

In a screening-level risk assessment, the PAH compounds are evaluated using one of two approaches:

- Noncarcinogenic PAHs and naphthalene – These PAHs are evaluated by comparing the laboratory analytical results to their chemical-specific risk-based screening levels;
- Eight carcinogenic PAHs (listed in Table 3-7) – The laboratory analytical results can be evaluated using one of two approaches. The results can either be aggregated using the relative potency factor (RPF) methodology specific for cPAHs to calculate a benzo[a]pyrene (BaP) equivalents (BaP_{eq}) concentration. The USEPA RPFs are listed in Table 3-7. The BaP_{eq} concentration is then compared to the BaP risk-based screening levels. Alternatively, comparison to the individual risk-based screening levels is possible. The oral cancer slope factors for the other cPAHs are scaled to BaP using the appropriate RPF.

PAHs, also known as polynuclear aromatic hydrocarbons (PNAs), are a class of compounds consisting of two or more fused aromatic rings (Boehm 2006). The sources of PAHs are varied and commonly grouped as either 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, and there are potentially tens of thousands of possible PAH structures from the smallest (naphthalene C₁₀H₈) through the largest, coronene (C₂₄H₁₂).

The number of PAHs tested in environmental investigations varies depending on the application. For soil and groundwater investigations, typically, only the 16 USEPA Priority Pollutant PAHs are tested. These PAHs originally were

selected by USEPA in the 1970s because they: (1) had the most toxicological information; (2) were suspected to be the most harmful; and (3) had been detected at the highest concentrations (thus posing the highest exposure risk) at National Priority List sites (ATSDR 1995d). For sediment investigations, USEPA (2003a, 2009i) recommends analysis for 34 PAH compounds as an operational definition of total PAHs.

Table 3-7 – PAHs in the ESLs and Relative Potency Factors for the Carcinogenic PAHs

PAH Compound (CAS No.)	Number of Benzene Rings	Carcinogenic?	Relative Potency Factor (RPF) ¹
Acenaphthene (83-32-9)	3	No	--
Anthracene (120-12-7)	3	No	--
Benzo[a]anthracene (56-55-3)	4	Yes	0.1
Benzo[b]fluoranthene (205-99-2)	4	Yes	0.1
Benzo[k]fluoranthene (207-08-9)	4	Yes	0.01
Benzo[a]pyrene (50-32-8)	5	Yes	1.0 (index compound)
Chrysene (218-01-9)	4	Yes	0.001
Dibenz[a,h]anthracene (53-70-3)	5	Yes	1.0
Fluoranthene (206-44-0)	3	No	--
Fluorene (86-73-7)	2	No	--
Indeno[1,2,3-cd]pyrene (193-39-5)	5	Yes	0.1
Naphthalene (91-20-3)	2	Yes	-- ²
Pyrene (85-01-8)	4	No	--

Table 3-7 Notes:

Note 1 –The relative potency factor (RPF) values for seven carcinogenic PAHs (excluding naphthalene) are the same as currently used by the USEPA RSLs, which are sourced from USEPA (1993a).

Note 2 – 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 detected at a site. The DTSC Advisory, Use of the Northern and Southern California Polynuclear Aromatic Hydrocarbon (PAH) Studies in the Manufactured Gas Plant Site Cleanup Process (DTSC 2009), which is intended for manufactured gas plant (MGP) sites, could be consulted for information on how to evaluate whether PAH concentrations in site soil may reflect ambient conditions.

3.6.9. Petroleum Mixtures

ESLs are provided for six petroleum-related mixtures: five hydrocarbon mixtures (gasoline, Stoddard solvent, jet fuel, diesel, and motor oil) and petroleum hydrocarbon oxidation products (HOPs), which are transformation products produced during the biodegradation of petroleum hydrocarbons. The derivation of petroleum mixture health risk-based ESLs is presented in Chapter 4.

3.7. Site-Specific Evaluations

Options for site-specific human health risk evaluations can include site-specific (quantitative) risk assessments (Tier 3), development of alternative exposure scenarios (e.g., trespasser), the relatively minor modification of screening levels by use of non-default exposure factors or fate and transport considerations, or other options. Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

Typical site-specific issues that necessitate discussions with the overseeing regulatory agency include the following:

- Determination of exposure units/areas and hotspots;
- Soil exposure depths;
- Exposure scenario development including evaluation of hypothetical future use of the land (e.g., residential scenario for unrestricted use and need for a land use covenant) and water (e.g., beneficial use);
- Use of averaging;
- Background/ambient concentrations of chemicals (e.g., metals); and
- Use of the construction worker pathway to evaluate the need for engineering and health and safety controls rather than cleanup.

4. Methods: Petroleum Mixture Screening Levels

What is TPH?

Historically, the petroleum mixture ESLs in the ESL Workbook were named TPH (total petroleum hydrocarbons) ESLs after the bulk analytical methods (e.g., USEPA Method 8015B). The 2019 edition of the ESLs replaced “TPH” with “Petroleum” in the Workbook (e.g., petroleum-jet fuel). “TPH” is reserved for the analytical methods designed to measure the bulk of petroleum hydrocarbons from a release. Section 4.5 discusses how to use TPH analytical methods to estimate concentrations of the six petroleum mixtures for comparison against the corresponding ESLs. Section 4.6 discusses the use of TPH fractionation methods for site-specific evaluations.

This chapter supplements Chapter 3 by describing the derivation of health-risk based ESLs for six petroleum mixtures for groundwater, soil, and indoor air. The **six petroleum mixtures** are:

- **Five petroleum hydrocarbon mixtures:** gasoline, Stoddard solvent, jet fuel, diesel, and motor oil and
- **One nonhydrocarbon mixture:** Petroleum hydrocarbon oxidation products (HOPs), which are generated by the partial transformation of petroleum hydrocarbons due to biodegradation and/or photooxidation.

These petroleum mixtures are listed in the ESL Workbook tables from lowest to highest starting boiling point: gasoline, Stoddard solvent, jet fuel, diesel, HOPs, and motor oil. Use of the petroleum mixture ESLs as part of a health risk evaluation that includes individual petroleum compounds ensures a more complete accounting of all petroleum-related compounds present and their potential toxicities and limits the potential underestimation of risk.

ESLs for five hydrocarbon fractions (see section 4.2.3) can be found on the groundwater, soil, soil gas, and indoor air human health risk-based calculation tables in the ESL Workbook (GW-1, S-1, SG-1, and IA-1) for consideration during site-specific risk assessments.

In general, the ESLs are not used at sites that are subject to the Low-Threat Underground Storage Tank Closure Policy (LTCP; State Water Board 2012b). Specifically, the LTCP does not use the ESLs to screen contaminants at petroleum-contaminated sites. Instead, the LTCP provides closure levels for petroleum carcinogens and general (narrative) criteria. ESLs may be used at sites with “unique attributes” to screen for constituents not already addressed by the LTCP.

4.1. Background

Health-risk based levels for petroleum/TPH mixtures were first developed under Regional Water Board oversight for the Presidio of San Francisco (Montgomery Watson 1995). The ESLs, first developed in 2000, have always included human health-risk based petroleum/TPH mixtures screening levels. In May 2013, the basis of the petroleum/TPH mixture ESLs was changed to a fraction approach for common petroleum mixtures. Our approach is described in Sections 4.2 and 4.3.

The following subsections 4.1.1 – 4.1.3 present technical background and the rationale for the development of the petroleum mixture ESLs.

4.1.1. Petroleum Chemistry

Hydrocarbons are chemicals composed of hydrogen and carbon atoms (only) which make up the organic molecules that constitute most crude oil mass. Most crude oils are complex mixtures containing tens of thousands of compounds, including hydrocarbons and nonhydrocarbons. The nonhydrocarbons include heteroatoms (nitrogen, sulfur, or oxygen atoms; also, NSO) (Stout et al. 2002). Whereas most hydrocarbon compounds are nonpolar or moderately polar (water-soluble), NSO compounds are significantly more polar because they contain strongly electronegative heteroatoms. In addition, there are smaller amounts of organometallic compounds and inorganic salts in crude oils. Crude oils are refined to produce different petroleum fuels, solvents, and oils based on performance needs and specifications. Much of the NSO (polar) compound content in crude oils is removed in the refining process, but biofouling or biodegradation after the refining process may inadvertently generate some NSO compounds in the final products before they leave the refinery.

The hydrocarbons can be divided into two broad classes based on molecular structure and electron distribution:

- Aliphatic hydrocarbons are nonpolar because electrons are shared fairly evenly between carbon and hydrogen. In other words, there is no electron excess (partial negative charge) or deficit (partial positive charge) in parts of the molecule that would facilitate the interaction with polar molecules such as water. In contrast, water molecules have a substantial negative charge on the oxygen and partial positive charges on the hydrogen atoms. Aliphatics can further be divided into several subclasses 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 (C₆, straight-chain or linear alkane), cyclohexane (C₆, cyclic alkane), and propene (C₃, alkene).
- Aromatic hydrocarbons are moderately polar because they have sets of conjugated double bonds that lead to “clouds” of loosely attached “delocalized” electrons (partial negative charges) 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 contain aliphatic attachments. Examples include benzene (C₆, a single ring aromatic or monoaromatic hydrocarbon), toluene (C₇, also methylbenzene) and naphthalene (C₁₀), which has a fused, double ring and is the smallest polycyclic aromatic hydrocarbon (PAH).

Aliphatic and aromatic hydrocarbons differ in their physical, chemical, and biological properties. Table 4-1 illustrates some of these differences. For instance, n-hexane (C₆ aliphatic) is about 15-times more volatile than benzene (C₆ aromatic) based on vapor pressure. Benzene, however, is about 200-times more soluble in water than n-hexane, a trait directly attributable to the polarity of benzene. Thus, the chemical properties of petroleum mixtures will vary depending on the individual compounds present and their proportions within the mixture.

Table 4-1: Physical-Chemical Properties of Selected Hydrocarbons and Hydrocarbon Oxidation Products

Chemical	Molecular Formula	Boiling Point (°C) ¹	Vapor Pressure (mm Hg) ¹	Henry's Law Constant (atm-m ³ /mol) ¹	Solubility (µg/L) ¹
Benzene	C ₆ H ₆	80	9.5E+01	5.6E-03	2.0E+06
n-Hexane	C ₆ H ₁₄	69	1.5E+02	1.8E+00	9.5E+03
2-Hexanone ²	C ₆ H ₁₂ O ₁	128	1.4E+01	9.3E-05	7.7E+06
Hexanoic Acid ²	C ₆ H ₁₂ O ₂	205	4.4E-02	7.6E-07	5.8E+06
Phenanthrene	C ₁₄ H ₁₀	327	4.3E-05	1.5E-05	6.8E+02
1H2NA ³	C ₁₁ H ₈ O ₃	375	1.3E-07	1.5E-10	2.3E+06

Table 4-1 Notes:

- 1 – Physical-chemical parameter values from USEPA Estimation Programs Interface (EPI) Suite
- 2 – n-Hexane metabolites: 2-hexanone and hexanoic acid
- 3 – Phenanthrene metabolite: 1H2NA (1-hydroxy-2-naphthoic acid)

4.1.2. Environmental Fate of Released Petroleum

Although petroleum mixtures can accumulate partial degradation products during storage and transmission, their composition tends to change more rapidly after release to the environment due to a variety of weathering processes. These include physical, chemical, and/or biological processes. Typically, the more dominant processes are physical and biological but the extent to which they occur depends on the structure of a given hydrocarbon and other factors:

different hydrocarbons have different tendencies to volatilize, dissolve, or biodegrade, based on their structure, size, and polarity (ITRC 2018). Further information on weathering is presented in TPH Criteria Working Group (1997b) and ITRC (2018).

Physical Weathering

Physical weathering processes include volatilization, dissolution, and adsorption. These partitioning processes redistribute certain types of hydrocarbons from the released nonaqueous phase liquid (NAPL) into other phases. Mainly low carbon range aliphatics and some of the smaller aromatics migrate into vapor. Some hydrocarbons adsorb onto soil particles. Mainly low and medium carbon range aromatics and some low carbon range aliphatics migrate into water. The remaining NAPL is continually depleted as these components are lost. This redistribution or partitioning is the result of different chemicals within petroleum having different properties as well as mixture effects, such as their effective volatility and solubility, which is based on Raoult's Law (ITRC 2018), and environmental conditions such as temperature. These processes can result in vapor and water phase compositions significantly different from the original or remaining NAPL.

Biological Weathering (Biodegradation)

Hydrocarbons are highly reduced organic molecules with many hydrogen atoms providing an abundance of electrons for reactions with chemicals that can accept electrons. This explains their reaction with oxygen, which acts as terminal electron acceptor. After release to the environment, petroleum mixtures typically undergo (at least some) biodegradation in the presence of water. Unlike combustion, biodegradation is a stepwise process that produces many partial oxidation products that often have multiple functional groups. Microbial biodegradation is a process in which groups or "consortia" of microorganisms break down the hydrocarbons. There are many factors that influence the rate and extent of biodegradation of a given type of hydrocarbons, notably the composition of the released mixture, nature of the resident microbial population, availability of oxygen or other electron acceptors, and overall conditions for the growth of microbial populations such as nutrient availability (e.g., nitrogen, phosphorus), geochemistry, pH, and soil temperature. Biodegradation occurs more rapidly in aerobic conditions but can occur in anaerobic conditions, albeit more slowly (TPH Criteria Working Group 1998b).

Susceptibility to biodegradation varies substantially for the different types of hydrocarbons, especially under anaerobic conditions. In general, the greater branching of hydrocarbons correlates with increased resistance from microbial attack (Atlas 1981; Watson et al. 2002; Booth et al. 2007). For example, n-alkanes are considered the most susceptible to biodegradation whereas cycloalkanes are very resistant.

Biodegradation, in contrast to oxidation by combustion, is a complex, stepwise, and therefore comparatively slow, process. However, stepwise biodegradation can ultimately also lead to carbon dioxide and water as the final products (mineralization). Biodegradation of hydrocarbon molecules is slow because the stepwise process requires many different catalytic activities and even a single type of hydrocarbon may require more than one type of microorganism to accomplish mineralization. Numerous transformation products are generated during biodegradation of petroleum hydrocarbons (Atlas 1981; Bekins et al 2016; Zemo et al. 2017), and some of them can persist for a long time. These partial degradation products, also known as metabolites, are termed petroleum HOPs in the ESLs as discussed in Section 4.1.3.

Thus, while biodegradation can reduce overall hydrocarbon mass and alter the composition of the vapor, water, and NAPL phases, the process results in new compounds with different exposure patterns and potentially altered toxicity characteristics for human and/or ecological receptors. As long as significant hydrocarbon mass remains at the site and conditions allow for biodegradation, HOPs will be continually generated (Bekins et al. 2016).

4.1.3. Petroleum Hydrocarbon Oxidation Products (HOPs)

The ESLs use the general term “petroleum hydrocarbon oxidation products” or “HOPs” for complex mixtures in the environment consisting of partially oxidized hydrocarbons generated during petroleum biodegradation. This term also includes photooxidation products of petroleum, which can be indistinguishable from microbially generated metabolites.

Other terms have been used to describe these petroleum breakdown products include polar compounds (in reference to their increased solubility), petroleum metabolites (in reference to their origin via biodegradation), petroleum degradates (terminology used in the 2016 ESL User’s Guide), or oxyhydrocarbons (term used sometimes in the literature).

The presence of one or more strongly electronegative oxygen atoms within the molecule increases the polarity of HOPs relative to the parent hydrocarbons and therefore their water solubility. This increased polarity facilitates dissolution into water at much higher concentrations compared to the parent hydrocarbons. For instance, concentrations as high as 40,000 µg/L bulk extractable TPH (TPH-diesel and TPH-motor oil) are not uncommon in groundwater near areas with significant petroleum contamination mass in soil (i.e., source or release areas). Significant concentrations of HOPs likely indicate areas of anaerobic biodegradation, which can allow the buildup of these compounds because of slower anaerobic biodegradation rates (Jobelius et al. 2011).

Table 4-1 presents the physical-chemical properties of three HOPs and parent hydrocarbons, hexanoic acid and 2-hexanone, which are metabolites of n-hexane, and 1H2NA, a metabolite of phenanthrene. As indicated, the HOPs can be significantly more soluble than the parent hydrocarbon. Moreover, the addition

of oxygen into the structure can result in a significantly higher boiling point. For instance, n-hexane boils in the gasoline range, but one of its metabolites (hexanoic acid) boils in the diesel range, which has implications for interpreting bulk extractable TPH analytical results (e.g., misinterpreting the detection of metabolites from gasoline biodegradation as being diesel range petroleum hydrocarbons). Most HOPs are relatively nonvolatile and not expected to partition into the vapor phase to a significant extent due to both their low volatility and high solubility.

Further information regarding these compounds and mixtures is provided in the technical memorandum Petroleum Metabolites: Literature Review and Assessment Framework (Regional Water Board 2016) and in TPH Risk Evaluation at Petroleum Contaminated Sites (ITRC 2018).

4.2. Approach to Evaluating Human Health Risks Posed by Petroleum Releases

A comprehensive approach is recommended for evaluating human health risks posed by petroleum releases. The preferred approach evaluates multiple components, including individual chemicals, bulk petroleum hydrocarbons, and transformation products (HOPs), discussed herein.

4.2.1. Risk Assessment Challenges for Petroleum Releases

The assessment of human health or ecological risks associated with petroleum releases is challenging because:

- Petroleum fuels and oils are complex mixtures, ranging from hundreds to thousands of compounds in some gasolines to tens of thousands of compounds in crude oils. The composition of the released mixture(s) is a key determinant of potential risks.
- The composition of petroleum mixtures changes in the environment over time due to unequal loss of components through weathering processes (e.g., volatilization, dissolution, adsorption, biodegradation), and the rates of these processes vary based on site-specific characteristics. Moreover, biodegradation produces partial transformation products (HOPs) with different properties from hydrocarbons (e.g., more soluble).
- It is impractical to analyze for hundreds or thousands of individual compounds.
- Even if it were practical to analyze for thousands of compounds, there are insufficient toxicity criteria for a compound-specific evaluation approach.

While a compound-specific evaluation approach is possible for the few toxicologically well-characterized petroleum hydrocarbons, there have been multiple efforts to devise an acceptable way to account for the risks posed by the bulk of hydrocarbon mixtures released into the environment. Various “TPH”

methods were originally developed for quantitation and delineation purposes and some have been adapted for bulk risk evaluation.

4.2.2. Individual Chemicals

Three groups of individual chemicals can be found in oils or petroleum products, or are associated with petroleum releases:

1. Individual Hydrocarbons – Some chemicals in petroleum have been adequately characterized toxicologically, and regulatory toxicity values are developed for either their carcinogenic or noncarcinogenic effects (or both). For example, the TPH Criteria Working Group (1997a) identified approximately 250 individual hydrocarbon chemicals in various petroleum fuels and crude oils that have been studied. Of these 250 compounds, 95 had toxicity data but only 25 had sufficient data to develop toxicity criteria. The individual chemicals in petroleum that are known carcinogens have been termed “indicator compounds” (e.g., TPH Criteria Working Group 1997a). These include benzene, ethylbenzene, naphthalene, and the seven carcinogenic PAHs (benzo[a]anthracene; benzo[b]fluoranthene; benzo[k]fluoranthene; benzo[a]pyrene; chrysene; dibenz[a,h]anthracene; and indeno[1,2,3,-cd]pyrene). These chemicals only make up a small percentage of the total composition of petroleum fuels/oils.

The most commonly analyzed individual hydrocarbons are benzene, toluene, ethylbenzene, xylenes and the 16 USEPA priority pollutant PAHs (listed in Table 3-7) The monoaromatics benzene, toluene, ethylbenzene and the three xylene isomers are commonly referred to as “BTEX.”

2. Performance Additives or Blending Agents – Nonhydrocarbon compounds have been added to various fuels for improving combustion performance, usually related to air quality. These agents have varied over time, seasons, regions, etc. For example, gasoline additives have included alkylated lead compounds (e.g., tetraethyl lead), lead scavengers (e.g., 1,2-dibromoethane also ethylene dibromide), oxygenates (methyl tertiary butyl ether or MTBE, tertiary butyl alcohol or TBA), and ethanol. Crude oils and other residual fuels (e.g., bunker fuel) may be blended for transportation or marketability purposes (e.g., pressure distillate added to crude oil to reduce viscosity and enable pipeline transport).
3. Other Chemicals Collocated with Petroleum Releases – Some chemicals have been documented to co-occur with releases of particular petroleum products or are known to be mobilized as a result of petroleum releases. These include:
 - All hydrocarbons: Arsenic – A potential secondary effect or consequence of the natural attenuation of hydrocarbons coupled with iron reduction is a release of naturally occurring arsenic to groundwater (Cozzarelli et al. 2015). This phenomenon can occur where there is petroleum or other readily biodegradable organic carbon (e.g.,

naturally occurring or present in landfills). Arsenic plume migration can be limited by the presence of downgradient oxygenated conditions.

- Stoddard solvent: Tetrachloroethene (PCE) – Older or long-operating dry cleaners used the petroleum-based Stoddard solvent before the majority of the industry switched to chlorinated solvents. Consequently, Stoddard solvent releases can be collocated with releases of chlorinated VOCs (e.g., PCE, TCE). Also, PCE was added to many dry-cleaning soaps used with petroleum solvents as a bacterial inhibitor, and TCE was 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 stored and released to the environment, such as former automotive service stations, constituents of potential concern can include chlorinated solvents (e.g., PCE, TCE), select heavy metals (the wear metals cadmium, chromium, nickel, lead and zinc), and PCBs.

Table 4-2 lists potential individual compounds to consider for inclusion in a petroleum risk evaluation.

Table 4-2: Potential Individual Chemicals of Concern for Different Petroleum Mixtures³

Petroleum Fuel or Oil	Benzene, Toluene, Ethylbenzene, Xylenes, and Naphthalene (BTEXN)	Polycyclic Aromatic Hydrocarbons (PAHs) ¹	Additives ²	Other
Gasoline	Yes	--	Yes	Arsenic (As)
Stoddard solvent	--	--	--	As, Chlorinated Volatile Organic Compounds (CVOCs)
Jet Fuel	Yes	--	--	As
Diesel Fuel	Yes	--	--	As
Motor Oil	--	Yes	--	As
Bunker Fuel	--	Yes	--	As
Crude Oil	Yes	Yes	Yes	As
Waste Oil or Unknown	Yes	Yes	Yes	Wear metals ³ , CVOCs, Polychlorinated biphenyls, As

Table 4-2 Notes:

- 1 – PAHs are typically 16 priority pollutant PAHs, including naphthalene. Other PAHs are addressed via the petroleum hydrocarbon mixture ESLs
- 2 – Additives – This is a general listing and is not intended to suggest that all of these compounds are present in a single fuel or release:
 - Unleaded gasolines: oxygenates (methyl tertiary butyl ether, ethyl tertiary butyl ether, tertiary butyl alcohol, diisopropyl ether, tertiary amyl butyl ether), methanol, ethanol.
 - Leaded gasolines: alkylated lead (tetraethyl lead), lead scavengers (1,2-dibromoethane, 1,2-dichloroethane).
- 3 – Wear metals (cadmium, chromium, nickel, lead and zinc).

Limitations of Single Chemical Petroleum Risk Approaches

Reliance solely on a few individual chemicals for assessing human health risks and hazards from petroleum releases likely underestimates the total magnitude of adverse effects (HDOH 2012; Brewer et al. 2013; ITRC 2018). This is particularly true of sites where the chemicals being evaluated represent a small proportion of the mixture mass, were never part of the original released mixture(s) or have subsequently been depleted during weathering.

³ See Section 4.2.2 for further discussion.

For example, a study performed by the Hawai'i Department of Health (HDOH 2012 and Brewer et al. 2013) found "The vapor intrusion risk (in general terms) posed by the non-specific, TPH component of petroleum vapors can override the risk posed by individual compounds such as benzene due to its overwhelming dominance of vapor phase compounds." This finding is consistent with data collected at a number of petroleum hydrocarbon release sites in the San Francisco Bay Region, including former and existing automobile service stations, where staff has observed high concentrations of TPH-gasoline and low concentrations of benzene in soil gas samples. Therefore, when conducting risk evaluated at petroleum release sites, TPH data should be collected in the appropriate media (groundwater, soil, soil gas, and indoor air) in addition to the typically sampled individual chemicals (e.g., BTEX). The only meaningful way to identify the risk driver is to evaluate both and determine how the risks/hazards differ.

4.2.3. Petroleum Hydrocarbon Fractions

Petroleum fractions are groups of hydrocarbons with similar molecular structures that are similar size and have similar fate characteristics in the environment (e.g., volatility, solubility, susceptibility to biodegradation) and/or are considered to have similar toxicity. Typically, petroleum fractions are divided by molecular structure into aliphatics and aromatics, and then each molecular structure type is subdivided into relevant carbon number ranges.

The fraction approach is currently the best approach for evaluating potential risks posed by petroleum mixtures that lack regulatory toxicity criteria for most individual components. The approach involves assigning representative toxicity surrogates to each fraction (MADEP 1994b; King et al. 1996; Washington DOE 1997; TPH Criteria Working Group 1999; ATSDR 1999; CCME 2008; USEPA 2009c; Atlantic PIRI 2012; Redman et al. 2014). This approach addresses the risk assessment challenges posed by petroleum releases (Section 4.2.1). The use of a "petroleum fraction approach" with TPH fractionation analytical methods (e.g., Texas Method 1006) is the considered the best for assessing risk because the approach provides hydrocarbon composition aligned with toxicity values and physical/chemical parameters (Zemo 2016; ITRC 2018). The approach can be applied to any petroleum mixture found in the environment, and it accounts for weathering though it does not necessarily account for changes in bioavailability and toxicity of fractions that may result from weathering processes (TPH Criteria Working Group 1999). The use of the TPH fractionation analytical methods is described in Section 4.6.2.

Surrogate chemicals or mixtures for which toxicity values can be obtained are selected to represent the toxicity of these fractions following an approach consistent with USEPA mixture risk assessment methods where dose-addition or

response-addition is assumed (USEPA 1986, 2000e; see also Section 3.6.1). The order of preference for surrogate selection is presented below:

1. Mixtures of similar composition
2. Representative component in the fraction and mixture – Options include using the most toxic chemical component if the toxicity varies considerably or the most abundant chemical, if a component represents a large proportion of the fraction. In some cases, compounds with more potent toxicities can be assessed separately while the remaining fraction mass is assessed using values for a surrogate mixture (e.g., 2-methylnaphthalene and C9 aromatic mixtures for the medium aromatic fraction).
3. Components Method – For fractions where the individual compounds are well characterized and with known toxicity values, the components are individually assessed (e.g., benzene, toluene, ethylbenzene, xylenes for the low aromatic fraction).

Table 4-3 presents the petroleum fractions used in the ESLs, which are consistent with MADEP (2003), USEPA (2009c), and DTSC (2021).

Table 4-3: ESL Petroleum Hydrocarbon Fractions, Partitioning Characteristics, and Toxicity Surrogates

Carbon (C) Range	Aliphatic Fractions	Aromatic Fractions
Low	Fraction 1: C5-C8 (EC5-EC8) (Soluble & Volatile) RfD surrogate: n-Hexane (USEPA 2009e) RfC surrogate: n-Hexane (USEPA IRIS 2005)	Fraction 4: C6-C8 (EC6-EC<9) (Soluble & Volatile) No surrogates – direct measurement and evaluation
Medium	Fraction 2: C9-C18 (EC>8-EC16) (Non-Soluble & Volatile) RfD and RfC surrogates: Mid-range aliphatic hydrocarbon streams (USEPA 2009e)	Fraction 5: C9-C16 (EC9-EC<22) (Soluble & Volatile) RfD and RfC surrogates: C9 aromatic mixtures (MADEP 2003)
High	Fraction 3: C19-C32 (EC16-EC35) (Non-Soluble & Non-Volatile) RfD Surrogate: White mineral oil (USEPA 2009g)	Fraction 6: C17-C32 (EC22-EC35) (Non-Soluble & Non-Volatile) RfD Surrogate: Fluoranthene (USEPA 2012e)

Table 4-3 Notes:

EC – Equivalent carbon. The TPH Criteria Working Group (1998b) introduced the equivalent carbon (EC) number for calibrating the retention time or x-axis of the chromatogram, which represents boiling points, to read molecule size. Because the boiling point is also somewhat affected by chemical structure, the EC numbers are normalized to the boiling point of n-alkanes. Because of their polarity, aromatics boil at slightly higher temperatures than aliphatics with the same numbers of carbons. For example, using this scale, n-hexane (C6 normal or n-alkane) is EC6 where benzene (C6 aromatic) is about EC6.5.

RfD – Oral reference dose

RfC – Inhalation reference concentration

4.2.4. Petroleum Hydrocarbon Oxidation Products (HOPs)

Petroleum hydrocarbon oxidation products (HOPs) are the partial transformation compounds of petroleum hydrocarbons generated through biodegradation (thus the commonly used name “metabolites”) as well as photooxidation. Increasingly, these polar transformation compounds and the mixtures in which they are found are being recognized as toxicologically relevant for a complete evaluation of both potential human health and ecological risks (Carney et al. 2008; Melbye et al. 2009; Bekins et al. 2016; Regional Water Board 2016b; Chibwe et al. 2015; Schrlau et al. 2017; Podgorski et al. 2018; McGuire et al. 2018).

Since the 2013 edition of the ESLs, HOPs (previously called polar compounds, metabolites or degradates) have been specifically included in the evaluation of petroleum sites to more comprehensively evaluate the potential adverse effects of hydrocarbon releases on human and ecological receptors. As explained in the 2013 and 2016 ESL editions, omitting the optional silica gel cleanup step from extractable TPH analyses permits the evaluation of both the parent hydrocarbons and portion of the HOPs together. In this 2025 edition of the ESLs, separate ESLs are developed for HOPs as described in Section 4.4. Laboratory analytical methods to measure HOPs are described in Section 4.5.3.

4.2.5. Selecting Chemicals of Potential Concern for Petroleum Releases

As discussed in preceding sections, a comprehensive evaluation of petroleum releases should include testing and evaluation for known or suspected individual chemicals, petroleum hydrocarbon mixtures and HOPs. These three categories comprise the generic chemicals of potential concern (COPCs) for petroleum sites. Table 4-4 shows how the three categories apply to various petroleum hydrocarbon mixtures.

Table 4-4: Chemicals of Potential Concern for Petroleum Risk Evaluations

Released Petroleum Hydrocarbon Mixture	Individual Chemicals (Table 4-2)	Petroleum Hydrocarbon Mixture	Petroleum HOPs
Gasoline	Yes	Yes	Yes
Stoddard solvent	Yes	Yes	Yes
Jet fuel	Yes	Yes	Yes
Diesel	Yes	Yes	Yes
Motor Oil	Yes	Yes	Yes
Bunker fuel	Yes	*	Yes
Crude Oil	Yes	*	Yes
Unknown or Waste Oil	Yes	*	Yes

Table 4-4 Note:

* TPH fingerprint or TPH fractionation methods should be employed first to gain insight into the carbon chain range and composition. See Sections 4.3.5 or 4.6.2 for further information.

4.3. Calculation of ESLs for Petroleum Hydrocarbon Mixtures

Noncancer ESLs for groundwater, soil, soil gas, and indoor air are developed for five petroleum hydrocarbon mixtures: gasoline, Stoddard solvent, jet fuel, diesel, and motor oil (cancer risk is only evaluated for individual petroleum-related chemicals with regulatory cancer toxicity criteria such as ethylbenzene). These petroleum hydrocarbon mixture ESLs are intended for comparison against laboratory analytical results from the commonly used bulk TPH laboratory analyses (e.g., USEPA Method 8015B). This enables a screening-level risk evaluation. Further discussion on the use and limitations of the bulk TPH analytical method (e.g., use of silica gel cleanup, determination of background naturally occurring organic compounds, basic review of chromatograms) is provided in Section 4.5.

ESLs for the petroleum hydrocarbon mixtures are calculated using:

- Petroleum fractions (Section 4.2.3) and properties (toxicity values and constants);
- Proportions of the fractions expected in each medium:
 - Soil – unweathered fuels/oil composition
 - Groundwater – proportions of the unweathered fuel/oil predicted to partition into water
 - Indoor Air and Soil Gas – proportions of the unweathered fuel/oil predicted to partition into vapor and attenuation during transport from the subsurface to indoor air
- USEPA RSL equations for calculating screening levels.

4.3.1. Petroleum Fraction Compositions for Each Petroleum Mixture Based on Medium

The proportion of each chemical fraction in a fresh petroleum mixture (e.g., diesel) is used to develop medium-specific toxicity values in ESL Workbook Table IP-9, which is discussed in Section 4.3.3. After a release, petroleum hydrocarbon mixtures in the environment can be found at a site as either NAPL (soil), vapors (soil gas, crawl space air, indoor air, outdoor air), water (groundwater, surface water). The following subsections present the compositions of the fractions in the various petroleum hydrocarbon mixtures and partitioned components.

Soil and NAPL Composition

Petroleum contamination in soil is indicative that NAPL has passed through the affected soil zone leaving some residual. For the petroleum mixture soil ESLs,

the assumption is that the soil contamination is from NAPL. The composition of the released NAPL is used for developing soil-specific toxicity values for each mixture, as indicated in ESL Workbook Table IP-9.

Water and Vapor Compositions

The partitioning of hydrocarbons from fuels and oils is briefly described in Section 4.1.2 (Physical Weathering). The partitioning behavior of each fraction in water (solubility) and air (volatility) is taken into consideration as follows:

- **Water** – 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; ITRC 2018). The soluble fractions include Fraction 1 (low aliphatics), Fraction 4 (low aromatics), and Fraction 5 (medium aromatics). The fractionally-soluble petroleum mixtures for which ESLs are derived include Stoddard solvent, jet fuel, and diesel.
- **Air** – The volatile constituents of petroleum hydrocarbon mixtures are the C_8 and smaller aliphatics and aromatics, with only minor amounts of C_9 - C_{12} aliphatics and aromatics (Hartman 1998; Brewer et al. 2013; ITRC 2018). The volatile fractions include Fraction 1 (low aliphatics), Fraction 2 (medium aliphatics), Fraction 4 (low aromatics), and Fraction 5 (medium aromatics). The semi-volatile petroleum mixtures for which ESLs are derived include Stoddard solvent, jet fuel, and diesel.

4.3.2. Petroleum Fraction Toxicity and Physical-Chemical Values

ESL Workbook Table IP-2 and Table IP-9 include noncancer ingestion and inhalation toxicity values for the six petroleum fractions described in Section 4.2.3.

ESL Workbook Table IP-9 also includes the Henry's Law Constant for each fraction. Other physical-chemical property values (e.g., solubility) not based on the fractions but on the whole mixture are provided in ESL Workbook Table IP-1 with sources of values listed in the notes.

4.3.3. Petroleum Mixture Toxicity Values and Henry's Law Constants

Calculating ESLs using the standard USEPA equations requires the input of a single value for toxicity and Henry's Law Constant (where needed). The mixture- and medium-specific toxicity value for each mixture (e.g., diesel for soil RfD) is developed using the fraction composition with one exception. For gasoline, Fraction 4 (low carbon range aromatic) is not used because the BTEX compounds are individually evaluated by analyzing for each compound. The

proportions for the other five fractions for gasoline are normalized so the BTEX noncancer hazard is not counted twice.

The ESLs calculate weighted-average toxicity values and Henry's Law Constants using a modified harmonic mean equation (Equation 4, from *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures*; USEPA 2000e).

Equation 4:

$$\text{Weighted Average Value} = \frac{1}{\left(\frac{\% \text{ F1}}{\text{TV1}} + \frac{\% \text{ F2}}{\text{TV2}} + \dots + \frac{\% \text{ F6}}{\text{TV6}} \right)}$$

Where:

%FX = Percentage of Fraction X

TVX = Toxicity value for fraction X

Each petroleum mixture's medium-specific toxicity value (NAPL/soil RfD, water-soluble RfD, and air-volatile RfC; as shown in ESL Workbook Table IP-9) is weighted based on the relative proportion of each petroleum fraction in a given medium. This means that for NAPL/soil RfDs, the fraction weighting is based on weight percent composition in the bulk fuel mixture (NAPL). The water-soluble RfD is calculated only for the soluble (petroleum gasoline) and fractionally-soluble petroleum mixtures (petroleum Stoddard solvent, jet and diesel) based on the weight percent composition of the soluble fractions in the mixture. The air-volatile RfC is calculated only for the volatile (petroleum gasoline) and fractionally-volatile petroleum mixtures (petroleum Stoddard solvent, jet, and diesel) based on the weight percent composition of the volatile fractions in the mixture. Weighted-average Henry's Law Constant values are calculated in a similar fashion as the toxicity values.

4.3.4. Screening Levels for Other Mixtures

ESLs for other petroleum mixtures can be developed using the fraction approach provided there is information on the fraction composition (weighting) and partitioning (solubility and volatility).

4.3.5. Summary

The petroleum mixture screening levels provide a reasonably quantitative way to account for the toxic effects of the large number of petroleum chemicals in mixtures (i.e., chemicals not specifically studied for their toxicological effects) where exact quantification is not feasible. This option is recommended for

screening-level evaluations because these screening levels can be compared against bulk TPH analytical method data (see Section 4.5). The primary limitation of this option is the screening levels only represent the compositions of example fresh fuels/oils. Different compositions of fuels/oils may result in different human health risks or hazards. In addition, the greater the weathering, the more the composition will deviate from fresh fuels/oils, which may also affect the risk estimate. A more site-specific approach would be to analyze samples using TPH fractionation analytical methods to better characterize the mixture composition. The fractionation results could be compared to the petroleum fraction ESLs (e.g., Petroleum Fraction 1 Low Aliphatic), which are presented in media-specific Screening Level Calculation Tables in the Workbook. This is discussed in Section 4.6.2.

4.4. Calculation of ESLs for Petroleum Fractions

The ESLs include human health risk-based screening levels for five aliphatic and aromatic petroleum fractions (e.g., Petroleum Fraction 1 – Low Aliphatic) to support more site-specific evaluations of composition and risk (discussed further in Section 4.7). As previously explained, the low range aromatics are individually analyzed so a screening level is not included for the Petroleum Fraction 4 – Low Aromatics. The low range aromatics consist of C6 to C8 hydrocarbons (e.g., benzene, toluene, ethylbenzene).

The petroleum fraction ESLs are calculated in the same manner as individual chemicals for soil, groundwater, soil gas, and indoor air, which are described in Chapter 3 and q using the values from ESL Workbook Tables IP-1 (Physical and Chemical Properties) and IP-2 (Toxicity Values).

4.5. Calculation of Groundwater ESLs for Petroleum HOPs

Since the 2013 edition of the ESLs, Regional Water Board staff has recommended groundwater samples be analyzed using the extractable bulk TPH method both with and without SGC to enable consideration of the full effects of petroleum releases (both the hydrocarbons and polar transformation products, HOPs). In effect, this assigned HOPs the same toxicity values (both RfD and RfC) as hydrocarbons. Based on newer information, there is consensus that HOPs are not significantly volatile (ITRC 2018), particularly for the compounds with boiling points corresponding to C10 to C28 n-alkanes. Therefore, with inhalation exposure excluded, the tapwater ESLs for HOPs are less stringent than when they were grouped with the hydrocarbons. Also, the HOPs tapwater ESL is greater than the typical range of background natural organic compounds (NOCs) concentrations, reducing the likelihood of exceedances due to the potential presence of naturally-occurring polar compounds unrelated to petroleum releases.

At this time, soil direct exposure ESLs for Petroleum HOPs have not been developed, although the rationale and approach would be similar to that for

groundwater. In most of the cases where SGC has been used with extractable TPH analysis for soil samples, the results do not appear to be significantly different from extractable TPH without SGC. This may be due to a number of issues such as sorption of polar compounds to silica in the soil matrix, incomplete cleanup due to insufficient mass of silica gel, etc. The development of soil direct exposure ESLs for Petroleum HOPs is not a priority at this time but may be revisited in the future.

4.5.1. Petroleum HOPs Toxicity and Physical-Chemical Values

The water RfD is selected based on the Petroleum Fraction 5 surrogates, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, 1,2,3-trimethylbenzene (1E-02 mg/kg-day). This is about the same boiling point range where most of the HOPs compounds are observed in the bulk extractable TPH analysis. No RfC is selected considering that most of these compounds are relatively nonvolatile (ITRC 2018). The rationale for applying the same RfD for hydrocarbons to that of the partial transformation products is:

- The toxic effects of many chemicals are mediated by their metabolites – For example, Pinto et al. (2016) found that metabolites from many types of chemicals have greater biological (estrogenic) effect than parent compounds. Another example is the metabolism of tetrachloroethene where the carcinogenicity increases as it breaks down to trichloroethene and vinyl chloride. Hydrocarbons also form toxic metabolites—examples include hexane and metabolite 2,5-hexanedione (IRIS) and anthracene and metabolite 9,10-anthraquinone (Zielinska-Park et al. 2004), which is also a photooxidation product (Mallakin et al. 1999). Moreover, toxicity testing of metabolite mixtures generated from microbial breakdown of phenanthrene, a relatively low toxicity PAH, found the metabolite mixtures to be more toxic than phenanthrene (Schrlau et al. 2017).
- Results from toxicity testing of a naphthenic acid mixture suggest similar toxicity as the selected value (2.0E-02 mg/kg-day) – A dose-response study of naphthenic acids results in an RfD of 6.0E-02 mg/kg-day (see Regional Water Board 2016b), which is a factor of three difference from the selected value. Naphthenic acids are a complex mixture of carboxylic acids associated with petroleum. They occur in crude oil due to incomplete catagenesis or biodegradation in the environment.
- Recent studies of bioremediation effectiveness have found toxicity increased due to transformation products – Chibwe et al. (2015) employed targeted testing and effects-directed analysis (EDA)⁴ to assess the

⁴ Effects-directed analysis (EDA) recognizes that environmental samples may contain thousands of organic chemicals and only a fraction can be analyzed by targeted chemical analysis (Brack 2003). Moreover, regulatory toxicity criteria are not available for the majority of these compounds. EDA utilizes biological effect to narrow down the long list of potential analytes and direct chemical analysis to

effectiveness of the bioremediation PAH-contaminated soils. Although the concentrations of the original 88 target PAH compounds were reduced after bioremediation, toxicity increased after bioremediation (metabolism). The researchers concluded that focusing solely on a short list of target compounds and not considering transformation products does not accurately capture the toxic effects of the partially degraded mixtures generated in environmental media.

Since the RfDs for parent hydrocarbon mixtures are based on limited numbers of compounds this approach is considered a reasonable approximation for metabolite-containing mixtures (HOPs).

The physical-chemical constants for HOPs are selected using 1-hydroxy-2-naphthoic acid (1H2NA; CAS 86-48-6) as a surrogate and values from the USEPA Estimation Parameter Interface Suite. 1H2NA is a known petroleum metabolite of phenanthrene (Kiyohara et al. 1994; Moody et al. 2001; Gao et al. 2013) and was detected in groundwater samples containing petroleum metabolites as reported in Zemo et al. 2017.

Although, in principle, this same approach is reasonable for soil, the generation of soil ESLs for HOPs is a low priority at this time.

4.5.2. Summary

Our approach for toxicity value assignment is consistent with USEPA guidance on chemical mixture risk assessment because of the implicit biological relationship between the parent compounds and their metabolites. As better scientific information becomes available (e.g., direct toxicity testing of HOPs mixtures), the RfD may be adjusted.

4.6. Laboratory Analytical Methods for Use with the Petroleum Mixture ESLs

The petroleum mixture ESLs are intended to be compared to sample concentrations measured with bulk TPH analytical methods (e.g., USEPA Method 8015C). This section presents background on the method and provides details for use of the bulk TPH methods and interpretation of the results to measure concentrations of petroleum hydrocarbon mixtures, petroleum HOPs, and determine NOCs levels.

those more likely to significantly contribute to effects. The approach includes biological testing and chemical fractionation in a sequential procedure. Elements of EDA are similar to USEPA Toxicity Identification Evaluations (USEPA 1991a; 1993b; 1993c).

4.6.1. Background: Bulk TPH Laboratory Method (USEPA Method 8015B)

Total Petroleum Hydrocarbons (TPH) refers to a non-specific laboratory analysis that provides a measure of the concentrations of all chemicals with carbon-hydrogen bonds (e.g., hydrocarbons, organic acids, chlorinated aliphatic hydrocarbons, etc.), present in a sample over a particular boiling point range (e.g., USEPA Method 8015C). The analysis does not measure only petroleum hydrocarbons, nor does it identify individual compounds. The TPH analysis will measure a mixture of many chemicals, thus use of the term “bulk.” The TPH analysis can be used, with adjustments described herein, to:

- measure petroleum hydrocarbon concentrations (Section 4.5.2),
- estimate HOPs concentrations (Section 4.5.3), and
- determine background NOCs levels that can interfere with the bulk TPH analysis if the intent is to quantify hydrocarbons-only or HOPs (Section 4.5.4).

The term “bulk” also is used to distinguish between “whole product” methods (e.g., TPH-gasoline or gasoline range organics, GRO) versus TPH “fractionation” analytical methods that separate aliphatic and aromatic hydrocarbons and then measure their concentrations over smaller carbon ranges (e.g., EC10-EC12). Use of TPH fractionation analytical methods for site-specific risk evaluations as an alternative to using petroleum mixture ESLs is discussed in Section 4.6.

Bulk TPH Method Description

Laboratory analysis for TPH in soil or groundwater samples is commonly applied in general accordance with USEPA Method 8015C *Nonhalogenated Organics by Gas Chromatography* (USEPA 2007a).

The key steps of TPH analysis are sample preparation/extraction, separation, and detection/quantification. Each of these steps has the potential for unequal recovery of sample constituents. Following extraction from an environmental sample with a nonpolar solvent (e.g., hexane or methylene chloride also known as dichloromethane), the sample is introduced into the GC where it is vaporized without decomposition and separated as the compounds travel through a single separation column. The column separates the compounds based on boiling point, with the more volatile compounds exiting the separation column first, followed by the less volatile compounds. After exiting, the compounds are analyzed in the attached detector. A flame ionization detector (FID) ionizes (burns) the carbon-containing molecules thus generating a signal proportional to the mass present in the sample. The results are plotted on a graph (chromatogram) with either boiling point or carbon number on the x axis and intensity of the response on the y axis. The concentration is determined by comparing the area under the sample peak/curve within a selected carbon range against the response from an unweathered fuel or oil standard.

The preparation methods differ for the more volatile mixtures (e.g. gasoline) and less volatile mixtures (e.g., diesel and motor oil):

- TPH-gasoline (gasoline range organics or GRO) – For gasoline-range compounds, TPH-gasoline is analyzed after a preparation step (e.g., purge and trap, which is: USEPA Method 5030B for water samples, USEPA 1996h; and 5035 for soil samples; USEPA 1996i).
- TPH-diesel and TPH-motor oil (diesel range organics or DRO and motor oil range organics or MORO, respectively) – For diesel- and motor oil-range compounds, the TPH-diesel and TPH-motor oil analyses are usually performed after liquid-liquid extraction using dichloromethane, and then the extract is evaporated to concentrate the extract before analysis (USEPA Method 3510C, USEPA 1996f). The term “extractable TPH” refers to bulk TPH analytical methods employing an extraction step.

Further information is presented in the ITRC (2018) Fact Sheet A.2 *TPH Analytical Methods*.

Bulk TPH Method Limitations and Interferences

Bulk TPH analysis can measure many different organic chemicals. Interferences (nontarget compounds) vary depending on the sampling/measurement objective. For example, if the objective is to measure only diesel-range hydrocarbons in groundwater for comparison to the petroleum-diesel groundwater ESL, then the measurement of HOPs or NOCs is an interference. On the other hand, if the objective is to measure HOPs concentrations in groundwater for comparison to the petroleum-HOPs groundwater ESL, then the measurement of hydrocarbons or NOCs is an interference.

Use of Silica Gel Cleanup (SGC) to Remove Nonhydrocarbons

This section describes silica gel and its uses.

- What is Silica Gel? – Combining silicon dioxide (SiO_2) with $2 \text{ H}_2\text{O}$ produces silica gel, a solid with many $-\text{OH}$ groups that can interact with polar chemicals. The more polar a chemical, the tighter it binds to $\text{Si}(\text{OH})_4$.
- Uses for Silica Gel – Silica gel is often used as a drying agent to remove water. Chemists use it to separate more polar from less polar compounds. It has two principal applications in TPH analysis:
- Removing polar compounds from petroleum mixtures that were extracted with a nonpolar solvent. This is called “silica gel cleanup” (SGC). It removes most of the polar natural organic compounds and HOPs and leaves most of the hydrocarbons.
- Separating aromatic from aliphatic hydrocarbons as part of fractionation. As described in the MADEP extractable phase hydrocarbon procedure,

the procedure requires great care so that the aromatics do not end up in the wrong fraction (MADEP 2004b).

- Use of Silica Gel Cleanup with the Bulk Extractable TPH Analysis – The use of a column silica gel cleanup (SGC; USEPA Method 3630C; USEPA 1996g) is an optional procedure that can be added to the bulk extractable TPH analysis, for additional cost. Using SGC will remove polar compounds including HOPs and NOCs. Extractable TPH results after SGC will only measure hydrocarbons. SGC cannot be used for volatile hydrocarbon analysis because the procedure would volatilize the target hydrocarbons. Further information is presented in the ITRC (2018) Fact Sheet A.5 Silica Gel Cleanup.

Data Interpretation: Basic TPH Chromatogram Review

Due to the non-specific nature of the bulk TPH analysis, bulk TPH analytical data are best interpreted considering the CSM and available lines of evidence. Lines of evidence that are most useful include knowledge of the type of fuel/oil released, location of the sample relative to the release area (e.g., downgradient), bulk extractable TPH analysis both with and without SGC, understanding of partitioning (hydrocarbons, HOPs), age of release and expected degree of weathering, and chromatogram shape/pattern. For instance, the chromatographic pattern and spatial relationship to the release (source) area can be used to help distinguish the source of polar nonhydrocarbons (HOPs and NOCs) in a sample (Zemo 2016).

The purpose of a basic chromatogram review is to confirm that the compounds being detected are the intended target compounds rather than interferences. Chromatograms, even from bulk TPH analysis, can provide information on fuel/oil type, presence of nonhydrocarbons (e.g., HOPs, NOCs, other chemicals like solvents), whether the material is dissolved or not, and degree and type of weathering (ITRC 2018). Chromatograms should be obtained and reviewed during the investigation phases of a project. Similarly, chromatogram review may be warranted prior to key decisions or when results are not consistent with the CSM/previous testing.

Scaled chromatograms of the samples, standards, and blanks should be obtained from the laboratory and included in technical reports. The chromatograms' x axis (retention time or elution time of indicated n-alkanes) should be the same scale for all chromatograms to facilitate comparison and interpretation. The y axes will necessarily vary for each sample/standard/blank depending on the intensity of the detector response (i.e., relative concentration). Chromatogram review is performed by comparing the sample to the standard chromatogram as illustrated in Figure 4-1. The compounds detected in the groundwater sample were determined to be petroleum HOPs only based on the following lines of evidence: (1) the detected compounds are polar because, after SGC, the results were non-detect; (2) the chromatogram pattern is typical of petroleum HOPs (examples of HOPs chromatograms are included in Lundegard

and Sweeney 2004, Lang et al. 2009, and Zemo 2016, described as weathered petroleum or polar compounds); (3) spatial relation to the petroleum release area (downgradient); and (4) non-detect background concentrations of NOCs.

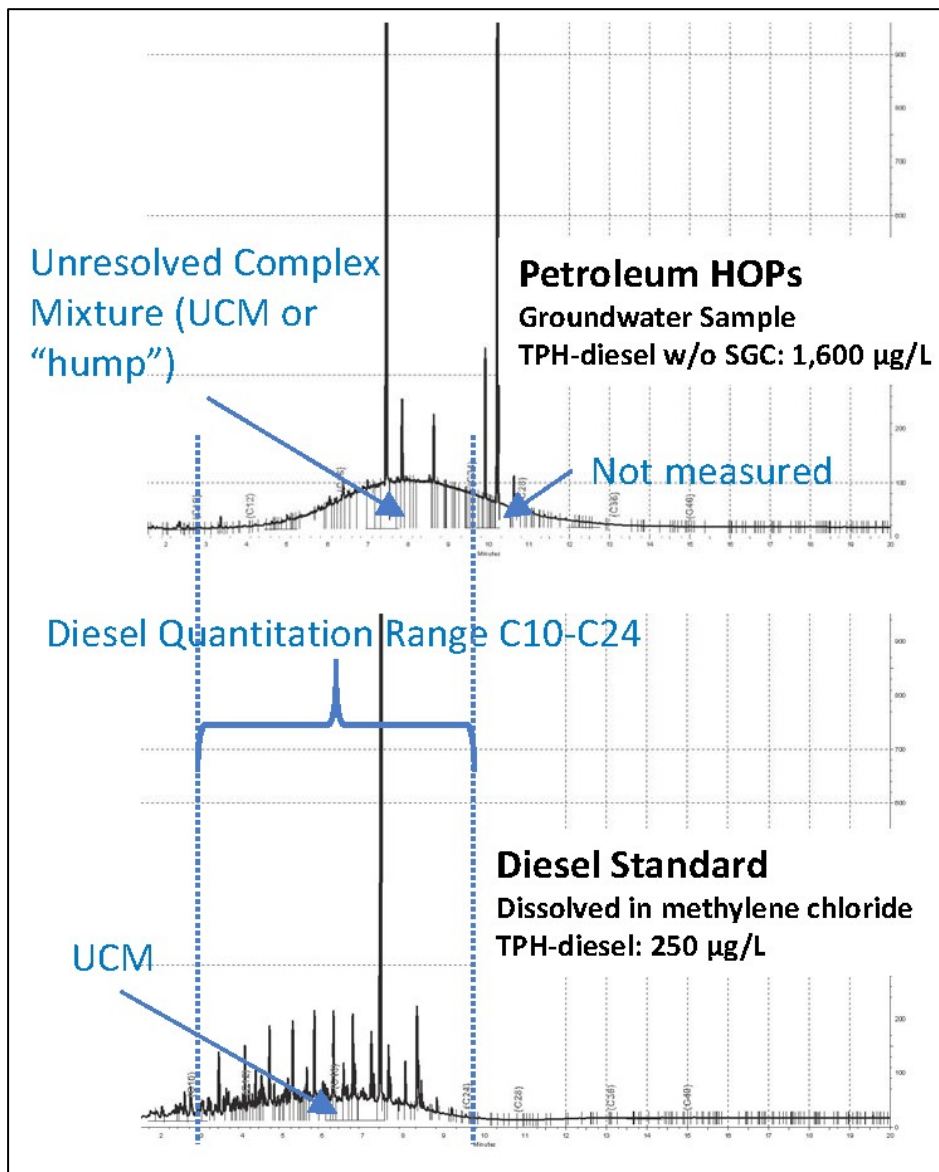


Figure 4-1: Example of Basic Petroleum Chromatogram Review for HOPs.

This figure illustrates the comparison of a chromatogram for a groundwater sample containing petroleum HOPs against a chromatogram for a diesel fuel standard. Note the HOPs UCM is shifted to the right (higher apparent EC number) compared to diesel standard. The tall peaks are lab standards used for quality control purposes. The background groundwater sample contains 27 µg/L NOCs (TPH-diesel without SGC).

Example chromatograms of petroleum and non-petroleum containing products or samples are provided in several articles or guidance documents:

- Fresh and weathered petroleum in soil and groundwater – Zemo et al. 1995; Zemo 2016; ITRC 2018 (Appendix A5 – Chromatograms: A Wealth of Information).
- HOPs – Lundegard and Sweeney 2004; Lang et al. 2009; Zemo 2016; and Figure 4-1.
- NOCs – Regional Water Board staff has observed these compounds in chromatograms primarily as single peaks (Figure 4-2).

When reviewing chromatograms from water samples, it is important to bear in mind the fuel/oil standards are dissolved in organic solvents and therefore the chromatographic pattern should not resemble the standard due to differential partitioning of individual compounds from a mixture into water. Figure 5a of Lang et al. (2009) provides a chromatogram illustrating single peaks indicative of dissolved hydrocarbons from fresh diesel.

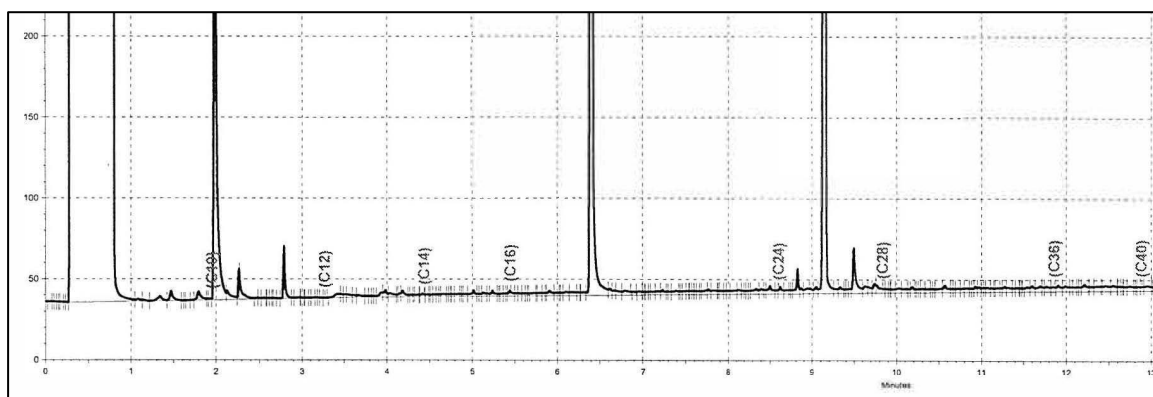


Figure 4-2: Example NOCs Chromatogram.

This figure presents an extractable TPH chromatogram (about C10 to C40) showing a pattern of random, single peaks typical for natural organic compounds (NOCs) unrelated to a petroleum release. The detected TPH-diesel without SGC concentration is 220 µg/L. The tall peaks are lab standards used for quality control purposes.

4.6.2. Measuring Hydrocarbons using the Bulk TPH Analytical Method

Petroleum hydrocarbon mixtures can be detected and quantified using the bulk TPH analyses. The TPH-gasoline analysis is performed without SGC because the process would volatilize hydrocarbons in the sample (ITRC 2018). The extractable range hydrocarbon mixtures (e.g., petroleum-Stoddard solvent, jet, diesel, and motor oil) is performed after SGC because the intent is to measure only hydrocarbons, so the nonhydrocarbons are considered non-target compounds and can be removed.

4.6.3. Measuring HOPs using the Bulk Extractable TPH Method

HOPs can be detected and reasonably quantified by the bulk extractable TPH analysis to some extent, but not if SGC is used. The bulk extractable TPH analysis appears to be the best method currently available for estimating HOPs concentrations because the chromatogram pattern can be used to confirm the types of compounds measured. Laboratory analytical reports should include scaled chromatograms from samples, standards, and blanks. For the best identification and quantitation of HOPs using available methods, Regional Water Board staff recommends the use of a bulk extractable TPH analysis quantified against a diesel standard over the carbon range C10 to C28. A less preferred alternative is to analyze for both TPH-diesel and TPH-motor oil (non-overlapping ranges) and add the results. The estimated HOPs concentration is determined via the equation 5 below and illustrated on Figure 4-3.

Equation 5:

$$[\text{HOPs}] = [\text{Total Organics}] - [\text{PHCs}] - [\text{NOCs}]$$

Where:

[] = Concentration

[Total Organics] = Plume sample measured with TPH-diesel C10-28 without SGC

[PHCs] = The same plume sample analyzed using TPH-diesel C10-28 with SGC measuring petroleum hydrocarbons (PHCs)

[NOCs] = Sample from an unimpacted (background) area with similar vegetative and hydrogeologic characteristics as plume sample (see Section 4.5.4) measured with TPH-diesel C10-28 without SGC

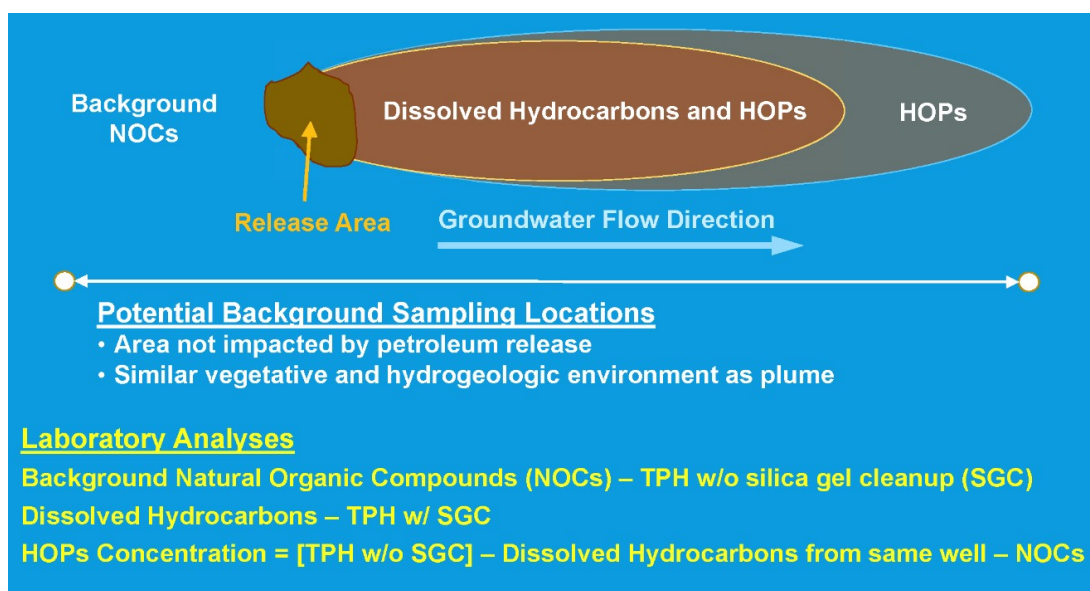


Figure 4-3: Conceptual Plume Map Showing How to Estimate Petroleum HOPs Concentrations

HOPs detected in groundwater samples using the bulk extractable TPH analysis typically manifest in the chromatogram as an unresolved complex mixture (UCM or hump) in the C15 to C28 range (Lundegard and Sweeney 2004; Lang et al. 2009; Zemo 2016; see also Figure 4-1). Due to the presence of oxygen in the structure, HOPs have higher apparent EC numbers than expected (see Section 4.1.3). Regional Water Board staff have frequently observed the UCM straddling the diesel and motor oil ranges for groundwater samples analyzed without SGC for TPH-diesel over C10-C24 and TPH-motor oil over C24-C36 (Figure 4-1). At older petroleum release sites, it is not uncommon to observe a polar UCM starting at about C12 to 14 (based on n-alkane boiling points) and extending into the low C30s, with the UCM apex between about C17 to C21.

Method Limitations

Bulk TPH analytical methods have shortcomings for detecting polar compounds such as HOPs. In a study of two crude oil spill sites, the USGS found that the extracted diesel-range organic compounds represent one-third to one-half of the total concentration of HOPs found in groundwater (Bekins et al. 2016). The USGS determined the main reasons for the difference resulted from the following three aspects:

- Polar compounds do not extract well in nonpolar organic solvents like methylene chloride or hexane (TPH Criteria Working Group 1998a), the solvents typically used for EPA Method 3510C (USEPA 1996f).
- Many polar compounds are not amenable to gas chromatography (GC); they do not readily pass through the GC column without derivatization (TPH Criteria Working Group 1998a), thus, important compounds of interest may be retained in the column.

- The narrow boiling point range of the TPH-diesel method (e.g., C10 to C24) means that some HOPs will not be measured. Some HOPs are above or below this range. As noted above, UCMs often extend beyond C24.

These limitations could result in a situation where HOPs are present but are not detected (Figure 4-4). Consequently, the extractable TPH analysis underestimates HOPs concentrations and better methods are needed.

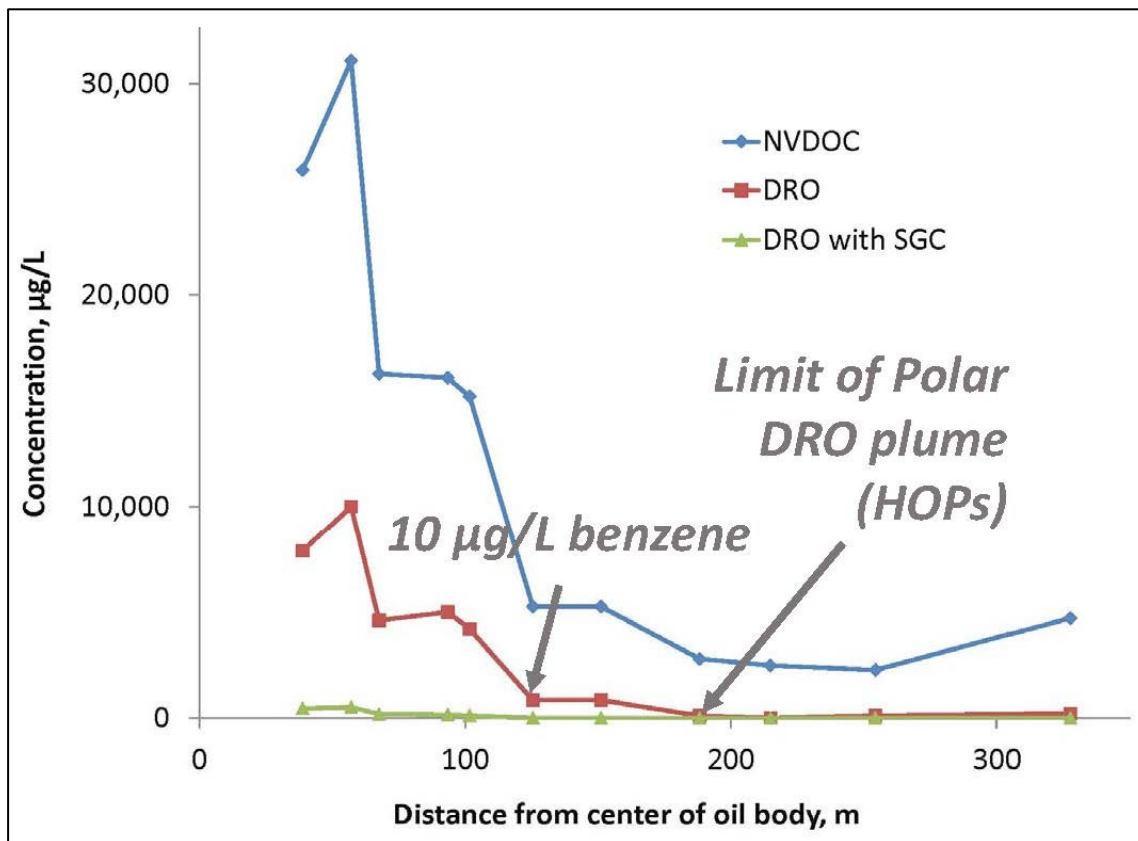


Figure 4-4: Illustration of the Key Shortcoming with the TPH-diesel (also “diesel-range organics” or “DRO”) Analysis for Measuring Petroleum HOPs Concentrations.

Figure 4-4 illustrates that a sample near the downgradient portion of a plume may be non-detect for TPH-diesel when petroleum HOPs are actually present. NVDOC is non-volatile dissolved organic carbon, an analytical method used by the US Geological Survey at the light crude oil release research site in Bemidji Minnesota. Upgradient background NOCs levels were non-detect for DRO without SGC and 1,500 µg/L NVDOC. Source: Bekins and Cozzarelli (2017).

4.6.4. Determining Background Levels of Natural Organic Compounds (NOCs)

In addition to HOPs, there are naturally-occurring organic compounds resembling hydrocarbons with polar functional groups, which we refer to as natural organic compounds (NOCs). These polar compounds are considered interferences to bulk TPH analyses where the intent is to measure only HOPs concentrations (Section 4.5.3).

Determination of background concentrations of NOCs can be performed by collecting samples in an area of the site with no known petroleum release and with a similar hydrogeologic and vegetation setting. While an upgradient location may be deemed ideal, cross-gradient or downgradient locations are equally acceptable if the hydrogeologic and vegetative setting is similar. Based on staff experience, concentrations of NOCs using bulk extractable TPH analysis typically are in low 100's of µg/L range, rarely exceeding 300 µg/L. Consultation with the overseeing regulatory agency is recommended before implementing a background testing program.

Near petroleum release areas (i.e., source areas), the concentrations of HOPs typically far exceed the concentrations of NOCs (Zemo and Foote 2003; Zemo et al. 2013), and the potential for significant interference from NOCs is negligible. However, during an initial investigation, when interpreting whether extractable TPH concentrations reflect a petroleum release, NOCs, or both, estimating the relative contribution of NOCs can be important.

The NOCs can manifest in the chromatogram as single peaks that do not resemble a UCM, and so chromatogram review can be a useful tool.

4.6.5. Recommended Bulk TPH Analyses for Soil and Groundwater Samples

Table 4-5 lists the recommended bulk TPH analyses, carbon range, and whether SGC use is appropriate for each petroleum mixture in the ESLs. Table 4-5 also provides recommendations for bunker fuel, crude oil, and unknown or waste oil mixtures. Bulk TPH analyses for wide carbon ranges (e.g., bunker fuel and crude oil) are not recommended as discussed in Section 4.3.5; instead TPH fractionation methods are recommended. Much less preferred would be to analyze for bulk TPHg, TPHd, and TPHmo. Similarly, for unknown fuels/oils or waste oil, a TPH fractionation approach is preferred, with the less preferred alternative being analysis for bulk TPHg, TPHd, and TPHmo.

Table 4-5 – Bulk TPH Laboratory Analysis for Soil and Groundwater Samples

Target Petroleum Mixture	Recommended Bulk TPH Analytical Methods ¹ (USEPA Method 8015B)	Use of Silica Gel Cleanup (USEPA Method 3630)
Gasoline	TPHg (C5-C12)	Cannot use ²
Stoddard solvent	TPHss (C7-C12)	Cannot use ²
Jet Fuel	TPHj (C9-C16)	Can use
Diesel	TPHd (C10-C24)	Can use
HOPs	TPHd (C10-C28) ³	Cannot use
Motor Oil	TPHmo (C24-C36)	Can use
Bunker Fuel (C12-C40), Crude Oil (C5-C44), Unknown, Waste Oil	Note 4	Note 4

Table 4-5 Notes:

- 1** – Compositions may vary from these ranges.
- 2** – SGC cannot be used. The procedure will volatilize the target hydrocarbons.
- 3** – HOPs typically elute at boiling points between the boiling points of C10 to C28 n-alkanes. The concentration of HOPs is not directly measured but is estimated via subtraction as described in Section 4.5.3.
- 4** – Bulk TPH analyses for wide carbon range fuels or oils are not recommended because they provide limited information for evaluating risk. Instead, TPH fractionation analyses are recommended. Further information is presented in Sections 4.3.5 and 4.2.6.

4.6.6. Recommendations for Vapor Analyses

At sites where significant contaminant mass remains close or directly beneath buildings and/or where other unique conditions prevent adequate aerobic biodegradation (e.g., geochemical conditions, preferential pathways, building susceptibility, significant pressure gradients), petroleum vapors can drive risk (Brewer et al. 2013). Laboratory analysis of vapor samples (indoor air and soil gas) for petroleum vapors can be performed in accordance with the USEPA Methods 8260, TO-3, TO-15, or TO-17.

Brewer et al. (2013) recommends petroleum vapor analysis as follows:

- Low and medium carbon range hydrocarbons – Petroleum vapors quantified from C5 to C12 against a gasoline standard in accordance with USEPA Method TO-15 or other acceptable method.
- Medium carbon range hydrocarbons – Petroleum vapors quantified from C12 to C18 against a diesel standard in accordance with USEPA Method TO-17 (sorber tube method) or other acceptable method.

The analysis of petroleum vapors most often will be performed for the evaluation of the vapor intrusion pathway. Including the analysis for fixed gases (oxygen, carbon dioxide, and methane) is recommended to enable an adequate evaluation for petroleum vapor biodegradation and vapor intrusion (see Chapter 5). ASTM Method D-1946 is one method commonly employed for fixed gases analysis.

4.7. Site-Specific Human Health Risk Evaluations for Petroleum Mixtures

This chapter supplements the site-specific risk evaluations (Section 3.7) by addressing specifics of risk evaluation at petroleum release sites, which involve complex mixtures that change in space and time after release to the environment. In general, the options for site-specific risk evaluations discussed in Section 3.7 also apply to petroleum risk evaluations.

Section 4.2 identified the three components associated with petroleum releases: individual chemicals, petroleum fractions, and HOPs. Screening-level risk evaluations can be employed for all three components using the ESLs (Section 4.6.1). Tier 2 or Tier 3 risk assessments can be performed for the individual chemicals and the petroleum fractions (Section 4.6.2).

Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted, before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

4.7.1. Screening Level Evaluations Using the Petroleum Mixture ESLs

Section 4.2 identified the three components associated with petroleum releases: individual chemicals, petroleum fractions, and HOPs. Screening-level risk evaluations can be employed for all three components using the ESLs. For the petroleum mixtures, screening level evaluations rely on comparison of bulk TPH data to the appropriate petroleum mixture ESLs.

4.7.2. Site-Specific Human Health Risk Evaluations of Petroleum Hydrocarbons: TPH Fractionation Methods

Tier 2 or Tier 3 risk assessments can be performed for the individual chemicals and the petroleum fractions at sites where petroleum mixtures were released. Such site-specific evaluations for petroleum hydrocarbon mixtures can include development of site-specific screening levels or site-specific risk assessments provided adequate testing is performed to estimate the petroleum fraction compositions throughout a site. This necessitates the use of TPH fractionation analytical methods to supplement bulk TPH analyses used for characterizing the distribution of the petroleum contamination.

TPH fractionation methods separate hydrocarbons into aliphatics and aromatics and measure concentrations for specific carbon number ranges (e.g., Petroleum Fraction 3 – High Aliphatic). Separation into aliphatics and aromatics is often accomplished by silica gel solid-phase extraction/fractionation processes.⁵ Fractionation methods differ for soil and water samples versus vapor samples. The advantages of TPH fractionation methods are: (1) the method overcomes the need to know the type of fuel/oil released; and (2) accurate measurement of the hydrocarbon types and concentrations over narrow carbon ranges addresses composition changes due to weathering.

Figure 4-5 illustrates the carbon ranges for bulk TPH and TPH fractionation analytical methods. Each color represents a single laboratory analytical method. The bulk TPH methods are illustrated for the ESL petroleum hydrocarbon mixtures and other mixtures (crude oil and bunker fuel). TPH fractionation methods recommended in Zemo (2016) also are illustrated. As shown, significantly greater composition information is provided by a TPH fractionation method (e.g., Texas Method 1006) as contrasted with the bulk TPH-crude oil analysis.

Three state agencies have developed TPH fractionation methods:

- MADEP – Volatile Petroleum Hydrocarbons (VPH) and Extractable Petroleum Hydrocarbons (EPH) for soil and water (MADEP 2004a and 2004b). Air Phase Hydrocarbons (APH) MADEP (2009).
- TCEQ – Method 1006 (TCEQ 2000).
- Washington Department of Ecology (WDOE) – VPH and EPH for soil and water (WDOE 1997)

The TCEQ and WDOE TPH fractionation methods are generally recommended for soil and groundwater samples. The MADEP Air Phase Hydrocarbons method

⁵ Because silica gel is employed in the fractionation methods, HOPs will be lost (removed) and will have to be separately assessed via the bulk extractable TPH analysis or other suitable methods.

is generally recommended for vapor samples modified to include identification and quantification of the “aliphatics” using the extracted ions 83 (alkylcyclohexanes), 85 (alkanes), and 113 (isoalkanes) per Zemo (2016). The document “White Paper: Analytical Methods for Total Petroleum Hydrocarbons (TPH)” (Zemo 2016) is a helpful reference that compares and contrast different TPH methods, including both Bulk TPH and TPH Fractionation methods.

The results of TPH fractionation data can be evaluated against the petroleum fraction ESLs, rather than the petroleum mixture ESLs. The latter are described in Section 4.4.

For petroleum sites under Regional Water Board staff oversight where a site-specific risk evaluation using TPH fractionation data is selected over a screening level evaluation, it will be necessary to develop and submit a work plan to adequately characterize petroleum fraction compositions and conduct a risk evaluation.

Issues that should be addressed in the work plan include, but are not limited to the following:

- Proposed TPH fractionation analyses description and rationale
- Given that the USEPA petroleum fractions carbon ranges are not matched with TPH fractionation methods, describe and provide justification for how the data will be aggregated to determine fraction concentrations and hazards.

A similar type of fraction or fractionation evaluation is not currently possible for HOPs, so evaluation of HOPs using the ESLs is limited to screening level evaluations.

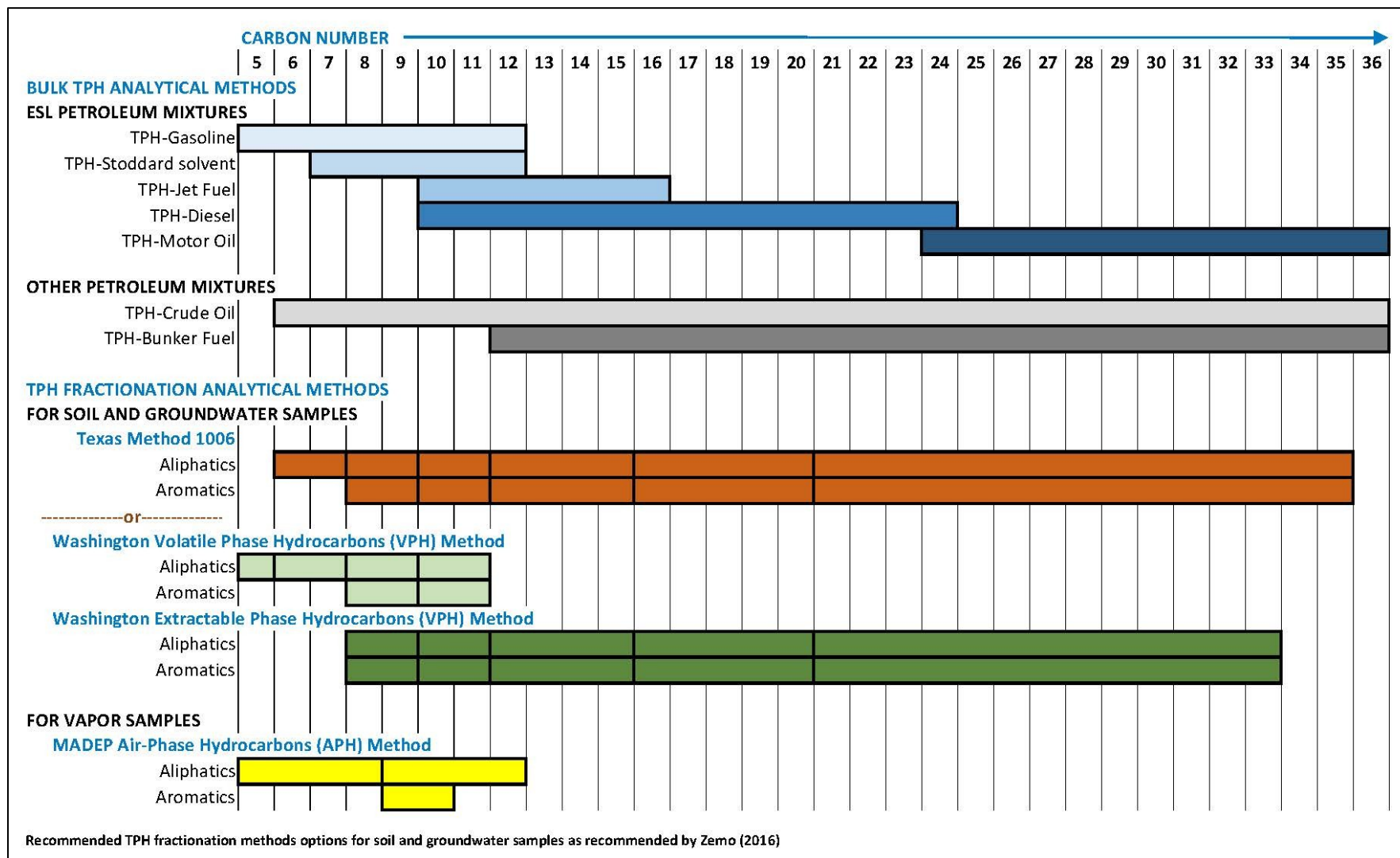


Figure 4-5: Example Carbon Ranges for Bulk TPH and TPH Fractionation Laboratory Analyses

5. Methods: Vapor Intrusion Risk Screening Levels for Groundwater and Subslab/Soil Gas

The vapor intrusion (VI) ESLs account for potential human health risk from exposure to contaminated indoor air caused by vapor transport from contaminated subsurface media (groundwater, soil, soil gas) into a building through bulk soil (a porous medium) via the conventional model for VI (Figure 5-1). Consequently, the VI ESLs represent an indirect exposure pathway because the media (groundwater and soil gas) are not the exposure medium, which is indoor air. The two general receptors considered for such exposure are residents and indoor commercial/industrial workers. VI ESLs are developed in two ESL Workbook Tables: GW-3 (groundwater) and SG-1 (soil gas⁶). These ESLs apply to existing and future buildings.

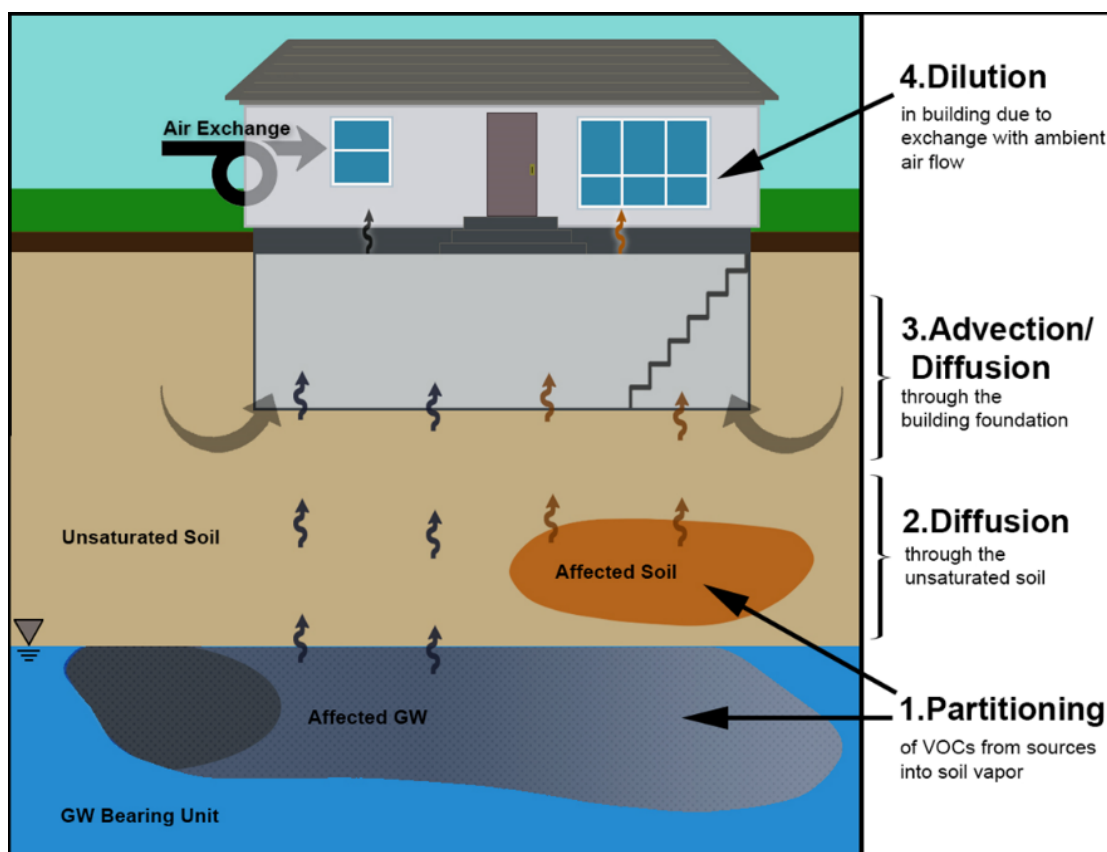


Figure 5-1: Conventional Conceptual Model for Vapor Intrusion

Source: McHugh et al. 2017b

⁶ Soil gas, as used in the ESLs, includes both exterior/deep soil gas and subslab soil gas (or subslab), which is a soil gas sample collected immediately beneath the base of the foundation).

In general, the VI ESLs are not used at sites that are subject to the Low-Threat Underground Storage Tank Closure Policy (LTCP; State Water Board 2012b). Specifically, the LTCP does not use the ESLs to screen contaminants at petroleum-contaminated sites. Instead, the LTCP provides closure levels for carcinogens and general (narrative) criteria. ESLs may be used at sites with “unique attributes” to screen for constituents not already addressed by the LTCP.

Use of the VI ESLs is consistent with the Supplemental Guidance: Screening and Evaluating Vapor Intrusion Final Draft (SVIG; DTSC and State Water Board 2023). In addition, the SVIG should be consulted for information regarding the locations, depths/heights, frequencies, and sampling methods used to collect indoor air, soil gas, and groundwater data that are compared to ESLs for VI risk screening assessments.

Other relevant VI guidance includes the San Francisco Bay Regional Water Board’s Vapor Intrusion Mitigation Guidance (Regional Water Board 2022), DTSC Vapor Intrusion Guidance (VIG; DTSC 2011b), and the USEPA VI Guide (USEPA 2015a).

5.1. Calculation of Soil Gas and Groundwater VI ESLs

A chemical is considered volatile if either: (1) the vapor pressure is greater than 1 millimeter of mercury or (2) the Henry’s Law Constant is greater than 1×10^{-5} atmospheres-cubic meter/mole (USEPA 2015a). The calculation of soil gas and groundwater VI ESLs relies on the Indoor Air ESLs (Excel Workbook IA-1, described in Chapter 3) and the development of vapor attenuation factors as described herein.

5.1.1. Vapor Attenuation Factors

Vapor attenuation refers to the reduction in volatile chemical concentrations during gaseous transport from the subsurface to indoor air. The attenuation factor (AF) is a measure of this reduction. AFs are calculated differently for soil gas and groundwater as described as follows.

Soil Gas to Indoor Air Attenuation Factor

The equation for the soil gas AF (equation 6), which applies to both subslab soil gas (subslab) and exterior/deep soil gas, is shown below. This AF can be used to predict VI at all buildings, regardless of design or use (e.g., crawl space, slab-on-grade, residential, or commercial).

Therefore, the AF is an inverse measurement of the concentration reduction (attenuation) of a volatile chemical that occurs during subsurface transport to indoor air. For instance, an AF of 0.03 corresponds to about a 33-times reduction in concentration: $AF = 1/\text{concentration reduction} = 1/33 = 0.03$. 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.

Equation 6:

$$AF_{SG} = \frac{C_{IA}}{C_{SG}}$$

where:

C_{IA} = Indoor air concentration in $\mu\text{g}/\text{m}^3$

C_{SG} = Soil gas (subslab and deep/exterior soil gas) concentration in $\mu\text{g}/\text{m}^3$

AF_{SG} = Attenuation factor for all soil gas (subslab and deep/exterior soil gas) (unitless)

Groundwater to Indoor Air Attenuation Factor

The AF for groundwater to indoor air differs from the soil gas AF because there are two steps. First, partitioning from the water phase to vapor phase should be estimated. Equilibrium partitioning is assumed to obey Henry's Law. This involves converting the groundwater concentration in micrograms per liter ($\mu\text{g}/\text{L}$) to an equivalent vapor concentration ($\mu\text{g}/\text{m}^3$) using the chemical-specific dimensionless Henry's Law Constant as shown in equation 7, below:

Equation 7:

$$C_{\text{Vapor-GW}} = C_{\text{GW}} \times H' \times \left(\frac{1,000\text{L}}{\text{m}^3} \right)$$

where:

$C_{\text{Vapor-GW}}$ = Vapor concentration in equilibrium with groundwater in $\mu\text{g}/\text{m}^3$

C_{GW} = Groundwater concentration in $\mu\text{g}/\text{L}$

H' = Chemical-specific Henry's Law constant (dimensionless) at the specified groundwater temperature.

L = Liters

m^3 = Cubic meters

Second, the groundwater AF is then calculated as shown in equation 8.

Equation 8:

$$AF_{\text{GW-IA}} = \frac{C_{IA}}{C_{\text{Vapor-GW}}}$$

where:

$AF_{\text{GW-IA}}$ = Groundwater to Indoor Air Attenuation Factor

C_{IA} = Indoor air concentration

$C_{\text{Vapor-GW}}$ = Vapor concentration in equilibrium with groundwater

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, 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 (McCarthy and Johnson 1993). Therefore, the use of an equilibrium groundwater concentration as a screening tool is usually conservative.

Basis of Attenuation Factors Used in the ESLs

Previous editions of the ESLs have employed AFs derived using versions of the Johnson and Ettinger vapor intrusion model as implemented by USEPA (“Johnson and Ettinger Model” or JEM). Beginning with the 2019 ESLs, an alternative approach is used based on the generic AFs developed from the USEPA Empirical VI Database (USEPA 2012c) and recommended by USEPA (Table 6-1 and Appendix A of USEPA 2015a). The AFs are:

- Subslab Soil Gas and Deep/Exterior AF (AF_{SG}) – 0.03
- Groundwater AF (AF_{GW}) – 0.001

As explained in the SVIG, these AFs are considered protective for all current and future buildings, residential and commercial/industrial.

5.1.2. Soil Gas VI ESLs

The soil gas VI ESL (ESL_{SG-IA}) values are calculated as follows in equation 9.

Equation 9:

$$ESL_{SG-IA} = \frac{C_{IA}}{AF_{SG}}$$

where:

C_{IA} Indoor air concentration in $\mu\text{g}/\text{m}^3$

AF_{SG} Attenuation factor for all soil gas (subslab and deep/exterior soil gas) (unitless), 0.03

C_{SG} Soil gas (subslab and deep/exterior soil gas) concentration in $\mu\text{g}/\text{m}^3$. This is the ESL value.

Soil gas VI ESLs are calculated using indoor air concentration goals for either protection of human health or odor nuisance. The human health-based soil gas VI ESLs are set at an excess lifetime cancer risk of one-in-a-million, 1×10^{-6} and a hazard quotient of 1.0 for noncancer hazard.

External soil gas sample depths generally should be no shallower than five feet bgs to reduce the likelihood of ambient air breakthrough (CalEPA 2015). For

other soil gas sampling depth considerations, see the slab capping effect discussion in the SVIG (DTSC and Water Boards 2022).

Generally, the Soil Gas VI ESLs should not be compared to average soil gas concentrations from across a site. For existing or known future building footprints, only soil gas concentrations within the building footprint should be considered for averaging unless it can be demonstrated that the diffusion/advection gradient will be toward the building.

5.1.3. Groundwater VI ESLs

The groundwater VI ESL (ESL_{GW-IA}) values are calculated in equation 10:

Equation 10:

$$ESL_{GW-IA} = \frac{C_{IA}}{H' \times \left(\frac{1,000L}{m^3} \right) \times AF_{GW}}$$

where:

C_{GW} Groundwater concentration in $\mu\text{g/L}$. This is the ESL value.

C_{IA} Indoor air concentration ($\mu\text{g/m}^3$)

H' Chemical-specific Henry's Law constant (dimensionless) at the specified groundwater temperature

L Liters

m^3 Cubic meters

AF_{GW} Attenuation factor for groundwater (unitless)

Groundwater VI ESLs are calculated using indoor air concentration goals for protection of human health. All human health-based ESLs are set at an excess lifetime cancer risk of one-in-a-million, 1×10^{-6} and a hazard quotient of 1.0 for noncancer hazard.

Use of the groundwater VI ESLs is not recommended for groundwater samples collected where the depth to groundwater is very shallow (less than 5 feet bgs) due to the potential for unattenuated or enhanced transport of vapors towards a receptor (USEPA 2024b). If groundwater is in contact with the foundation or if there are seeps into the building, sampling indoor is appropriate. For situations where contaminated first encountered groundwater is deep, soil gas analysis can better predict VI potential.

5.2. Chemical-Specific Exceptions

Groundwater VI ESLs are not calculated in ESL Workbook Table GW-3 for the volatile petroleum mixtures (gasoline, Stoddard solvent, jet fuel, and diesel). Instead, it is recommended that vapor data (e.g., soil gas) be collected to evaluate potential VI.

5.3. Site-Specific Evaluations

For sites where soil gas or groundwater VOC concentrations exceed the VI ESL in proximity to a current building, the default assumption is that VI may be occurring unless demonstrated otherwise via site-specific evaluation.

Characterizing the distribution and extent of contaminated groundwater and soil gas and assessing groundwater and vapor plume stabilities are critical steps necessary to determine the need for further evaluation and/or a response action (e.g., mitigation, remediation).

In general, the options for site-specific risk evaluations discussed in Sections 3.7 (human health risk evaluations) and 4.6 (petroleum risk evaluations) apply to VI risk evaluations. In addition, the following VI documents can be used to help develop site-specific VI risk evaluations, including but are not limited to:

- SVIG (DTSC and Water Board 2023) Sections:
 - Step 4A: Risk Assessments to Support Risk Management Decisions (including averaging and building specific attenuation factors)
 - Application to Other Building Types (including multistory and crawl space buildings)
 - Attachment 1: Lines of Evidence
 - Attachment 2: Petroleum-Specific Considerations (including bioattenuation factors)
 - Attachment 3: Sewers and Other Vapor Conduits as Preferential Pathways for Vapor Intursion
- VIMG (Regional Water Board 2022):
 - Attachment 2: Lines of Evidence for VI Evaluations (including VI modeling and building-specific attenuation factors)

5.3.1. Site-Specific VI Risk Evaluation Scoping Meeting

Typical site-specific issues that necessitate discussions with the overseeing regulatory agency include the following:

- Determination of exposure units/areas and hotspots;
- Exposure scenario development including evaluation of hypothetical future land and water use;
- Future building design and construction (e.g., slab capping effect for future slab-on-grade buildings);
- Use of averaging (in general, VI data should only be averaged over the footprint of an existing or future building rather than large areas of a site);

- Ambient concentrations of chemicals in ambient air and potentially soil gas; and
- Use of VI models to estimate site-specific AFs.

6. Methods: Short-Term Exposure Levels

The ESL Workbook Table entitled “Short Term Exposure Levels” presents TCE and elemental mercury levels for groundwater, soil gas, and indoor air, based on the concern for potential adverse effects over short exposure periods to contaminated indoor air or drinking water. TCE and elemental mercury are the main chemicals with the potential to cause health impacts from short-term exposures to typically concentrations observed at cleanup sites. The purpose of the short-term levels and suggested responses is to be protective of sensitive and vulnerable populations, particularly unborn babies. TCE is considered to have the potential to cause fetal cardiac malformations resulting from exposure during the first trimester of pregnancy (USEPA 2011b). Elemental mercury is considered to have the potential to cause developmental effects to the central nervous system of fetus and young children. Exceedances of the Short-Term Exposure Levels indicate the potential need for consideration of quick response actions to protect human health.

6.1. Trichloroethene Short-Term Exposure Levels

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. Developmental effects are the result of short-term exposure, in this case a timeframe of three weeks during the first trimester of pregnancy. Developmental toxicity has been linked to inhalation of TCE vapors and ingestion of TCE-contaminated drinking water with more substantial evidence for the latter.

6.1.1. USEPA TCE Indoor Air Response Levels

The indoor air short-term exposure levels were originally introduced to the Regional Water Board in a letter from USEPA Region 9 staff (USEPA 2013b). Subsequently, USEPA Region 9 issued a memorandum entitled *Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion* (USEPA 2014b). In addition, groundwater and soil gas short-term exposure levels, termed “trigger levels,” were developed as discussed in Section 6.3.

The USEPA short-term action levels, responses, and response time thresholds for TCE in indoor air are presented in ESL Workbook Table entitled “Short Term Exposure Levels for TCE” under the Indoor Air Levels column. USEPA provided for tiered responses based on TCE levels in indoor air as follows:

- TCE in indoor air < accelerated action level – monitor
- TCE in indoor air > accelerated action level – mitigate (within weeks)
- TCE in indoor air > urgent action level – mitigate (within days)

Interim response actions are actions taken by the responsible party or occupant to reduce or eliminate exposure after indoor air sample results exceed the appropriate residential or commercial/industrial TCE accelerated or urgent action level. These actions include encouraging the occupant to immediately take precautions to reduce exposure. Short-term response actions (mitigation) include, but are not limited to those listed below:

- Increase ventilation – Increase outdoor air intake, increase building pressurization (buildings with HVAC systems).
- Seal potential conduits
- Treat indoor air
- Temporarily relocate occupants
- Once a response action has been implemented, monitor indoor air as needed to verify success of the response action and determine when additional measures are needed.

Longer term measures include installing a VI mitigation system until the source can be remediated. For further information on vapor intrusion mitigation options, see the *Vapor Intrusion Mitigation Guidance* (Regional Water Board 2022).

The short-term exposure levels, associated response actions, and potential expedited laboratory turnaround times may need to be incorporated into indoor air sampling work plans and associated response contingency plans.

6.1.2. Groundwater and Soil Gas Trigger Levels for TCE Vapor Intrusion

TCE short-term exposure levels for groundwater and soil gas are also provided to help determine when expedited indoor air sampling may be needed. These levels are called “trigger levels.” These trigger levels are calculated using the recommended vapor intrusion attenuation factors (Section 5.1.1) and the USEPA Accelerated Response level (based on noncancer hazard) as the indoor air target concentration.

For sites with deep groundwater (>20 feet bgs) and TCE concentrations only slightly above the TCE groundwater trigger level, expedited soil gas sampling at

15 feet bgs (see SVIG for soil gas sample depth information) could be considered before indoor air sampling, on a site-specific basis.

6.1.3. TCE Drinking Water Response Level

The USEPA Region 9 response action levels only address the recent changes regarding the inhalation route 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 Workbook 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 by responsible parties/dischargers should not be delayed.

6.2. Elemental Mercury Short-Term Exposure Levels

At levels of elemental mercury exposure potentially observed at cleanup sites, the kidneys and brain, especially the developing brain, are sensitive targets. Short term maternal exposure to mercury vapor during pregnancy may result in long lasting neurobehavioral effects in the offspring (OEHHA 2015, ATSDR 2012).

6.2.1. Elemental Mercury Indoor Air Short-Term Exposure Levels

The following Accelerated and Urgent Exposure ESLs for short-term indoor air exposure are presented in ESL Workbook Table entitled “Short Term Exposure Levels”.

- Accelerated Response Level: OEHHA's acute Reference Exposure Level (REL) of 0.6 µg/m³ (OEHHA 2015). This level was developed for conducting health risk assessments under the Air Toxics Hot Spots Program (Health and Safety Code Section 44360 (b) (2)).
- Urgent Response Level: ATSDR's action level for isolation (e.g., evacuation, limited access, etc.) of 10 µg/m³ (ATSDR 2012). This level was developed at the request of USEPA for use at cleanup sites.

These levels are both based on acute exposure scenarios and are therefore applicable to both residential and commercial exposures. The responses and response time thresholds for exceedance of these elemental mercury response levels are generally the same as those discussed for TCE above. However, unlike TCE, doctors can measure elemental mercury in human blood and urine to assess exposure. Therefore, notification and coordination with local public health officials is important to help exposed individuals get tested.

6.2.2. Groundwater and Soil Gas Trigger Levels for Elemental Mercury Vapor Intrusion

Elemental mercury trigger levels for groundwater and soil gas were developed using a similar method as TCE. Specifically, the trigger levels are calculated using the recommended vapor intrusion attenuation factors (Section 5.1.1) and the Accelerated Response ESL as the indoor air target concentration. An exceedance of either the groundwater or soil gas trigger levels would indicate the need for expedited indoor air sampling at nearby buildings. For sites with deep groundwater (>20 feet bgs) and TCE concentrations only slightly above the TCE groundwater trigger level, expedited soil gas sampling at 15 feet bgs (see SVIG for soil gas sampling depth information) could be considered before indoor air sampling, on a site-specific basis.

7. Methods: Aquatic Habitat Screening Levels for Groundwater

The ESLs for protection of aquatic habitat presented in ESL Workbook Table GW-2 apply to pollutants in groundwater where there is the threat of discharge to surface water. Protecting beneficial uses of aquatic habitat is required by the Basin Plan. Aquatic habitat ESLs consider potential adverse effects to aquatic receptors based on accepted toxicity criteria, and potential impacts to humans based on promulgated bioaccumulation criteria for human ingestion of seafood (e.g., shellfish, fish).

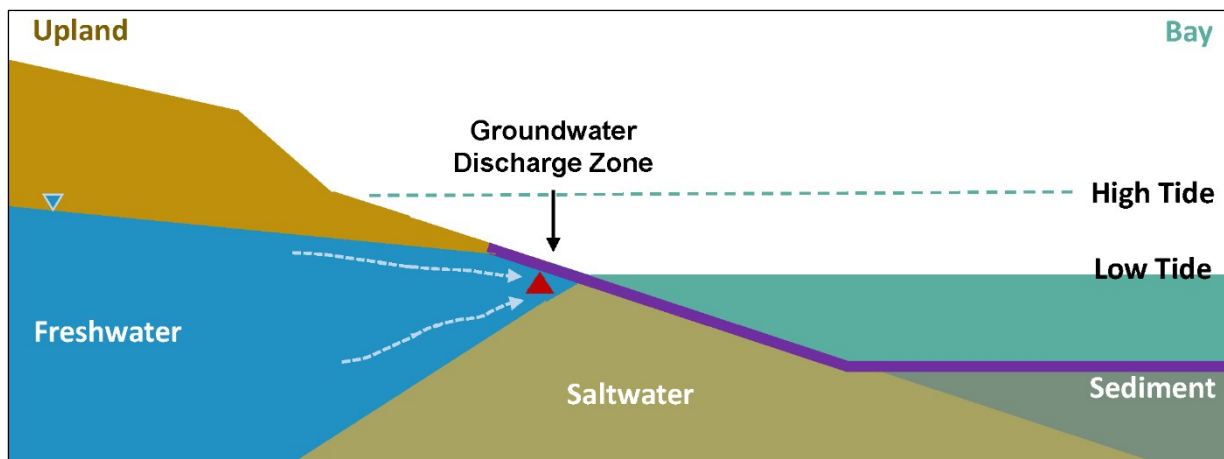


Figure 7-1: Bay Margin Groundwater Discharge Conceptual Model

This figure depicts contaminant transport via groundwater flow through sediments with potential benthic habitat and then into surface water. The red triangle marks a location for sediment porewater sampling that is immediately upgradient of transition zone biota (see Section 7.4.1). The biologically active zone is depicted as a purple line.

The generic CSM, illustrated in Figure 7-1, assumes pollutants in groundwater migrate toward and discharge into a surface waterbody, and transport occurs through porous media (e.g., soils/sediments). Potential aquatic receptors include pelagic organisms and biota in the groundwater/surface water transition zone.⁷ Transition zone biota can include benthic organisms and the microbial community. The transition zone represents a region at or beneath the sediment–water interface (SWI) in a surface-water body where conditions change from a groundwater-dominated system to surface water-dominated system (USEPA 2008b). Transition zones are important ecologically because they store and

⁷ The transition zone, also known as the hyporheic zone, is an ecological term that generally refers to an ecologic zone where both groundwater and surface water are present in shoreline or streambed sediments along with a specific set of biota. USEPA has chosen to use the broader term “groundwater/surface water transition” zone (USEPA 2000d).

retain nutrients, transform compounds biologically and chemically, provide refuge to benthic invertebrates, and are the base of the aquatic food web (USEPA 2000d). The generic CSM does not consider dilution or attenuation of groundwater upon discharge to surface water because benthic organisms or other biota in the transition zone may be exposed to the full concentration of contaminants in groundwater prior to mixing with surface water.

7.1. Aquatic Receptor Toxicity Criteria

The Aquatic Habitat ESLs consider toxicity from the three following types of exposure risk:

- Direct water exposure for aquatic receptors;
- Food web bioaccumulation-based exposure for aquatic receptors; and
- Seafood ingestion exposure for human receptors.

Chronic and acute aquatic receptor toxicity criteria from various sources are compiled in two ESL Workbook Tables:

- IP-5 (California levels) – These are the toxicity criteria for aquatic receptors specific to California:
 - California Toxics Rule (USEPA 2000b);
 - A Compilation of Water Quality Goals (State Water Board 2016);
 - California Ocean Plan (State Water Board 2019); and
 - Other Criteria - the Basin Plan (Regional Water Board 2024), Total Maximum Daily Loads, values derived from testing performed under Regional Water Board staff oversight (e.g., petroleum mixture values), or values derived by staff from review of databases or literature (e.g., USEPA ECOTOX).
- IP-6 (USEPA and other levels) – Additional sources of toxicity criteria for aquatic receptors include:
 - 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).

ESL Workbook Table IP-7 (Seafood Ingestion Aquatic Habitat Goals) contains human health risk-based toxicity criteria for bioaccumulation and consumption of aquatic organisms from the following sources:

- California Toxics Rule (USEPA 2000b);
- California Ocean Plan (State Water Board 2019; and
- USEPA National Recommended Water Quality Criteria (USEPA 2002a).

7.2. Hierarchy for Aquatic Receptor Toxicity Criteria

The Final Aquatic Habitat Screening Level used as the Tier 1 ESL is the lowest value among the Seafood Ingestion Human Health ESLs, Freshwater Ecotoxicity ESLs, and Saltwater Ecotoxicity ESLs. The Seafood Ingestion Human Health ESLs are the lowest of applicable human health risk-based screening levels in ESL Workbook Table IP-7. The Freshwater and Saltwater Ecotoxicity ESLs are the lowest value considering both bioaccumulation exposure and direct water exposure risk-based screening levels for the applicable freshwater or saltwater receptors.

There are several sources of direct water exposure toxicity criteria for aquatic receptors such as promulgated criteria, recommendations based on evaluation of results from multiple studies or databases, and individual study results. These criteria include both chronic and acute exposures. Table 7-1 presents a hierarchy of criteria, with the highest being promulgated criteria applicable for chronic exposures. If a criterion is not available from the highest tier, then a value is selected from the next tier with a criterion value. ESL Workbook Table GW-2 uses the hierarchy to determine the Final Freshwater and Saltwater Goals, as described herein:

- For each chemical, a final chronic and acute toxicity level for both freshwater and saltwater receptors is selected. Per the Basin Plan, freshwaters are those in which the salinity is equal to or less than 1 part per thousand for 95 percent of the time. Marine waters (saltwater) are those in which the salinity is equal to or greater than 10 parts per thousand for 95 percent of the time. For waters in which the salinity is between 1 and 10 parts per thousand, the applicable screening levels are the more stringent (i.e., lower) of the freshwater or saltwater levels.
- The chronic level is selected using the hierarchy, shown in Table 7-1. However, if there is a more protective Basin Plan objective value, it will be prioritized over the value selected using the hierarchy.
- If no chronic level or Basin Plan objective value is available, 10% of an acute level (termed “adjusted acute goal”) based on the hierarchy is used instead.

Table 7-1: Hierarchy for Aquatic Receptor Direct Water Exposure Toxicity Criteria

Tier	Exposure Timeframe	Sources of Values
1	Chronic	CTR CCC
2	Chronic	USEPA CCC
3	Chronic	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 c) 50 percent USEPA Chronic LOEL ¹
4	Chronic	USDOE Chronic PRG
5	Chronic	50 percent MOEE Chronic AWQC or LOEL
1	Acute	CTR CMC
2	Acute	USEPA CMC (or Acute LOEL if no CMC)
3	Acute	Other aquatic water quality criteria (LC50)

Table 7-1 Note-1: 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.

Table 7-1 Abbreviations:

AWQC – USEPA Ambient Water Quality Criteria

CCC – Criterion Continuous Concentration

CMC – Criterion Maximum Concentration

CTR – California Toxics Rule (USEPA 2000b)

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)

Ontario MOEE – Ontario Ministry of Environment and Energy

7.3. Chemical-Specific Exceptions

7.3.1. Barium

The USEPA Ecotox freshwater goal for barium (3.9 µg/L; USEPA 1996a) was excluded from ESL Workbook Table IP-6 due to low confidence in the goal.

7.3.2. Methyl Tertiary Butyl Ether (MTBE)

The freshwater and saltwater surface water goals for MTBE were developed by Regional Water Board staff (Regional Water Board 1998b).

7.3.3. Per- and Polyfluoroalkyl Substances (PFAS)

The aquatic receptor ecotoxicity screening levels for PFAS were taken from the following sources, listed in order of preference:

- Derivation of PFAS Ecological Screening Values (ANL 2024)
- Approach for Assessing PFAS Risk to Threatened and Endangered Species (Divine et al., 2020)

7.3.4. Petroleum Mixtures

The freshwater and saltwater surface water goals for the petroleum mixtures (e.g., jet fuel, HOPs) are based on aquatic toxicity testing in accordance with Whole Effluent Toxicity (WET) methods or similar methods. Some of the goals are based on toxicity testing of laboratory-prepared Water-Accommodated Fractions of fresh (unweathered) mixtures while some are based on toxicity testing of contaminated groundwater samples from specific sites.

When site samples are used for biological effects testing, the tests implicitly address the combined or aggregate effects of all known or unknown potential toxicants in the mixture as well as other factors such as weathering, soil characteristics (e.g., texture, moisture, temperature, pH, carbon content), and microbial community. Consequently, it is difficult to conclude with certainty what caused the toxic response. These values are adopted because the tested mixtures may have caused or contributed to the toxic response in the test species. Therefore, an exceedance of these values indicates when it may be appropriate to perform site-specific aquatic toxicity testing.

Information on the specific mixtures, species, and citations are listed below. ESL User's Guide Chapter 4 also contains relevant information regarding the petroleum mixture ESLs, including laboratory analytical methods (Section 4.6).

Petroleum Gasoline

The freshwater value of 443 µg/L is based on site-specific, chronic toxicity testing of gasoline-contaminated groundwater using the *Ceriodaphnia dubia* (water flea) (Montgomery Watson 1999), specifically the 25% effect concentration (EC25).⁸ The test design was consistent with recommended test design discussed in Section 7.4.2—toxicity testing was performed in a groundwater sample

⁸ EC25 – Point estimate of the toxicant concentration that would cause a 25% observable adverse effect as compared to the control test organisms.

downgradient from the release area as well as a groundwater sample collected from a background location unimpacted by the petroleum release—no toxicity was found in the background sample. The conclusion is that the toxicity is caused directly or indirectly by the petroleum release.

The saltwater value of 3,700 µg/L is based on chronic toxicity testing of a water-accommodated fraction (WAF) of fresh (unweathered) gasoline using *Strongylocentrotus purpuratus* (sea urchin) (Burns and McDonnell Waste Consultants, Inc. 1997). The testing yielded a value of 37,000 µg/L, which was adjusted to a final value of 3,700 µg/L using an acute-to-chronic ratio of 10 (Regional Water Board 1998a). The final value was incorporated into subsequent Board Order 99-045 (Regional Water Board 1999).

Petroleum Stoddard Solvent

The Petroleum Stoddard Solvent freshwater and saltwater values are based on the Petroleum Jet Fuel saltwater value as a surrogate.

Petroleum Jet Fuel

The Petroleum Jet Fuel freshwater value is based on the saltwater value (basis described below) as a surrogate. The saltwater value of 640 µg/L is based on chronic toxicity testing of a WAF of fresh (unweathered) Jet A fuel using the *Americamysis bahia* (mysid shrimp) (Burns and McDonnell Waste Consultants, Inc. 1999; Regional Water Board 1999), specifically the 25% inhibition concentration (IC25).⁹

Petroleum Diesel

The Petroleum Diesel freshwater and saltwater values are based on the Petroleum Jet Fuel saltwater value as a surrogate.

Petroleum HOPs

The Petroleum HOPs freshwater and saltwater values of 640 µg/L are based on the Petroleum Jet Fuel saltwater value (described above). The rationale for applying the petroleum hydrocarbon mixture value to HOPs is that the toxic effects of many chemicals, including hydrocarbons, are caused by their metabolites. A more detailed discussion is presented in Section 4.5.1.

7.3.5. Selenium

The freshwater and saltwater surface water goals for selenium in ESL Workbook Table IP-6 are from the California Toxics Rule as promulgated in 40 Code of

⁹ IC25 – Point estimate of the toxicant concentration that would cause a 25% reduction in a sublethal biological measurement (e.g., growth) calculated from a continuous model (i.e., interpolation method).

Federal Regulations Part 131: *Water Quality Standards, Establishment of Numerical Criteria for Priority Toxic Pollutants for the State of California* (USEPA 2000b). These goals are based on total recoverable, rather than dissolved, concentrations. In contrast, the saltwater “Other” criterion column value is a dissolved total value, where total refers to the addition of all selenium species. As indicated in the table footnotes, this is the Total Maximum Daily Load target for North San Francisco Bay based on Board Resolution R2-2015-0048, which was approved by USEPA in 2016.

7.3.6. Tertiary Butyl Alcohol (TBA)

The freshwater chronic aquatic goal is based on staff review of the USEPA ECOTOX database for TBA in 2003. Ten percent of the acute LC50 concentration for *Lepomis macrochirus* (Bluegill) was selected as the most conservative goal, based on the data available at that time.

7.3.7. 1,2,3-Trichloropropane

The freshwater and saltwater chronic aquatic goals are based on staff review of the USEPA ECOTOX database (August 2018). Ten percent of the lowest acute LC50 concentration for *Pimephales promelas* (fathead minnow) was selected as the freshwater goal. Ten percent of the lowest acute LC50 concentration for *Chaetogammarus marinus* (amphipod) was selected as the saltwater goal.

7.4. Site-Specific Evaluations

For sites where groundwater concentrations exceed the aquatic habitat ESL in proximity to a surface water body, the default assumption is that a potentially harmful discharge is occurring until demonstrated otherwise via site-specific evaluation. Characterizing the distribution and extent of contaminated groundwater and assessing plume stability are critical steps necessary to determine the need for further evaluation and/or remediation.

Several options for site-specific evaluations are discussed below. Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

7.4.1. Groundwater Discharge Evaluation

The term “groundwater discharge evaluation” is used to describe the general type of groundwater discharge to surface water investigation necessary where it is not possible to determine the extent of contaminated groundwater in proximity to surface water using conventional tools for upland field investigations

(e.g., wheeled or tracked drilling rigs). The objectives of the groundwater discharge evaluation are:

- locate and characterize the current or potential discharge area(s) or define the extent (if contaminants are not discharging);
- evaluate the rates or magnitude (flux) of the current or potential discharge; and
- assess the severity/risk/threat to aquatic habitat (e.g., toxicity assessment).

The areas(s) where discharge is occurring or likely to occur should be located so that sampling can be focused to enable the proper evaluation of ecological risks to receptors in the transition zone (USEPA 2008b, TCEQ 2013, NJDEP 2016, MDEQ 2018).

The spatial distribution and rates of groundwater discharge, if occurring, are influenced by the type of associated water body (e.g., stream, wetland, estuary, ocean), the elevation of surface water versus groundwater, and the nature of the sediment substrate (e.g., rocky versus muddy) and hydrogeology. Discharge locations and rates may also be subject to temporal variability due to seasonal and other changes in hydrogeologic conditions.

Due to the dynamic nature of this pathway, a multiple lines of evidence approach is necessary. Typically, the sequence of steps is: (1) evaluate existing information (hydrogeology, hydraulic head, groundwater plume nature and extent); (2) locate potential groundwater discharge areas by visual inspection, temperature and conductivity surveys (or other tracer techniques); (3) determine the nature and quality of sediment porewater¹⁰ in the potential discharge areas; and (4) measure seepage/flow and estimate mass discharge. Surface water sampling near the SWI can be helpful as a supporting line of evidence, recognizing that significant dilution can occur (i.e., surface water sampling alone should not be used to conclude there is no discharge to surface water).

Sampling sediment porewater is an important line of evidence for understanding whether contamination migrating toward the surface water body may potentially cause adverse effects to transition zone biota (MDEQ 2018). Locations for sampling sediment porewater typically should be positioned to be upgradient of the biologically active zone (see Figure 7-1). Tools and methods for groundwater discharge evaluations are described in several documents (Kalbus et al. 2006; Chadwick and Hawkins 2008; USEPA 2008b; Washington DOE 2009; and NJDEP 2016).

¹⁰ Sediment porewater, or interstitial water, is the water in the spaces between sediment particles. The origin of porewater can be surface water, groundwater, or a mixture. In a discharge area, porewater is groundwater.

If contaminated groundwater is discharging to a storm sewer or other manmade conveyance that in turn discharges to surface water, the CSM is different and the discharge would be subject to Federal pollution discharge elimination requirements under the Clean Water Act, or waste discharge requirements under the California Water Code.

7.4.2. Fate and Transport Modeling

Modeling typically is used as one line of evidence to evaluate the mass flux of contaminated groundwater discharge to surface water and to help focus sampling or evaluate dilution-attenuation factors. If proposed, the modeling approach should employ a generally recognized and scientifically valid method and representative field data should be used to calibrate and verify the model. Weighting of the findings (e.g., degree of confidence) will depend on the degree of calibration and whether empirical data are collected to verify estimates and predictions. Ultimately, however, models are not a substitute for sampling to characterize the groundwater to surface water transport pathway.

7.4.3. Ecological Risk Assessment

An ecological screening evaluation should be performed at all cleanup cases under Regional Water Board oversight. ERA development should be consistent with Water Board policies (e.g., Resolution 92-49, Resolution 2018-0028) and generally consistent with USEPA and DTSC documents for ecological risk assessment (ERA; USEPA 1997b; DTSC 1996a, 199b). Section 2.6 of the Preliminary Endangerment Assessment Guidance Manual (DTSC 2015) describes a streamlined process for an initial ecological screening evaluation, including key questions, biological characterization, pathway assessment, and qualitative summary.

Historically, Tier 3 aquatic ecological risk assessments (ERAs) were most commonly associated with sediment pollution and not typically developed for sites where the concern is pollutants in groundwater migrating towards a surface water body. Such ERAs do not consider the ecological importance of the transition zone, instead focusing on biota associated with the SWI or the overlying surface water column (USEPA 2008b). The Regional Water Board does not consider such ERAs an adequate substitute where contaminated groundwater is potentially impacting aquatic habitat in both the transition zone and the SWI. Groundwater chemistry and toxicity should be integrated as lines of evidence in ERAs also including bulk sediment chemistry and toxicity and community surveys.

Groundwater Aquatic Toxicity Testing

Site-specific aquatic toxicity testing typically is most appropriate when the contaminated groundwater contains:

- Chemicals/mixtures whose toxicity is unknown;

- Several unknown/unidentified chemicals/mixtures;
- Several chemicals known to be toxic to aquatic organisms, but whose individual concentrations do not exceed their respective toxicity criteria (cumulative or synergistic effects);
- Total Dissolved Solids (TDS) concentrations that are significantly different than that of the receiving water; and/or
- A mixture of chemicals/mixtures from multiple releases and the toxicity of the combined mixture cannot be adequately predicted.

Whole Effluent Toxicity (WET) testing can be performed on contaminated groundwater to assess acute and chronic aquatic toxicity and potentially develop site-specific cleanup goals for a specific release. WET testing is not suitable for evaluating bioaccumulation, which could be addressed using other methods (e.g., tissue sampling, food web modeling). WET testing methods are a component of the National Pollutant Discharge Elimination System permit program, authorized by the Clean Water Act, that controls water pollution by regulating point source discharges to waters of the United States (SETAC 2004, USEPA 1991b, USEPA 2000c). WET methods are standardized methods for use as water quality regulatory tools (USEPA 2002d, 2002e, and 2002f). In addition, OEHHA (2004b) provides a description of test methods for freshwater and marine toxicity tests for water column, whole sediment, and sediment porewater.

WET testing of uncharacterized complex effluents (mixtures) typically is performed using three relevant species from different taxa for lethal and sublethal endpoints (USEPA 1991b). For uncharacterized complex effluents (mixtures), it is not expected that all test species will show toxic effects. If any single endpoint shows statistically significant toxicity attributable to a pollutant, then that pollutant mixture is deemed toxic. Typically, the most sensitive receptor and endpoint are retained for monitoring of permitted discharges.

Relevant methods and species should be selected considering their known sensitivity to a particular contaminant/mixture. The availability of approved methods and species is necessarily limited by factors such as a need for a high degree of standardization, year-round availability, availability of commercial cultures, ease of maintenance and culture in the laboratory, and well-known biology and test requirements (Verslycke et al. 2007). Necessarily, a given test species serves as a surrogate for similar species, even though the test species may not reside at a particular site (USEPA 1994). For example, in the San Francisco Bay region, previous toxicity testing of water samples polluted by petroleum hydrocarbons or their transformation products have found the mysid *Americamysis bahia* (formerly *Mysidopsis bahia*) to be a sensitive species (Burns and McDonnell Waste Consultants 1999; Terraphase Engineering 2018). This is consistent with the literature (Barron et al. 1999; Neff et al. 2000) and with the NPDES permit chronic toxicity monitoring programs for four of the five refineries in our region (Phillips 66, Shell, Tesoro, and Valero). Although *Americamysis bahia* does not reside in the Bay, it is a standard test species (USEPA Method

1007.0) and therefore serves as a surrogate for similar mysids in the Bay (e.g., *Neomysis mercedis*; Verslycke et al. 2007).

General considerations for WET testing include the potential loss of contaminants during the sample collection/handling and test protocols (e.g., volatilization or biodegradation due to the need to oxygenate) and other potential confounding factors (e.g., un-ionized ammonia, metals, ionic strength).

Specific considerations for WET testing using groundwater matrices/samples include:

- Confirming the test protocol/species will be compatible with the groundwater chemistry;
- Assessing the potential need to adjust the salinity of the groundwater to simulate test conditions for saltwater species;
- Testing a background groundwater sample (unimpacted by the spill in an upgradient or nearby location that has similar hydrogeologic and vegetative characteristics);
- Controlling for potential confounding factors in sample locations proximal to tidally-influenced surface water bodies (e.g., contaminated surface water from other sources or sites); and
- Performing two rounds of testing during different seasons (e.g., wet and dry) to address potential variations in composition and concentrations.

8. Methods: Terrestrial Habitat Screening Levels for Soil

The Terrestrial Habitat ESLs in ESL Workbook Table S-2 protect terrestrial receptors (animals and plants) against potential adverse effects from chronic direct exposure to contaminated upland soil. Protecting soil quality ensures a healthy functioning ecosystem capable of sustaining current and future uses of a site by these ecological receptors. The generic conceptual model for exposure to animals and plants assumes the potential maximum depth of exposure to be 10 feet bgs (Sample et al. 2014).

The Terrestrial Habitat ESLs are intended for use only at developed properties and not in agricultural or open lands where special status species¹¹ may be present (e.g., typical habitat of such species). They can be used for screening at such sites but should not be used as the sole basis for screening out these types of sites. The Terrestrial Habitat ESLs also are not applicable to aquatic habitats (e.g., wetlands; ephemeral, intermittent or perennial streams; rivers and mudflats; ponds or lakes; vernal pools; marine intertidal areas). Moreover, Terrestrial Habitat ESLs cannot be used as sediment screening levels; sediment screening levels should be selected on a site-specific basis (see Section 12.5).

8.1. Background and Basis for Screening Levels

Terrestrial Habitat ESLs based on values published in Ontario Ministry of the Environment (MOE) guidance (MOEE 1996) have been used in prior versions of the ESLs from 2001 through 2013. During the 2016 ESL update, the Terrestrial Habitat ESLs were removed. The current Terrestrial Habitat ESLs are based on updated Ontario MOE guidance (MOE 2011). The following provides a summary of the relevant MOE screening levels and how the information has been adapted for use as the Terrestrial Habitat ESLs.

8.1.1. Background on Ontario Ministry of the Environment (MOE) Screening Levels

The screening levels were developed to ensure site soils provide a healthy functioning ecosystem capable of sustaining the current and likely future uses of the site by ecological receptors. These levels were generated through review of scientific literature and other guidance (e.g., Canada and the Netherlands), compilation of data, and a derivation procedure. The literature and guidance review focused on data regarding direct biological effects to growth, reproduction, and mortality to agricultural crops, native plant species and soil-dwelling organisms (e.g., soil invertebrates such as microorganisms, earthworms, insect

¹¹ Special status species include California species of special concern; state and federally listed rare, threatened, or endangered species; and species that are proposed or recommended for state or federal listing (DTSC 2015).

larvae). The process generated data for three land use categories: 1) agricultural or other; 2) residential, parkland, or institutional; and 3) industrial, commercial, or community. The values for the first two categories are the same while the values for the third category are higher than the first two, recognizing that the level of protection can be less stringent for commercial/industrial uses than for agricultural and residential uses.

The MOE guidance develops two types of soil screening levels (termed “component values”) for two types of terrestrial receptors and exposure pathways, as follows:

- Plants and Soil-Dwelling Organisms: Direct Contact – These component values address direct contact (ingestion, inhalation, dermal contact) for both soil-dwelling organisms and plants. In addition, the component values address aesthetic concerns only for plants. MOEE also created two sets of screening levels based on soil texture: fine- and medium-grained soils and coarse-grained soils. The coarse-grained soil values are about 25% more stringent based on the expectation that the bioavailability of contaminants likely is higher in coarse-grained soils. The fine- and medium-grained soil values are employed in the ESLs.
- Mammals and Birds: Ingestion – These screening levels address both mammals and birds based on food web models with exposure pathways that include a direct or indirect link to soil, including: (1) ingestion of plants; (2) incidental ingestion of soil resulting from feeding on plants and soil invertebrates; and (3) ingestion of prey by carnivores. Due to the large number of potential terrestrial organisms, MOE selected a limited number of terrestrial receptors (typical of agricultural and natural ecosystems in southern Ontario) to serve as surrogates:
 - Meadow Vole (*Microtus Pennsylvanicus*) – surrogate for small herbivorous mammals;
 - Short-Tailed Shrew (*Blarina brevicauda*) – surrogate for species with very high rates of food consumption relative to body weight, which increases exposure and increase their sensitivity;
 - Red-Winged Blackbird (*Agelaius phoeniceus*) - surrogate for herbivorous birds;
 - American Woodcock (*Scolopax minor*) - surrogate for omnivorous birds (e.g. robin, killdeer);
 - Red Fox (*Vulpes vulpes*) - surrogate for other predators of small mammals (e.g. coyote, bobcat, lynx, mink);
 - Red-Tailed Hawk (*Buteo jamaicensis*) – surrogate for carnivorous bird; and
 - Sheep (*Ovis aries*) – surrogate for domestic ruminants (e.g. deer).

It was MOE's intention to include reptiles and amphibians, but due to lack of information these receptors could not be included. Similarly, there was a lack of information regarding dermal and inhalation exposures to birds and mammals, so these pathways could not be included.

8.1.2. Development of Terrestrial Habitat ESLs

The MOE screening levels previously discussed are included in ESL Workbook Table IP-8 under two categories of terrestrial receptors: (1) plants and soil-dwelling organisms and (2) mammals and birds. Instead of providing ESLs for residential and commercial land use scenarios, as was done by MOE, the Terrestrial Habitat ESLs consider the degree to which a site is vegetated. For example, the amount of potential terrestrial habitat is much greater at a residence in a rural setting (e.g., open lands) than in a high-density urban residential setting or commercial/industrial setting where much of the surface is covered with buildings or pavement. Therefore, the ESLs were compiled for either: (1) Significantly Vegetated Areas; or (2) Minimally Vegetated Areas. The MOE screening levels derived for residential, parkland, or institutional areas are used for the Significantly Vegetated ESLs while the Minimally Vegetated ESLs are those derived for industrial, commercial, or community areas.

The factors to be considered when determining the vegetation level of a given property can include, but are not limited to the following:

- Urbanization level of the surrounding area
- Percentage of the site covered by vegetation
- Observed animal habitat

A suburban residence with over 50% of the property is covered by vegetation could be considered a substantially vegetated area. On the other hand, almost all high-density urban properties could be considered minimally vegetated areas. Commercial/ industrial properties likely will be considered minimally vegetated areas.

Ultimately, for a given vegetation level, the lowest value of those for the different receptors is selected for each chemical in Workbook Table S-2. The Tier 1 Soil ESLs assume a significantly vegetated area.

8.2. Exceptions

This section discusses other documents that were used to determine Terrestrial Habitat ESL values for common chemicals that do not have relevant screen levels in the 2011 Ontario MOE guidance.

8.2.1. Dichlorodiphenyltrichloroethane (DDT)

The Significantly Vegetated Area ESL value for habitat of transitory species (mammals and birds) for Dichlorodiphenyltrichloroethane (DDT) is adopted from the USEPA Ecological Soil Screening Levels for DDT and Metabolites (USEPA, 2007b).

8.2.2. Petroleum Hydrocarbon Mixtures

The Terrestrial Habitat ESL values for petroleum hydrocarbon mixtures (gasoline, Stoddard solvent, jet fuel, diesel, and motor oil) are based on the results of toxicity testing of weathered mixtures in soil samples collected in the State of Washington (Washington DOE 2016). The toxicity tests were performed using lettuce seed (*Lactuca sativa*) and earthworms (*Eisenia fetida*). When site samples are used for biological effects testing, the tests implicitly address the combined or aggregate effects of all known or unknown potential toxicants in the mixture as well as other factors such as weathering, soil characteristics (e.g., texture, moisture, temperature, pH, carbon content), and microbial community. Consequently, it is difficult to conclude with certainty what caused the toxic response. These values are adopted because the tested mixtures may have caused or contributed to the toxic response in the test species.

8.2.3. PFAS

The Terrestrial Habitat ESL values for PFAS were selected from either (A) 2020 Department of Defense Strategic Environmental Research and Development Program (SERDP) guidance document (Divine 2020), or (B) Argonne National Laboratory (ANL) guidance document (ANL 2024). The lowest screening level of all receptor categories, considering levels from both guidance documents, were selected for the Significantly Vegetated Area ESLs. The lowest level based on the lowest observed adverse effect level (LOAEL) in the SERDP guidance (Divine 2020), considering all receptor categories, was selected for the Minimally Vegetated Area ESL. If there was no LOAEL value for a chemical, the Significantly Vegetated Area ESL was used for the Minimally Vegetated Area ESL.

8.3. Site-Specific Evaluations

An ecological screening evaluation should be performed at all cleanup cases under Regional Water Board oversight. Section 2.6 of the Preliminary Endangerment Assessment Guidance Manual (DTSC 2015) describes a streamlined process for an initial ecological screening evaluation, including key questions, biological characterization, pathway assessment, and qualitative summary.

For sites where soil concentrations exceed the Terrestrial Habitat ESLs, further evaluation is necessary. This evaluation generally should be consistent with Water Board policies (e.g., Resolution 92-49, Resolution 2018-0028) and

generally consistent with USEPA and DTSC guidance for ecological risk assessment (USEPA 1997b; DTSC 1996a, 199b). For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

Site-specific evaluations could encompass a number of aspects, including but not limited to the following:

- Biologically-Relevant Exposure Depth – It may be appropriate to adjust the exposure depth on a site-specific basis. DTSC (1998) specifies a potential exposure depth of 6 feet bgs for burrowing mammals and burrow-dwelling birds. USEPA (2015c) discusses exposure depths for terrestrial organisms and notes that the majority of biotic activity by soil-dwelling organisms occurs in the A horizon, and generally the top 30 centimeters of the soil profile could be considered for the biologically-relevant sampling depth. Sample et al. (2014) documents a site-specific evaluation of the biologically active zone in an upland habitat and ultimately indicates that maximum exposures could be up to about 10 feet bgs, while 8 feet bgs would be protective for the majority of biota.
- Terrestrial Toxicity Testing – Toxicity test methods for soil-dwelling organisms are available from various sources (e.g., ASTM, Organization for Economic Co-operation and Development; and USEPA). OEHA (2009a) provides a description of test methods for terrestrial microorganisms, plants, invertebrates and vertebrates.

Typical site-specific issues that necessitate discussions with the overseeing regulatory agency include the following:

- Determination of exposure units/areas and hotspots;
- Soil exposure depths;
- Habitat exposure scenario development, including evaluation of hypothetical future land use (e.g., residential scenario with unrestricted use);
- Use of averaging;
- Background/ambient concentrations of chemicals (e.g., metals); and
- Bioavailability.

9. Methods: Leaching to Groundwater Screening Levels for Soil

The “soil leaching ESLs” presented in ESL Workbook Table S-3 provide for the protection of groundwater from leaching and migration of chemicals in vadose zone soil. Two categories of leaching screening levels (shown in the Tier 1 and Soil Summary ESL Tables) are calculated based on target groundwater ESLs for two broad groundwater use categories:

- Drinking Water Source – Tier 1 Groundwater ESLs, which are the lowest of all groundwater ESLs. Note that the Tier 1 ESLs do not consider Tapwater ESLs for chemicals with an MCL (i.e., MCL Priority as discussed in Section 3.1.2).
- Nondrinking Water Source – Lowest of the aquatic habitat screening level, gross contamination water screening level, groundwater vapor intrusion screening level, or non-drinking water odor nuisance screening level.

In addition, the ESL Workbook Table S-3 (Soil Leaching) contains soil leaching ESLs for some site-specific groundwater use categories that can be considered in Tier 2 risk assessments. The Tier 2 ESL Workbook screening tool (discussed in Section 2.4) can be used to determine which of the site-specific leaching ESLs is most applicable to a site. Section 9.4 (Site-Specific Evaluations) provides information for assessing leaching risks at site-specific scenarios not considered in the Tier 2 ESLs (e.g., No VI concern for sites where groundwater contamination is not beneath current or future buildings).

The soil leaching ESLs are intended for use as an indicator of potential threats to groundwater quality. In general, these ESLs should not be used as the sole line of evidence to screen out further evaluation of groundwater impacts because it can be difficult to find the location in soil where the contamination was transported to groundwater. As discussed in Section 9.4, direct sampling of groundwater is always preferred.

9.1. Leaching Model

The soil leaching level equation presented in Section 9.2 was developed by MADEP (1994a) using a method originally developed by Anderson (1992). The objective of these studies was to develop conservative soil leaching values that would minimize potential groundwater impacts at most sites. The efforts focused on organic contaminants because of the site-specific complexities (e.g., soil pH and redox potential) associated with inorganic contaminants.

9.1.1. Conceptual Model

The conceptual model developed by Anderson (1992) for the development of soil leaching values is illustrated in Figure 9-1. The model includes a three-meter (10 feet) thick vadose zone consisting of three layers of sand, each one meter thick. The middle layer is contaminated while the top and bottom layers are clean.

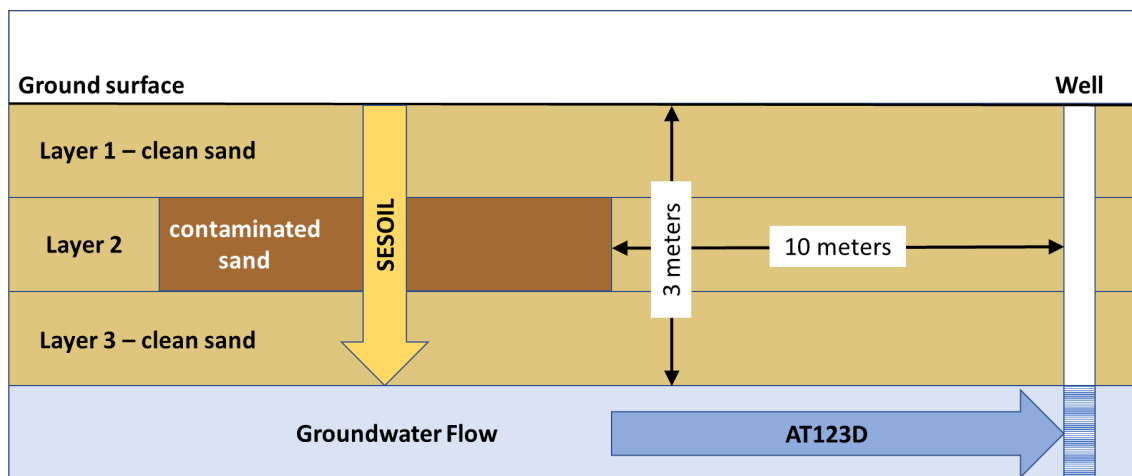


Figure 9-1: Conceptual Model for Soil Leaching ESLs

This conceptual model represents a site with limited soil contamination. The contaminated layer is 10 meters wide and 1 meter thick. The clean soil layer at the surface reduces the loss of volatiles and provides a more conservative estimate of the mass of volatile contaminants that could reach groundwater. After reaching groundwater, the contaminated leachate is mixed and transported 10 meters downgradient to a well.

The following are other important aspects of the overall conceptual model:

- The model applies only for organic chemicals, not inorganic chemicals (e.g., metals)
- Annual rainfall – 1,100 mm (about 43 inches). A total of 720 mm (28 inches) is assumed to infiltrate the ground surface and reach groundwater.
- Soil organic carbon – 0.1 percent
- Biodegradation is not considered
- Resorption and revolatilization of chemicals in the leachate are allowed based on chemical and soil properties used in the model
- Groundwater is assumed to flow at a moderate rate of 73 meters (28 feet) per year
- A chemical's concentration in leachate is further reduced about a factor of three by dilution and mixing with groundwater.

These assumptions were specifically used by MADEP (1994a) to generate the DAF equation (equation 11) discussed in the following section.

9.1.2. Generic Dilution-Attenuation Factor (DAF) Equation

A dilution-attenuation factor (DAF) can be used to predict the amount of attenuation that will occur as a contaminant leaches from soil into groundwater, as described in Section 9.2. Chemical-specific DAF values can be calculated using equation 11.

Equation 11:

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

where:

H = Henry's Law Constant (atm-m³/mol)
K_{oc} = organic carbon partition coefficient (cm³/g)

This equation was generated by MADEP (1994a) using an approach originally developed by Anderson (1992). This approach first uses mathematical models to predict the amount of soil leaching that would occur under the conditions defined by the given conceptual model. Input parameters for the models included annual precipitation, soil characteristics, aquifer parameters, and physical-chemical constants for the modeled contaminants. The only difference between the MADEP (1994a) and Anderson (1992) approaches were climate inputs, Boston for the former and Portland for the latter. The following two mathematical models were used in both approaches:

- **SESOIL** – The Seasonal Soil compartment model (SESOIL) is a one-dimensional screening model that simulates vertical transport in the unsaturated (vadose) zone to groundwater. The model considers transport and fate based on diffusion, adsorption, volatilization, biodegradation, cation exchange, and hydrolysis. The model was originally developed by Arthur D. Little, Inc. (1981) and subsequently modified. The version used by Anderson (1992) was dated 1987.
- **AT123D** – The Analytical Transient 1-, 2-, and 3-Dimensional Simulation of Waste Transport in the Aquifer System (AT123D) is a groundwater transport model. The model considers advection, dispersion, diffusion, adsorption, and biodegradation. AT123D was developed by Yeh (1981) and subsequently modified. Anderson (1992) used the version of this model dated 1985 to generate a one-dimensional groundwater transport model.

The two models were used in a software package that allowed for SESOIL output to be incorporated as input to AT123D.

MADEP (1994a) ran the models for eight contaminants. The ratio of the initial soil concentration input and the maximum groundwater concentration (at the water table surface) predicted using the models were compiled for each contaminant. This information was compared to the organic carbon partition coefficient (K_{oc}) and Henry's Law Constants (H) of each contaminant in order to determine the general relationship between a contaminant's physical-chemical constants and its ability to leach from soil to groundwater. The resulting relationship is defined by the above DAF equation.

9.2. Calculation of Soil Leaching Screening Levels

The soil leaching levels are calculated using one of the two following approaches depending on the contaminant's ability to sorb to soil.

9.2.1. Chemicals with Low to Moderate Soil Sorptivity

The soil leaching levels are calculated using the following soil leaching level equation 12.

Equation 12:

$$C_{\text{soil}} = C_{\text{gw}} \times \text{DAF} \times 0.001 \text{ mg}/\mu\text{g}$$

where:

C_{soil} = leaching based soil concentration (mg/kg)

C_{gw} = target groundwater screening level ($\mu\text{g}/\text{L}$)

DAF = dilution-attenuation factor; chemical-specific DAF input values are calculated using the DAF equation given in Section 9.1.2.

9.2.2. Chemicals with High Soil Sorptivity

For highly sorptive chemicals, the screening levels are set to each chemical's theoretical soil saturation (C_{sat}), which is described in Chapter 10. Examples of highly sorptive chemicals in the ESLs include benzo[a]pyrene, chlordane, DDT, dioxin, heptachlor, PCBs, pyrene, and toxaphene.

Highly sorptive chemicals are identified if both of the following chemical-specific criteria are true:

- Calculated C_{soil} is greater than 0.001 mg/kg; and
- K_{oc} is greater than 30,000 cm^3/gram .

The K_{oc} threshold of 30,000 cm^3/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 inputs 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 those expected for California, and therefore use of this threshold K_{oc} value for determination of highly sorptive chemicals in California is conservative.

9.3. Exceptions

9.3.1. Metals

Soil leaching ESLs were not developed for metals because leaching of metals from soil is highly dependent on the species of the metal present and the geochemical nature of the soil (e.g., pH, redox). At sites where physical-chemical conditions may promote enhanced leaching of metals and other chemicals from soils or waste piles, direct groundwater sampling or the use of laboratory-based leaching tests is recommended (see Section 9.4).

In contrast to the ESLs, the USEPA RSLs include soil leaching values for metals for resident soil to groundwater based on target groundwater levels for tapwater or the MCL. Development of the soil leaching RSLs for metals is based on pH-specific assumptions that should be confirmed when applying soil leaching RSLs for metals to a particular site. Further information is presented in the RSL User's Guide under "soil to groundwater" (USEPA 2024b).

9.3.2. Perchlorate

A soil leaching ESL was developed for perchlorate (ClO_4^-). Perchlorate is a salt, and is not sorptive, volatile, or biodegradable under normal conditions. Use of the SESOIL/AT123D approach was therefore not considered appropriate. As an alternative, the chemical partitioning model presented in the USEPA Soil Screening Level Guidance document (USEPA 1996b) was used (equation 13).

This model can be used to 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_{oc} and H' are presumed to be zero and the equation reduces to equation 14. The default water-filled porosity in the models is 0.15 and the default soil bulk density is 1.5 per Workbook Table IP-3. A dilution/attenuation factor of 20 was incorporated to account for mixing of leachate with groundwater (USEPA 1996a, 2001).

Equation 13:

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

Equation 14:

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

where:

C_{soil}	=	soil screening level for leaching concerns (mg/kg);
C_{water}	=	target dissolved-phase concentration (mg/L);
K_{oc}	=	organic carbon partition coefficient;
f_{oc}	=	fraction organic carbon in soil;
θ_w	=	water-filled porosity;
θ_a	=	air-filled porosity;
H'	=	dimensionless Henry's Law constant;
ρ_b	=	soil bulk density (g/cm ³);
DAF	=	dilution/attenuation factor

9.3.3. PFAS

Leaching ESLs were not calculated for PFAS since the current ESL leaching model does not account for the unique properties of PFAS. Specifically, PFAS are surfactants—the molecules include a hydrophobic end and a hydrophilic end. Many PFAS will self-assemble into films at the air-water interface, with the hydrophobic end of the molecule oriented towards the air and the hydrophilic end dissolved in the water. This behavior could significantly affect vadose zone transport. For example, soils with more air/water interfacial area available for PFAS partitioning could increase retention of PFAS (Anderson 2019). Groundwater should be sampled to determine if leaching has occurred when feasible. Alternatively, calculation of site-specific soil leaching screening levels using alternative leaching models can be considered, as discussed in Section 9.4 of the ESL User's Guide.

9.4. Site-Specific Evaluations

For sites where soil concentrations exceed the soil leaching ESL, the default assumption is that chemicals are being leached to groundwater until demonstrated otherwise via site-specific evaluation. Site-specific evaluations may be needed more often in the following cases where the SESOIL/AT123D approach has been shown to be more conservative:

- Leaching of highly volatile chemicals;
- Leaching of highly sorptive chemicals;

- Leaching of highly biodegradable chemicals;
- Sites where the first groundwater is significantly greater than one meter below the bottom of the contaminated soil.

Several options for site-specific evaluation are discussed below. Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

9.4.1. Calculate Leaching Screening Level for a Specific Groundwater Target Level

There may be situations where the user wishes to manually calculate a soil leaching to groundwater level for a specified groundwater target that represents a single concern (e.g., aquatic habitat ESL, tapwater ESL) rather than the drinking water or non-drinking water target categories that aggregate multiple targets or endpoints used in the Leaching ESLs. The following are instructions for the calculational of groundwater target specific leaching screening levels:

- Select the DAF for the target chemical from ESL Table S-3 or IP-1.
- Select the target groundwater concentration (C_{gw}) for the user's specific application.
- Multiply the $DAF \times C_{gw} \times 0.001$ mg/ μ g to calculate the chemical's soil leaching level.

9.4.2. Calculating Site Specific DAFs

DAFs address the mixing of contaminants leached from soil with groundwater and can be calculated by inputting site-specific parameters into the 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.

9.4.3. Groundwater Testing

For older release sites where groundwater is relatively shallow (e.g., less than 10 feet bgs), the preferred approach to evaluating soil leaching to groundwater is to conduct a

groundwater investigation. However, if the depth to groundwater is great (e.g., more than 100 feet bgs), site-specific evaluations might include fate and transport modeling and/or simulated leaching tests performed in a laboratory, with appropriate confirmation sampling.

9.4.4. Leachability Testing

The more common leachability testing 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 site groundwater. For inorganic constituents, the USEPA Leaching Environmental Assessment Framework (LEAF) methods should be considered (USEPA 2017a).

9.4.5. Evaluating Saturated Soils

Although the 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 from saturated zones will detect both contaminants sorbed to the soil matrix as well as dissolved in groundwater. Therefore, direct comparison to soil or groundwater screening levels may be inappropriate.

10. Methods: Gross Contamination Screening Levels for Groundwater and Soil

ESL Workbook Tables GW-4 (Water Gross Contamination) and S-4 (Soil Gross Contamination) include gross contamination screening levels for groundwater and soil. These screening levels are intended to help identify the potential presence of non-aqueous phase liquid (NAPL or “free product”). The generic CSM for the ESLs applies to development of these screening levels. These levels could be considered when evaluating source control measures.

10.1. Calculation of Gross Contamination Screening Levels

10.1.1. Groundwater

The gross contamination screening levels for groundwater rely on solubility to indicate the potential presence of NAPL. The selected threshold is one-half of the water solubility for each chemical or mixture. For chemicals where the threshold exceeds 50,000 µg/L, a maximum value of 50,000 µg/L is used to limit the amount of resource degradation (ESL Workbook Table GW-4, after MADEP 1994a).

10.1.2. Soil

The gross contamination soil ESLs are based on the theoretical saturation level of a chemical in soil (C_{sat} ; ESL Workbook Table S-4). As shown in equation 15, C_{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 the saturation of soil pore air have been reached (USEPA 1996b). Therefore, above these concentrations, contaminants are present as NAPL or pure phase solids (for liquids and solids respectively) which are generally more likely to migrate.

Equation 15:

$$C_{sat} = \frac{S}{\rho_b} [(K_d \times \rho_b) + \Theta_w + (H \times \Theta_a)]$$

where:

S = Solubility

ρ_b = Dry Soil Bulk Density

K_d = Soil-Water Partition Coefficient

Θ_w = Water Filled Soil Porosity

H = Henry's Law Constant

Θ_a = Air Filled Soil Porosity

Gross contamination ESLs do not address risk from “residual NAPL,” which is the proportion of NAPL that becomes adsorbed in soil pores and is immobile due

to capillary forces. Residual NAPL can also be referred to as “discontinuous NAPL” (USEPA 1995b). Since residual NAPL is immobile it only poses a risk within its immediate vicinity. Those risks are addressed by the direct exposure and odor nuisance ESLs.

10.2. Exceptions

The only exceptions to the methodology described above are for petroleum hydrocarbon mixture ESLs for soil. For chemical mixtures such as petroleum hydrocarbon fuels and oils that are fractionally soluble in water, C_{sat} values calculated using equation 15 above significantly underestimate the concentration where there is mobile or migrating NAPL because it does not consider effective solubility or vapor pressure (Brost and DeVaul 2000). In addition, the proportion of immobile residual petroleum NAPL is dependent on many factors related to the characteristics of the mixture (e.g., viscosity, density) and soils (e.g., pore sizes) (USEPA 1995b). In finer-grained soils, residual saturation values are higher because there is greater surface area for capillary forces to hold NAPL in place. Therefore, to address these issues and provide a more reasonable estimate of petroleum mobility, the C_{sat} (or residual saturation) values used for the TPH gross contamination soil ESLs correspond to values developed in Brost and DeVaul (2000) based on coarse gravel saturation:

- 1,000 mg/kg (Petroleum-Gasoline);
- 2,300 mg/kg (Petroleum-Stoddard Solvent, Petroleum-Jet Fuel, and Petroleum-Diesel; the diesel value is applied to the other two mixtures as a surrogate); and
- 5,100 mg/kg (Petroleum-Motor Oil).

10.3. Site-Specific Evaluations

For sites where groundwater or soil concentrations exceed the gross contamination ESL, the default assumption is that NAPL is present and potentially mobile.

Several options for site-specific evaluations are discussed below. Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

Typically, site-specific evaluations for the presence of NAPL might include installing monitoring wells to assess the thickness of light NAPL (LNAPL; e.g., petroleum hydrocarbon mixtures) that will float on the groundwater due to lower density. Previously, field methods for finding the thickness of dense NAPL

(DNAPL; e.g., chlorinated solvent mixtures) have been less successful (Einarson et al. 2018).

Other methods for finding petroleum NAPL have included laser-induced fluorescence, which fluoresces in response to aromatic hydrocarbon content (USEPA 1997). DyeLIF is a new technology that can be used for chlorinated solvent NAPLs (Einarson et al. 2018).

Site-specific evaluations of residual saturation for petroleum hydrocarbons can also be conducted (USEPA 1996d).

11. **Methods: Taste and Odor Nuisance Screening Levels for All Media**

The ESLs consider potential nuisance conditions for humans due to unpleasant tastes in groundwater or unpleasant odors in groundwater, soil gas, soil, and indoor air resulting from site contamination. The “nuisance” ESLs are presented in four ESL Workbook tables where the exposure point is groundwater (Workbook Table GW-5), soil (Workbook Table S-5), and indoor air (Workbook Table SG-2 and IA-2).

11.1. **Background**

Aesthetic concerns such as taste and odor are addressed in the State Water Resources Control Board Division of Drinking Water (DDW) and USEPA Secondary MCLs for select chemicals and general water quality parameters (e.g., pH, total dissolved solids, odor); these are also known as “consumer acceptance contaminant levels.” The Basin Plan requires that waters shall not contain taste- or odor-producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible products of aquatic origin, that cause nuisance (e.g., concentrations above secondary MCLs), or that adversely affect beneficial uses.

General methods used for taste and odor determinations under the Safe Drinking Water Act include Standard Method 2160 for taste and 2150 for odor (APHA 2017). These are sensory methods that provide an assessment of the presence or absence of flavor or odor to human panelists.

Much of the research regarding odors has been conducted in the context of drinking water, industrial hygiene for worker protection or, more recently, in understanding the cause and methods to mitigate odors from landfills, wastewater treatment plants, composting facilities and other agricultural activities (e.g., animal housing facilities). Findings from work at these types of facilities indicate the following are the primary odorous compounds (Iowa State University 2004; ALS Environmental 2019):

- Amines (nitrogenous compounds; examples trimethylamine, dimethylamine, butylamine) – produced by high temperature processes and microbial decomposition of amino acids
- Ammonia – commonly co-occurs with amines and is the result of aerobic and anaerobic decomposition, typically landfills, wastewater treatment plants (untreated sewage), composting, and animal waste
- Carboxylic acids (volatile fatty acids or organic acids; examples include acetic, propanoic, butyric, valeric, and isovaleric acids) – Associated with agricultural activities, landfills, wastewater treatment plants and composting. Carbohydrates in animal waste include sugars, starch, and cellulose. Starch and cellulose are broken into glucose (sugar) units as the

first step of decomposition. Under anaerobic conditions, sugars are broken into alcohols, aldehydes, ketones, and organic acids. These compounds are odorous and can be further metabolized and transformed into methane, carbon dioxide, and water (non-odorous end-products) if conditions allow the methane-producing microorganisms to function.

- Reduced sulfur compounds
- VOCs (e.g., terpenes, phenols, high molecular weight aldehydes and alcohols)

Odors are typically measured by using air samples diluted with non-odorous air or headspace air samples over water diluted with non-odorous water, which are then presented to human panelists for odor detection and/or recognition. The odor threshold or detection threshold is a term used to identify the concentration at which 50% of panelists can identify the presence of an odor or odorant without identifying the odor. The recognition threshold is the concentration at which 50% of panelists can identify the odorant or odor.

11.2. Groundwater Taste and Odor Nuisance Thresholds

The conceptual model for potential nuisance conditions in groundwater considers both taste and odor through the same exposure pathways described in Chapter 3 (groundwater used as tapwater for common domestic activities, such as drinking, bathing/showering, cooking, dishwashing/laundry, and flushing the toilet) and Chapter 7 (contaminated groundwater migrates toward and discharges into a body of surface water). The groundwater nuisance odor ESLs are presented in ESL Workbook Table GW-5. The application of these ESLs to a cleanup site implies that there is a discharge to surface water or that a well screened across a zone of groundwater contamination is the source of tapwater. Consideration of this exposure pathway should always be included when the designated beneficial uses of the groundwater include drinking water. Note that odor transport from in-situ groundwater to indoor air via the vapor intrusion pathway is not considered.

11.2.1. Sources of Taste and Odor Threshold Values

Source of taste and odor threshold values are listed below.

- DDW Secondary MCLs – These criteria are promulgated in California Code of Regulations Title 22, Division 4, Chapter 15, Article 16. These values are not to be exceeded in the water supplied to the public by community water systems. The Secondary MCLs also include an Odor Threshold with a value of three threshold odor units, which is the total volume of both the original sample and added blank (odorless) water divided by the total volume.
- USEPA Secondary MCLs – USEPA has established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 contaminants related to aesthetic considerations, such as

taste, color, and odor. These levels are intended to assist public water systems in managing their drinking water.

- DDW Drinking Water Notification Levels – Formerly called “Action Levels” through 2004, notification levels are health-based advisory levels established for chemicals in drinking water that lack MCLs. When chemicals are found at concentrations greater than their notification levels, certain requirements and recommendations apply. Further information is available in “Drinking Water Notification Levels and Response Levels: An Overview” (DDW 2018).
- Odor Thresholds from MADEP (1994a) and MOEE (1996) – These guidance documents include water-dilution odor thresholds for groundwater and air-dilution odor thresholds for air.
- Odor Thresholds from State Water Board (2016) – This guidance includes water-dilution odor thresholds from various sources.

Most of the nuisance criteria used in the ESLs are based on odor considerations. However, the contaminants in the ESLs with Secondary MCLs related to taste include copper and zinc.

11.2.2. Hierarchy for Taste and Odor Nuisance Thresholds

A hierarchy for the different taste and odor thresholds available for groundwater is presented in Table 11-1. ESL Workbook Table GW-5 presents nuisance taste and odor screening levels for two categories of groundwater use: drinking water resource and non-drinking water resource. The hierarchy is used in selecting criteria for each category. For the drinking water resource category, criteria are selected from the highest available tier. For the non-drinking water resource criteria, criteria are selected starting with Tier 3.

Table 11-1: Hierarchy of Taste and Odor Thresholds for Groundwater

Tier	Source
1	Division of Drinking Water (DDW) Secondary MCLs
2	USEPA Secondary MCLs
3	DDW Taste and Odor Action Levels
4	Water-dilution odor thresholds presented in Massachusetts DEP (MADEP 1994a) and Ontario MOEE (MOEE 1996) guidance documents
5	Water-dilution odor thresholds (State Water Board 2016)

11.3. Soil Odor Nuisance Thresholds

The conceptual model for potential nuisance conditions in soil considers odor through the same exposure pathway described in Chapter 3: via intrusive activities such as landscaping or digging and inhalation of vapors released from the soil. Consequently, the soil nuisance odor ESLs are presented in ESL Workbook Table S-5.

A chemical's potential to cause nuisance odors is dictated by its volatility and potency of its odor. A chemical's vapor pressure (in Torr, at 20-30 degrees Celsius) can be used to assess relative volatility, and its odor-recognition threshold can be used to assess relative potency of the chemical's odor. These are used to derive an Odor Index, which is a relative ranking of a chemical's potential to cause nuisance odors, in the following equation 16 (MADEP 1994a):

Equation 16:

$$\text{Odor Index} = \frac{\text{Vapor Pressure}}{\text{Odor Recognition Threshold}}$$

where:

vapor pressure = Torr at 20 to 30 degrees Celsius

odor recognition threshold = $\mu\text{g}/\text{m}^3$

Values and sources for vapor pressure and odor recognition threshold for each chemical are listed in ESL Workbook Table IP-1. Using the Odor Index and vapor pressure values allows the assignment of specific upper limit soil contamination levels based on land use in accordance with Table 11-2 (MADEP 1994a). These upper limit levels were used as the final odor nuisance soil ESLs.

Table 11-2: Criteria for Assignment of Odor Upper Limit Levels for Soil

Land Use, Soil Exposure Depth	Odor & Volatilization Criteria	Upper Limit Level (mg/kg)
Residential, Shallow Soil	Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr	100
Residential, Shallow Soil	$0.1 \leq \text{Odor Index} < 100$	500
Residential, Shallow Soil	Odor Index ≤ 0.1	1,000
Commercial/ Industrial, Shallow Soil	Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr	500
Commercial/ Industrial, Shallow Soil	$0.1 \leq \text{Odor Index} < 100$	1,000
Commercial/ Industrial, Shallow Soil	Odor Index ≤ 0.1	2,500
Any Land Use, Deep Soil	Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr	500
Any Land Use, Deep Soil	$0.1 \leq \text{Odor Index} < 100$	1,000
Any Land Use, Deep Soil	Odor Index ≤ 0.1	2,500

11.4. Indoor Air and Soil Gas Odor Nuisance Thresholds

The conceptual model for potential nuisance conditions in indoor air considers odor transport from vapors in soil (soil gas) via the vapor intrusion pathway (soil gas nuisance odor ESLs in ESL Workbook Table SG-1) and direct exposure in indoor air (indoor air nuisance odor ESLs in ESL Workbook Table IA-2).

Odor-based ESLs for indoor air reflect the 50 percent odor-recognition thresholds described for soil screening levels. For soil gas, the 50 percent odor thresholds were divided by the generic soil gas attenuation factor of 0.03 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 5).

11.5. Exceptions

Although Petroleum HOPs are considered to be relatively nonvolatile, experienced field staff have reported the presence of odors during excavations of petroleum-contaminated soil at older (weathered) release sites. It is suspected the odors are the result of the generation of volatile carboxylic acids during anaerobic biodegradation. Therefore, the nuisance odor ESL for Petroleum-Diesel are used as a surrogate for the Petroleum-HOPs nuisance groundwater ESL.

11.6. Site-Specific Evaluations

For sites where media concentrations exceed the odor thresholds, the default assumption is that there is the potential for nuisance odor conditions.

Several options for site-specific evaluations are discussed below. However, such site-specific evaluations have yet to be performed under Regional Water Board staff oversight. Alternative approaches will be considered, provided there is adequate technical justification. For regulatory review, either a detailed work plan should be submitted, or a thorough scoping meeting conducted before completing the evaluation or submitting a report of findings. This important step reduces the likelihood of unnecessary and costly work and greatly improves the likelihood of regulatory concurrence.

11.6.1. Field Investigations of Potential Nuisance Odor Condition

Potential options for field investigations might include a site inspection(s) to assess nuisance odor conditions at ground surface or in buildings under ambient conditions or intrusive investigations (e.g., trenching) to assess potential conditions during future subsurface work (e.g., excavations, utility emplacement or repair). The use of field screening devices (e.g., a scentometer such as the Nasal Ranger or other tool) could be considered.

Water samples could be collected for evaluation for the potential odors via human panelists (e.g., Standard Method 2150, ASTM D1292-15, or other suitable methods) or by analyzing for specific potential odorants.

Similarly, air or soil gas samples might be collected for the potential odors via human panelists (e.g., ASTM E679-04 or other suitable methods) or for specific potential odorants using Draeger tubes or other methods.

As discussed in Section 11.1, specific potential odorants include amines, ammonia, volatile carboxylic acids, reduced sulfur compounds, and VOCs. Potential analytical methods for such investigations are discussed in the brochure “Odor Testing” (ALS Environmental 2019).

11.6.2. Attenuation of Petroleum Vapors and Odors

As discussed in Attachment 2 of the SVIG (DTSC and State Water Board 2023), aerobic biodegradation in the vadose zone can significantly reduce concentrations of petroleum vapors, presumably the cause of the odors. Provided there is adequate characterization of the distribution and extent of soil impacts and, in addition, biodegradation is demonstrated to be sufficiently attenuating petroleum vapors, an appropriate bioattenuation factor, as discussed in Attachment 2 of the SVIG, can be applied to evaluate the potential for nuisance odors emitted from soil to impact outdoor air and to impact indoor air via soil gas. When adjusting the nuisance odor soil ESLs, the Odor Index should be adjusted by application of an appropriate bioattenuation factor, as discussed in the SVIG, and then selecting the land use-based limit for soil in accordance with Table 11-2.

Soil gas samples can additionally be analyzed for odorants potentially associated with the petroleum mixture (e.g., reduced sulfur compounds for less refined fuels/oils and crude oil) and anaerobic biodegradation (e.g., reduced sulfur compounds, volatile carboxylic acids).

12. Additional Considerations

12.1. Multiple Chemical Species

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 (Cr III or Cr^{3+}) and chromium VI (Cr VI or Cr^{6+}). In addition, some chemicals can have various ionic charges depending on their protonation state at a given pH, such as cyanide (HCN versus CN^-). The charge of these chemicals can change when the chemicals partition 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.

12.1.1. Cyanide

The ESLs are based on the most toxic form, which is the protonated form (HCN) versus the negatively charged form (CN^-).

12.1.2. Chromium

The ESLs include screening levels for both Cr III and Cr VI, which are both naturally occurring forms of chromium and inter-convertible in the environment (OEHHA 2011). Cr VI is the more toxic species with both carcinogenic toxicity (including a mutagenic mode of action) and noncarcinogenic toxicity (USEPA 2005). Cr III only has noncarcinogenic toxicity and has much higher screening levels than Cr VI.

The ESLs do not include risk-based soil screening levels for total chromium. Since there is no set ratio for proportions of the different forms of chromium in the environment, screening levels for total chromium can give a false sense of security if they assume lower levels of Cr VI than are actually present at a site. Therefore, we recommend that the concentration of Cr VI (the most toxic species) or both species be measured for comparison to risk-based screening levels. For older data sets where speciation was not performed, it would be prudent to conduct some sampling to ascertain the concentrations of the different forms present. Currently, the MCL for chromium in drinking water is 50 $\mu\text{g/L}$ for total Cr, which is well above the risk-based level for Cr VI.

12.2. Chemicals Without ESLs

ESLs for chemicals or mixtures not included can be developed in consultation with the overseeing regulatory agency if sufficient information is available (e.g., toxicity values, physical/chemical constants). As an initial step, consult DTSC Human Health Risk Assessment Note 3 (DTSC-modified screening

levels), and then the USEPA RSLs and VISLs because these agencies maintain screening levels for more chemicals. These screening levels are briefly described in Section 1.4.

Keep in mind that the lack of a risk-based ESL does not mean that nothing needs to be done or that there is no concern at any level. If this situation arises, close consultation and coordination with the Regional Water Board or overseeing regulatory agency is strongly advised. In California, no one has a vested right to discharge chemicals to the groundwaters or surface waters of the state.

12.3. Chemical Degradation and Generation of Transformation Products

Considering the degradation of a chemical (“parent compound”) to toxic breakdown products (“daughter products”) is an important aspect of site investigation. Living organisms including microorganisms present in environmental media, break down organic molecules in several steps and some intermediates may be relatively persistent and contribute to the toxicity of the release. 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 geochemistry, which affect the nature of the resident microbial populations). In most cases, both the parent compound and daughter products are present together; therefore, the cumulative risk should be considered as described in Section 3.5. Transformative processes are sometimes distinguished from destructive processes. The processes can be described as follows (NJDEP 2016):

- Transformative processes can be biotic or abiotic and result in a net change of chemical composition and accompanying changes in contaminant toxicity and/or mobility. Examples of such processes are microbially mediated dechlorination reactions found in reducing environments. Transformative processes may result in a toxicity decrease or increase. One of the better-known 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, whereas dichloroethene is less toxic than the parent compounds. Another example is the biotransformation of mercuric ions to methylmercury, which is much more toxic than the parent contaminants.
- Destructive processes can be biotic or abiotic and result in net mineralization (i.e., breakdown of the compound to carbon dioxide, water, and other inorganic metabolites). Transformative changes can be part of a sequential series of reactions leading to destructive processes.

12.4. 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.

The natural background concentration of a chemical can vary substantially between sites, or even within a single site (e.g., soil type, geochemical conditions) for soil or groundwater. For instance, background concentrations of barium, boron, copper, lead, mercury, selenium, thallium, and zinc in groundwater, exceeding the aquatic habitat ESLs, have been reported in the Bay Area.

For situations where naturally occurring background concentrations exceed an ESL (see arsenic section in this chapter), it could be appropriate to substitute the background concentration for the ESL to the extent consistent with Resolution 92-49, and this is a site-specific decision that should be made in consultation with the overseeing regulatory agency. For quantitative risk assessments, USEPA recommends that background be carried through and included in the cumulative risk assessment because knowledge of background risks can help community members to put chemical risks from site releases in perspective. However, it is not appropriate to require cleanup to concentrations below the naturally occurring background concentrations.

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. Documents that may be useful for distinguishing concentrations of chemicals in soil and groundwater from background include:

- Selecting Inorganic Constituents as Chemicals of Potential Concern at Risk Assessments at Hazardous Waste Sites and Permitted Facilities (DTSC 1997)
- HERO HHRA Note 4 (DTSC 2016b) includes updated recommendations regarding the evaluation of background. Specifically, Note 4 recommends

both site-related risk and hazard and background-related risk and hazard be calculated, consistent with USEPA (2002c).

- Engineering Forum Issue Paper: Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites (USEPA 1995a);
- Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites (USEPA 2002c)

Concentrations of naturally occurring metals should be considered on a site-by-site-basis. All reasonable efforts should be made to measure site-specific background levels.

There are several sources for published background values for metals that could be considered for sites in the region. These are listed in Table 12-1 for the user's convenience and are not an unrestricted endorsement. Identification and selection of appropriate background values for a specific site should be discussed with the overseeing regulatory agency.

Table 12-1: Publications Regarding Naturally Occurring Background Levels

Year	Title and Author
1984	Elemental Concentrations in Soils and Other Surficial Materials of the Conterminous United States (USGS)
1991	Background Metal Concentrations in Soils in Northern Santa Clara County (Scott)
1996	Background Concentrations of Trace and Major Elements in California Soils (Kearney Foundation of Soil Science)
2009	Analysis of Background Distributions of Metals in the Soil at Lawrence Berkeley National Laboratory (Lawrence Berkeley National Laboratory)
2011	Establishing Background Arsenic in Soil of the Urbanized San Francisco Bay Region (Duvergé)

12.4.1. Example: Naturally Occurring Arsenic

Arsenic concentrations in site soils typically exceed risk-based screening levels (e.g., residential direct contact soil is 0.032 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 in similar urbanized flatland areas in consultation with the overseeing regulatory agency.

12.4.2. Example: Anthropogenic Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs), discussed in Chapter 3, 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, manufactured gas plant residues) 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.

12.5. Sediment Screening Levels

ESLs are not derived for sediment¹² because Regional Water Board staff recommends that sediment be evaluated based on sediment chemistry, toxicity tests, and condition of the benthic community in a multiple lines of evidence approach. Consequently, the evaluation of sediment can be challenging. In addition, sediment environments are more dynamic; sediments can be moved, be buried, or eroded over time. This introduces a temporal component atypical of upland soils.

Table 12-2 provides a list of some documents with sediment criteria or pertinent information for deriving sediment criteria. These are provided for the user's convenience and are not an unrestricted endorsement. Identification and selection of appropriate sediment criteria for a specific site should be discussed with the overseeing regulatory agency.

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 petroleum gasoline and 144 mg/kg petroleum fuel oil (diesel range) were developed based on toxicity tests using amphipods (IT Corporation 1997).

¹² 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.

Table 12-2: Sediment Chemical Criteria or Relevant Guidance

Year	Title and Author
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. <i>Environmental Management</i> 19(1): 81-97.
1996a	ECO Update: <i>Ecotox Thresholds</i> (USEPA)
1997	Preliminary Remedial Goals for Ecological Endpoints (USDOE)
2000a	Draft Staff Report – Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines (Regional Water Board)
2003a	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)
2012d	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)

12.6. Laboratory Data Issues

12.6.1. Detection Limits and Reporting Limits

Method detection limits¹³ and laboratory reporting limits¹⁴ for individual chemicals are 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

¹³ 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.

¹⁴ 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.

drivers), alternate low-detection-level methods may be appropriate. For determining a reasonable laboratory reporting limit to substitute as the screening level for a given chemical, the following approach is suggested, but ultimately should be approved by the overseeing regulatory agency: obtain reporting levels from three laboratories and use either the lowest or the median level, considering appropriate factors (e.g., protectiveness, cost, etc.)

12.6.2. Soil Data Reporting: Dry Weight Basis

All soil data should be reported on a dry-weight basis. This is because soil ingestion rates assumed in direct-exposure models are based on dry-weight studies (USEPA 1997b). 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 the California Total Threshold Limit Concentrations, which are used for waste classification purposes (see Chapter 1), are in wet weight format.

12.7. Physical Hazards

The ESLs do not address physical hazards such as asphyxiation or fire and explosions. Nevertheless, methane and explosion hazards potentially can be encountered during site investigations due to biodegradation of petroleum releases and gasoline releases, respectively. Brief discussions are provided below.

12.7.1. Methane

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 and the vapor pressure gradient in soil to assess potential methane formation and flux into a structure.

12.7.2. Explosion Hazards

The ESLs do not consider explosion hazards. One source for Lower Explosive Limit/LEL and Upper Explosive Limit/UEL values is NIOSH (2007).

12.8. 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 to the water quality impairment. TMDLs adopted for the San Francisco Bay region are listed on the Regional Water Board's website.¹⁵ 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 should be reduced to an average of 1 µg/kg, again, a ten-fold decrease. The fact sheet “San Francisco Bay PCBs TMDL – Implementation at Cleanup & Spill Sites” discusses how the PCB sediment TMDL relates to upland soil cleanup sites (Regional Water Board 2017a). Regional Water Board staff recommends the use of

¹⁵

http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/

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). These lower detection limits 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 is much lower than the direct contact soil ESL for PCBs.

13. References

The references listed in this section are cited in the User's Guide, Workbook, or the Frequently Asked Questions.

ALS Environmental. 2019. Analytical Methods for Odor Investigations: Carboxylic Acids, Amines, Reduced Sulfur Compounds and VOC Screen. Accessed March 20. ([Webpage](#))

Amoore J. E. and Hautala E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. *Journal of Applied Toxicology* 3: 272-290. December.

Anderson, M. 1992. Development of Generic Soil Clean-up Levels Based on Analysis of Leachate Pathway. Environmental Clean-up Division, Department of Environmental Quality, State of Oregon.

APHA [American Public Health Association]. 2017. Standard Methods for the Examination of Water and Wastewater.

ANL (Argonne National Laboratory), Air Force Civil Engineer Center, U.S. Department of Energy. 2024. Derivation of PFAS Ecological Screening Values. October.

Arp, Hans Peter H., Christian Niederer, and Kai-Uwe Goss. 2006. Predicting the Partitioning Behavior of Various Highly Fluorinated Compounds. *Environmental Science and Technology* 40(23): 7298-7304.

Arthur D. Little, Inc. 1981. SESOIL: A Seasonal Soil Compartment Model. Prepared for USEPA (prepared by M. Bonazountas and J. Wagner). December.

ASTM (American Society of Testing and Materials). 2015. D1292-15 – Standard Test Method for Odor in Water.

ASTM E679-04. 2011. Standard Practice for Determination of Odor and Taste Thresholds By a Forced-Choice Ascending Concentration Series Method of Limits.

Atlantic PIRI [Partnership in Risk-Based Corrective Action]. 2012. Atlantic RBCA for Petroleum-Impacted Sites in Atlantic Canada, Version 3, User Guidance. July.

Atlas, R. M. 1981. Microbial Degradation of Petroleum Hydrocarbons: An Environmental Perspective. *Microbiol. Rev.* 45 (1), 180–209.

- ATSDR [Agency for Toxic Substances and Disease Registry]. 1994. Toxicological Profile for Chlordane. U.S. Department of Health and Human Services, Public Health Service. May.
- ATSDR. 1995a. Toxicological Profile for Fuel Oils. U.S. Department of Health and Human Services, Public Health Service. June.
- ATSDR. 1995b. Toxicological Profile for Gasoline. U.S. Department of Health and Human Services, Public Health Service. June.
- ATSDR. 1995c. Toxicological Profile for Stoddard Solvent. U.S. Department of Health and Human Services, Public Health. June.
- ATSDR. 1995d. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. U.S. Department of Health and Human Services, Public Health Service. August.
- ATSDR. 1999. Toxicological Profile for Total Petroleum Hydrocarbons (TPH). U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. September.
- ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). U.S. Department of Health and Human Services, Public Health Service. November.
- ATSDR. 2002. Toxicological Profile for DDT, DDE, and DDD. U.S. Department of Health and Human Services, Public Health Service. September.
- ATSDR. 2012. Chemical-Specific Health Consultation for Joint EPA/ATSDR National Mercury Cleanup Policy Workgroup: Action Levels for Elemental Mercury Spills. Division of Toxicology and Environmental Medicine, Prevention, Response and Medical Support Branch Emergency Response Team. March 22.
- ATSDR. 2015. Toxicological Profile for Endosulfan. U.S. Department of Health and Human Services. Public Health Service. August.
- ATSDR. 2017. Toxicological Profile for JP-5, JP-8, and Jet A Fuels. U.S. Department of Health and Human Services. Public Health Service. March.
- Barron, M.G., T. Podrabsky, S. Ogle, and R.W. Ricker. 1999. Are Aromatic Hydrocarbons the Primary Determinant of Petroleum Toxicity to Aquatic Organisms? *Aquatic Toxicology* 46:253–268.
- Bekins, B.A., I.M. Cozzarelli, M.L. Erickson, R.A. Steenson, and K.A. Thorn. 2016. Crude Oil Metabolites in Groundwater at Two Spill Sites. *Groundwater*, 54(5), 681-691. DOI:10.1111/gwat.12419.

- Bekins, B. A. and Cozzarelli, I. M. 2017. Nonvolatile dissolved organic carbon and diesel range organics concentrations measured in 2016 at the USGS crude oil study site near Bemidji, Minnesota, USA. U. S. Geological Survey Data Release. ([Webpage](#))
- Boehm, P.D. 2006. Polycyclic Aromatic Hydrocarbons (PAHs) in Environmental Forensics—Contaminant Specific Guide. Edited by B.L. Murphy and R.D. Morrison. Elsevier. pp. 313-334.
- Booth, A.M., P.A. Sutton, C.A. Lewis, A.C. Lewis, A. Scarlett, W. Chau, J. Widdows, and S.J. Rowland. 2007. Unresolved Complex Mixtures of Aromatic Hydrocarbons: Thousands of Overlooked Persistent, Bioaccumulative, and Toxic Contaminants in Mussels. *Environmental Science and Technology*, 41, pp. 457-464.
- Brack W. 2003. Effect-Directed Analysis: A Promising Tool for the Identification of Organic Toxicants in Complex Mixtures. *Analytical and Bioanalytical Chemistry* 377:397-407.
- Brewer, R., Nagashima, J., Kelley, M. and M. Rigby. 2013. Risk-Based Evaluation of Total Petroleum Hydrocarbons in Vapor Intrusion Studies: *International Journal of Environmental Research and Public Health*, Volume 10, pp 2441-2467. June.
- Brost, E.J. and G.E. DeVaul. 2000. Non-Aqueous Phase Liquid (NAPL) Mobility Limits in Soil. *Soil and Groundwater Research Bulletin No. 9*. American Petroleum Institute. June.
- Burns & McDonnell Waste Consultants, Inc. 1997. Aquatic Toxicity of Petroleum Products (Task 3B) at the San Francisco International Airport, San Mateo County. March.
- Burns & McDonnell Waste Consultants, Inc. 1999. Toxicity Test of Jet A Fuel to Mysids. March 26.
- CalEPA [California Environmental Protection Agency]. 2005. Use of California Human Health Screening Levels (CHHSLs) in Evaluation of Contaminated Properties. California Environmental Protection Agency. January.
- CalEPA. 2015. Advisory – Active Soil Gas Investigations. California Environmental Protection Agency, Department of Toxic Substances Control, Los Angeles Regional Water Quality Control Board, and San Francisco Bay Regional Water Quality Control Board. July.
- Carney, M.W., K. Erwin, R. Hardman, B. Yuen, D.C. Volz, D.E. Hinton, and S.W. Kuhlman. 2008. Differential Developmental Toxicity of Naphthoic Acid Isomers in Medaka (*Oryzias latipes*) Embryos. *Marine Pollution Bulletin*, vol. 57, pp. 255-266.

- CCME [Canadian Council of Ministers of the Environment]. 2008. Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale.
- Chadwick B. and A. Hawkins, 2008. Monitoring of Water and Contaminant Migration at the Groundwater-Surface Water Interface (ER200422) – Final Report, SPAWAR Systems Center San Diego Technical Report 1967. January.
- Chaplin, B.P., G.N. Delin, R.J. Baker, and M.A. Lahvis. 2002. Long-Term Evolution of Biodegradation and Volatilization Rates in a Crude Oil-Contaminated Aquifer. *Bioremediation Journal*, 6:3, 237 — 255.
- Chibwe, L., M.C. Geier, J. Nakamura, R.L. Tanguay, M.D. Aitken, S.L.M. Simonich. 2015. Aerobic Bioremediation of PAH Contaminated Soil Results in Increased Genotoxicity and Developmental Toxicity. *Environ. Sci. Technol.* 2015, 49 (23), 13889–13898.
- Cole, S., I.D. Codling, W. Parr and T. Zabel. 1999. Guidelines for Managing Water Quality Impacts within UK European Marine Sites. Prepared for the United Kingdom Marine Special Areas of Conservation (SAC) Project. October.
- Cozzarelli, I.M., M.E. Schreiber, M.L. Erickson, and B.A. Ziegler. 2015. Arsenic Cycling in Hydrocarbon Plumes: Secondary Effects of Natural Attenuation. *Groundwater*, pp. 1-11.
- DDW (State Water Resources Control Board – Division of Drinking Water). 2018. Drinking Water Notification Levels and Response Levels: An Overview. California Environmental Protection Agency, State Water Board. July 13.
- Divine, C., J. Zodrow, M. Frenchmeyer, K. Dally, D. Osborn, P. Anderson. 2020. Approach for Assessing PFAS Risk to Threatened and Endangered Species. SERDP Project ER18-1653. March 31.
- DTSC [Department of Toxic Substances Control]. 1996a. Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities; Part A Overview. California Environmental Protection Agency, DTSC. July 4.
- DTSC. 1996b. Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities; Part B Scoping Assessment. California Environmental Protection Agency, DTSC. July 4.
- DTSC. 1997. Selecting Inorganic Constituents as Chemicals of Potential Concern at Risk Assessments at Hazardous Waste Sites and Permitted Facilities. California Environmental Protection Agency, DTSC. February.
- DTSC. 1998. HERO Ecological Risk Assessment Note 1 – Depth of Soil Samples Used to Set Exposure Point Concentration for Burrowing Mammals and

Burrow-Dwelling Birds in an Ecological Risk Assessment. California Environmental Protection Agency, DTSC, Human Health and Ecological Risk Office. May 15.

DTSC. 2002. Response Actions for Sites Where Future Uses May Include Sensitive Uses. California Environmental Protection Agency, DTSC, Site Mitigation and Brownfields Reuse Program, Management Memo EO-02-002-MM (July 10, 2002).

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

DTSC. 2009. Use of the Northern and Southern California Polynuclear Aromatic Hydrocarbon (PAH) Studies in the Manufactured Gas Plant Site Cleanup Process. California Environmental Protection Agency, DTSC. July 1.

DTSC. 2011b. Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance). California Environmental Protection Agency, DTSC. October.

DTSC. 2011c. Final Vapor Intrusion Mitigation Advisory, Revision 1. California Environmental Protection Agency, DTSC. October.

DTSC. 2012. Evaluation of Biogenic Methane: A Guidance Prepared for the Evaluation of Biogenic Methane in Constructed Fills and Dairy Sites. California Environmental Protection Agency, DTSC. March 28.

DTSC. 2015. Preliminary Endangerment Assessment Guidance Manual. California Environmental Protection Agency, DTSC. October.

DTSC. 2016a. Human Health Risk Assessment Note 6, Issue: Recommended Methodology for Evaluating Site-Specific Arsenic Bioavailability in California Soils. California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). August 22.

DTSC. 2016b. Human Health Risk Assessment Note 4, Issue: Screening Level Human Health Risk Assessments. California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). October 26.

DTSC. 2017. Human Health Risk Assessment Note 2 – Interim, Issue: Remedial Goals for Dioxins and Dioxin-like Compounds for Consideration at California Hazardous Waste Sites. California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). April.

- DTSC. 2018. Final Statement of Reasons: Toxicity Criteria for Human Health Risk Assessments, Screening Levels, and Remediation Goals. California Environmental Protection Agency, DTSC. September 4. ([Webpage](#))
- DTSC. 2021. Human Health Risk Assessment Note 12, Guidance for Evaluating Human Health Risk at Sites Contaminated by Petroleum Hydrocarbons and Related Chemicals of Potential Concern (COPC). California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). June.
- DTSC. 2024. LeadSpread 9.1 – Information for Users. California Environmental Protection Agency, California DTSC, Office of Human and Ecological Risk (HERO). December.
- DTSC. 2025a. 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. California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). April.
- DTSC. 2025b. Human Health Risk Assessment Note 3, Issue: DTSC-modified Screening Levels (DTSC-SLs). California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). April.
- DTSC. 2025c. Human Health Risk Assessment Note 10 Toxicity Criteria, Issue: Required Toxicity Criteria under sections (§) 69021(a), (b), and (c) of the Toxicity Criteria for Human Health Risk Assessments, Screening Levels, and Remediation Goals Rule and Specification of DTSC-Recommended Toxicity Criteria for Other Analytes Evaluated in Human Health Risk Assessments, Screening-Levels, and Remediation-Goal Calculations. California Environmental Protection Agency, DTSC, Office of Human and Ecological Risk (HERO). April.
- DTSC and State Water Board. 2023. Final Draft Supplemental Guidance: Screening and Evaluating Vapor Intrusion. California Environmental Protection Agency, DTSC and State Water Board. February. ([Webpage](#))
- Duvergé, D.J., 2011. Establishing Background Arsenic in Soil of the Urbanized San Francisco Bay Region. Master's thesis, San Francisco State University.
- Einarson, M., A. Fure, R. St. Germain, S. Chapman, and B. Parker. 2018. DyeLIF: A New Direct-Push Laser-Induced Fluorescence Sensor System for Chlorinated Solvent DNAPL and Other Non-Naturally Fluorescing NAPLs. Groundwater Monitoring & Remediation, 38 (3): 28-42.
- Ettinger, R.A., S. Luis, N. Weinberg, T. McAlary, G. Plantz, H. Dawson, J. Sickenger. 2018. Empirical Analysis of Vapor Intrusion Attenuation Factors

- for Sub-Slab and Soil Vapor – An Updated Assessment for California Sites. Presented at the Air & Waste Management Association Vapor Intrusion, Remediation, and Site Closure Conference. December.
- Gao, S., J. Seo, J. Wang, Y. Keum, J. Li, and Q.X. Li. 2013. Multiple Degradation Pathways of Phenanthrene by *Stenotrophomonas Maltophilia* C6. *Biodexterior Biodegradation* 79: 98-104.
- Guo, Y., C. Holton, H. Luo, P. Dahlen, K. Gorder, E. Dettenmaier, and P.C. Johnson. 2015. Identification of Alternative Vapor Intrusion Pathways Using Controlled Pressure Testing, Soil Gas Monitoring, and Screening Model Calculations. *Environmental Science & Technology*, 49, pp. 13472–13482.
- Hartman, B. 1998. The Great Escape—From the UST: LUSTLine Vol. 30, 18–20.
- HDOH [Hawai'i Department of Health]. 1995. Risk-Based Corrective Action and Decision Making at Sites with Contaminated Soil and Groundwater. State of Hawai'i, Department of Health, December. 1995 (revised June 1996).
- HDOH. 2011 (Updated January 2012). Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater.
- HDOH. 2012. Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors: Implications for Potential Vapor Intrusion Hazards. Hawai'i Department of Environmental Health. August.
- HDOH. 2017. Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill. Hawai'i Department of Environmental Health. October.
- Holton, C., H. Luo, P. Dahlen, K. Gorder, E. Dettenmaier and P.C. Johnson. 2013. Temporal Variability of Indoor Air Concentrations under Natural Conditions in a House Overlying a Dilute Chlorinated Solvent Groundwater Plume. *Environmental Science & Technology* 47, pp. 13347-13554.
- Hughes, S.A., A. Mahaffey, B. Shore, J. Baker, B. Kilgour, C. Brown, K.M. Peru, J.V. Headley, and H.C. Bailey. 2017. Using Ultrahigh-Resolution Mass Spectrometry and Toxicity Identification Techniques to Characterize the Toxicity of Oil Sands Process-Affected Water: The Case for Classical Naphthenic Acids. *Environmental Toxicology & Chemistry*, vol. 36 (11), pp. 3148-3157.
- Iowa State University. 2004. The Science of Smell Part 2 – Odor Chemistry. Air Quality and Animal Agriculture. PM 1963b. May.

- IT Corporation., 1997 Report of Petroleum Hydrocarbon Bioassay and Point-of-Compliance Concentration Determinations, Saltwater Ecological Protection Zone, Presidio of San Francisco, California. December.
- ITRC [Interstate Technology & Regulatory Council]. 2005. Examination of Risk-Based Screening Values and Approaches of Selected States. December.
- ITRC. 2008. Use of Risk Assessment in Management of Contaminated Sites. August
- ITRC. 2014. Petroleum Vapor Intrusion – Fundamentals of Screening, Investigation, and Management. October.
- ITRC. 2015. Decision Making at Contaminated Sites – Issues and Options in Human Health Risk Assessment. January.
- ITRC. 2018. TPH Risk Evaluation at Petroleum Contaminated Sites. November. ([Webpage](#))
- ITRC. 2023. Per- and Polyfluoroalkyl Substances (PFAS). September. ([Webpage](#))
- Jobelius, C., B. Ruth, C. Griebler, R.U. Meckenstock, J. Hollender, A. Reineke, F.H. Frimmel, and C. Zwiener. 2011. Metabolites Indicate Hot Spots of Biodegradation and Biogeochemical Gradients in a High-Resolution Monitoring Well. *Environmental Science & Technology*, 45, p. 474–481.
- Johnson, P.C. and R.A. Ettinger. 1991. Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings. *Environmental Science & Technology*, 25, p. 1445–1452.
- Johnson, P.C. 2002. Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model. American Petroleum Institute, Technical Bulletin No. 17, May.
- Kalbus, E., Reinstorf, F., and Schirmer, M., 2006. Measuring Methods for Groundwater-Surface Water Interactions: A Review. *Hydrology and Earth System Sciences*, v. 10, p. 873-887.
- Kaiser, M. A., C. A. Barton, M. Botelho, R. C. Buck, L. W. Buxton, J. Gannon, C.-P. C. Kao, B. S. Larsen, M. H. Russell, N. Wang, R. L. Waterland. 2006. Understanding the Transport of Anthropogenic Fluorinated Compounds in the Environment. *Organohalogen Compounds* 68: 675-678.
- Kearney Foundation of Soil Science. 1996. Background Concentrations of Trace and Major Elements in California Soils. University of California Davis, Division of Agriculture and Natural Resource (Prepared by G.R. Bradford,

- A.C. Change, A.L. Page, D. Bakhtar, J.A. Frampton, and H. Wright). March.
- Kim, Minhee, Loretta Y. Li, John R. Grace, and Chaoyang Yue. Selecting reliable physicochemical properties of perfluoroalkyl and polyfluoroalkyl substances (PFASs) based on molecular descriptors. *Environmental pollution* 196 (2015): 462-472.
- King D.J., R.L. Lyne, A. Girling, D.R. Peterson, R. Stephenson, D. Short. 1996. *Environmental Risk Assessment of Petroleum Substances: The Hydrocarbon Block Method*. Brussels, Belgium: CONCAWE. Report 96/52.
- Kiyohara, H., S. Torigoe, N. Kaida, T. Asaki, T. Iida, H. Hayashi, and N. Takizawa. 1994. Cloning and Characterization of a Chromosomal Gene Cluster, *pah*, that Encodes the Upper Pathway for Phenanthrene and Naphthalene Utilization by *Pseudomonas Putida* OUS82. *Journal of Bacteriology*, 2439-2443. April.
- Kwan, Wai Chi. Physical property determination of perfluorinated surfactants. PhD diss. National Library of Canada = Bibliothèque nationale du Canada, 2001.
- Lang, D.A., T.P. Bastow, B.G.K. van Aarssen, B. Warton, G.B. Davis, and C.D. Johnson. 2009. Polar Compounds from the Dissolution of Weathered Diesel. *Groundwater Monitoring & Remediation* 29: 85–93.
- Lawrence Berkeley National Laboratory. 2002 (Revised April 2009). *Analysis of Background Distributions of Metals in the Soil at Lawrence Berkeley National Laboratory. Environmental Restoration Program* (Prepared by D. Diamond, D. Baskin, D. Brown, L. Lund, J. Najita and I. Javandel). June.
- Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of Adverse Biological Effects of Chemical Concentrations in Marine and Estuarine Sediments. *Environmental Management* 19(1): 81-97.
- Lundegard, P.D., R.E. Sweeney, and G.T. Rice. 2000. Soil Gas Methane at Petroleum Contaminated Sites: Forensic Determination of Origin and Source. *Environmental Forensics*, 1, p. 3-10.
- Lundegard, P.D., and R. Sweeney. 2004. Total Petroleum Hydrocarbons in Groundwater—Evaluation of Nondissolved and nonhydrocarbon fractions. *Environmental Forensics* 5: 85–95.
- MADEP [Massachusetts Department of Environmental Protection]. 1994a. *Background Documentation for the Development of the MCP Numerical Standards*. April.

- MADEP. 1994b. Interim Final Petroleum Report: Development of Health-Based Alternative to the Total Petroleum Hydrocarbon (TPH) Parameter. August.
- MADEP. 1997. Characterizing Risks Posed by Petroleum Contaminated Sites: Implementation of the MADEP VPH/EPH Approach (and supporting spreadsheet, May 25, 1999).
- MADEP. 2003. Final Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH/APH Methodology. November.
- MADEP. 2004a. Method for the Determination of Volatile Petroleum Hydrocarbons (VPH). May.
- MADEP. 2004b. Method for the Determination of Extractable Petroleum Hydrocarbons (EPH). May.
- MADEP. 2009. Method for the Determination of Air-Phase Petroleum Hydrocarbons (APH). Final. Revision 1. December.
- Mallakin, A., B.J. McConkey, G. Miao, B. McKibben, V. Snieckus, D.G. Dixon and B. Greenberg. 1999. Impacts of Structural Photomodification on the Toxicity of Environmental Contaminants: Anthracene Photooxidation Products. *Ecotoxicology and Environmental Safety*, 43, 204-212.
- McCarthy, K.A. and R.L. Johnson. 1993. Transport of Volatile Organic Compound Across the Capillary Fringe. *Water Resources Research*, 29, 6, pp. 1675-1683. June.
- McGuire, J.T., I.M. Cozzarelli, B. Bekins, H. Link, and D. Martinovic-Weigelt. 2018. Toxicity Assessment of Groundwater Contaminated by Petroleum Hydrocarbons at a Well-Characterized, Aged, Crude Oil Release Site. *Environmental Science & Technology*, DOI: 10.1021/acs.est.8b03657. October.
- McHugh, T., L. Beckley, T. Sullivan, C. Lutes, R. Truesdale, R. Uppencamp, B. Cosky, J. Zimmerman, and B. Schumacher. 2017a. Evidence of a Sewer Vapor Transport Pathway at the USEPA Vapor Intrusion Research Duplex. *Science of the Total Environment*, 598, pp. 772-779.
- McHugh, T., P. Loll, and B. Eklund. 2017b. Recent Advances in Vapor Intrusion Site Investigations. *Journal of Environmental Management. Journal of Environmental Management*, 204: 783-792.
- McHugh, T. and L. Beckley. 2018a. Conceptual Model for Sewer/Utility Tunnel Vapor Intrusion, ESTCP Project ER-201505, Version 2. November.
([Webpage](#))

- McHugh, T. and L. Beckley. 2018b. Final Report: Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors and Investigation Protocol. Environmental Security Technology Certification Program (ESTCP) Project ER-201505. November. ([Webpage](#))
- McHugh, T. and L. Beckley. 2018c. Protocol for Sewer/Utility Tunnel Vapor Intrusion Investigations, ESTCP ER-201505, Version 2. November. ([Webpage](#))
- MDEQ [Michigan Department of Environmental Quality]. 2018. Groundwater-Surface Water Interface Pathway Compliance Options. Michigan Department of Environmental Quality. Remediation and Redevelopment Division Resource Materials. April.
- Melbye, A.G., O.G. Brakstad, J.N. Hokstad, I.K. Gregersen, B.H. Hansen, A.M. Booth, S.J. Rowland, and K.E. Tollefsen. 2009. Chemical and Toxicological Characterization of an Unresolved Complex Mixture-Rich Biodegraded Crude Oil. Environmental Toxicology and Chemistry, vol. 28, no. 9, pp. 1815-1824.
- McCarthy, K.A. and R.L. Johnson. 1993. Transport of Volatile Organic Compound Across the Capillary Fringe. Water Resources Research, 29, 6, pp. 1675-1683. June.
- MOEE [Ontario Ministry of Environment and Energy]. 1996. Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria for Use at Contaminated Sites in Ontario. Standards Development Branch. December.
- MOE [Ontario Ministry of Environment and Energy]. 2011. Rationale for the Development of Soil and Ground Water Standards for Use at Contaminated Sites in Ontario. Standards Development Branch. April 15.
- Montgomery Watson. 1995 (Revised March 1996). Fuel Product Action Level Development Report, Presidio of San Francisco. Prepared by Montgomery Watson consultants for the U.S. Army Corps of Engineers. October.
- Montgomery Watson. 1999. Development of Point of Compliance Concentrations for Gasoline in Surface Waters and Sediments of the Proposed Freshwater Stream, Presidio of San Francisco, California. Prepared by Montgomery Watson consultants for Presidio of San Francisco (Board Order No. 96-070), May 1999.
- Moody, J.D., J.P. Freeman, D.R. Doerge, and C.E. Cerniglia. 2001. Degradation of Phenanthrene and Anthracene by Cell Suspensions of Mycobacterium sp. Strain PYR-1. Applied and Environmental Microbiology, 1476-1483. April

- NIOSH [National Institute for Occupational Safety and Health]. 2007. NIOSH Pocket Guide to Chemical Hazards. US Department of Health and Human Services, Centers for Disease Control and Prevention. September. www.cdc.gov/niosh/npg/npg.html.
- NJDEP [New Jersey Department of Environmental Protection]. 2016. Characterization of Contaminated Ground Water Discharge to Surface Water Technical Guidance. Version 1.0. January.
- NOAA [National Oceanic and Atmospheric Administration]. 2008. NOAA Screening Quick Reference Tables. Office of Response and Restoration Division. OR&R Report 08-1 (Prepared by M.F. Buchman).
- NRC [National Research Council]. 1983. Risk Assessment in the Federal Government: Managing the Process. Washington, D.C.: National Academies Press.
- NRC. 2005. Contaminants in the Subsurface: Source Zone Assessment and Remediation. Washington, DC: National Academy Press.
- Neff J.M., S. Ostazeski, W. Gardiner, and I. Stejskal. 2000. Effects of Weathering on the Toxicity of Three Offshore Australian Crude Oils and Diesel Fuel to Marine Animals. *Environmental Toxicology and Chemistry*, vol. 19, pp. 1809–1821.
- OEHHA [Office of Environmental Health Hazard Assessment]. 2004a. Human-Health-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil (revised January 2005). California Environmental Protection Agency, OEHHA.
- OEHHA. 2004b. Overview of Freshwater and Marine Toxicity Tests: A Technical Tool for Ecological Risk Assessment. California Environmental Protection Agency, OEHHA. April.
- OEHHA. 2007. Development of Health Criteria for Schools Site Risk Assessment Pursuant to Health and Safety Code Section 901(g): Child-Specific Benchmark Change in Blood Lead Concentration for School Site Risk Assessment. California Environmental Protection Agency, OEHHA. April.
- OEHHA. 2009a. Soil Toxicity and Bioassessment Test Methods for Ecological Risk Assessments: Toxicity Test Methods for Soil Microorganisms, Terrestrial Plants, Terrestrial Invertebrates, and Terrestrial Vertebrates. California Environmental Protection Agency, OEHHA. January.
- OEHHA. 2009b. Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures. California Environmental Protection Agency, OEHHA, Air Toxicology and Epidemiology Branch. May.

- OEHHA. 2011. Public Health Goals in Drinking Water for Hexavalent Chromium (Cr VI). California Environmental Protection Agency, OEHHA. July.
- OEHHA. 2014. Memorandum to County Site Cleanup Program Managers: U.S. EPA (Region 9) Recommendations for Addressing Trichloroethylene (TCE) Vapor Intrusion at Contaminated Sites. California Environmental Protection Agency, OEHHA, Air, Community and Environmental Research Branch (David Siegel). July 22.
- OEHHA. 2015. Air Toxics Hot Spots Program Guidance Manual for the Preparation of Health Risk Assessments. California Environmental Protection Agency, OEHHA, Air, Community, and Environmental Research Branch. February.
- OSHA [Occupational Safety & Health Administration]. 2016. Permissible Exposure Limits – Annotated Tables. United States Department of Labor. Accessed January 4, 2016.
- Pennell, K.G., M.K. Scammell, M.D. McClean, J.A.B. Weldon, L. Friguglietti, E.M. Suuberg, R. Shen, P.A. Indeglia, and W.J. Heiger-Bernays. 2013. Sewer Gas: An Indoor Air Source of PCE to Consider During Vapor Intrusion Investigations. *Ground Water Monitoring & Remediation*, 33, pp. 119-126.
- Pinto, C.L., K. Mansouri, R. Judson, and P. Browne. 2016. Prediction of Estrogenic Bioactivity of Environmental Chemical Metabolites. *Chemical Research in Toxicology*, 29, 1410–1427.
- Podgorski, D. C.; Zito, P.; McGuire, J. T.; Martinovic-Weigelt, D.; Cozzarelli, I. M.; 437 Bekins, B.; Spencer, R. G. M. 2018. Examining Natural Attenuation and Acute Toxicity of Petroleum-Derived Dissolved Organic Matter (DOMHC) with Optical Spectroscopy. *Environ. Sci. Technol.* 52(11), 6157-6166; DOI 10.1021/acs.est.8b00016.
- Redman, A.D., T.F. Parkerton, M.H. Comber, M.L. Paumen, C.V. Eadsforth, B.Dmystrasz, D.King, C.S. Warren, K. den Haan, and N. Djemel. 2014. PETRORISK: A Risk Assessment Framework for Petroleum Substances. *Integr. Environ. Assess. Manage.* 10(3), 437-448;
- Regional Water Board [San Francisco Bay Regional Water Quality Control Board]. 1996. Supplemental Instructions to State Water Board December 8, 1995, Interim Guidance on Required Cleanup at Low Risk Fuel Sites. California Environmental Protection Agency, Regional Water Board. January 5.
- Regional Water Board. 1998a. Staff's Comments on the Proposed Task 3B and 3D Reports Submitted in Compliance with Board Order No. 95-136 Adopted for San Francisco International Airport, San Mateo County,

California. California Environmental Protection Agency, Regional Water Board. July 16.

Regional Water Board. 1998b. Recommended Interim Water Quality Objectives (or Aquatic Life Criteria) for Methyl Tertiary-Butyl Ether (MTBE). California Environmental Protection Agency, Regional Water Board Memorandum. October 1.

Regional Water Board. 1999. Adoption of Revised Site Cleanup Requirements - San Francisco International Airport: California Environmental Protection Agency, Regional Water Board, Order No. 99-045. June 16.

Regional Water Board. 2000a. Draft Staff Report – Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines – For Planning Purposes Only. California Environmental Protection Agency, Regional Water Board. (Prepared by E. Christian and F. Hetzel). May. ([Webpage](#))

Regional Water Board. 2000b. Risk-Based Screening Levels for Impacted Soil and Groundwater. California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board. September 20.

Regional Water Board. 2009. Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites – Interim Final. California Environmental Protection Agency, Regional Water Board. July 31. ([Webpage](#))

Regional Water Board. 2016. Technical Resource Document: Petroleum Metabolites Literature Review and Assessment Framework. California Environmental Protection Agency, Regional Water Board. June 27. ([Webpage](#))

Regional Water Board. 2017a. San Francisco Bay PCBs TMDL – Implementation at Cleanup & Spill Sites. California Environmental Protection Agency, Regional Water Board. March. ([Webpage](#))

Regional Water Board. 2022. Vapor Intrusion Mitigation Guidance. California Environmental Protection Agency, Regional Water Board. June. ([Webpage](#))

Regional Water Board. 2024. San Francisco Bay Basin Water Quality Control Plan (Basin Plan). California Environmental Protection Agency, Regional Water Board. July 22. ([Webpage](#))

Sample, B.E., J. Lowe, P. Seeley, M. Markin, C. McCarthy, J. Hansen, and A.H. Aly. 2014. Depth of the Biologically Active Zone in Upland Habitats at the Hanford Site, Washington: Implications for Remediation and Ecological Risk Management. Integrated Environmental Assessment and Management 11(1):150–160.

- San Francisco Estuary Institute. 2015. Updated Ambient Concentrations of Toxic Chemicals in San Francisco Bay Sediments. Regional Monitoring Program (Prepared by D. Yee, P. Trowbridge, and J. Sun). July.
- Schrlau, J.E., A.L. Kramer, A. Chlebowski, L. Truong, R.L. Tanguay, and S.L.M. Simonich. 2017. Formation of Developmentally Toxic Phenanthrene Metabolite Mixtures by Mycobacterium sp. ELW1. Environmental Science & Technology, 51(15), pp.8569–8578.
- Schumacher, B., J. Zimmerman, G. Swanson, J. Elliot, and B. Hartman. 2010. Field Observations on Ground Covers/Buildings. Presented at the 20th Annual International Conference on Soils, Sediments, Water, and Energy, San Diego, CA. March 16.
- Scott, C.M. 1991. Background Metal Concentrations in Soils in Northern Santa Clara County, California. Master's thesis, University of San Francisco. December.
- SETAC [Society of Environmental Toxicology and Chemistry]. 2004. Whole Effluent Toxicity Testing – technical issue paper.
- Shen, R., Pennell, K.G., Suuberg, E.M., 2014. Analytical Modeling of the Subsurface Volatile Organic Vapor Concentration in Vapor Intrusion. Chemosphere 95, 140-149.
- Shiu, W.Y., M. Bobra, A.M. Bobra, A. Maijanen, L. Suntio, and D. Mackay. 1990. The Water Solubility of Crude Oils and Petroleum Products. Oil & Chemical Pollution. Vol. 7, No. 1, pp. 57-84.
- State Water Board [State Water Resources Control Board]. 1988. Adoption of Policy Entitled "Sources of Drinking Water" (as revised by Resolution 2006-0008). California Environmental Protection Agency, State Water Board.
- State Water Board. 1992. Resolution No. 92-49: Policies and Procedures for Investigation, Cleanup and Abatement of Discharges Under Water Code Section 13304 (As Amended on April 21, 1994 and October 2, 1996). California Environmental Protection Agency, State Water Board.
- State Water Board. 2012a. Technical Justification for Vapor Intrusion Media-Specific Criteria. California Environmental Protection Agency, State Water Board. March 21.
- State Water Board. 2012b. Low-Threat Underground Storage Tank Case Closure Policy California Environmental Protection Agency, State Water Board. August 17. ([Webpage](#))

- State Water Board. 2015. Leaking Underground Fuel Tank Guidance Manual. California Environmental Protection Agency, State Water Board. December.
- State Water Board. 2016. A Compilation of Water Quality Goals (17th Edition). California Environmental Protection Agency, State Water Board. January.
- State Water Board. 2018. Resolution 2018-0028: Adoption of Amendments to the Water Quality Control Plan for Enclosed Bays and Estuaries: Sediment Quality Provisions, and the Staff Report including the Substitute Environmental Documentation. June 5.
- State Water Board. 2019. Resolution Number 2018-0038: Adoption of Amendment to the Water Quality Control Plan for Ocean Waters of California. California Environmental Protection Agency, State Water Board. February 4.
- State Coalition for Remediation of Drycleaners. 2009. Chemicals Used in Drycleaning Operations. July.
- Steele, W.V., R. D. Chirico, S. E. Knipmeyer, and A. Nguyen. 2002. Vapor Pressure, Heat Capacity, and Density along the Saturation Line: Measurements for Benzenamine, Butylbenzene, sec-Butylbenzene, tert-Butylbenzene, 2,2-Dimethylbutanoic Acid, Tridecafluoroheptanoic Acid, 2-Butyl-2-ethyl-1,3-propanediol, 2,2,4-Trimethyl-1,3-pentanediol, and 1-Chloro-2-propanol. *Journal of Chemical Engineering Data*. 47(4): 648-666.
- Stout, S.A., A.D. Uhler, K.J. McCarthy, and S. Emsbo-Mattingly. 2002. Chemical Fingerprinting of Hydrocarbons in Introduction to Environmental Forensics. Edited by B.L. Murphy and R.D. Morrison. Academic Press. pp. 137-260.
- Terraphase Engineering. 2018. Polar Compounds Testing Assessment Report, Former Point Molate Naval Fuel Depot, Richmond, California. August 31. GeoTracker ID T0609592138.
- TCEQ [Texas Commission on Environmental Quality]. 2000. Characterization of Nc6 to Nc35 Petroleum Hydrocarbons in Environmental Samples. Draft. Texas Natural Resource Conservation Commission (TNRCC) Method 1006.
- TCEQ. 2013. Determining Representative Concentrations of Chemicals of Concern for Ecological Receptors. RG-366/TRRP-15eco. November.
- TPH Criteria Working Group. 1997a. Development of Fraction Specific Reference Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons (TPH). TPHCWG Series, Volume 4 (prepared by Edwards,

D.A., M.D. Andriot, M.A. Amoruso, A.C. Tummey, C.J. Bevan, A. Tveit, L.A. Hayes, S.H. Youngren, and D.V. Nakles).

TPH Criteria Working Group. 1997b. Selection of Representative TPH Fractions Based on Fate and Transport Considerations, TPHCWG Series, Volume 3. (prepared by Gustafson, JB, J.G. Tell, and D. Orem). July.

TPH Criteria Working Group. 1998a. Analysis of Petroleum Hydrocarbons in Environmental Media, TPHCWG Series, Volume 1 (prepared by Weisman, W.). March.

TPH Criteria Working Group. 1998b. Composition of Petroleum Mixtures, TPHCWG Series, Volume 2 (prepared by Potter, T.L. and K.E. Simmons). May.

TPH Criteria Working Group. 1999. Human Health Risk-Based Evaluation of Petroleum Release Sites: Implementing the Working Group Approach. TPHCWG Series, Volume 5 (prepared by Vorhees, D.J., W.H. Weisman, and J.B. Gustafson). June.

Uhler, A.D., K.J. McCarthy, S.D. Emsbo-Mattingly, S.A. Stout, and G.S. Douglas. 2010. Predicting Chemical Fingerprints of Vadose Zone Soil Gas and Indoor Air from Non-Aqueous Phase Liquid Composition. *Environmental Forensics*, 11: 342-354.

USDOE [US Department of Energy]. 1997. Preliminary Remediation Goals for Ecological Endpoints. U.S. Department of Energy, Office of Environmental Management (prepared by R.A. Efroymsen, G.W. Suter II, B.E. Sample and D.S. Jones), ES/ER/TM-162/R2. August.

USEPA [US Environmental Protection Agency]. 1974. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037.

USEPA. 1985. Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Publication No. AP-42. Fourth Edition. September 1985.

USEPA. 1986. Guidelines for Health Risk Assessment of Chemical Mixtures. EPA 630/R-98/002. Risk Assessment Forum. Fed. Reg. 51(185):34014–34025. September 24.

USEPA. 1989. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A) – Interim Final: Office of Emergency and Remedial Response, Publication EPA/540/1-89/092. December.

USEPA. 1991a. Methods for Aquatic Toxicity Identification Evaluations: Phase I Toxicity Characterization Procedures (2nd edition). Office of Research and Development. EPA/600/6-91/003. February.

- USEPA. 1991b. Technical Support Document for Water Quality-based Toxics Control. Office of Water. EPA/505/2-90-001. March.
- USEPA. 1991c. Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual, Part B (Development of Preliminary Remediation Goals). Interim Final. Washington, D.C.: Office of Superfund Remediation and Technology Innovation. December.
- USEPA. 1993a. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. Office of Research and Development. EPA/600/R-93/089. July.
- USEPA. 1993b. Methods for Aquatic Toxicity Identification Evaluations: Phase II Toxicity Identification Procedures for Samples Exhibiting Acute and Chronic Toxicity. Office of Research and Development. EPA/600/R-92/080. September.
- USEPA. 1993c. Methods for Aquatic Toxicity Identification Evaluations: Phase III Toxicity Confirmation Procedures for Samples Exhibiting Acute and Chronic Toxicity. Office of Research and Development. EPA/600/R-92/081. September.
- USEPA. 1994. ECO Update: Using Toxicity Tests in Ecological Risk Assessment. U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response, Publication 9345.0-05I. March.
- USEPA. 1995a. Engineering Forum Issue Paper. Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites. Office of Research and Development, Office of Solid Waste and Emergency Response, Washington, DC. EPA/540/S-96/500.
- USEPA. 1995b. Ground Water Issue: Light Nonaqueous Phase Liquids. Office of Research and Development. EPA/540/S-95/500.
- USEPA. 1995c. Final Water Quality Guidance for the Great Lakes System, U.S. Environmental Protection Agency, Code of Federal Regulations, Title 40, Parts 9, 122, 123, 131 and 132, www.access.gpo.gov/nara/cfr/.
- USEPA. 1996a. Eco Update Volume 3, Number 2 - Ecotox Thresholds. Office of Solid Waste and Emergency Response, EPA 540/F-95/038. January.
- USEPA. 1996b. Soil Screening Guidance: Technical Background Document. Office of Emergency and Remedial Response, Publication 9355.4-17A. May.
- USEPA. 1996c. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Washington, D.C.: Office of Solid Waste and Emergency Response. July.

- USEPA. 1996d. How to Effectively Recover Free Product at Leaking Underground Fuel Tank Sites: A Guide for State Regulators. Office of Solid Waste and Emergency Response. EPA -510-R-99-001. September.
- USEPA. 1996e. PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures. National Center for Environmental Assessment, Office of Research and Development. EPA/600/P-96/001F. September.
- USEPA. 1996f. Method 3510C: Separatory Funnel Liquid-Liquid Extraction, Revision 3. In Test Methods for Evaluating Solid Waste (SW-846). Office of Solid Waste and Emergency Response. December.
- USEPA. 1996g. Method 3630C: Silica Gel Cleanup, Revision 3. In Test Methods for Evaluating Solid Waste (SW-846). Office of Solid Waste and Emergency Response. December.
- USEPA. 1996h. SW-846: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Method 5030B: Purge-and-Trap for Aqueous Samples, Revision 2. December.
- USEPA. 1996i. SW-846: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Method 5035: Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples, Revision 0. December.
- USEPA. 1997a. The Rapid Optical Screening Tool (ROST) Laser-Induced Fluorescence (LIF) System for Screening of Petroleum Hydrocarbons in Subsurface Soils. Office of Research and Development. EPA/600/R-97/020. February.
- USEPA. 1997b. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments – Interim Final. Environmental Response Team, Interim Final. EPA 540-R-97-006. June.
- USEPA. 2000a. Toxicological Review of Vinyl Chloride (CAS No. 75-01-4): In Support of Summary Information on the Integrated Risk Information System (IRIS). May.
- USEPA. 2000b. Water Quality Standards; Establishment of Numerical Criteria for Priority Toxic Pollutants for the State of California; Rule. Federal Register, 40 CFR Part 131, Thursday, May 18, 2000.
- USEPA. 2000c. Method Guidance and Recommendations for Whole Effluent Toxicity (WET) Testing (40 CFR Part 126). Office of Water. EPA 821-B-00-004. July.

- USEPA. 2000d. Proceedings of the Ground-Water/Surface-Water Interactions Workshop. Solid Waste and Emergency Response. EPA/542/R-00/007. July.
- USEPA. 2000e. Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures. Risk Assessment Forum, Washington, DC. EPA/630/R-00/002. August.
- USEPA. 2001. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) – Final. Office of Emergency and Remedial Response. Publication 9285.7-47. December.
- USEPA. 2002a. National Recommended Water Quality Criteria- 2002. Office of Water, EPA-822-R-02-047.
- USEPA. 2002b. Role of Background in the CERCLA Cleanup Program. OSWER 9285.6-07. April 26.
- USEPA. 2002c. Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites. Office of Solid Waste and Emergency Response. 9285.7-41. September.
- USEPA. 2002d. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms (Fifth Edition). U.S. Environmental Protection Agency. Office of Water. October.
- USEPA. 2002e. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms (Fourth Edition). U.S. Environmental Protection Agency. Office of Water. October.
- USEPA. 2002f. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms (Third Edition). U.S. Environmental Protection Agency. Office of Water. October.
- USEPA. 2002g. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites. Office of Solid Waste and Emergency Response, OSWER 9285.6-10. December.
- USEPA. 2002h. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Office of Solid Waste and Emergency Response, OSWER 9355.4-24. December.
- USEPA. 2003a. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. Office of Research and Development. EPA-600-R02-013. November.

- USEPA. 2003b. Human Health Toxicity Values in Superfund Risk Assessments. Office of Solid Waste and Emergency Response. OSWER Directive 9285.7-53. December 5.
- USEPA. 2004a. User's Guide for Subsurface Vapor Intrusion into Buildings. Prepared by Environmental Quality Management for U.S. Environmental Protection Agency Office of Emergency and Remedial Response. February 22.
- USEPA. 2004b. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) – Final. Office of Emergency and Remedial Response. EPA/540/R/99/005, OSWER 9285.7-02EP. July.
- USEPA. 2005. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. Risk Assessment Forum, EPA/630/R-03/003F, March.
- USEPA. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process. EPA QA/G-4. EPA/240.B-06/001. February.
- USEPA. 2007a. Method 8015C Nonhalogenated Organics by Gas Chromatography, Revision 2. In Test Methods for Evaluating Solid Waste (SW-846). Office of Solid Waste and Emergency Response. February.
- USEPA 2007b. Ecological Soil Screening Levels for DDT and Metabolites. Office of Solid Waste and Emergency Response, OSWER. Directive 9285.7-57. April.
- USEPA. 2007c. Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment. Office of Solid Waste and Emergency Response. OSWER 9285.7-80. May.
- USEPA. 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. Office of Research and Development, National Health and Environmental Effects Research Laboratory. EPA/600/R-02/016. March.
- USEPA. 2008b. ECO Update/Ground Water Forum Issue Paper: Evaluating Ground-Water/Surface Water Transition Zones in Ecological Risk Assessments. Office of Solid Waste and Emergency Response. Publication 9285.6-17, EPA-540-R-06-072. July.
- USEPA. 2009a. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment): Office of Superfund Remediation and Technology Innovation, Publication EPA-540-R070-002. January.

- USEPA. 2009b. Final Provisional Peer-Reviewed Toxicity Values for Commercial or Practical Grade Hexane. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009c. Final Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009d. Final Provisional Peer-Reviewed Toxicity Values for High Flash Aromatic Naphtha. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009e. Final Provisional Peer-Reviewed Toxicity Values for Midrange Aliphatic Hydrocarbon Streams. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009f. Final Provisional Peer-Reviewed Toxicity Values for n-Hexane. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009g. Final Provisional Peer-Reviewed Toxicity Values for White Mineral Oil. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 29.
- USEPA. 2009h. Final Provisional Peer-Reviewed Toxicity Values for Vanadium and Its Soluble Inorganic Compounds Other Than Vanadium Pentoxide (CASRN 7440-62-2 and Others): Derivation of Subchronic and Chronic Oral RfDs. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. September 30.
- USEPA. 2009i. Evaluating Ecological Risk to Invertebrate Receptors from PAHs in Sediments at Hazardous Waste Sites. Office of Research and Development. October.
- USEPA. 2010. Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds. EPA/100/R-10/005. December.
- USEPA. 2011a. Exposure Factors Handbook: 2011 Edition. Office of Research and Development, Publication EPA/600/R-09/052F. September.

- USEPA. 2011b. Toxicological Review of Trichloroethylene (CAS No. 79-01-6): In Support of Summary Information on the Integrated Risk Information System (IRIS). September.
- USEPA. 2011c. Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model. July.
- USEPA. 2012a. Conceptual Model Scenarios for the Vapor Intrusion Pathway. Office of Solid Waste and Emergency Response. February.
- USEPA. 2012b. Petroleum Hydrocarbons and Chlorinated Solvents Differ in their Potential for Vapor Intrusion. Office of Underground Storage Tanks. March. ([Webpage](#))
- USEPA. 2012c. U.S. EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings. Office of Solid Waste and Emergency Response. March 16.
- USEPA. 2012d. 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. Office of Research and Development, National Health and Environmental Effects Research Laboratory. EPA/600/R-02/012. December.
- USEPA. 2012e. Final Provisional Peer-Reviewed Toxicity Values for Fluoranthene. Superfund Health Risk Technical Support Center, National Center for Environmental Assessment, Office of Research and Development, Cincinnati, OH. December 27.
- USEPA. 2013a. Tier 3 Toxicity Value White Paper. Office of Solid Waste and Emergency Response 9285.7-86. May.
- USEPA. 2013b. EPA Region 9 Guidelines and Supplemental Information Needed for Vapor Intrusion Evaluations at the South Bay National Priorities List (NPL) Sites. Letter to California Regional Water Quality Control Board – SF Bay Region. December 3.
- USEPA. 2014a. Memorandum: Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors. Office of Solid Waste and Emergency Response Directive 9200.1-120. February 6.
- USEPA. 2014b. EPA Region 9 Memorandum Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion. July 9.

- USEPA. 2014c. Challenges in Bulk Soil Sampling and Analysis for Vapor Intrusion Screening of Soil. Office of Research and Development, EPA/600/R-14-277, December.
- USEPA. 2015a. OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Source to Indoor Air. Office of Solid Waste and Emergency Response (OSWER). Publication 9200.2-154. June. ([Webpage](#))
- USEPA. 2015b. Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites. Office of Underground Storage Tanks (OUST). EPA 510-R-15-001. June.
- USEPA. 2015c. Determination of the Biologically Relevant Sampling Depth for Terrestrial and Aquatic Ecological Risk Assessments. EPA/600/R-15/176. U.S. Environmental Protection Agency. Office of Research and Development. October.
- USEPA. 2015d. Human Health Ambient Water Quality Criteria. June.
- USEPA. 2016a. Lead at Superfund Sites: Frequent Questions from Risk Assessors on the Adult Lead Methodology. U.S. Environmental Protection Agency. Accessed May 26.
- USEPA. 2016. ProUCL Version 5.1.00 User Guide and Technical Guide – Statistical Support Software for Environmental Applications for Data Sets with and without Nondetect Observations. EPA/600/R-07/041. Office of Research and Development. June 20.
- USEPA. 2017a. Leaching Environmental Assessment Framework (LEAF) How-To Guide. October.
- USEPA. 2017b. Update for Chapter 5 of the Exposure Factors Handbook. September.
- USEPA. 2019 [accessed]. Estimation Parameters Interface (EPI) Suite.
- USEPA. 2022. Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons (various CASRNs). Office of Research and Development, Center for Public Health and Environmental Assessment. EPA/690/R-22/003F. September
- USEPA. 2024a. Fact Sheet: Understanding the Final PFAS National Primary Drinking Water Regulation Hazard Index Maximum Contaminant Level. April. ([Webpage](#))
- USEPA. 2024b. Regional Screening Levels – Tables, User’s Guide, Frequent Questions. November. ([Webpage](#))

- USEPA. 2024c. VISL User's Guide. November. ([Webpage](#))
- U.S. Geological Survey. 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. U.S. Geological Survey Professional Paper 1270 (prepared by Shacklette, H.T., and J.G. Boerngen).
- van den Berg, M, L.S. Birnbaum, and M. Denison, M. 2006. The 2005 World Health Organization Re-Evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds. *Toxicol Sci* 93(2):223–241.
- Verslycke, T., A. Ghekiere, S. Raimondo, and C. Janssen. 2007. Mysid Crustaceans as Standard Models for the Screening and Testing of Endocrine-Disrupting Chemicals. *Ecotoxicology*, 16(1): 205-219. February.
- Verslycke, T., A. Ghekiere, S. Raimondo, and C. Janssen. 2007. Mysid Crustaceans as Standard Models for the Screening and Testing of Endocrine-Disrupting Chemicals. *Ecotoxicology*, 16(1): 205-219. February.
- Wang, Zhanyun, Matthew MacLeod, Ian Cousins, Martin Scheringer, and Konrad Hungerbuhler. 2011. Using COSMOtherm to Predict Physicochemical Properties of Poly- and Perfluorinated Alkyl Substances (PFAS). *Environmental Chemistry* 8 (4): 389-398.
- Washington DOE [State of Washington State Department of Ecology]. 1997. Analytical Methods for Petroleum Hydrocarbons. June.
- Washington DOE. 2009. High-Resolution Porewater Sampling Near the Groundwater/Surface Water Interface. Publication No. 09-03-017. April.
- Washington DOE. 2016. Toxicity Testing of Soils Contaminated with Gasoline, Diesel, and Heavy Oil. October.
- Watson, J. S. Jones, D. M. Swannell, R. P. J. van Duin, A. C. T. 2002. Formation of Carboxylic Acids During Aerobic Biodegradation of Crude Oil and Evidence of Microbial Oxidation of Hopanes. *Organic. Geochemistry*, 33, pp. 1153-1169.
- Weber, A.K, L.B. Barber, D.R. LeBlanc, E.M. Sunderland, and C.D. Vecitis. 2017. Geochemical and Hydrologic Factors Controlling Subsurface Transport of Poly- and Perfluoroalkyl Substances, Cape Cod, Massachusetts. *Environmental Science & Technology* 51: 4269-4279.
- Wickliffe, J., E. Overton, S. Frickel, J. Howard, M. Wilson, B. Simon, S. Echsner, D. Nguyen, D. Gauthier, D. Blake, C. Miller, C. Elferink, S. Ansari, H. Fernando, E. Trapido, and A. Kane. 2014. Evaluation of Polycyclic Aromatic Hydrocarbons Using Analytical Methods, Toxicology, and Risk

Assessment Research: Seafood Safety after a Petroleum Spill as an Example. *Environmental Health Perspectives*, 122, no. 1, pp. 6-9.

- Winkler, R. F. Ruckerbauer, and K. Bunzl. 2001. Radon Concentration in Soil Gas: A Comparison of the Variability Resulting from Different Methods, Spatial Heterogeneity and Seasonal Fluctuations. *Science of the Total Environment*, 272, pp. 272-282.
- Yao, Y., Y. Wang, Z. Zhong, M. Tang, and E.M. Suuberg. 2017. Investigating the Role of Soil Texture in Vapor Intrusion from Groundwater Sources. *J. Environ. Qual.* 46:776–784.
- Yeh, G.T. 1981. AT123D: Analytical Transient One-, Two-, and Three-dimensional Simulation of Waste Transport in the Aquifer System. Report ORNL-5602, Oak Ridge, Tennessee, USA.
- Zemo, D.A. 2016. White Paper: Analytical Methods for Total Petroleum Hydrocarbons (TPH). Prepared for American Petroleum Institute (API), Soil & Groundwater Research Program. August.
- Zemo, D.A. and K.A. Synowiec. 1995. TPH Detections in Groundwater: Identification and Elimination of Positive Interferences. In *Proceedings of the 1995 Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water*, p. 257-271. Westerville, Ohio. National Ground Water Association.
- Zemo, D.A., J.E. Bruya, and T.E. Graf. 1995. The Application of Petroleum Hydrocarbon Fingerprint Characterization in Site Investigation and Remediation. *Groundwater Monitoring & Remediation*, v. 15, no. 2, pp. 147-156. May.
- Zemo, D.A. and G.R. Foote. 2003. The Technical Case for Eliminating the Use of the TPH Analysis in Assessing and Regulating Dissolved Petroleum Hydrocarbons in Ground Water. *Ground Water Monitoring & Remediation* 23: 95–156.
- Zemo, D.A., K.T. O'Reilly, R.E. Mohler, A.K. Tiwary, R.I. Magaw, and K. A. Synowiec. 2013. Nature and Estimated Human Toxicity of Polar Metabolite Mixtures in Groundwater Quantified as TPHd/DRO at Biodegrading Fuel Release Sites. *Groundwater Monitoring & Remediation*, Vol. 33, pp. 44-56.
- Zemo, D. A.; O'Reilly, K. T.; Mohler, R. E.; Magaw, R. I.; Espino Devine, C.; Ahn, S.; Tiwary, A. K. 2017. Life Cycle of Petroleum Biodegradation Metabolite Plumes, and Implications for Risk Management at Fuel Release Sites. *Integr. Environ. Assess. Manage.* 13(4), 714-727; DOI:10.1002/ieam.1848.
- Zielinska-Park, J., J. Nakamura, J.A. Svenberg and M.D. Aitken. *Aldehydic*. 2004. DNA lesions in calf thymus DNA and HeLa S3 cells produced by bacterial

quinone metabolites of fluoranthene and pyrene. Carcinogenesis 25 (9): 1727-1733.

3M Company. 2021. Final Report: Summary of Physical/Chemical and Environmental Parameters for PFAS : Subject to Interim Special Order by Consent No. 20-086-CWP/AP/GW/HW/DW/SW, paragraph 37(J)(3). Laboratory Request Number: E21-0037. January.

14. Acronyms and Abbreviations

14.1. A

ADAF	Age dependent adjustment factor used for chemicals with a mutagenic mode of action
AF	Attenuation Factor
APH	Air Phase Hydrocarbons
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

14.2. B

BaP	Benzo[a]pyrene
BaPeq	Benzo[a]pyrene equivalents
Basin Plan	San Francisco Bay Basin Water Quality Control Plan
bgs	below ground surface
BTEX	Benzene, toluene, ethylbenzene and xylenes

14.3. C

C or Ca	Cancer
CAS	Chemical Abstracts Service
C _{soil}	Leaching based soil concentration (mg/kg)
C _{gw}	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
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Also known as Superfund.

CHHSL	CalEPA California Human Health Screening Level
COPC	Chemical of Potential Concern
CSM	Conceptual Site Model (sometimes called Site Conceptual Model)
CTR	California Toxics Rule
CVI	Chlorinated [compound] Vapor Intrusion

14.4. D

DAF	Dilution-Attenuation Factor
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDW	California State Water Resources Control Board, Division of Drinking Water
DDT	Dichlorodiphenyltrichloroethane
DNA	Deoxyribonucleic acid
DRO	Diesel-Range Organics
DTSC	California Environmental Protection Agency, Department of Toxic Substances Control

14.5. E

EC	Equivalent Carbon Number
EDA	Effects-Directed Analysis
EPC	Exposure Point Concentration
EPH	Extractable Petroleum Hydrocarbons
ERA	Ecological Risk Assessment
ESL	Regional Water Board Environmental Screening Level
ESTCP	Environmental Security Technology Certification Program
Estuary	In the context of the ESLs, the lowest of freshwater and saltwater values

Exterior Soil Gas

Soil gas located outside the footprint of a building

14.6. F

FAQs	Frequently Asked Questions
FCV	Final Chronic Value
FID	Flame Ionization Detector

14.7. G

GC	Gas Chromatography
GI	Gastrointestinal (tract)
GW	Groundwater

14.8. H

H	Henry's law constant ($\text{atm}\cdot\text{m}^3/\text{mol}$)
H'	dimensionless Henry's law constant
HDOH	Hawai'i Department of Health
HI	Hazard index
HOPs	Petroleum Hydrocarbon Oxidation Products
HQ	Hazard Quotient
HVAC	Heating, ventilation, and air conditioning

14.9. I

IA	Indoor Air
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.

14.10. J

JEM	Johnson & Ettinger model (Johnson and Ettinger 1991)
-----	--

14.11. K

K_{oc}	Organic carbon partition coefficient (cm^3/g)
----------	---

14.12. L

LC50	Lethal concentration (50th percentile)
LOE	Line of evidence
LOEL	Lowest Observed Effect Level
LTCP	Low-Threat Underground Storage Tank Closure Policy (State Water Board 2012b)

14.13. M

MADEP	Massachusetts Department of Environmental Protection
MCL	Maximum Contaminant Level
mg/kg	Milligrams per kilogram, or parts per million
MLE	Multiple lines of evidence
MRLs	ATSDR Minimum Risk Levels
MTBE	Methyl tertiary butyl ether (also tert-methyl butyl ether)

14.14. N

NAPL	Non aqueous phase liquid (also free product)
NC	Noncancer
NCP	National Contingency Plan
NIOSH	National Institute for Occupational Safety and Health
NOCs	Background natural organic compounds
NPDES	National Pollution Discharge Elimination System
NSO	Nitrogen, Sulfur, and Oxygen Atoms
NVDOC	Nonvolatile Dissolved Organic Carbon

14.15. O

OEHHA	California Environmental Protection Agency, Office of Environmental Health Hazard Assessment
Ontario	
MOE	Ontario Ministry of Environment
Ontario	
MOEE	Ontario Ministry of Environment and Energy
OSHA	Occupational Safety and Health Administration (federal)
OSWER	USEPA Office of Solid Waste and Emergency Response (now Office of Land and Emergency Management or OLEM)
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).

14.16. P

PAH	Polycyclic aromatic hydrocarbon (also PNA)
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene (also perchloroethylene)
PEL	Permissible Exposure Limit
PHC	Petroleum Hydrocarbon
PNA	Polynuclear aromatic hydrocarbon (also PAH)
PPRTV	USEPA Provisional Peer-Reviewed Toxicity Value
PRGs	USEPA Preliminary Remediation Goals (now RSLs)
PVI	Petroleum [compound] vapor intrusion

14.17. R

RAGS	Risk Assessment Guidance for Superfund
RBSLs	Risk Based Screening Levels
RCRA	Resource Conservation and Recovery Act
Release Area	The area of vadose zone soil contamination that extends from a source
RfC	Inhalation Reference Concentration (noncarcinogens)
RfD	Oral Reference Dose (noncarcinogens), also RfDo
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
RSLs	USEPA Regional Screening Levels (formerly PRGs)

14.18. S

SFo	Cancer oral slope factor
SG	Soil Gas

SGC Silica gel cleanup

Slab Capping Effect

A concrete slab acts as a barrier or cap limiting the downward flow of ambient air and the upward venting of contaminated soil gas.

State Water Board

California Environmental Protection Agency, State Water Resources Control Board

Source Release point of contamination, such as tanks, ponds, pipelines, clarifiers, and landfills.

STLC Soluble Threshold Limit Concentration (liquid criterion for leaching from soils under landfill-like conditions)

Subslab Subslab soil gas. Soil gas collected immediately beneath a concrete slab.

SWI Surface water interface

14.19. T

T2 Tier 2

TBA Tertiary butyl alcohol

TCE Trichloroethene

TCE VI Framework

Interim Framework for Assessment of Vapor Intrusion at TCE Contaminated Sites in the San Francisco Bay Region (Regional Water Board 2014)

TDS Total Dissolved Solids

TEF Toxicity equivalence factor

TEQ Toxic equivalents

TMDL Total Maximum Daily Load

TPH Total petroleum hydrocarbons

TSCA Toxic Substances Control Act

TTLC Total Threshold Limit Concentration (for solids)

14.20. U

UCM Unresolved complex mixture or chromatogram hump, referring to numerous co-eluting compounds

URAL USEPA Urgent Response Action Level (for indoor air sample results)

USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
UST	Underground Storage Tank

14.21. V

Vapor Source

Contaminated soil or groundwater, sometimes referred to as secondary sources.

VI	Vapor Intrusion
VIG	DTSC Vapor Intrusion Guidance (DTSC 2011b)
VISL	USEPA Vapor Intrusion Screening Level calculator (USEPA 2024c)
VOC	Volatile organic compound/chemical
VPH	Volatile Petroleum Hydrocarbons

14.22. W

Washington DOE

State of Washington Department of Ecology

WET	Whole Effluent Toxicity method
-----	--------------------------------

14.23. Unit Abbreviations

µg/L	Micrograms per liter or parts per billion
µg/m ³	Micrograms per cubic meter

15. Appendix A: Equations for Direct Exposure Screening Levels

15.1. Noncarcinogenic Risk-Based Screening Levels

15.1.1. Ingestion Noncarcinogenic Risk-Based Screening Levels

Tapwater Ingestion

$$C_{\text{water}} = \frac{\text{THQ} \times \text{ED} \times \left(\frac{365 \text{ days}}{1 \text{ year}}\right) \times \text{BW} \times \left(\frac{1000 \mu\text{g}}{1 \text{ mg}}\right)}{\text{EF} \times \text{ED} \times \left(\frac{1}{\text{RfD}_0}\right) \times \text{IRW}}$$

Soil Ingestion

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{ED} \times \left(\frac{365 \text{ days}}{1 \text{ year}}\right) \times \text{BW}}{\text{EF} \times \text{ED} \times \left(\frac{1}{\text{RfD}_0}\right) \times \text{IRS} \times \left(\frac{10^{-6} \text{ kg}}{\text{mg}}\right)}$$

15.1.2. Inhalation Noncarcinogenic Risk-Based Screening Levels

Tapwater Vapor Inhalation

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

Soil and Particulate Inhalation

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

Indoor Air Inhalation

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

15.1.3. Dermal Noncarcinogenic Risk-Based Screening Levels

Tapwater Dermal Exposure

- Inorganic Chemicals

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

- Organic Chemicals

If $ET_{wc} \leq t^*$ then,

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{2 \times FA \times K_p \times \sqrt{\frac{6T \times ET_w}{\pi}}}$$

If $ET_{wc} > t^*$ then,

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{FA \times K_p \times \left[\frac{ET_w}{(1+B)} + \left(2T \times \frac{(1+3B+3B^2)}{(1+B)^2} \right) \right]}$$

Soil Dermal Exposure

$$C_{\text{water}} = \frac{THQ \times ED \times 365 \frac{\text{days}}{\text{year}} \times BW}{EF \times ED \times \left(\frac{1}{RfD_o \times GIABS} \right) \times SA_s \times AF \times ABS_d \times \frac{10^{-6} \text{kg}}{\text{mg}}}$$

15.2. Carcinogenic Risk-Based Screening Levels

15.2.1. Ingestion Carcinogenic Risk-Based Screening Levels

Tapwater Ingestion

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

Soil Ingestion

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

15.2.2. Inhalation Carcinogenic Risk-Based Screening Levels

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 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

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

15.2.3. Dermal Carcinogenic Risk-Based Goals

Tapwater Dermal Exposure

- Inorganic Chemicals

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

- Organic Chemicals

If $ET_{\text{wadj}} \leq t^*$ then,

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{2 \times FA \times K_p \times \sqrt{\frac{6\tau \times ET_{\text{wadj}}}{\pi}}}$$

If $ET_{\text{wadj}} > t^*$ then,

$$C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{\text{L}}}{FA \times K_p \times \left[\frac{ET_{\text{wadj}}}{(1+B)} + \left(2\tau \times \frac{(1+3B+3B^2)}{(1+B)^2} \right) \right]}$$

Soil Dermal Exposure

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

15.3. Total Cancer or Noncancer Screening Levels for All Exposure Pathways

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

16. Appendix B: ESL Frequently Asked Questions (FAQs)

16.1. GENERAL QUESTIONS

16.1.1. How often are the ESLs revised?

The ESLs are revised periodically to reflect changes in toxicity values, changes in our understanding of the fate and transport of contaminants, and other developments in environmental risk assessment. The revision schedule is dictated by practical considerations and limited staff resources. Major updates are published every few years, and users are notified via our electronic mailing list (see FAQ #16.1.3). Minor revisions will be made as soon as any errors in the ESL values are identified. The ESL Workbook will indicate the date of the major update and the current revision number (e.g., January 2019 - Rev. 1).

The ESLs are considered “evergreen,” as they change over time to reflect the most current scientific information. We have to prioritize items for updating since we usually do not have time to address all identified issues during each update. Since the ESLs are never “final”, we use the term “interim final” to describe the major update versions of the ESLs. If you think you found an error or have suggestions for new topics or clarifications to be included in a future update, please let us know by contacting the ESL Team at RB2-ESLs@waterboards.ca.gov. We appreciate comments from users and try to address them or incorporate them in future updates to the extent possible.

16.1.2. How do I know if I have the most recent version of the ESLs?

The most recent version of the ESLs will be available on the website: http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/esl.shtml. On the website under Update Process, there is an ESL status sheet file for the current (major) update with information and dates for all current minor revisions. In addition, the version information is listed on each table of the ESL Workbook.

16.1.3. How can I find out about updates?

If you would like to be notified when new ESL updates are available, you may subscribe to our email list on the following web page: http://www.waterboards.ca.gov/resources/email_subscriptions/reg2_subscribe.shtml. Alternatively, consult the ESL status sheet on the website (see FAQ #16.1.2).

16.1.4. Which are the ESL documents?

The ESLs consist of four components: 1) Cover Memo; 2) Microsoft Excel Workbook; 3) Summary ESL Tables (PDF); and 4) User’s Guide. Starting in the 2025 edition of the ESLs, the Frequently Asked Questions are included as an appendix, instead of a separate document.

16.1.5. Can I get the password for the Workbook?

The Regional Water Board does not provide the password. Having multiple versions in circulation at one time diminishes the ESLs' credibility and usefulness and potentially causes confusion.

16.2. APPLICATION OR USE QUESTIONS

16.2.1. What is the effective date of the ESLs?

There is no effective date, but the date the Workbook is posted to the ESL webpage (e.g., January 24, 2019).

16.2.2. Do the new ESLs have to be used as soon as the Workbook is posted?

The ESLs are a tool with the latest technical information and are never mandatory. In general, we recommend the current version be used, but there can be exceptions. The following table provides a general suggested timeline for when to apply the new ESLs, but ultimately the timeline for each case depends on the status of a case.

Case Status	When to Use the 2025 ESLs
New case	Promptly following release
Prior to RAP approval	Promptly following release
Post RAP approval – TCE sites	By end of 2025
Post RAP approval – non-TCE sites	During next 5-year review
Pre-Closure	During low-threat closure assessment

Acronyms:

RAP = remedial action plan

TCE = trichloroethene

We recommend consulting with the Regional Water Board case manager when determining the applicability of the new ESLs. For example, use of the new ESLs might not be needed for cases where the site is well-characterized with sufficient current information for a site-specific risk evaluation.

16.2.3. Are the ESLs applicable throughout California?

The ESLs are developed and maintained by the San Francisco Bay Regional Water Quality Control Board (Region 2) whose jurisdiction is limited to its defined geographic limits. The ESLs are used by Region 2 staff and publicly shared for transparency and to facilitate communication. Other agencies, whether within or outside Region 2, may elect to use the ESLs. We recommend directly contacting the known or likely overseeing agency to find out what screening levels they use.

The ESL User's Guide Chapter 1 provides a brief introduction to other agency screening levels used in California (e.g., USEPA RSLs and DTSC-modified SLs).

The conceptual site model used to determine the ESLs is applicable to many sites throughout California. In general, the ESLs could be used at any site, provided all stakeholders agree. The primary suitability issues for application to different areas of the state are related to the fate and transport aspects, particularly soil leaching to groundwater. As described in ESL User's Guide Chapter 9, the modeled scenario includes a one-meter clean sand layer between the overlying contaminated sand layer and underlying groundwater. For sites where the separation distance between soil contamination and groundwater is significantly greater than one meter or the soil type is predominantly fine-grained, application of the soil leaching ESLs can be overly conservative.

16.2.4. Are the ESLs applicable to petroleum underground storage tank sites?

Petroleum releases from underground storage tanks (USTs) must be evaluated using the State Water Resource Control Board's Low-Threat Underground Storage Tank (UST) Case Closure Policy. The ESLs may be used at such sites to screen for constituents not addressed by the Policy.

16.2.5. Does the Regional Water Board re-open cases because the ESLs changed?

In general, we do not casually re-open cases. However, Regional Water Board staff may re-open any case if data indicates that residual contamination poses an unacceptable risk to public safety, health, or the environment or if previously undetected contamination is discovered. Examples of situations where a case may be re-opened include:

- An environmental site assessment reveals that contamination remains at the property at concentrations that are no longer considered protective; or
- Data from a nearby, open case suggests contamination has migrated and is significantly impacting offsite receptors.

A case brought to the attention of Regional Water Board staff will be re-evaluated to determine whether it should be re-opened. Decisions will be made only after thorough review by the case manager and supervisor.

Currently, Regional Water Board staff are considering whether closed TCE cases should be re-evaluated for potential re-opening. At this time, there is no schedule for such an effort.

16.2.6. Can the ESLs be used to determine when spill reporting to an agency is necessary?

The ESLs are not intended to be used for determining when the presence of contamination warrants reporting of a spill to an agency. In California, the requirements for spill reporting generally are based on the quantity of the release, not a concentration. We recommend reviewing the [Governor's Office of Emergency Services Spill Release Reporting webpage](#). This webpage includes a list of essential documents that provide guidance regarding spill notification and the types of releases that are reportable. Alternatively, consult an environmental attorney.

16.2.7. Can the ESLs be used to determine whether import fill soil is clean?

No. Clean fill soil is defined as natural materials (e.g., soil, clay, silt, sand, gravel, rock, or a mixture or combination of such materials) that have concentrations of naturally occurring chemicals (e.g., metals) at or below background levels at the receiving site while concentrations of man-made chemicals are absent. Clean fill soil is also free of trash or debris.

See also FAQ #16.2.8.

16.2.8. Can the ESLs be used to evaluate marginally contaminated soil for on-site reuse?

Partially. The ESLs do not consider all potential exposure pathways (e.g., surface water transport of contaminants in the dissolved phase or as particulates) so any such use would need to be supplemented with consideration of additional aspects (e.g., erosion control for the surface water pathway; location of wetland, sensitive environments, jurisdictional waters of the State or US, habitats, and potential presence of special status species/habitats; ecological risk assessment). Regional Water Board staff currently is evaluating the development of a technical memorandum on the topic. Previous guidance on this topic *Draft Technical Resource Document: Technical Resource Document – Characterization and Reuse of Petroleum Hydrocarbon Impacted Soil as Inert Waste* dated October 20, 2006 is no longer current. In the interim, staff will consider such proposals on a site-specific basis.

16.2.9. Do the ESLs have to be used as cleanup levels?

No. ESLs are not default cleanup levels. Setting cleanup levels is detailed in Section 4.25.2.3 of the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan; Regional Water Board 2024). Cleanup levels are approved on a case-by-case basis by the Regional Water Board. Proposed final cleanup levels are based on a discharger-developed feasibility study of cleanup alternatives that compares effectiveness, cost, time to achieve cleanup standards, and a risk assessment to determine impacts on beneficial uses,

human health, and the environment. Cleanup levels should also take into account the mobility and volume of pollutants. For all sites performing human site-specific health risk assessments, an alternative with an excess cancer risk of 1 in 1,000,000 (10^{-6}) or less should be considered.

16.2.10. Have the PFAS MCLs for PFNA, PFBS, PFHxS, and GenX been rescinded?

On May 14, 2025, USEPA announced their intention to rescind the regulations and reconsider the regulatory determinations for PFHxS, PFNA, HFPO-DA (commonly known as GenX), and the Hazard Index based MCL for mixture of these three plus PFBS to ensure that the determinations and any resulting drinking water regulation follow the legal process laid out in the Safe Drinking Water Act. Once new/updated MCLs for these PFAS and mixtures have been determined, use those values instead of the current values provided in the ESLs.

16.3. HUMAN HEALTH EXPOSURE QUESTIONS

16.3.1. Why did the hierarchy for human health toxicity criteria change from the 2019 ESLs?

In the 2025 ESL update, the toxicity value hierarchy described in ESL User's Guide Chapter 3 was synchronized with the new toxicity criteria regulation by DTSC. The citation is California Code of Regulations (CCR), Title 22, Division 4.5, sections 68400.5, 69020-69022 ("Toxicity Criteria for Human Health Risk Assessment"), effective September 4, 2018.

Prior versions of the ESLs employed a slightly different hierarchy based on a variation of the USEPA Superfund Toxicity Criteria Hierarchy (USEPA 2003b, USEPA 2013a). The Superfund hierarchy consists of seven tiers: (1) IRIS values; (2) PPRTVs; (3) ATSDR values; (4) OEHHA values; (5) PPRTV screening toxicity values (in PPRTV appendices); (6) USEPA Health Effects Assessment Summary Table (HEAST); and (7) other sources. The previous ESL hierarchy followed the Superfund hierarchy except when OEHHA values were more stringent than values in Tiers 1 through 3, in which case the OEHHA values were prioritized. In the new hierarchy, only those OEHHA values meeting the CCR requirements are prioritized. Further information on the regulation is provided in the Final Statement of Reasons (DTSC 2018).

16.3.2. Can the Tapwater ESLs be used for evaluating construction worker exposure to groundwater?

No. Applying the Tapwater ESLs to a construction worker scenario would be overly conservative. A construction worker likely would be seeking to avoid groundwater contact (especially ingestion of groundwater). Moreover, it is generally considered unsafe construction practice to allow workers to enter excavations with significant accumulated water due to geotechnical stability concerns (e.g., sidewall collapse). In contrast, the Tapwater ESLs consider

exposure via ingestion, inhalation, and dermal exposure due to the use of groundwater for drinking and showering.

For situations where, remaining concentrations of contaminants are significant, then a site-specific evaluation could be performed. Such an evaluation might include a risk evaluation for the inhalation or dermal exposure routes. Keep in mind that inhalation exposure is possible in a trench but dispersion in open air above the trench or in a larger excavation is expected to sharply and rapidly decrease potential exposure concentrations.

16.3.3. Why are the 2019 Vapor Intrusion ESLs for subslab/soil gas and groundwater lower than the 2016 ESLs?

Regional Water Board staff have found that VI is occurring at some of our sites at levels that indicate the previous VI ESLs were not sufficiently protective for all buildings. The previous groundwater and subslab/soil gas VI ESLs were based on attenuation factors (AFs) developed using the USEPA (2004) version of the Johnson & Ettinger Model (JEM). The typical practice has been to use the JEM to estimate site-specific AFs, but rarely have the model predictions been verified. Consequently, there are little or no data confirming the protectiveness of the previously-used AFs. In addition, recent publications have highlighted vapor transport directly into buildings via vapor conduit preferential pathways (e.g., sewer airspace, utility conduit airspace) not considered in the current VI models. Therefore, to ensure protectiveness and adequate evaluations, the 2019 ESLs employ the more stringent AFs recommended by USEPA (2015a) which are based on an evaluation of the USEPA final empirical Vapor Intrusion Database (USEPA 2012c). These attenuation factors are based on statistical analysis of empirical data collected from many sites across the US. Moreover, the USEPA database and report have undergone peer review. Nearly 80% of the subslab soil gas attenuation factors currently recommended by other states are at least as stringent as USEPA.

16.3.4. Did the ESL Team consider using VI attenuation factors based on California data?

The ESL Team has evaluated the electronically available VI sampling data available in GeoTracker. Most data in GeoTracker is in PDF format and would require a significant investment of time to extract the data. We also suspect that there will be a limited amount of historical data that meets the data quality objectives for determining attenuation factors. Recent updates to GeoTracker and the use of sampling recommendations provided in the pending CalEPA Supplemental Vapor Intrusion Guidance will increase the likelihood that future GeoTracker data can be used to determine California-specific AFs.

In addition, we reviewed the recent conference paper “Empirical Analysis of Vapor Intrusion Attenuation Factors for Sub-Slab and Soil Vapor – An Updated Assessment for California Sites” (the “article”) and corresponding database (Ettinger et al. 2018). The database includes compiled paired indoor air and soil

gas/subslab soil gas data from several California cleanup sites. Several different soil gas/subslab soil gas attenuation factors (ranging from 0.0014 to 0.0046) were calculated using subsets of the data (e.g. subslab vs. soil gas samples or samples from residential vs. commercial buildings).

The article's AFs may underrepresent a certain subset of residential buildings captured in the USEPA database that are more prone to VI (e.g. buildings with basements, aged or damaged buildings with compromised slabs). In addition, the database does not contain enough data to conclusively determine that AFs less stringent than USEPA are sufficiently protective for use as generic AFs in California. Use of these values as the generic AF for VI subslab/soil gas screening levels is not appropriate without further data, evaluation, and justification. However, these results suggest there is value to continuing to compile VI data into a database for future evaluation.

The following reflects the considerations by the ESL Team in making this determination:

- Appropriate Application of USEPA Subslab to Indoor Air AF – USEPA's default subslab to indoor air AF (0.03) was calculated using sampling data from 218 residential buildings with slab foundations. This type of building is expected to provide the least amount of vapor attenuation (particularly for buildings with basements). Therefore, this AF is expected to be the most protective and appropriate for initial screening at buildings where building design, use, and condition has not been determined.
- Article's Subslab to Indoor Air AF – The paper presents a subslab to indoor air AF (0.0026) using data from 65 total buildings of various designs and uses (residential, commercial, industrial, school). Only 20 of those buildings are residential.
- Article's Soil Gas to Indoor Air AF – The paper presents a soil gas to indoor air AF (0.0016) using data from 82 total buildings of various designs and uses (residential, commercial, industrial, school) with either crawlspace or slab foundations. Only 31 of those buildings are residential buildings and 11 of those 31 have slab foundations.
- Article's Lack of AFs for Specific Building Types – The article did not include calculations of AFs for specific building types (e.g. residential buildings with crawlspaces, commercial buildings with slabs). Presumably, this is because there are less than 25 buildings of any one building type. Based on this limited dataset, there is insufficient data to definitively determine if there is a difference in attenuation for different building types.

**16.3.5. Why are the subslab ESLs the same as soil gas ESLs?
Shouldn't there be some attenuation as VOCs migrate from
deeper soils?**

The subslab/soil gas ESLs conservatively assume that attenuation only occurs as subslab soil gas moves into the building and is diluted by mixing with indoor air. While there can be additional attenuation as vapors diffuse through the soil from a deeper contaminated soil or groundwater (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 have less attenuation than the areas surrounding buildings. See User's Guide Chapter 5 for further information.
- A low soil moisture content zone that enhances vapor transport can develop beneath buildings because the building limits rainwater infiltration.
- 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 contaminated soil or groundwater is great.

Consequently, we chose to apply the same attenuation factor to non-subslab soil gas and renamed the soil gas ESLs to subslab/soil gas ESLs. In addition, see Appendix A of USEPA (2015a) regarding why USEPA chose to apply the subslab AF is applied to exterior soil gas (soil gas outside the building footprint).

16.3.6. Why are there no Soil VI ESLs?

VI ESLs for soil are not developed because of the uncertainty associated with the partitioning equations and the potential loss of volatiles during sample collection, preservation, and analysis (DTSC 2011b; USEPA 2014e, USEPA 2015a). Loss of VOCs from soil samples in this manner is a particular concern in samples collected before use of USEPA Method 5035 (e.g., DTSC 2004) for field preservation. Soil matrix data are not considered a primary line of evidence and should never be used as the sole line of evidence for assessing VI. Per USEPA (2015a), non-detect soil data for VOCs cannot be used to conclude the absence of VOCs, and therefore in turn cannot be used to conclude no potential for VI. However, soil samples can be helpful for estimating the release area (i.e., the area of vadose zone soil contamination that extends from a source). Determining the location and extent of all release areas is a critical LOE for a complete CSM and vapor transport assessment.

16.3.7. Why are there no Crawl Space Air VI ESLs?

VI ESLs for crawl space air are not published; instead crawl space air samples can be compared directly to the indoor air ESLs. A crawl space to indoor air AF of

1 should be used when calculating risk for screening. USEPA found little attenuation between crawl space air and indoor air. USEPA concluded that air exchange between the crawl space air and indoor air leads to approximate equilibration in air concentrations within the two spaces (USEPA 2012c).

16.3.8. Why are there no Sewer Air VI ESLs?

VI ESLs for sewer or utility conduit air (vapor conduit pathway) are not published. Regional Water Board staff recommends the use of the sewer/utility air-to-indoor air AF of 0.03 as recommended in *Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors and Investigation Protocol* (McHugh and Beckley 2018b). Divide the human health based indoor air ESLs by 0.03 to generate sewer/utility air-to-indoor air screening levels; practically speaking, these values are the same as the subslab/soil gas ESLs. See Section 5.4.1 for information regarding how to evaluate the vapor conduit pathway.

16.3.9. Can fate and transport models like the USEPA Johnson and Ettinger model be used to evaluate vapor intrusion?

Fate and transport models are not considered appropriate during the early screening phase of a project when the site is not adequately characterized and information about the condition and operation of existing buildings typically is limited. Models should be used with caution given that current models do not address how buildings change over time due to modifications/renovations, damage or operational changes (e.g., new HVAC, opening of windows and doors). Moreover, current models do not consider vapor conduit pathways such as sewer/utility conduit air VI. Further information is provided in User's Guide Chapter 5.

16.4. ECOTOXICITY QUESTIONS

16.4.1. Why are site-specific values used as aquatic habitat goals for some chemicals?

For commonly encountered chemicals lacking promulgated ecological toxicity criteria, the ESLs employ values derived from published data or databases (e.g., USEPA ECOTOXicology knowledgebase or ECOTOX) or values derived from site-specific toxicity testing. These chemicals are identified in ESL User's Guide Section 7.3 along with a discussion of the uncertainties associated with using these values as screening levels. Examples of the former include MTBE and 1,2,3-trichloropropane. Examples of the latter include petroleum mixtures (e.g., petroleum-gasoline since 2003, petroleum-HOPs since 2019 though previously HOPs were evaluated in conjunction with petroleum-diesel). Employing these values is considered a practical alternative to requiring all sites with pollution near a surface water body to conduct toxicity testing. As new information becomes available, these values can be revised. Alternative screening levels can always be proposed for regulatory oversight agency consideration.

16.5. CHEMICAL-SPECIFIC QUESTIONS

16.5.1. Asbestos: Is there an ESL for asbestos in soil?

The ESLs are designed for chemicals known to be common contaminants found in subsurface soils and groundwater at cleanup sites. Since the hazards posed by airborne asbestos fibers differ from those of typical chemicals addressed in the ESLs, asbestos is not included in the ESLs. Information regarding the regulation of airborne asbestos is available from the [Air Resources Board](#). Information regarding managing asbestos hazardous waste is available from the [Department of Toxics Substances Control](#).

16.5.2. Arsenic: Why are risk-based ESLs for arsenic in soil published when those concentrations can be significantly lower than naturally occurring background concentrations?

The risk-based ESLs are calculated using currently accepted methodologies and inputs. Background levels are not considered in the calculation of the ESLs. Background levels vary from site to site or even within a site; there is no single value for arsenic applicable throughout the Bay Area. As discussed in ESL User's Guide Section 12.4, consideration of background is carried out separately as part of the overall site-specific risk assessment.

16.5.3. Chromium: Why are there no ESLs for total chromium?

There is no set ratio between the different forms of chromium in the environment and use of a total chromium screening levels derived based on a fixed ratio of different forms of chromium gives a false sense of security. Instead, the ESLs include risk-based soil screening levels for chromium III (trivalent chromium) and chromium VI (hexavalent chromium), which are both naturally occurring forms of chromium and inter-convertible in the environment (OEHHA 2011). Chromium VI is a carcinogen and is considered to have a mutagenic mode of action (USEPA 2005; see User's Guide Section 3.4.7). Previous versions of the ESLs included direct contact soil values for total chromium based on the following:

- Assumption of chromium VI: chromium III ratio of 1:6 – This was done in the 2001 ESLs, and discontinued beginning with the 2003 ESLs.
- Substitution of a mean chromium background value (58 mg/kg) from Analysis of Background Distributions of Metals in the Soil at Lawrence Berkeley National Laboratory (Lawrence Berkeley National Laboratory 2002). This was done in the 2005 ESLs, and discontinued with the November 2007 ESLs (Revised May 2008). The evaluation of background is discussed in ESL User's Guide Section 12.4.

Therefore, we recommend that the concentration of the most toxic species (chromium VI) or both species (chromium III and VI) be measured for comparison to the individual risk-based screening levels. For older data sets where speciation of the different chromium forms was not performed, it would be prudent to conduct some sampling to ascertain the concentrations of the different forms present.

16.5.4. Nickel: Why is the construction worker ESL for direct soil exposure to nickel lower than for the resident?

The construction worker scenario is described in User's Guide Chapter 3. The scenario assumes a relatively short exposure period, but more intensive soil contact than for a resident. For estimating direct contact soil exposures, the ESLs use the USEPA Regional Screening Level equations, which for the resident includes the "resident soil equations" and for the construction worker includes the "construction worker soil equations for other than standard vehicle traffic (e.g.,

grading, tilling, excavating, dozing and wind).” The toxicity values and default exposure factors are discussed in User’s Guide Chapter 3. For nickel, the difference between the construction worker and resident ESLs has to do with the relative relationship between nickel’s toxicity values for the different exposure routes (ingestion, inhalation, and dermal) and the default construction worker exposure factors that assume much more dust is generated during the more intensive soil moving activities.

Tier 1 ESLs that are driven by the construction worker soil direct contact are rarely selected as cleanup levels. Instead, soil management plans (also referred to as risk management plans) are often used to control potential risk to construction workers, and cleanup levels are based on residential soil exposure. This is an acceptable approach that may require a deed restriction to prohibit future activities inconsistent with the soil management plan.

16.5.5. Petroleum Hydrocarbons: Why are ESLs not published for crude oil or bunker fuels?

ESLs are not published for crude oils, bunker fuels because bulk TPH methods for these mixtures provide no useful information on the size of the carbon chains in the samples in addition to the limitations of bulk TPH analyses, which do not distinguish between hydrocarbon classes. Moreover, there are no typical crude oil or bunker fuel compositions and compositions span the low to high carbon range. Rather than a screening level evaluation, Regional Water Board staff recommend a site-specific evaluation using TPH fractionation analytical methods for crude oil and bunker fuel release sites (Section 4.6.2). An alternative approach using bulk TPH analyses at a crude oil release site would be to analyze samples for TPH-gasoline, TPH-diesel, and TPH-motor oil and those analytical results can be used with the appropriate ESLs to calculate hazard quotients. Cumulative hazard index should then be evaluated. For a bunker fuel release site, analyze samples for TPH-diesel and TPH-motor oil, and those analytical results can be used with the appropriate ESLs to calculate hazard quotients. Cumulative hazard index should then be evaluated.

For situations where there are existing bulk TPH-crude oil data, a screening level evaluation could be conducted by assuming each sample result is composed of one-third each of TPH-gasoline, TPH-diesel, and TPH-motor oil. The data could then be used with the petroleum-gasoline, petroleum-diesel, and petroleum-motor oil ESLs to calculate hazard quotients. Cumulative hazard index should then be evaluated. For a bunker fuel release site, the TPH-bunker sample results could be assumed to be composed of one-half each of TPH-diesel and TPH-motor oil. The data could then be used with the petroleum-diesel and petroleum-motor oil ESLs to calculate hazard quotients. Cumulative hazard index should then be evaluated.

Other approaches may be acceptable but should be determined in consultation with the overseeing regulatory agency.

16.5.6. Petroleum Hydrocarbon Fractions: Why were the old carbon ranges for the medium and high aromatic hydrocarbon fractions not changed given changes by USEPA (2022)?

An updated *Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons* was published in 2022 (USEPA 2022)—the previous version was published in 2009 (USEPA 2009c). USEPA narrowed the carbon range of the medium aromatic fraction and increased the carbon range of the high aromatic fraction, as follows:

- Medium Aromatic Fraction Carbon Range – The previous USEPA medium aromatic carbon range was C9 to C16 (EC9 to EC<22) and the new medium aromatic carbon range is C9 to C10 (EC9 to EC<11).
- High Aromatic Fraction Carbon Range – The previous USEPA high aromatic carbon range was C17 to C32 (EC22 to EC35) and the new high aromatic carbon range is C10 to C32 (EC11 to EC35).

The ESL Team elected not adopt to this change because we consider the existing medium and high aromatic carbon ranges to better reflect the environmental fate of hydrocarbons (e.g., partitioning, transport). For instance, C10 to C16 hydrocarbons are much more mobile (e.g., soluble, volatile) in the environment than the larger hydrocarbons (e.g., C24 to C32). In addition, retaining the existing fraction definitions is consistent with DTSC HERO Note 12 (DTSC 2021).

16.5.7. Petroleum Hydrocarbon Fractions: Why was cyclohexene not used as the surrogate for the low aliphatic hydrocarbon fraction oral reference dose consistent with USEPA (2022)?

Cyclohexene was not adopted as the surrogate for the low aliphatic hydrocarbon fraction oral reference dose because cyclohexene is not a primary component of gasoline. It is sometimes used as an additive to gasoline. Hence, n-hexane was retained as the surrogate for the low aliphatic hydrocarbon fraction oral reference dose.

16.5.8. Petroleum Hydrocarbon Oxidation Products (HOPs): How do I analyze for this mixture?

Measurement of HOPs concentrations consists of two steps. First analyze a sample for both TPH-diesel (C10-C28) with and without silica gel cleanup (SGC). Second, subtract the TPH-diesel with SGC result from the TPH-diesel without SGC result. In addition, if a background sample (collected from an unimpacted by petroleum contamination and with similar vegetative and hydrogeologic characteristics) has been analyzed for TPH-diesel without SGC, then that result can also be subtracted from the TPH-diesel without SGC result. This is also described in ESL User's Guide Section 4.5 and illustrated in Figure 4-2.

16.5.9. Petroleum Hydrocarbon Oxidation Products (HOPs): With the HOPs ESLs, do I have to analyze groundwater samples for extractable TPH (TPH-diesel and TPH-motor oil) both with and without silica gel cleanup?

Not necessarily. Another option is to analyze for extractable TPH without silica gel cleanup and compare those results to the Petroleum-Diesel ESL. We also recommend consulting with the overseeing regulatory agency's case manager.

16.5.10. Petroleum Mixtures: What Carbon Ranges Should I Use When Analyzing Soil or Groundwater Samples for the Petroleum Mixtures?

Recommended carbon ranges are discussed in ESL User's Guide Section 4.5 and listed in Table 4-5 as follows:

- Gasoline – C5 to C12
- Stoddard Solvent – C7 to C12
- Jet Fuel – C9 to C16
- Diesel – C10 to C24
- HOPs – C10 to C28
- Motor Oil – C24 to C36

Recommendations for bunker fuel, crude oil, unknown mixtures, and waste oil are discussed in ESL User's Guide Sections 4.3.5 and 4.5.

16.5.11. Tetrachloroethene (PCE): Why are the human health risk-based USEPA RSLs and ESLs for PCE different?

The USEPA Regional Screening Levels (RSLs; USEPA 2024b) and ESLs employ different human health toxicity values for PCE. The ESLs employ a toxicity value hierarchy consistent with California Code of Regulations, Title 22, Division 4.5, sections 68400.5, 69020-69022 ("Toxicity Criteria for Human Health Risk Assessment"), effective September 4, 2018. For PCE, the OEHHA inhalation unit risk value, which is more stringent than the USEPA IRIS value, meets the requirements in the regulation therefore must be used for human health risk assessments and development of screening levels in California. See also FAQ #15.

16.6. FAQ References

The references for the FAQ are listed in the main ESL reference section 13, above.