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). Mount Diablo sneaks into the upper left corner as the isolated pyramid shaped peak.

DISCLAIMER

This User’s Guide: Derivation 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, rather that additional evaluation is warranted. Use of the ESLs as cleanup goals 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).

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Executive Summary

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

The ESLs allow dischargers and regulators 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>
<thead>
<tr>
<th>Medium</th>
<th>Human Health</th>
<th>Drinking Water Resource (Current or Potential)</th>
<th>Aquatic Receptors (Discharge to Surface Water)</th>
<th>Terrestrial Receptors (Direct Contact)</th>
<th>Source Control</th>
<th>Nuisance and Odors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground-water</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Soil/ Soil Gas</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Indoor Air</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Users of this guide should be aware of site-specific circumstances before applying ESLs to any given site. This includes an understanding of current/future land use type, media affected by contamination, and site-specific factors (collectively, the Conceptual Site Model or “CSM”). If used correctly, ESLs are considered to be 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 web site and identify the version for the record in all relevant communications.

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1 Introduction and Background

The Environmental Screening Levels (ESLs) are groundwater, soil, soil gas, and indoor air concentrations derived 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:

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

The following sections provide regulatory 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 developed 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 2017b) 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 2017b).
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 must be undertaken as quickly as possible. Activities that may potentially pollute groundwater must 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 creation 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:

1. **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 demonstrated otherwise. 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 and must be approved by 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).

2. **All Groundwater is Assumed to Ultimately Discharge to Surface Water and Potentially Affect Aquatic Organisms and Habitats** – This assumption can be overly conservative for sites far from surface water bodies 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 developed to protect both drinking water resources and aquatic habitats.

### 1.1.2 Environmental Concerns in the Basin Plan

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

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

<table>
<thead>
<tr>
<th>Medium</th>
<th>Human Health</th>
<th>Drinking Water Resource</th>
<th>Aquatic Receptors (Discharge to Surface Water)</th>
<th>Terrestrial Receptors (Direct Contact)</th>
<th>Source Control</th>
<th>Nuisance Taste and Odor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Soil/Soil Gas</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Indoor Air</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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. The five basic components of site investigation are:

1. Preliminary site assessment to confirm the discharge/identify the discharger; identify affected or threatened waters of the State and their beneficial uses; and develop preliminary information on the nature and horizontal and vertical extent of the discharge;

2. Soil and water investigation to determine the source, nature, and extent of the discharge with sufficient detail to provide the basis for decisions regarding subsequent cleanup, if any are determined by the Regional Water Board as necessary;

3. Proposal and selection of cleanup action to evaluate feasible and effective cleanup and abatement actions and to develop preferred cleanup and abatement alternatives;

4. Implementation of cleanup and abatement action to implement the selected alternative and to monitor in order to verify progress; and

5. Monitoring to confirm short- and long-term effectiveness of cleanup and abatement.

Minimum cleanup and abatement methods include:

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

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 developed 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); and February 2016 (three revisions).

1.3 Intended Use of the ESLs

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

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 require further investigation or evaluation to better assess the threat. The ESLs do not address hazards such as asphyxiation or explosions.

The ESLs are intended to be conservative, but reasonable.

The main purpose of screening levels is to quickly enable users to distinguish which sites pose a significant threat. In developing screening levels, there must 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.

The ESLs are a communication tool amongst the various stakeholders.

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. For many sites, ESLs are selected as cleanup goals, but only after going through the process of evaluation and adoption. The Regional Water Board typically accepts ESLs as preliminary cleanup goals.

The ESLs save time and money.

Preparation of quantitative environmental risk assessments for multiple pathways at contaminated sites requires a greater level of expertise and frequently requires a multi-disciplinary team (toxicologists or risk assessors, chemists, engineers, environmental scientists, and geologists). The costs 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.

The ESLs are a prioritization tool.

Regional Water Board staff is required to prioritize 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 2018b) 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 2018a) that calculates groundwater and soil gas (subslab and deeper or exterior soil gas) vapor intrusion screening levels using USEPA default 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, $10^{-6}$ 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.
Table 1-2 – Environmental Concerns for ESLs versus Other Screening Levels

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

**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”)¹ or DTSC recommends more stringent criteria in Human Health Risk Assessment Note 10 (DTSC 2019a). For chemicals meeting these

¹ DTSC website for the California Toxicity Criteria Rule: https://www.dtsc.ca.gov/LawsRegsPolicies/Regs/Toxicity-Criteria-for-Human-Health-Risk-Assessment.cfm
exceptions, DTSC publishes DTSC-modified screening levels (DTSC-SLs) in Human Health Risk Assessment Note 3 (DTSC 2019c) for soil, tapwater, and air, as needed. Human Health Risk Assessment Note 3 is updated twice per year.

### 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:

1. Chemical in question is used in the industrial process;
2. Workers and others who might be exposed to the chemical have knowledge of the chemical's presence;
3. Workers receive appropriate health and safety training; and,
4. Workers may be provided with protective gear to minimize exposures.
The OSHA PELs are derived for adult, healthy workers and are not intended to protect children, pregnant women, the elderly, or people with compromised immune systems. OSHA recognizes that many of its PELs are outdated and inadequate for ensuring protection of worker health and is presently evaluating how to update them (United States Department of Labor – Occupational Safety & Health Administration 2016).

The question of applicability OSHA PELs versus ESLs typically arises when 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 applicable 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, the ESLs apply. Distinguishing between sources can be challenging, but there are various techniques that can be employed (e.g., comparison of chemical ratios in subsurface and indoor air samples, compound-specific isotopes, use of portable instruments such as gas chromatographs with mass spectrometry detector GC-MS, and continuous analyzers that are in development). More information on these techniques and references are presented in the Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region (TCE Framework; Regional Water Board 2014).

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. USEPA Region 9 (USEPA...
2014b) has developed accelerated response action levels (ARALs) and urgent response action levels (URALs) for trichloroethene (TCE) in indoor air for the protection of women of child-bearing age in residential and commercial settings. Based on the acute nature of the potential effects of exposure to TCE actions should be taken to reduce exposure to TCE exceeding the ARALs or URALs in weeks or days. This is discussed further in Chapter 6.

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. A discharger, for instance, may prefer to conduct a site-specific risk assessment to assist in developing cleanup goals. Similarly, a regulator may conclude that the ESLs do not address a key concern for a given site, such as backyard gardening, which requires a site-specific assessment.

Regional Water Board staff uses either of two approaches for evaluating sites for regulatory closure or No Further Action: The Low-Threat Underground Storage Tank Closure Policy (LTCP; State Water Board 2012b) or Closure Criteria 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.

The LTCP does not use the ESLs to screen contaminants at petroleum-contaminated sites. Instead the LTCP provides closure levels for 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).

Table 1-3 – Low-Threat UST Case Closure Policy (LTCP) General Criteria

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

1.5.2 Closure Criteria for Non-UST Sites

In 2009, the Regional Water Board’s Groundwater Committee developed an Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites (Regional Water Board 2009). The tool presents nine narrative criteria that must be satisfied to demonstrate remaining contamination will have a minimal impact on the environment, human and/or ecological receptors, and present or future drinking water resources. The criteria fall into three groups: (1) site characterization, (2) source control and mitigation and (3) demonstration that future land and water use is not adversely affected (Table 1-4). Although the document title includes chlorinated solvents, these criteria are versatile and can be applied to releases of other chemicals and mixtures. As of January 2019, 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 criteria for site evaluations.

Table 1-4 – Regional Water Board Closure Criteria for Non-UST Sites

<table>
<thead>
<tr>
<th>No.</th>
<th>Narrative Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Develop a complete conceptual site model (CSM)</td>
</tr>
<tr>
<td></td>
<td>1a) Pollutant sources are identified and evaluated</td>
</tr>
<tr>
<td></td>
<td>1b) The site is adequately characterized</td>
</tr>
<tr>
<td></td>
<td>1c) Exposure pathways, receptors, and potential risks, threats, and other environmental concerns are identified and assessed</td>
</tr>
</tbody>
</table>

|     | Control sources and mitigate risks and threats |
|     | 2a) Pollutant sources are remediated to the extent feasible |
|     | 2b) Unacceptable risks to human health, ecological health, and sensitive receptors, considering current and future land and water uses, are mitigated |
|     | 2c) Unacceptable threats to groundwater and surface water resources, considering existing and potential beneficial uses, are mitigated |

|     | Demonstrate that residual pollution in all media will not adversely affect present and anticipated land and water uses |
|     | 3a) Groundwater plumes are decreasing |
|     | 3b) Cleanup standards can be met in a reasonable timeframe |
|     | 3c) Risk management measures are appropriate, documented, and do not require ongoing, active Regional Water Board oversight |

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>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Supplemental Instructions to the State Water Board December 8, 1995, Interim Guidance on Required Cleanup at Low Risk Fuel Sites</td>
</tr>
<tr>
<td>2009</td>
<td>Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites</td>
</tr>
<tr>
<td>2014</td>
<td>Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region (TCE Framework)</td>
</tr>
</tbody>
</table>
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 in context. 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). The CSM should describe the nature and extent of contamination, how contamination is moving in space and time, and what receptors are likely to be impacted. The CSM should be detailed enough to understand whether site characteristics are consistent with the assumptions used to derive ESL values. The CSM should be 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

<table>
<thead>
<tr>
<th>Site Data</th>
<th>Interpretation of Site Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local and Regional Geology</td>
<td>Contaminant Type(s) and Source(s)</td>
</tr>
<tr>
<td>Hydrogeology</td>
<td>Affected Media Type(s)</td>
</tr>
<tr>
<td>Site Activity and Use History</td>
<td>Contaminant Amount</td>
</tr>
<tr>
<td>Current and Future Site Use</td>
<td>Lateral/Vertical Contamination Extent</td>
</tr>
<tr>
<td>Nearby Land and Groundwater Use</td>
<td>Degradability of Contamination</td>
</tr>
<tr>
<td>Analytical Chemistry Data</td>
<td>Mobility of Contamination</td>
</tr>
<tr>
<td>Monitoring Data</td>
<td>Receptors and Exposure Pathways</td>
</tr>
</tbody>
</table>

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 should include three basic elements described below:

1. **A description of the nature and extent of contaminants at the site.**

   ESLs should only be used once there is a relatively clear picture of the contamination type(s) and 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.
2. **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.

3. **An evaluation of the potential receptors and exposure pathways.** This is often shown as a chart indicating which media are impacted and the exposure pathways from each medium to potential receptors. For initial screening at the Tier 1 level, default receptors are assumed (see Section 2.3 and Figure 2-4). For more detailed evaluations, a site-specific description of the actual receptors – both human and environmental - should be included and the presence of sensitive receptors such as hospitals, schools, day care centers, wetlands, or endangered species highlighted (e.g., Figure 2-5). Exposure pathways and receptors which may be present at the site but are not considered by the ESLs should be noted (e.g., consumption of backyard produce grown in contaminated soil or ingestion of contaminated surface water by endangered species).
Figure 2-2 – Example Illustrating Horizontal Extent of Tetrachloroethene in Shallow Groundwater
Figure 2-3 – Example Cross Section Illustrating Contaminant Distribution
Figure 2-4 – Default Evaluation of Receptors and Exposure Pathways Used in a Tier 1 Assessment

*The ESLs do not include soil to indoor air screening levels. Soil gas must be sampled to evaluate this transport pathway.*
Figure 2-5 – Example of a Site-Specific Evaluation of Receptors and Exposure Pathways

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

**Exposure routes not considered in the ESLs, must be evaluated on a site-specific basis."
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

<table>
<thead>
<tr>
<th>Site Scenario Criteria</th>
<th>Tier 1 ESL Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>Residential</td>
</tr>
<tr>
<td>Vegetation Level</td>
<td>Substantial</td>
</tr>
<tr>
<td>Groundwater Use</td>
<td>Drinking Water Resource</td>
</tr>
<tr>
<td>MCL Priority over Risk Based Levels</td>
<td>Yes</td>
</tr>
<tr>
<td>Discharge to Surface Water</td>
<td>Saltwater &amp; Freshwater</td>
</tr>
<tr>
<td>Groundwater VI Attenuation Factor</td>
<td>0.001</td>
</tr>
<tr>
<td>Soil Gas VI Attenuation Factor</td>
<td>0.03</td>
</tr>
<tr>
<td>Soil Contamination Depth</td>
<td>Shallow (≤ 10 ft bgs)</td>
</tr>
</tbody>
</table>

### 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.
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.

Step 2: Identify Chemicals of Potential Concern

An appropriate risk evaluation must 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, subslab/soil gas, and indoor air within areas located both on- and off-site.

- Identify maximum concentrations of chemicals present in the media of concern.

Step 3: Land Use Selection

The selected ESLs for soil, subslab/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 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 requirement for possibly unneeded institutional controls, such as a deed restriction that prohibits residential land use, which would only be 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.

**Step 4: Vegetation Level Selection**

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

1. the level of urbanization in surrounding areas;
2. the percentage of the site that is covered by vegetation; and
3. 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.
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 must be adequately assessed as well as the potential for vapor intrusion.

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)\textsuperscript{2} 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.

**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).

**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 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 were removed.

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

\textsuperscript{2} 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.
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 determining the final screening level for groundwater, soil, subslab/soil gas, and indoor air, respectively.

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. Guidance 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
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.

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 1x10^{-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.

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 (AF) 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 subslab/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.

### 2.1 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.
**Figure 2-10 – ESL Workbook Interactive Tool Tier 2 ESL Input and Output Table T2-1 for Example Scenario**

<table>
<thead>
<tr>
<th>Select Site Contaminants:</th>
<th>Contaminant 1</th>
<th>Contaminant 2</th>
<th>Contaminant 3</th>
<th>Contaminant 4</th>
<th>Contaminant 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tetrachloroethene</td>
<td>Trichloroethene</td>
<td>cis-1,2-Dichloroethene</td>
<td>Vinyl chloride</td>
<td>Petroleum - Stoddard Solvent</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tier 2 ESLs:</th>
<th>Soil (mg/kg):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8.0E-02 Leaching</td>
</tr>
<tr>
<td></td>
<td>8.5E-02 Leaching</td>
</tr>
<tr>
<td></td>
<td>1.6E+00 Leaching</td>
</tr>
<tr>
<td></td>
<td>1.5E-03 Leaching</td>
</tr>
<tr>
<td></td>
<td>2.6E+02 Terr Habitat</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Groundwater (μg/L):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8E+00 VI HHR</td>
</tr>
<tr>
<td></td>
<td>7.5E+00 VI HHR</td>
</tr>
<tr>
<td></td>
<td>2.1E+02 VI HHR</td>
</tr>
<tr>
<td></td>
<td>1.4E-01 VI HHR</td>
</tr>
<tr>
<td></td>
<td>2.5E+03 Gross Contam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Subslab/ Soil Gas (μg/m³):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.7E+01 VI HHR</td>
</tr>
<tr>
<td></td>
<td>1.0E+02 VI HHR</td>
</tr>
<tr>
<td></td>
<td>1.2E+03 VI HHR</td>
</tr>
<tr>
<td></td>
<td>5.2E+00 VI HHR</td>
</tr>
<tr>
<td></td>
<td>3.3E+04 VI Odor/Nuis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Indoor Air (µg/m³):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.0E+00 Dir Exp</td>
</tr>
<tr>
<td></td>
<td>3.0E+00 Dir Exp</td>
</tr>
<tr>
<td></td>
<td>3.5E+01 Dir Exp</td>
</tr>
<tr>
<td></td>
<td>1.6E-01 Dir Exp</td>
</tr>
<tr>
<td></td>
<td>1.6E+03 Odor/Nuis</td>
</tr>
</tbody>
</table>

**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.
### Table T2-2: Tier 2 – Site-Specific Cumulative Risk and Hazard Calculator

<table>
<thead>
<tr>
<th>Contaminant inputs from T2-1:</th>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Concentration (mg/kg) - dry weight:</td>
<td>0.50</td>
<td>0.30</td>
<td>60.00</td>
<td>5.00</td>
<td>3,000.00</td>
</tr>
<tr>
<td>Groundwater Concentration (μg/L):</td>
<td>100.00</td>
<td>40.00</td>
<td>60.00</td>
<td>5.00</td>
<td>500.00</td>
</tr>
<tr>
<td>Subslab/Soil Gas Concentration (μg/m³):</td>
<td>50,000</td>
<td>1,000</td>
<td>100</td>
<td>100</td>
<td>400,000</td>
</tr>
<tr>
<td>Indoor Air Concentration (μg/m³):</td>
<td>10.00</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Soil Gas VI Attenuation Factor (Use 0.03 for Screening): 0.0300

### Cancer Risk:

#### Soil Exposure Risk:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9E-07</td>
<td>4.9E-08</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

#### Tapwater Exposure Risk:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

#### Current* Vapor Intrusion Exposure Risk:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0E-06</td>
<td>1.7E-07</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

#### Future** Vapor Intrusion Exposure Risk:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5E-04</td>
<td>1.0E-04</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

### Noncancer Hazard:

#### Soil Exposure Hazard:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4E-03</td>
<td>1.7E-02</td>
<td>–</td>
<td>–</td>
<td>2.7E+00</td>
</tr>
</tbody>
</table>

#### Tapwater Exposure Hazard:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

#### Current* Vapor Intrusion Exposure Hazard:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7E-02</td>
<td>5.7E-02</td>
<td>8.8E-02</td>
<td>8.8E-03</td>
<td>8.7E+00</td>
</tr>
</tbody>
</table>

#### Future** Vapor Intrusion Exposure Hazard:

<table>
<thead>
<tr>
<th>Tetrachloroethene</th>
<th>Trichloroethene</th>
<th>cis,1,2-Dichloroethene</th>
<th>Vinyl chloride</th>
<th>Petroleum - Stoddard Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6E+00</td>
<td>3.4E+00</td>
<td>8.8E-02</td>
<td>8.8E-03</td>
<td>8.7E+00</td>
</tr>
</tbody>
</table>

### 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.

** 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 indoor air data, subslab/soil gas or groundwater data is used to predict current indoor air concentrations.

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.

---

### Selected Site Scenario (from T2-1)

- **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

---

**Figure 2-11 – Interactive ESL Workbook Tool Table T2-2 for the Example Scenario**
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 (µg/L): 100.00
- Soil Gas (µg/m³): 50,000
- Indoor Air (µg/m³): 10.00

ESLs Exceeded (‘X’). Further evaluation of identified concerns recommended.

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

<table>
<thead>
<tr>
<th>Medium/Workbook Table</th>
<th>Resident Exposure Routes</th>
<th>Commercial/Industrial Worker Exposure Routes</th>
<th>Construction Worker Exposure Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater (Table GW-1 Tapwater Columns)</td>
<td>Ingestion, Inhalation, Dermal</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Shallow Soil (≤10 ft bgs) (Table S-1)</td>
<td>Ingestion, Inhalation, Dermal</td>
<td>Ingestion, Inhalation, Dermal</td>
<td>Ingestion, Inhalation, Dermal</td>
</tr>
<tr>
<td>Deep Soil (&gt;10 ft bgs) (Table S-1)</td>
<td>--</td>
<td>--</td>
<td>Ingestion, Inhalation, Dermal</td>
</tr>
<tr>
<td>Indoor Air (Table IA-1)</td>
<td>Inhalation</td>
<td>Inhalation</td>
<td>--</td>
</tr>
</tbody>
</table>

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.

• **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. 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. Lastly, the Final MCL Priority Screening Level is determined by selecting the MCL value or, if there is no MCL value, the lowest value of the cancer risk and noncancer hazard Final Human Health Screening Levels.

The concept behind the MCL Priority category is that California MCLs can be used in place of the health risk-based levels to represent the Basin Plan water quality objectives. The groundwater Tier 1 ESLs only consider the most conservative of California primary or secondary MCLs and not the other direct exposure health risk values (also called MCL Priority) for all chemicals with established MCLs to reflect the Basin Plan water quality objectives. Therefore, the Tier 1 ESLs for groundwater are not necessarily the lowest or most stringent possible 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 $1 \times 10^{-5}$ 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

<table>
<thead>
<tr>
<th>Soil Depth</th>
<th>Land Use: Residential, Receptor: Resident</th>
<th>Land Use: Commercial/Industrial, Receptor: Worker</th>
<th>Land Use: Any, Receptor: Construction Worker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Deep</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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 $1 \times 10^{-5}$ 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 ($10^{-6}$) 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 must 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 Academy of Sciences (NAS 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 status, 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 (CSFi) and the inhalation reference dose (RfD). 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 2018b)** – 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 a residential land use.

- **Commercial or Industrial Workers** – Primary receptors considered for sites with a commercial or industrial land use are commercial/industrial workers. The commercial/industrial scenario represents a variety of workers, from those who spend most of their work day indoors to those who frequently work outdoors, but not workers involved in excavation activities. A commercial/industrial worker is assumed to be an adult who will have eight hours of exposure during the course of a work day as a full-time employee of a company operating 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 work day for the duration of a single on-site construction project, lasting one year. Even though work durations are typically of shorter length due to the short-term nature of typical construction projects, 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 $1 \times 10^{-6}$ and the target noncancer hazard index is unity (or 1), based on the USEPA recommended points of departure.

### 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.

### 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.

Table 3-2 – Human Health Toxicity Value Hierarchy

<table>
<thead>
<tr>
<th>Tier</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>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 – OEHHA values meeting regulation requirements for peer-review and California-specific aspects (sensitive subpopulations considered). See also DTSC 2019a.</td>
</tr>
<tr>
<td>2</td>
<td>USEPA Integrated Risk Information System (IRIS)</td>
</tr>
<tr>
<td>3</td>
<td>Other sources (e.g., USEPA Provisional Peer-Reviewed Toxicity Values (PPRTVs), ATSDR, etc.)</td>
</tr>
</tbody>
</table>

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 must 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**: 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.
- **Kp**: Dermal permeability coefficient of a chemical in water through the outer skin layer (stratum corneum).
- **τ** \text{ 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 do not use extrapolated inhalation toxicity values as a rule (also see the USEPA RSL Frequent Questions). Two exceptions are cis- and trans-1,2-dichloroethene which are prevalent throughout the region 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, we extrapolated a RfC for each compound from
the corresponding RfD available in the USEPA IRIS. This route extrapolation is also performed in DTSC HHRA Note 3.

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 2019b)
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 3-3 – Exposure Factor Selection

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Weight (BW)</strong></td>
<td>NC: Child C: Age Adj.</td>
<td>NC: Child C: Age Adj.</td>
<td>Adult</td>
<td>--</td>
<td>--</td>
<td>Adult</td>
<td>Adult</td>
<td>--</td>
</tr>
<tr>
<td><strong>Soil: Surface Area (SA) Exposed Skin</strong></td>
<td>--</td>
<td>NC: Child C: Age Adj.</td>
<td>Const. Worker</td>
<td>--</td>
<td>--</td>
<td>Com/Ind Worker</td>
<td>Const. Worker</td>
<td>--</td>
</tr>
<tr>
<td><strong>Water: Surface Area (SA) Exposed Skin</strong></td>
<td>NC: Child C: Age Adj.</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>All Media: Exposure Time (ET) per day</strong></td>
<td>--</td>
<td>NC: Child C: Age Adj.</td>
<td>Const. Worker</td>
<td>--</td>
<td>--</td>
<td>Com/Ind Worker</td>
<td>Const. Worker</td>
<td>--</td>
</tr>
<tr>
<td><strong>Water Event Exposure Time (ET)</strong></td>
<td>--</td>
<td>NC: Child C: Age Adj.</td>
<td>Const. Worker</td>
<td>--</td>
<td>--</td>
<td>Com/Ind Worker</td>
<td>Const. Worker</td>
<td>--</td>
</tr>
<tr>
<td><strong>Soil to Skin Adherence Factor (AF)</strong></td>
<td>NC: Child C: Age Adj.</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Soil Ingestion Rate (IR)</strong></td>
<td>--</td>
<td>Resident Worker</td>
<td>Resident</td>
<td>--</td>
<td>--</td>
<td>Worker</td>
<td>Worker</td>
<td>Worker</td>
</tr>
<tr>
<td><strong>Water Ingestion Rate (IR)</strong></td>
<td>NC: Child C: Age Adj.</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Exposure Frequency (EF)</strong></td>
<td>Resident</td>
<td>Resident</td>
<td>Const. Worker</td>
<td>Resident</td>
<td>--</td>
<td>Com/Ind Worker</td>
<td>Const. Worker</td>
<td>Com/Ind Worker</td>
</tr>
<tr>
<td><strong>Exposure Duration (ED)</strong></td>
<td>NC: Child C: Age Adj.</td>
<td>NC: Child C: Age Adj.</td>
<td>Const. Worker</td>
<td>Age Adj.</td>
<td>--</td>
<td>Com/Ind Worker</td>
<td>Const. Worker</td>
<td>Com/Ind Worker</td>
</tr>
</tbody>
</table>
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 2007b). 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 below in a separate subsection) and exposure to lead-contaminated soil (described in the Equations section of this chapter). For other chemicals, relative bioavailability could be considered as part of a site-specific evaluation. For example, DTSC has developed a recommended methodology for evaluating site-specific arsenic bioavailability in soils (DTSC 2016a).

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 3-4 – Mutagens

<table>
<thead>
<tr>
<th>Chemical</th>
<th>CAS No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium VI</td>
<td>18540-29-9</td>
</tr>
<tr>
<td>1,2-Dibromo-3-chloropropane</td>
<td>96-12-8</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>75-09-2</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>79-01-6</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>75-01-4</td>
</tr>
<tr>
<td>Benz[a]anthracene [PAH]</td>
<td>56-55-3</td>
</tr>
<tr>
<td>Benzo[k]fluoranthene [PAH]</td>
<td>207-08-9</td>
</tr>
<tr>
<td>Benzo[a]pyrene [PAH]</td>
<td>50-32-8</td>
</tr>
<tr>
<td>Chrysene [PAH]</td>
<td>218-01-9</td>
</tr>
<tr>
<td>Dibenz[a,h]anthracene [PAH]</td>
<td>53-70-3</td>
</tr>
</tbody>
</table>

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).

Two blood lead models are employed to calculate the soil direct contact levels for lead. Both 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. The two blood lead models include:

- **The LeadSpread 8 (DTSC 2011a)** is used to estimate the concentration in soil that would lead to a 1 µg/dL increase in blood lead for a child resident exposed to that soil. The central tendency soil ingestion rate for a child resident is 100 milligrams per day.

- **The DTSC-Modified USEPA Adult Lead Model**, which is included in the LeadSpread 8 Excel workbook, (DTSC 2011a) is used to estimate the concentration in soil that would lead to a 1 µg/dL increase in blood lead for a pregnant adult worker exposed to that soil. For the commercial/industrial worker, the central tendency soil ingestion rate is 50 milligrams per day. For the construction worker, the central tendency soil ingestion rate is 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 noncancerous health effects.

At sites where more than one contaminant is present, cumulative cancer risk and noncancerous 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).

$$\text{Risk} = \left[ \left( \frac{\text{Conca}}{\text{ESLa}} \right) + \left( \frac{\text{Concb}}{\text{ESLb}} \right) + \left( \frac{\text{Concc}}{\text{ESLc}} \right) + \ldots + \left( \frac{\text{Conci}}{\text{ESLi}} \right) \right] \times 10^{-6}$$

(equation 1)

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 noncancerous hazard index (HI) (equation 2).

$$\text{HI} = \left[ \left( \frac{\text{Conca}}{\text{ESLa}} \right) + \left( \frac{\text{Concb}}{\text{ESLb}} \right) + \left( \frac{\text{Concc}}{\text{ESLc}} \right) + \ldots + \left( \frac{\text{Conci}}{\text{ESLi}} \right) \right]$$

(equation 2)

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, noncancerous chemicals 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 given priority over groundwater data for these calculations.
  - 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 chemical constituents. Key elements of these approaches are summarized below:

- **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.³

- **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:
  - **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:
    1. **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).

³ 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).
2. 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.

3. Hazard index (HI) – The HI method requires only similarity in target organ, and this is routinely used to evaluate the cumulative hazard posed by noncancerous. 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 of the mixture for which adequate dose-response information is available.

   - **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), ß-chlordene, heptachlor, and trans-nonachlor. Further information on chlordane composition is provided in the RSL Frequent Questions (USEPA 2018b).

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

Weathered chlordane is expected to include its metabolite heptachlor epoxide. There are separate ESLs for heptachlor and heptachlor epoxide.
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 3-5 – World Health Organization Toxic Equivalency Factors for Dioxins and Furans (2005)

<table>
<thead>
<tr>
<th>Compound</th>
<th>TEF ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,3,7,8-TCDD</td>
<td>1</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDD</td>
<td>1</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDD</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDD</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDD</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDD</td>
<td>0.01</td>
</tr>
<tr>
<td>OCDD</td>
<td>0.0003</td>
</tr>
<tr>
<td>2,3,7,8-TCDF</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8-PeCDF</td>
<td>0.03</td>
</tr>
<tr>
<td>2,3,4,7,8-PeCDF</td>
<td>0.3</td>
</tr>
<tr>
<td>1,2,3,4,7,8-HxCDF</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDF</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDF</td>
<td>0.1</td>
</tr>
<tr>
<td>2,3,4,6,7,8-HxCDF</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDF</td>
<td>0.01</td>
</tr>
<tr>
<td>1,2,3,6,7,8,9-HpCDF</td>
<td>0.01</td>
</tr>
<tr>
<td>OCDF</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

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
8080 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 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.

### 3.6.7 Polycyclic Aromatic Hydrocarbons (PAHs)

The ESL Workbook includes screening levels for 16 polycyclic aromatic hydrocarbons (PAHs), presented in alphabetical order (not grouped). These 16 PAHs are identified as priority pollutants by USEPA and are listed in Table 3-7.
Table 3-6 – PAHs in the ESLs and Relative Potency Factors for the Carcinogenic PAHs

<table>
<thead>
<tr>
<th>PAH Compound</th>
<th>CAS No.</th>
<th>Number of Benzene Rings</th>
<th>Carcinogenic?</th>
<th>Relative Potency Factor (RPF)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acenaphthene</td>
<td>83-32-9</td>
<td>3</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Acenaphthylene</td>
<td>208-96-8</td>
<td>3</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Anthracene</td>
<td>120-12-7</td>
<td>3</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Benzo[a]anthracene</td>
<td>56-55-3</td>
<td>4</td>
<td>Yes</td>
<td>0.1</td>
</tr>
<tr>
<td>Benzo[b]fluoranthene</td>
<td>205-99-2</td>
<td>4</td>
<td>Yes</td>
<td>0.1</td>
</tr>
<tr>
<td>Benzo[k]fluoranthene</td>
<td>207-08-9</td>
<td>4</td>
<td>Yes</td>
<td>0.01</td>
</tr>
<tr>
<td>Benzo[g,h,i]perylene</td>
<td>191-24-2</td>
<td>5</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Benzo[a]pyrene</td>
<td>50-32-8</td>
<td>5</td>
<td>Yes</td>
<td>1.0 (index compound)</td>
</tr>
<tr>
<td>Chrysene</td>
<td>218-01-9</td>
<td>4</td>
<td>No</td>
<td>0.001</td>
</tr>
<tr>
<td>Dibenz[a,h]anthracene</td>
<td>53-70-3</td>
<td>5</td>
<td>Yes</td>
<td>1.0</td>
</tr>
<tr>
<td>Fluorantheine</td>
<td>206-44-0</td>
<td>3</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Fluorene</td>
<td>86-73-7</td>
<td>2</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Indeno[1,2,3-cd]pyrene</td>
<td>193-39-5</td>
<td>5</td>
<td>Yes</td>
<td>0.1</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>91-20-3</td>
<td>2</td>
<td>Yes</td>
<td>--(^2)</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>85-01-8</td>
<td>3</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Pyrene</td>
<td>129-00-0</td>
<td>4</td>
<td>No</td>
<td>--</td>
</tr>
</tbody>
</table>

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.
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;

- **Seven carcinogenic PAHs (listed in Table 3-8)** – 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 C$_{10}$H$_{8}$) through the largest, coronene (C$_{24}$H$_{12}$).

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.

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), although 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.
3.6.8 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). 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 need for engineering and health and safety controls rather than cleanup.
4 Methods: Petroleum Mixture Screening Levels

What is TPH?
Previously, 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). This edition of the ESLs replaces “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 while 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 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.

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.
4.1 Background

The first under Regional Water Board oversight to develop health-risk based levels for petroleum/TPH mixtures was 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 the majority of the crude oil mass. Most crude oils are complex mixtures containing tens of thousands of compounds, including hydrocarbons and nonhydrocarbons. The latter 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/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. 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 classes including straight-chain, saturated aliphatics (alkanes); branched alkanes (isoalkanes); cyclic alkanes (cycloalkanes); and various unsaturated aliphatics (alkenes and alkyynes). 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**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Molecular Formula</th>
<th>Boiling Point (°C)¹</th>
<th>Vapor Pressure (mm Hg)¹</th>
<th>Henry's Law Constant (atm-m³/mol)¹</th>
<th>Solubility (µg/L)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>C₆H₆</td>
<td>80</td>
<td>9.5E+01</td>
<td>5.6E-03</td>
<td>2.0E+06</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>C₆H₁₄</td>
<td>69</td>
<td>1.5E+02</td>
<td>1.8E+00</td>
<td>9.5E+03</td>
</tr>
<tr>
<td>2-Hexanone²</td>
<td>C₆H₁₂O₁</td>
<td>128</td>
<td>1.4E+01</td>
<td>9.3E-05</td>
<td>7.7E+06</td>
</tr>
<tr>
<td>Hexanoic Acid²</td>
<td>C₆H₁₂O₂</td>
<td>205</td>
<td>4.4E-02</td>
<td>7.6E-07</td>
<td>5.8E+06</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>C₁₄H₁₀</td>
<td>327</td>
<td>4.3E-05</td>
<td>1.5E-05</td>
<td>6.8E+02</td>
</tr>
<tr>
<td>1H2NA³</td>
<td>C₁₁H₈O₃</td>
<td>375</td>
<td>1.3E-07</td>
<td>1.5E-10</td>
<td>2.3E+06</td>
</tr>
</tbody>
</table>

**Table 4-1 Notes:**

Note 1 – Physical-chemical parameter values from USEPA Estimation Programs Interface (EPI) Suite

Note 2 – n-Hexane metabolites: 2-hexanone and hexanoic acid

Note 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 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.

2. The most commonly analyzed individual hydrocarbons are benzene, toluene, ethylbenzene, xylenes and the 16 USEPA priority pollutant
The monoaromatics benzene, toluene, ethylbenzene and the three xylene isomers are commonly referred to as “BTEX.”

3. 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).

4. 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:

   a. All hydrocarbons: Arsenic – A potential secondary effect of the natural attenuation of hydrocarbons coupled with iron reduction is a release of naturally occurring arsenic to groundwater (Cozzarelli et al. 2015). This 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.

   b. 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).

   c. 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,

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4 Naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[g,h,i]perylene, indeno[1,2,3-c,d]pyrene, and dibenz[a,h]anthracene.
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 Mixtures**

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

**Table 4-2 Notes:** See Section 4.2.2 for further discussion.

Note 1 – PAHs are typically 16 priority pollutant PAHs, including naphthalene. Other PAHs are addressed via the petroleum hydrocarbon mixture ESLs

Note 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).

Note 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.

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

The risk from a mixture of petroleum hydrocarbons lacking regulatory toxicity criteria for most individual components can be evaluated using an approach based on petroleum hydrocarbon fractions and representative toxicity surrogates (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). Such an approach addresses the risk assessment challenges posed by petroleum releases (Section 4.2.1). Petroleum fractions are groups of hydrocarbons with similar molecular structures that have similar fate characteristics in the environment (e.g., volatility, solubility, susceptibility to biodegradation) and/or are considered to have similar toxicity. 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 quantitation 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.
History of Petroleum Fraction Approaches

Two of the most widely cited early efforts to develop risk-based approaches to the evaluation of petroleum-contaminated sites using modifications to the bulk TPH analytical method were made by the Massachusetts Department of Environmental Protection (MADEP 1994b) and the TPH Criteria Working Group (1997a, 1997b, 1998a, 1998b, and 1999). These efforts focused on identifying groups of hydrocarbons with similar structure and environmental fate, termed “fractions,” and assigning physical/chemical parameters, toxicity values, and creating associated TPH “fractionation” analytical methods.

Other agencies have adopted similar fraction-based approaches, such as ATSDR (1999), Canada (CCME 2008; Atlantic PIRI 2012), Texas (TCEQ undated and 2001), Washington (Washington DOE 1997). In Europe, a similar approach called the “hydrocarbon block method” is used to assess whether the risks of petroleum mixtures in commerce are safe for intended uses (King et al. 1996; Redman et al. 2014).

In 2009, USEPA issued guidance for the Superfund Program adopting a fraction approach entitled Final Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons (USEPA 2009c), based on the fraction approaches developed by MADEP and the TPH Criteria Working Group, which were considered to be reasonable, flexible, and the best available methodology for assessing risk from releases of complex hydrocarbon mixtures. USEPA scientists also evaluated the approach using computational chemistry and statistical methods and found supporting evidence for selecting the fractions (Wang et al. 2012). In recent years, the USEPA Regional Screening Levels have included TPH fraction screening levels (e.g., TPH aliphatic medium).

The USEPA petroleum fractions are divided by molecular structure into aliphatics and aromatics, and then each structure is subdivided into three carbon number ranges (low, medium, and high) for a total of six fractions. Figure 4-1 illustrates the six fractions based on hydrocarbon class and equivalent carbon number (EC).

Equivalent Carbon (EC) Number

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.
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). USEPA selected surrogates for each fraction in the following order of preference (hierarchy):

1. Mixtures of similar composition

2. **Representative compound in the fraction** – Options include using the most toxic component if the toxicity varies considerably or the most abundant, if a component represents a large proportion of the fraction. In some cases, such as the medium carbon range aromatics, compounds with more potent toxicities (i.e., 2-methylnaphthalene) can be assessed separately while the remaining fraction mass is assessed using values for a surrogate mixture (i.e., high-flash aromatic naphtha).

3. **Components Method** – For fractions where the individual compounds are well characterized and with known toxicity values, the components are individually assessed.

![Diagram Illustrating the Petroleum Fractions in the ESLs by Equivalent Carbon Number](after USEPA 2009c)

**ESL Fraction Approach**

In 2013, the USEPA (2009c) petroleum fractions and associated toxicity values were selected for use in the ESLs for the following reasons: (1) the fraction approach is currently the best approach for evaluating potential risks posed by petroleum residues as evidenced by successful use of fraction approaches across multiple agencies within and outside the US; (2) the fraction approach is consistent with USEPA guidance on the health risk assessment of chemical
mixtures (USEPA 1986 and 2000e); and (3) the surrogates and toxicity values are well supported in the seven provisional peer-reviewed toxicity value (PPRTV) documents (USEPA 2009b through 2009g and 2012e) and their selection is consistent with the ESL toxicity value hierarchy (Table 3-3) as there are neither OEHHA nor IRIS toxicity values for the petroleum fractions. Table 4-3 presents the fractions, designated as Fraction 1 through Fraction 6, and lists their partitioning characteristics.

### Table 4-3 – ESL Petroleum Hydrocarbon Fractions and Partitioning Characteristics

<table>
<thead>
<tr>
<th>Carbon (C) Range</th>
<th>Aliphatic Fractions</th>
<th>Aromatic Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low</strong></td>
<td>Fraction 1: C5-C8 (EC5-EC8) (Soluble &amp; Volatile)</td>
<td>Fraction 4: C6-C8 (EC6-EC&lt;9) (Soluble &amp; Volatile)</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>Fraction 2: C9-C18 (EC&gt;9-EC16) (Non-soluble &amp; Volatile)</td>
<td>Fraction 5: C9-C16 (EC9-EC&lt;22) (Soluble &amp; Volatile)</td>
</tr>
</tbody>
</table>

#### 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 2019 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>
<thead>
<tr>
<th>Released Petroleum Hydrocarbon Mixture</th>
<th>Individual Chemicals (Table 4-2)</th>
<th>Petroleum Hydrocarbon Mixture</th>
<th>Petroleum HOPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Stoddard solvent</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Jet fuel</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Diesel</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Motor Oil</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bunker fuel</td>
<td>Yes</td>
<td>*</td>
<td>Yes</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>Yes</td>
<td>*</td>
<td>Yes</td>
</tr>
<tr>
<td>Unknown or Waste Oil</td>
<td>Yes</td>
<td>*</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**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

Unlike the RSLs, the ESLs do not include TPH fraction screening levels for separate aromatic and aliphatic fractions (e.g., TPH-aliphatic low). Such fraction-
Specific screening levels are not compatible with the routinely used bulk TPH analytical methods quantified against specific petroleum mixtures (e.g., gasoline, diesel). Such screening levels would necessitate the use of TPH fractionation analytical methods (e.g., Texas Method 1006) for all samples.

Noncancer ESLs for groundwater, soil, 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:

1. Petroleum fractions (Section 4.2.3) and properties (toxicity values and constants);
2. Proportions of the fractions expected in each medium:
   a. Soil – unweathered fuels/oil composition
   b. Indoor Air – proportions of the unweathered fuel/oil predicted to partition into vapor
   c. Groundwater – proportions of the unweathered fuel/oil predicted to partition into water
3. 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 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\textsubscript{14} and smaller), and smaller aliphatic hydrocarbon molecules with 6 or fewer carbon items (C\textsubscript{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\textsubscript{8} and smaller aliphatics and aromatics, with only minor amounts of C\textsubscript{9}-C\textsubscript{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 fractionally-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 developed by USEPA (2009c) as previously 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 testing 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 3, from *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures*; USEPA 2000e).

\[
\text{Weighted Average Value} = \frac{1}{\left(\frac{\% F_1}{TV_1} + \frac{\% F_2}{TV_2} + \ldots + \frac{\% F_6}{TV_6}\right)}
\]

Where:
- \(FX\) = Fraction X
- \(TVX\) = Toxicity value for fraction X

(equation 3)

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 Lack of ESLs for Crude Oils and 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 all 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 recommends 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.

Should it be deemed necessary to conduct a screening level evaluation with existing bulk TPH-crude oil data, it is recommended each sample result be assumed to be composed of one-third each of TPH-gasoline, TPH-diesel, and TPH-motor oil. The data can 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 be assumed to be composed of one-half each of TPH-diesel and TPH-motor oil. The data can 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.

4.3.6 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. An option for a more site-specific approach is presented in Section 4.6.2.

4.4 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 presence of these 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.

4.4.1 Petroleum HOPs Toxicity and Physical-Chemical Values

The water RfD is selected based on the Petroleum Fraction 5 surrogate, high-flash aromatic naphtha (2E-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-hexanediol (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) to assess the 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

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5 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 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).
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.

4.4.2 Summary

We conclude that 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.

4.5 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.

4.5.1 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 (SiO₂) with 2 H₂O produces silica gel, a solid with many –OH groups that can interact with polar chemicals. The more polar a chemical, the tighter it binds to Si(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:

1. 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.
2. 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), 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 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 4-2. 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 (literature examples of HOPs include Lundegard and Sweeney 2004 and Lang et al. 2009, 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 4-2 – 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 a number of articles or guidance documents:

- HOPs – Lundegard and Sweeney 2004; Lang et al. 2009; Zemo 2016; and Figure 4-2.
- NOCs – Regional Water Board staff have observed these compounds in chromatograms primarily as single peaks.

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.

### 4.5.2 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.

### 4.5.3 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 4 below and illustrated on Figure 4-3.

\[
[HOPs] = [Total \ Hydrocarbon] - [PHC] - [NOCs]
\]

Where:
\[\text{[ ]} = \text{Concentration}\]
\[[Total \ Hydrocarbon]\] = Plume sample measured with TPH-diesel C10-24 without SGC
\[[PHC]\] = The same plume sample measured with TPH-diesel C10-28 with SGC
\[[NOCs]\] = 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

(equation 4)

![Conceptual Plume Map Showing How to Estimate Petroleum HOPs Concentrations](image)

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; see also Figure 4-2). 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 has 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 4-2). 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).

4.5.4 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, in some cases, be a useful tool.

### 4.5.5 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

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

Table 4-5 Notes:

- Note 1 – Compositions may vary from these ranges.
- Note 2 – SGC cannot be used. The procedure will volatilize the target hydrocarbons.
- Note 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.
- Note 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.

4.5.6 Recommendations for Vapor Analyses

At sites where significant contaminant mass remains and/or where other unique conditions prevent adequate aerobic biodegradation (e.g., geochemical conditions, preferential pathways, building susceptibility, significant pressure gradients), TPH vapors can drive risk (Brewer et al. 2013). Laboratory analysis of vapor samples (indoor air and soil gas) for TPH can be performed in accordance with the USEPA Methods TO-3, TO-15, or TO-17. Based on Brewer et al. (2013), the following are recommended for the analysis of TPH vapors:
• Low and medium carbon range hydrocarbons – TPH vapors quantified from C₅ to C₁₂ against a gasoline standard in accordance with USEPA Method TO-15 or equivalent.

• Medium carbon range hydrocarbons – TPH vapors quantified from C₁₂ to C₁₈ against a diesel standard in accordance with USEPA Method TO-17 or equivalent (note that TO-17 is a sorbent tube sampling method).

The analysis of TPH 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.

4.6 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.

4.6.1 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.
4.6.2 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.

TPH fractionation methods separate hydrocarbons into aliphatics and aromatics and measure concentrations for specific carbon number ranges. Separation into aliphatics and aromatics is often accomplished by silica gel solid-phase extraction/fractionation processes. 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:

- TCEQ – Method 1006 (TCEQ 2000).
- Washington Department of Ecology (WDOE) – VPH and EPH for soil and water (WDOE 1997)

Because silica gel is employed in the fractionation methods, petroleum metabolites will be lost (removed) and will have to be separately assessed via the bulk extractable TPH analysis or other suitable methods.
The TCEQ and WDOE TPH fractionation methods are generally recommended for soil and groundwater samples. The MADEP Air Phase Hydrocarbons method is generally recommended for vapor samples. 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.

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 contaminated subsurface media (groundwater, soil, soil gas). 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 gas). These ESLs apply to existing and future buildings.

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.

5.1 Background

Use of the VI ESLs is consistent with the Regional Water Board’s approach to chlorinated VOC vapor intrusion (CVI), which is described in the TCE Framework (Regional Water Board 2014). Other relevant guidance includes the DTSC Vapor Intrusion Guidance or VIG (DTSC 2011b) and the OSWER VI Guide (USEPA 2015a).

5.1.1 Conceptual Model for Vapor Intrusion into Buildings

The conventional model for VI consists of contaminated vapor transport through bulk soil (a porous medium) into a building. Over the last decade, an alternative pathway has been recognized as another important VI mechanism: contaminated vapor transport through sewer or utility conduit airspace into buildings (McHugh and Beckley 2018b). Researchers have found that sewer lines potentially are either the primary or a significant contributing pathway for about 20 percent of VI sites (McHugh et al. 2017b). Both conceptual models for VI are described below.

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).
The VI ESLs address the conventional model for VI; Section 5.1.5 and Section 5.4.1 discuss how to evaluate vapor conduit pathways (e.g., sewer and utility conduit air).

**Conventional Model for Vapor Intrusion**

There are four components to the transport of contaminated subsurface soil gases through bulk soil into buildings: 1) partitioning from the VOC source (groundwater or soil) into the vapor phase; 2) primarily diffusive vapor transport through the subsurface from the VOC source toward the building; 3) vapor entry primarily via advection into the building; and, 4) mixing with air inside a building (Figure 5-1)

Near contaminant release areas (i.e. the area of vadose zone soil contamination that extends from a source), VOC vapors can be emitted from both the impacted vadose zone soil and groundwater. However, away from release areas, the VOC vapor source is typically groundwater. VOC vapor concentrations will decrease (or attenuate) as VOCs diffuse upward and laterally away from a vapor source. The amount of vapor attenuation will depend on both subsurface characteristics (e.g., moisture content, soil type), surface characteristics (e.g., type of material or structure covering the ground surface) and weather conditions that influence the air exchange between a VOC vapor source and the ambient air.

Less attenuation is expected beneath buildings with a slab (e.g., slab-on-grade or basement) due to the “slab capping effect,” where a concrete slab acts as a barrier or cap limiting the downward flow of ambient air and the upward venting of contaminated soil gas (Figure 5-2) (Schumacher et al. 2010; Shen et al. 2014). In general, the slab capping effect increases as the area of a slab increases (e.g., larger buildings) or as the permeability of a slab decreases (e.g. thicker slabs). When slab capping effects are significant, VOC soil gas samples collected just above the vapor source (commonly referred to as “near-source soil gas”) typically correlate better than shallow exterior soil gas samples with subslab soil gas (Figure 5-2 A; DTSC, 2011b; USEPA, 2012a and 2015a). When predicting worst case subslab soil gas concentrations coming from a deep groundwater (> 20 ft bgs) vapor source, soil gas samples at roughly 15 ft bgs should be deep enough to account for slab capping effects (Figure 5-2 B). For buildings where slab capping effects are not expected (e.g., crawl space foundations with dirt floors), shallower exterior soil gas samples may be sufficient to predict soil gas concentrations directly beneath the building.
Figure 5-1 – Conventional Conceptual Model for Vapor Intrusion
Source: McHugh et al. 2017b

For a groundwater VOC vapor source, diffusion first occurs through the capillary fringe, which has high moisture content and low air content. Consequently, groundwater VOC sources are subject to much greater attenuation than vadose zone soil VOC sources (McCarthy and Johnson 1993). Furthermore, the thicker the capillary fringe, which is generally controlled by grain size (fine-grained soils such as silts and clays have thicker capillary fringes than coarse-grained soils such as sands and gravels), the greater the overall resistance to vapor transport.
Recent technical literature has recognized the importance of high-capacity preferential pathways for transporting contaminated vapors into buildings (vapor conduit pathways), such as sewer lines and utility conduits (Pennell et al. 2013; Guo et al. 2015; McHugh et al. 2017a and 2017b; McHugh and Beckley 2018a, b, and c). VOCs may enter sewer pipes that intersect contaminated soil or groundwater. Once inside the sewer pipe, VOCs can be transported beneath or directly into the building (Figure 5-3). While sewer plumbing systems inside buildings are designed to prevent sewer gases from entering the building, many components of sewer systems leak or become compromised. The locations where contaminated vapors from these pathways can enter buildings are variable. Examples include cracked or punctured pipes, loose fittings or degraded gaskets, dry plumbing traps (e.g., p-traps), diffusion through stagnant p-trap water, or via building foundation drains. Due to greater void space in the pipe, vapor transport typically is greater than the backfill (porous media).
5.1.2 **Multiple Lines of Evidence (MLE) Approach to Evaluating Vapor Intrusion**

Evaluating the VI pathway can be challenging due to:

- Numerous factors affecting the extent to which contaminant vapors migrate from the subsurface into overlying buildings (e.g., subsurface geology, building design, and climate conditions).

- Levels of volatile chemicals in background air (from outdoor or indoor sources) that can confuse or confound the use of indoor air results to detect and measure contaminated vapors emitted from subsurface releases.

- The considerable uncertainty associated with individual lines of evidence resulting from the spatial and temporal variability of volatile contaminant concentrations in groundwater, soil gas (including subslab soil gas), and indoor air (Holton et al. 2013; Winkler et al. 2001).
Consequently, evaluation of potential VI necessitates a multiple lines of evidence (MLE) approach to reduce uncertainties and increase confidence in making site management decisions. Each line of evidence (LOE) is evaluated, weighted, and the degree of concordance with the CSM assessed. Use of a single LOE to screen a site out from further review is generally not appropriate.

The following basic principles apply for evaluating LOEs:

- **Using LOEs to Develop and Maintain the CSM** — Information from each LOE should be used to inform the CSM and the CSM should be revised as LOEs are added or conflicting LOEs are resolved.

- **Weighting LOEs Based on Proximity of Sample Medium to the Receptor** — Typically, the closer the sampled medium is to the receptor, the greater those data are weighted. However, this does not negate the need to consider and weigh LOEs based on their quality and representativeness.

- **Minimum Number of Sample Medium Data LOEs for Decision Making** — Reliance on a single sample medium data LOE (e.g., groundwater or soil gas sample data) generally is not considered adequate. In most cases at least two concordant sample medium data LOEs are necessary for a complete VI evaluation. When different sample medium data LOEs conflict, additional LOEs should be considered such as, continued temporal monitoring to better resolve a data LOE, or increasing data density.

- **Limitations of LOEs** — Each LOE should be weighed based on an understanding of its limitations (e.g., variability, data quality). For instance, subslab soil gas concentrations typically shows spatial and temporal variability. Therefore, reliance on a single subslab soil gas sample from a single sampling event would introduce significant uncertainty into a site management decision.

### 5.1.3 Lack of VI ESLs for Soil

The 2005 ESLs were the last edition with soil levels for VI concerns. Subsequently, the Regional Water Board discontinued publishing soil ESLs for VI concerns due to the uncertainty associated with the partitioning equations and the potential loss of volatile organic compounds (VOCs) during sample collection, preservation, and analysis (DTSC 2011b; USEPA 2014c, 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. For these reasons, soil matrix data are not considered a primary LOE and should never be used as the sole LOE for assessing VI. Moreover, VOC concentrations of soil samples collected before use of USEPA Method 5035 (e.g., DTSC 2004) for field preservation, likely are biased low. However, soil samples may be necessary for evaluating direct exposure concerns and can be helpful for estimating the release area (i.e., the area of vadose zone soil contamination).
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.

5.1.4 Lack of VI ESLs for Crawl Space Air

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).

5.1.5 Lack of VI ESLs for Sewer/Utility Conduit Air

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.

5.2 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 $1 \times 10^{-5}$ 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.

5.2.1 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 5), 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).

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

where:
- $C_{IA}$ = Indoor air concentration in µg/m³
- $C_{SG}$ = Soil gas (subslab and deep/exterior soil gas) concentration in µg/m³
- $AF_{SG}$ = Attenuation factor for all soil gas (subslab and deep/exterior soil gas) (unitless)

(equation 5)

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 a 33-times reduction in concentration: $AF = 1/concentration
decrease = 1/33 = 0.03$. 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.

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 must be estimated. Equilibrium partitioning is assumed to obey Henry’s Law. This involves converting the groundwater concentration in micrograms per liter (µg/L) to an equivalent vapor concentration (µg/m³) using the chemical-specific dimensionless Henry’s Law Constant as shown in equation 6, below:

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

where:
- $C_{Vapor-GW}$ = Vapor concentration in equilibrium with groundwater in µg/m³
- $C_{GW}$ = Groundwater concentration in µg/L
- $H'$ = Chemical-specific Henry’s Law constant (dimensionless) at the specified groundwater temperature.
- $L$ = Liters
- $m^3$ = Cubic meters

(equation 6)
Second, the groundwater AF is then calculated as shown in equation 7 below:

\[
AF_{GW-IA} = \frac{C_{IA}}{C_{Vapor-GW}}
\]

where:
- \(AF_{GW-IA}\) = Groundwater to Indoor Air Attenuation Factor
- \(C_{IA}\) = Indoor air concentration
- \(C_{Vapor-GW}\) = Vapor concentration in equilibrium with groundwater

(equation 7)

Conversion of the groundwater concentration to an equivalent vapor equation assumes there is complete equilibrium between groundwater and soil gas. Typically, this is not the case due to the capillary fringe described in Section 5.1.1. 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

These AFs apply to all buildings, residential and commercial/industrial, current and future.

These empirical AFs are considered both protective and the best science available for the reasons listed herein.

- Empirical VI data are considered superior to VI model predictions because the actual measurements can capture aspects of this complex pathway that may not be adequately considered in models (e.g., preferential pathways) such as the JEM. Most of the JEM inputs are not measured leaving considerable uncertainty. Further, the model assumption of homogeneous subsurface conditions frequently is inconsistent with site conditions. Heterogeneity may be due to natural variation or may result from the construction process (e.g., compaction, preferential pathways around utility conduits). Moreover, the JEM has not been fully validated (McHugh et al. 2017b).
USEPA recommended VI AFs are the 95th percentile values that provide a high degree of protectiveness, which is appropriate for screening evaluations. Numerous states have adopted these AFs. The USEPA empirical VI database is the only such database developed by a US regulatory agency and it has been peer-reviewed.

Overall, Regional Water Board staff have greater confidence in the protectiveness of the USEPA AFs versus our previous model-based AFs. For site-specific evaluations, our previous model-based approach focused on the review of model inputs rather than verification of model predictions. Consequently, there are little or no data confirming the protectiveness of model-based AFs to support their continued use.

5.2.2 Soil Gas VI ESLs

The soil gas VI ESL ($ESL_{SG-IA}$) values are calculated as follows in equation 8:

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

where:
- $C_{IA}$ Indoor air concentration in µg/m³
- $AF_{SG}$ 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 µg/m³. This is the ESL value.

(equation 8)

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 Section 5.1.1.
5.2.3 Groundwater VI ESLs

The groundwater VI ESL (ESL\text{GW-IA}) values are calculated in equation 9:

\[
\text{ESL}_{\text{GW-IA}} = \frac{C_{IA}}{H' \times \left(\frac{1,000 \text{L}}{\text{m}^3}\right) \times A\text{FGW}}
\]

where:
- \(C_{GW}\) Groundwater concentration in µg/L. This is the ESL value.
- \(C_{IA}\) Indoor air concentration (µg/m\(^3\))
- \(H'\) Chemical-specific Henry’s Law constant (dimensionless) at the specified groundwater temperature
- \(L\) Liters
- \(m^3\) Cubic meters
- \(A\text{FGW}\) Attenuation factor for groundwater (unitless)

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 2018a). 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 (see Figure 5-2 and the “slab capping effect” discussion in Section 5.1.1).

5.3 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.

5.4 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).
Options for site-specific evaluations include, but are not limited to, those discussed below, which are not presented in a particular order. 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.

5.4.1 Vapor Conduit Pathway Evaluations: Sewer/Utility Conduit Air


A key conclusion of the ESTCP guidance is that the complete VI pathway should not be ruled out based on subslab, soil gas or groundwater sample data alone without evaluating the sewer/utility conduit air VI pathway. The Investigation Protocol consists of two steps:

- **Desktop Screening** – Identify the locations and depths of sewers and utility conduits in the vicinity of release areas or groundwater plumes. Review the information to classify the site as either a greater or lower threat as follows:
  - Greater threat – Sites where a sewer or utility conduit directly intersect a groundwater plume or release area.
  - Lower threat – Sites where the sewer or utility conduit are in the vadose zone above a groundwater plume or away from release areas.

- **Field Sampling Investigation** – For greater threat sites, sampling of sewer/utility conduit air is recommended for the three highest threat locations identified. These locations are access points (e.g., manholes) located within or downstream of the area where the sewer/conduit intersects contaminated groundwater or NAPL. For lower threat sites, a conventional VI investigation (subsurface media and indoor air) is recommended first. Sewer/utility conduit air sampling can be implemented later if the conventional VI investigation results suggest preferential pathways are a concern. The guidance provides further information such as types of samples (grab vs. time-integrated) and characterization of temporal variability.
The ESTCP guidance recommends the following sewer to indoor air AFs, developed based on tracer testing, as reasonable upper bound values to evaluate field data: (1) 0.03 for sewer/utility air-to-indoor air; and (2) 0.03 for groundwater-to-sewer/utility conduit air. Note that these two AFs can be combined to yield an overall groundwater via sewer/utility conduit air-to-indoor air AF of 0.001.

Regional Water Board staff recommends the use of the ESTCP Investigation Protocol (McHugh and Beckley 2018c) on an interim basis until formal regulatory agency guidance is developed.

### 5.4.2 Estimating Site-Specific Attenuation Factors: Vapor Intrusion Models

This section provides background regarding past site-specific model usage in VI evaluations and current expectations for appropriate model usage for estimating site-specific AFs. A checklist is provided in Appendix B indicating the necessary documentation and evaluation required for Regional Water Board staff review.

#### Background Regarding Site-Specific Model Usage

In the past, fate and transport models such as the USEPA version of the Johnson & Ettinger model (JEM; USEPA 2004a) have been routinely used as part of site specific VI risk assessment for both screening and evaluating risk management measures (e.g., setting cleanup goals). Typically, however, model predictions have not been confirmed via verification monitoring. Findings from the peer-reviewed USEPA VI Empirical Database (USEPA 2012c) indicate that attenuation factors generated by the JEM do not predict the 95th percentile of the empirical data. In 2015, USEPA withdrew the 2004 version of the JEM and provided recommendations regarding calibration in Section 6.6 of the OSWER VI Tech Guide (USEPA 2015a). In 2017, USEPA issued a revised version of the JEM (USEPA 2017b). The revised model employs a default subslab AF of 0.003, which corresponds to the median from the USEPA VI Database. The model therefore does not provide the high degree of protection necessary for risk screening evaluations. The model is best used for developing a conceptual understanding of the average VI site scenario but should not be used in a deterministic fashion (e.g., to generate a single AF for a site/building).

#### Estimating Site-Specific Attenuation Factors

Fate and transport models can be helpful in confirming site-specific subsurface attenuation resulting from the specific geology/hydrogeology beneath a building or in an area where a future building is planned. Such models can be used as a LOE in an MLE evaluation only after a site has been adequately characterized.
and provided the model is adequately constructed, documented, and verified (USEPA 2015a). The most important element to ensure confidence in a model as a LOE is verification of model predictions (e.g., attenuation factor), which will necessitate post-construction verification sampling for future buildings. Therefore, fate and transport models are not considered appropriate during the early screening phase of a project when the site is not adequately characterized and knowledge about the buildings and underlying geology/hydrogeology typically is limited.

Furthermore, 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, traditional VI models do not consider vapor conduit pathways such as sewer/utility conduit air VI. Therefore, preferential pathways must be ruled out to allow the use of traditional VI models (see Section 5.4.1).

For VI models proposed to predict VI risk at either existing or future buildings, the subslab to indoor air attenuation factor should be fixed at 0.03. The use of 0.03 ensures changes in a building’s vapor attenuation overtime are accounted for when assessing future VI risk. For example, a building's condition (e.g., age, damage), design (e.g., remodeling), and use (e.g., HVAC operation, opening of windows and doors) will change overtime and affect the soil gas entry and air exchange rates of a building. However, the vapor source to subslab (subsurface) component of the model is less likely to change over time. Therefore, the subsurface component can be based on current site-specific conditions (see Figure 5-4). The Water Board staff review process for VI models is described in the next section.

\[
(AF_{SG-IA}) = (AF_{SG-SS}) \times (AF_{SS-IA})
\]

Figure 5-4 – Conceptual Model for the Development of a Site-Specific Vapor Intrusion Attenuation Factor (AF)
**VI Model Review Process**

The Checklist for VI Models should be submitted with all proposed site-specific models/reports and supporting information. An example is included in Appendix B; the most current version is posted on the ESL webpage under Technical Resources. As indicated by the checklist, Water Board staff will review the information regarding the CSM, inputs, outputs and model evaluation. In general, for future buildings where verification with indoor air sampling is not currently possible, a conditional approval may be issued. After adequate post-construction verification sampling and sufficient ongoing performance monitoring have been completed demonstrating that the model is adequately predictive, final approval can be issued.

5.4.3 **Petroleum Vapor Intrusion (PVI)**

“Petroleum vapor intrusion” (PVI) is defined as the intrusion of vapors from subsurface petroleum hydrocarbons and non-petroleum hydrocarbon fuel additives into overlying or nearby buildings and structures (USEPA 2015b).

At most cleanup sites, chlorinated volatile organic compounds (CVOC) and petroleum hydrocarbons are the main contaminants that pose VI threats. Consequently, CVOC VI has been referred to as “CVI.” In contrast to most CVOCs, petroleum hydrocarbons biodegrade readily under aerobic (oxygenated) subsurface conditions due to microbial activity in soil. Aerobic biodegradation can limit the upward migration of petroleum vapors in the vadose zone. This is referred to as “bioattenuation.” Such bioattenuation is particularly effective at small petroleum release sites (e.g., gasoline service stations; State Water Board 2012a and 2012b) but occurs to varying extent at all petroleum release sites.

A discussion of the differences between CVI and PVI is presented in *Petroleum Hydrocarbons and Chlorinated Solvents Differ in their Potential for Vapor Intrusion* (USEPA 2012b). Other helpful guidance for understanding PVI include the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (OUST PVI Guide; USEPA 2015b) and *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management* (ITRC 2014). These are listed for the user’s convenience and are not an unrestricted endorsement; consult the overseeing regulatory agency regarding application to a specific site.

**PVI Approaches**

Petroleum UST sites should follow the LTCP. The LTCP describes physical separation distances between vapor sources and potential receptors, and screening criteria for a subset of petroleum compounds. The *Technical Justification for Vapor Intrusion Media-Specific Criteria* (State Water Board 2012a) provides the technical rationale.
At some sites, particularly at complex petroleum release sites such as refineries and bulk terminals, bioattenuation may not be occurring at a sufficient rate to eliminate the PVI threat due to factors such as geochemical conditions, the overall mass of contamination (i.e., size of release), and proximity to the receptor. Figure 5-5 provides examples of two buildings:

- **Building A** – There is ample vertical separation distance with clean soil between the contamination and building foundation. Bioattenuation is occurring to a sufficient degree to render the PVI pathway incomplete.

- **Building B** – The contamination is close or directly beneath the foundation. It is uncertain whether biodegradation is occurring to a sufficient degree to render the PVI pathway incomplete. A site-specific biodegradation assessment is warranted. If the PVI pathway is determined to be complete or potentially complete, then an indoor air investigation (indoor air, outdoor air, and subslab soil gas) would be warranted for Building B.

Figure 5-5 – Conceptual Model for the Petroleum Vapor Intrusion Pathway Illustrating When the Pathway is Incomplete and Potentially Complete

Source: ITRC 2014.

**Site-Specific Biodegradation Assessment**

For sites where it is unclear whether biodegradation is occurring to a sufficient degree (as indicated above for Building B), the lines of evidence to evaluate whether there is sufficient bioattenuation of vapors include:
• **Soil Gas Data** – Samples from multi-depth soil vapor probes should be analyzed for petroleum, oxygen, carbon dioxide, and methane. The presence of sufficient concentrations of oxygen indicates the potential for biodegradation. The carbon dioxide profile is expected to be the opposite of the oxygen profile. Elevated methane concentrations indicate anaerobic conditions. The methane concentration profile typically follows the same trend as the hydrocarbon concentration profile. For further information see Figure 5-6 below and USEPA (2012b).

• **Soil Data** – Soil samples should be collected for petroleum analysis between the ground surface and the known or suspected petroleum contamination release area to confirm the presence of a clean soil layer where bioattenuation of petroleum vapors can occur. The presence of residual, less volatile hydrocarbons in contaminated soil increases oxygen demand that can limit bioattenuation of petroleum vapors.

**Use of the VI ESLs at Complex Petroleum Sites**

The VI ESLs for petroleum chemicals and mixtures can be employed for characterization purposes or as part of a site-specific risk assessment as outlined in the LTCP PVI media-specific criteria. The ESLs for petroleum constituents do not account for bioattenuation and therefore can be overly conservative if bioattenuation is adequately reducing petroleum vapor concentrations as demonstrated via a site-specific biodegradation assessment. After adequate characterization and delineation, it may be appropriate to employ a bioattenuation factor of 1,000 (State Board 2012a and 2012b) for risk screening (i.e., Petroleum Soil Gas VI ESL x 1,000) and evaluation of the need for further actions. This site-specific decision should be made in consultation with the overseeing regulatory agency.
Figure 5-6 – Typical Vertical Profiles for Concentrations of Petroleum Hydrocarbons (PHCs), Oxygen, Carbon Dioxide and Methane in the Vadose Zone

Source: USEPA 2012b
6 Methods: Short-Term Action Levels for TCE in All Media

The ESL Workbook Table entitled “Short Term Action Levels for TCE” presents TCE action levels for groundwater, soil gas, and indoor air, based on the concern for potential adverse effects to developing fetuses when pregnant women inhale low doses of TCE over short exposure periods. The purpose of the action levels and 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). These action levels are not screening levels (i.e. VI ESLs should still be used to assess long term risk). Rather, exceedances of the Short-Term Action Levels necessitate certain prescribed response(s) within the corresponding timeframes.

6.1 Background on TCE Noncancer Effects

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.

6.2 Short-Term Action Levels, Response Times and Response Actions for TCE Exposure in Indoor Air

The short-term action 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). Regional Water Board staff
included the indoor air action levels in the Draft Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region (TCE VI Framework; Regional Water Board 2014). In addition, groundwater and soil gas action 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 Action Levels for TCE” under the Indoor Air Action 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 – For information on indoor air treatment, see Adsorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air (USEPA 2017a).
- 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 mitigation system until the source can be remediated. For further information on vapor intrusion mitigation systems, see the TCE VI Framework and the Vapor Intrusion Mitigation Advisory (DTSC 2011c).

The short-term action levels, associated response actions, and potential expedited laboratory turnaround times should be incorporated into indoor air sampling work plans and associated response contingency plans.
6.3 Action Levels and Response Actions for TCE Vapor Intrusion from Groundwater and Soil Gas

TCE action levels for groundwater and soil gas were developed as a way to expedite indoor air sampling at sites with a higher probability of TCE indoor air concentrations exceeding the short-term response action levels. In the TCE VI Framework, these levels were called “trigger levels.” These trigger levels are calculated using the recommended vapor intrusion attenuation factors (Section 5.2.1) and the short-term action level (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 Figure 5-2) could be considered before indoor air sampling, on a site-specific basis.

6.4 Potential for Rapid Response Due to TCE Exposure Via Ingestion

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.
7 Methods: Aquatic Habitat Screening Levels for Groundwater

The ESLs for protection of aquatic habitat presented in ESL Workbook Table GW-2 apply to contaminated 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).

The generic CSM, illustrated in Figure 7-1, assumes contaminated groundwater migrates toward and discharges into a body of surface water, and migration occurs through porous media (e.g., soils/sediments). Potential aquatic receptors include pelagic organisms and biota in the groundwater/surface water transition zone. 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 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.

---

8 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).
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 point of compliance (red triangle) is not a fixed location and is located in groundwater outside the influence of surface water and upgradient of transition zone biota (see Section 7.4.1). The biologically active zone is depicted as a purple line.

7.1 Aquatic Receptor Toxicity Criteria

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

- **IP-5 (California levels)** – These are currently the primary sources of the toxicity criteria, specific to California:
  - California Toxics Rule (USEPA 2000b);
  - A Compilation of Water Quality Goals (State Water Board 2016); and,
  - Other Criteria - the Basin Plan (Regional Water Board 2017b), 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 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,

• IP-7 (Seafood Ingestion Aquatic Habitat Goals) – These are California Toxics Rule criteria for bioaccumulation and human consumption of aquatic organisms.

7.2 Hierarchy for Aquatic Receptor Toxicity Criteria

There are several sources of toxicity criteria for aquatic receptors such as promulgated criteria, guidance 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. ESL Workbook Table GW-2 uses the hierarchy to determine the Final Freshwater and Saltwater Goals. If a criterion is not available from the highest tier, then a value is selected from the next tier with a criterion value, 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.

The Final Aquatic Habitat Screening Level used as the Tier 1 ESL is the lowest value among the Seafood Ingestion (Bioaccumulation) ESL, Final Freshwater Goal, and Final Saltwater Goal.

Table 7-1 – Hierarchy for Aquatic Receptor Toxicity Criteria

<table>
<thead>
<tr>
<th>Tier</th>
<th>Exposure Timeframe</th>
<th>Sources of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chronic</td>
<td>CTR CCC</td>
</tr>
<tr>
<td>2</td>
<td>Chronic</td>
<td>USEPA CCC</td>
</tr>
<tr>
<td>Tier</td>
<td>Exposure Timeframe</td>
<td>Sources of Values</td>
</tr>
<tr>
<td>------</td>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>Chronic</td>
<td>Lowest of:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) USEPA AWQC;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) FCV Threshold Value (or the Tier II value cited in the Ecotox Thresholds if no AWQC or FCV); or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) 50 percent USEPA Chronic LOEL(^1)</td>
</tr>
<tr>
<td>4</td>
<td>Chronic</td>
<td>USDOE Chronic PRG</td>
</tr>
<tr>
<td>5</td>
<td>Chronic</td>
<td>50 percent MOEE Chronic AWQC or LOEL</td>
</tr>
<tr>
<td>1</td>
<td>Acute</td>
<td>CTR CMC</td>
</tr>
<tr>
<td>2</td>
<td>Acute</td>
<td>USEPA CMC (or Acute LOEL if no CMC)</td>
</tr>
<tr>
<td>3</td>
<td>Acute</td>
<td>Other aquatic water quality criteria (LC50)</td>
</tr>
</tbody>
</table>

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 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 testing of laboratory-prepared Water-Accommodated Fractions of fresh (unweathered) mixtures while some are based on 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, exceedance of these values indicates when it is appropriate to perform site-specific aquatic toxicity testing.

- Information on the specific mixtures, species, and citations are listed below.

**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). The test design was consistent with recommended test design discussed in Section 7.4.2—toxicity testing was performed in a groundwater sample 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).

**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 value is based on the saltwater value as a surrogate. The saltwater value of 510 µg/L is based on site-specific, chronic toxicity of HOPs-contaminated groundwater using the *Americamysis bahia* (mysid) (Terraphase Engineering 2018). The test design was consistent with the recommended test design discussed in Section 7.4.2—toxicity testing was performed in groundwater samples 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.

### 7.3.4 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 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.

7.3.5 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.

7.3.6 1,2,3-Trichloropropene

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);
- 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 must 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 porewater\(^9\) in the potential discharge areas; and (4) measure seepage/flow and estimate mass discharge. Surface water sampling near the SWI may also be helpful.

The location of the point of compliance (POC) for groundwater discharge evaluations is not by default at the SWI. Rather, the POC should be located to: (1) represent groundwater outside the influence of surface water; and (2) demonstrate if there are potential adverse effects on transition zone biota (MDEQ 2018).

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).

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\(^9\) 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 the contaminated groundwater discharge is to a storm sewer or other
manmade conveyance that discharges to surface water, the CSM is different and
the POC location would be the conveyance outfall. In that case, 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 Site-Specific 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 aquatic toxicity and potentially develop site-specific
cleanup goals. 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
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
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.

7.4.3 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 discharge to surface water migration pathway.

### 7.4.4 Additional Considerations for Site-Specific Evaluations

Additional considerations are highlighted below:

- **Integration of Groundwater Line of Evidence into Ecological Risk Assessments** – Traditionally, ecological risk assessments (ERAs) have not considered the ecological importance of the transition zone, instead focusing on biota associated with the SWI or the overlying surface water column (USEPA 2008b). ERAs that do not consider the biota in the transition zone and are focused solely on surface sediments are not an adequate substitute for a groundwater discharge evaluation where contaminated groundwater is potentially impacting aquatic habitat in both the transition zone and the SWI. Groundwater chemistry and toxicity in the discharge zone should be integrated as lines of evidence in ERAs also including bulk sediment chemistry and toxicity and community surveys (USEPA 2008b).

- **Background Concentrations of Metals in Groundwater** – Background concentrations of barium, boron, copper, lead, mercury, selenium, thallium, and zinc in groundwater, exceeding the aquatic habitat ESLs, have been reported in in the Bay Area. Evaluation of concentrations of naturally occurring background or ambient chemicals is discussed in Chapter 12.
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 species\(^{10}\) 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

\(^{10}\) 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).
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 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. MOE 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 (*Agelarius phoenicus*) - 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 derived for either:

1. Significantly Vegetated Areas;
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

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.

8.3 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 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). OEHHA (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. They are calculated based on target groundwater ESLs for two groundwater uses:

- **Drinking Water** – Tier 1 Groundwater ESLs, which are based on MCL Priority as discussed in Section 3.1.2.
- **Nondrinking Water** – 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.

The calculation soil leaching screening levels with site-specific groundwater targets is discussed in Section 9.4 (Site-Specific Evaluations).

The soil leaching ESLs are intended for use as general indicator of potential leachability. 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 10) 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 10:

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

where:

- $\text{H}$ = Henry's Law Constant (atm-m$^3$/mol)
- $\text{K}_{oc}$ = organic carbon partition coefficient (cm$^3$/g)

(equation 10)

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 ($\text{K}_{oc}$)
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 11:

\[ C_{\text{soil}} = C_{\text{gw}} \times DAF \times 0.001 \, \text{mg/μg} \]

where:
- \( C_{\text{soil}} \) = leaching based soil concentration (mg/kg)
- \( C_{\text{gw}} \) = target groundwater screening level (μg/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\text{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 \( C_{\text{soil}} \) is greater than 0.001 mg/kg; and
- \( K_{\text{oc}} \) is greater than 30,000 cm\(^3\)/gram.

The \( K_{\text{oc}} \) 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 \( K_{\text{oc}} \) 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 2018c).

9.3.2 Polychlorinated Biphenyls (PCBs)

The default $K_{oc}$ of 33,000 cm$^3$/g in ESL Workbook Table S-3 is considered adequately conservative for Aroclor mixtures 1242, 1254, or 1260, which are the typical mixtures encountered at Bay Area cleanup sites. For less chlorinated PCB mixtures, a site-specific evaluation could be performed.

9.3.3 Perchlorate

A soil leaching ESL was developed for perchlorate ($\text{ClO}_4^-$). Perchlorate is a salt, and is not sorptive, volatile, or biodegradable under normal conditions. Use of the SESOIL/AT123D 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 12).

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 13:
\[ C_{\text{soil}} = C_{\text{water}} \times \left( (K_{\text{oc}} \times f_{\text{oc}}) + \left( \frac{\theta_{\text{w}} + (\theta_{\text{a}} \times H')}{\rho_{\text{b}}} \right) \right) \times DAF \]

where:
- \( C_{\text{soil}} \) = soil screening level for leaching concerns (mg/kg);
- \( C_{\text{water}} \) = target dissolved-phase concentration (mg/L);
- \( K_{\text{oc}} \) = organic carbon partition coefficient;
- \( f_{\text{oc}} \) = fraction organic carbon in soil;
- \( \theta_{\text{w}} \) = water-filled porosity;
- \( \theta_{\text{a}} \) = air-filled porosity;
- \( H' \) = dimensionless Henry's Law constant;
- \( \rho_{\text{b}} \) = soil bulk density (g/cm³);
- \( DAF \) = dilution/attenuation factor

(equation 12)

\[ C_{\text{soil}} = C_{\text{water}} \times \left( \frac{\theta_{\text{w}}}{\rho_{\text{b}}} \right) \times DAF \]

(equation 13)

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.

### 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 targets used in the Leaching ESLs. The following are instructions for the calculational of groundwater target specific leaching screening levels:

1. Select the DAF for the target chemical from ESL Table S-3 or IP-1.
2. Select the target groundwater concentration \( (C_{gw}) \) for the user’s specific application.
3. Multiply the DAF x \( C_{gw} \times 0.001 \) mg/µg 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 2017c).

### 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\text{sat}, ESL Workbook Table S-4). As shown in equation 12, C\text{sat} corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and 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.

\[ C_{\text{sat}} = \frac{S}{\rho_b} \left[ (K_d \times \rho_b) + \theta_w + (H \times \theta_a) \right] \]

where:
\begin{align*}
S &= \text{Solubility} \\
\rho_b &= \text{Dry Soil Bulk Density} \\
K_d &= \text{Soil-Water Partition Coefficient} \\
\theta_w &= \text{Water Filled Soil Porosity} \\
H &= \text{Henery's Law Constant} \\
\theta_a &= \text{Air Filled Soil Porosity}
\end{align*} 

(equation 14)
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, \( C_{\text{sat}} \) values calculated using equation 14 above significantly underestimate the concentration where there is mobile or migrating NAPL because it does not consider effective solubility or vapor pressure (Brost and DeVauill 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 \( C_{\text{sat}} \) (or residual saturation) values used for the TPH gross contamination soil ESLs correspond to values developed in Brost and DeVauill (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

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

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 15 (MADEP 1994a):

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

where:
- vapor pressure = Torr at 20 to 30 degrees Celsius
- odor recognition threshold = µg/m³

(equation 15)

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

<table>
<thead>
<tr>
<th>Land Use, Soil Exposure Depth</th>
<th>Odor &amp; Volatilization Criteria</th>
<th>Upper Limit Level (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential, Shallow Soil</td>
<td>Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr</td>
<td>100</td>
</tr>
<tr>
<td>Residential, Shallow Soil</td>
<td>0.1 ≤ Odor Index &lt; 100</td>
<td>500</td>
</tr>
<tr>
<td>Residential, Shallow Soil</td>
<td>Odor Index ≤ 0.1</td>
<td>1,000</td>
</tr>
<tr>
<td>Commercial/Industrial, Shallow Soil</td>
<td>Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr</td>
<td>500</td>
</tr>
<tr>
<td>Commercial/Industrial, Shallow Soil</td>
<td>0.1 ≤ Odor Index &lt; 100</td>
<td>1,000</td>
</tr>
<tr>
<td>Commercial/Industrial, Shallow Soil</td>
<td>Odor Index ≤ 0.1</td>
<td>2,500</td>
</tr>
<tr>
<td>Any Land Use, Deep Soil</td>
<td>Odor Index ≥ 100 OR Vapor Pressure ≥ 1 Torr</td>
<td>500</td>
</tr>
<tr>
<td>Any Land Use, Deep Soil</td>
<td>0.1 ≤ Odor Index &lt; 100</td>
<td>1,000</td>
</tr>
<tr>
<td>Any Land Use, Deep Soil</td>
<td>Odor Index ≤ 0.1</td>
<td>2,500</td>
</tr>
</tbody>
</table>

### 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 Section 5.4.3, 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 in accordance with Section 5.4.3, the
bioattenuation factor of 1,000 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, as follows:

- **Adjustment of Nuisance Odor Soil Gas ESLs** – For soil gas, the nuisance
  odor soil gas ESL should be multiplied by 1,000.

- **Adjustment of Nuisance Odor Soil ESLs** – For soil, the Odor Index should
  be adjusted by dividing by 1,000 then select 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 it partitions between different media or when site conditions change. In these cases, every attempt should be made to determine the concentration of the most toxic species for comparison to risk-based screening levels.

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 µg/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, if necessary, the UEPA RSLs because these agencies maintain screening levels for more chemicals. These screening levels are briefly described in Chapter 1.

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 in soil or groundwater can vary substantially between sites, or even between soil types within a single site. For situations where naturally occurring background concentrations exceed an ESL (see arsenic section in this chapter), it may be appropriate to substitute the background concentration for the ESL, but this is a site-specific decision that should be made in consultation with the overseeing regulatory agency. Cleanup to less than background or ambient concentrations is not generally required (USEPA 2002b). For quantitative risk assessments, USEPA recommends that background be carried through 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 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. Guidance 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 where appropriate.

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

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

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 0.067 mg/kg) by one or more orders of magnitude. In many situations, this is due to naturally occurring background
concentrations although site-specific evaluations are still warranted. Duvergé (2011) conducted a study of regional background concentrations of arsenic in undifferentiated urbanized flatland soils and proposed an upper estimate for background arsenic (99th percentile) of 11 mg/kg. This value can be used, as appropriate based on the study parameters, 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 sediment\(^{11}\) because Regional Water Board staff requires 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 list of some documents with sediment criteria or pertinent information for deriving sediment criteria. These are listed 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.

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\(^{11}\) 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.
In addition, some sediment toxicity testing has been performed on cleanup sites in the region. At the Presidio, saltwater sediment criteria of 12 mg/kg for TPH gasoline and 144 mg/kg TPH fuel oil (diesel range) were developed based on toxicity tests using amphipods (IT Corporation 1997).

Table 12-2 - Sediment Chemical Criteria or Relevant Guidance

<table>
<thead>
<tr>
<th>Year</th>
<th>Title and Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996a</td>
<td>ECO Update: Ecotox Thresholds (USEPA)</td>
</tr>
<tr>
<td>1997</td>
<td>Preliminary Remedial Goals for Ecological Endpoints (USDOE)</td>
</tr>
<tr>
<td>2000a</td>
<td>Draft Staff Report – Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines (Regional Water Board)</td>
</tr>
<tr>
<td>2003a</td>
<td>Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures (USEPA)</td>
</tr>
<tr>
<td>2008</td>
<td>NOAA Screening Quick Reference Tables NOAA OR&amp;R Report 08-1 (Buchman)</td>
</tr>
<tr>
<td>2008a</td>
<td>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)</td>
</tr>
<tr>
<td>2012d</td>
<td>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)</td>
</tr>
<tr>
<td>2015</td>
<td>Updated Ambient Concentrations of Toxic Chemicals in San Francisco Bay Sediments (San Francisco Estuary Institute)</td>
</tr>
</tbody>
</table>
12.6 Laboratory Data Issues

12.6.1 Detection Limits and Reporting Limits

Method detection limits\(^{12}\) and laboratory reporting limits\(^{13}\) 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 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.

\(^{12}\) 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.

\(^{13}\) 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.
12.7 Acute Hazards

The ESLs do not address acute 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. The following are two examples of TMDLs that can have implications for cleanup sites:

- **Mercury (San Francisco Bay) (2008)** – The TMDL includes no (zero) allocation for discharge of mercury from cleanup sites. In addition, the Basin Plan Amendment vacated the water column water quality objective and replaced it with a fish tissue objective, which has implications for screening. The ESL team is evaluating this issue.

- **PCBs (San Francisco Bay) (2010)** – The TMDL established an initial 20-year timeframe for reducing PCBs in fish tissue to safe levels for human consumption, a ten-fold reduction. To achieve this, surface sediment PCB concentrations in San Francisco Bay must be reduced to an average of 1 µg/kg, again, a ten-fold decrease. The 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 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

http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/
0.001 mg/kg (1 µg/kg), which contrasts with the residential direct contact soil ESL of 0.25 mg/kg or the commercial/industrial direct contact soil ESL of 1 mg/kg for PCBs.
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# 14 Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAF</td>
<td>Age dependent adjustment factor used for chemicals with a mutagenic mode of action</td>
</tr>
<tr>
<td>AF</td>
<td>Attenuation Factor</td>
</tr>
<tr>
<td>APH</td>
<td>Air Phase Hydrocarbons</td>
</tr>
<tr>
<td>ARAL</td>
<td>USEPA Accelerated Response Action Level (for indoor air sample results)</td>
</tr>
<tr>
<td>ATSDR</td>
<td>U.S. Department of Public Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry</td>
</tr>
<tr>
<td>AWQC</td>
<td>Aquatic Water Quality Criteria</td>
</tr>
<tr>
<td>BaP</td>
<td>Benzo[a]pyrene</td>
</tr>
<tr>
<td>BaPeq</td>
<td>Benzo[a]pyrene equivalents</td>
</tr>
<tr>
<td>Basin Plan</td>
<td>San Francisco Bay Basin Water Quality Control Plan</td>
</tr>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>BTEX</td>
<td>Benzene, toluene, ethylbenzene and xylenes</td>
</tr>
<tr>
<td>C or Ca</td>
<td>Cancer</td>
</tr>
<tr>
<td>CAS</td>
<td>Chemical Abstracts Service</td>
</tr>
<tr>
<td>Csoil</td>
<td>Leaching based soil concentration (mg/kg)</td>
</tr>
<tr>
<td>Cgw</td>
<td>Target groundwater screening level (μg/L)</td>
</tr>
<tr>
<td>CalEPA</td>
<td>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.</td>
</tr>
<tr>
<td>CCC</td>
<td>Criterion for Continuous Concentration</td>
</tr>
<tr>
<td>CCM</td>
<td>Criterion for Maximum Concentration</td>
</tr>
<tr>
<td>CDPH</td>
<td>California Department of Public Health</td>
</tr>
<tr>
<td>CHHSL</td>
<td>CalEPA California Human Health Screening Level</td>
</tr>
</tbody>
</table>
COPC  Chemical of Potential Concern
CSM   Conceptual Site Model (sometimes called Site Conceptual Model)
CTR   California Toxics Rule
CVI   Chlorinated [compound] Vapor Intrusion

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

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

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

GC    Gas Chromatography
GI  Gastrointestinal (tract)
GW  Groundwater

H  Henry's law constant (atm-m³/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

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.

JEM  Johnson & Ettinger model (Johnson and Ettinger 1991)

K_{oc}  Organic carbon partition coefficient (cm³/g)

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)

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)
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAPL</td>
<td>Non aqueous phase liquid (also free product)</td>
</tr>
<tr>
<td>NC</td>
<td>Noncancer</td>
</tr>
<tr>
<td>NCP</td>
<td>National Contingency Plan</td>
</tr>
<tr>
<td>NIOSH</td>
<td>National Institute for Occupational Safety and Health</td>
</tr>
<tr>
<td>NOCs</td>
<td>Background natural organic compounds</td>
</tr>
<tr>
<td>NPDES</td>
<td>National Pollution Discharge Elimination System</td>
</tr>
<tr>
<td>NSO</td>
<td>Nitrogen, Sulfur, and Oxygen Atoms</td>
</tr>
<tr>
<td>NVDOC</td>
<td>Nonvolatile Dissolved Organic Carbon</td>
</tr>
<tr>
<td>OEHHA</td>
<td>California Environmental Protection Agency, Office of Environmental Health Hazard Assessment</td>
</tr>
<tr>
<td>MOE</td>
<td>Ontario Ministry of Environment</td>
</tr>
<tr>
<td>MOEE</td>
<td>Ontario Ministry of Environment and Energy</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration (federal)</td>
</tr>
<tr>
<td>OSWER</td>
<td>USEPA Office of Solid Waste and Emergency Response (now Office of Land and Emergency Management or OLEM)</td>
</tr>
<tr>
<td>OSWER VI Guide</td>
<td>OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Source to Indoor Air (USEPA 2015a)</td>
</tr>
<tr>
<td>OUST</td>
<td>USEPA Office of Underground Storage Tanks</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic aromatic hydrocarbon (also PNA)</td>
</tr>
<tr>
<td>PCB</td>
<td>Polychlorinated biphenyl</td>
</tr>
<tr>
<td>PCE</td>
<td>Tetrachloroethene (also perchloroethylene)</td>
</tr>
<tr>
<td>PEL</td>
<td>Permissible Exposure Limit</td>
</tr>
<tr>
<td>PHC</td>
<td>Petroleum Hydrocarbon</td>
</tr>
<tr>
<td>POC</td>
<td>Point of Compliance</td>
</tr>
</tbody>
</table>
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

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 RfD₀
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)

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.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STLC</td>
<td>Soluble Threshold Limit Concentration (liquid criterion for leaching from soils under landfill-like conditions)</td>
</tr>
<tr>
<td>Subslab</td>
<td>Subslab soil gas. Soil gas collected immediately beneath a concrete slab.</td>
</tr>
<tr>
<td>SWI</td>
<td>Surface water interface</td>
</tr>
<tr>
<td>T2</td>
<td>Tier 2</td>
</tr>
<tr>
<td>TBA</td>
<td>Tertiary butyl alcohol</td>
</tr>
<tr>
<td>TCE</td>
<td>Trichloroethene</td>
</tr>
</tbody>
</table>

**TCE VI Framework**

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

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>TDS</td>
<td>Total Dissolved Solids</td>
</tr>
<tr>
<td>TEF</td>
<td>Toxicity equivalence factor</td>
</tr>
<tr>
<td>TEQ</td>
<td>Toxic equivalents</td>
</tr>
<tr>
<td>TMDL</td>
<td>Total Maximum Daily Load</td>
</tr>
<tr>
<td>TPH</td>
<td>Total petroleum hydrocarbons</td>
</tr>
<tr>
<td>TSCA</td>
<td>Toxic Substances Control Act</td>
</tr>
<tr>
<td>TTLC</td>
<td>Total Threshold Limit Concentration (for solids)</td>
</tr>
<tr>
<td>UCM</td>
<td>Unresolved complex mixture or chromatogram hump, referring to numerous co-eluting compounds</td>
</tr>
<tr>
<td>URAL</td>
<td>USEPA Urgent Response Action Level (for indoor air sample results)</td>
</tr>
<tr>
<td>USDOE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>USEPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>UST</td>
<td>Underground Storage Tank</td>
</tr>
</tbody>
</table>

**Vapor Source**

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

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>Vapor Intrusion</td>
</tr>
<tr>
<td>VIG</td>
<td>DTSC Vapor Intrusion Guidance (DTSC 2011b)</td>
</tr>
<tr>
<td>VISL</td>
<td>USEPA Vapor Intrusion Screening Level calculator (USEPA 2018a)</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compound/chemical</td>
</tr>
</tbody>
</table>
VPH  Volatile Petroleum Hydrocarbons
µg/L  Micrograms per liter or parts per billion
µg/m³  Micrograms per cubic meter

Washington DOE
State of Washington Department of Ecology
WET  Whole Effluent Toxicity method
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**

\[ C_{\text{water}} = \frac{\text{THQ} \times \text{ED} \times \left(\frac{365 \text{ days}}{1 \text{ year}}\right) \times \text{BW} \times \left(\frac{1000 \text{ μg}}{1 \text{ mg}}\right)}{\text{EF} \times \text{ED} \times \left(\frac{1}{\text{RfD}_o}\right) \times \text{IRW}} \]

**Soil Ingestion**

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

15.1.2 Inhalation Noncarcinogenic Risk-Based Screening Levels

**Tapwater Vapor Inhalation**

\[ C_{\text{water}} = \frac{\text{THQ} \times \text{ED} \times \left(\frac{365 \text{ days}}{1 \text{ year}}\right) \times \left(\frac{1000 \text{ μg}}{1 \text{ mg}}\right)}{\text{EF} \times \text{ED} \times \text{ET} \times \left(\frac{1 \text{ day}}{24 \text{ hr}}\right) \times \left(\frac{1}{\text{RfC}}\right) \times K} \]
Soil and Particulate Inhalation

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

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

\[
C_{\text{water}} = \frac{\text{DA} \times 1000 \frac{\text{cm}^3}{L}}{K_p \times \text{ET}_w}
\]

- Organic Chemicals

If \(\text{ET}_{wc} \leq t^*\) then,

\[
C_{\text{water}} = \frac{\text{DA} \times 1000 \frac{\text{cm}^3}{L}}{2 \times \text{FA} \times K_p \times \sqrt{\frac{6\tau \times \text{ET}_w}{\pi}}}
\]

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

**Soil Dermal Exposure**

\[ C_{\text{water}} = \frac{\text{THQ} \times \text{ED} \times 365 \frac{\text{days}}{\text{year}} \times \text{BW}}{\text{EF} \times \text{ED} \times \left( \frac{1}{\text{RfD}_o \times \text{GIABS}} \right) \times \text{SA}_s \times \text{AF} \times \text{ABS}_d \times 10^{-6} \frac{\text{kg}}{\text{mg}}} \]

**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**

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

**Soil and Particulate Inhalation**

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

**Indoor Air Inhalation**

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

15.2.3 Dermal Carcinogenic Risk-Based Goals

**Tapwater Dermal Exposure**

- Inorganic Chemicals
  \[
  C_{\text{water}} = \frac{\text{DA} \times 1000 \text{ cm}^3/L}{K_p \times \text{ET}_{\text{wmadj}}}
  \]

- Organic Chemicals
  If \(\text{ET}_{\text{wmadj}} \leq t^*\) then,
\[
C_{\text{water}} = \frac{DA \times 1000 \frac{\text{cm}^3}{L}}{2 \times FA \times K_p \times \sqrt{\frac{6\tau \times ET_{wmadj}}{\pi}}}
\]

If \( ET_{wmadj} > t^* \) then,

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

**Soil Dermal Exposure**

\[
C_{\text{soil}} = \frac{TR \times LT \times \left( \frac{365 \text{ days}}{\text{1 year}} \right)}{\left( \frac{\text{CSF}_0}{\text{GIABS}} \right) \times DFS_{adj} \times ABS_d \times \left( \frac{10^{-6} \text{kg}}{\text{mg}} \right)}
\]

15.3 Total Cancer or Noncancer Screening Levels for All Exposure Pathways

\[
\text{Final Screening Level (SL)} = \left( \frac{1}{\text{Ingestion SL}} \right) + \left( \frac{1}{\text{Dermal Contact SL}} \right) + \left( \frac{1}{\text{Inhalation SL}} \right)
\]
16 Appendix B – Checklist for Vapor Intrusion Models
Environmental Screening Levels (ESLs)
CHECKLIST FOR VAPOR INTRUSION MODELS
2019 ESL User’s Guide Revision 0

The following list is provided to ensure efficiency in model/report review by reducing the number of comment rounds. Please fill out and submit this checklist with all vapor intrusion models to show you have included all the following:

☐ Model runs that are specific to a single existing or future building

☐ Geologic cross sections and boring logs that are representative of conditions below the building and support the selection of modeled soil layers and soil types

☐ Grain-size analyses of soil samples are representative of conditions below the building and meet the following criteria:
  ○ Three or more soil samples analyzed for each modeled soil layer;
  ○ Soil samples were not impacted by transient soil moisture (e.g., collected near the surface during the rainy season or after a storm or after irrigation system operation) or within/near the capillary fringe; and
  ○ Soils classified using the USDA Soil Conservation Service Soil Texture Classification. If not, consider using the online calculator or the Excel file version (search “USDA soil texture calculator”).

☐ All subsurface preferential pathways have been identified and locations illustrated on a map (User’s Guide Section 5.4.1). Mark those that apply:
  ○ Sewer lines and/or utility corridors
  ○ Backfilled excavations
  ○ Other: Describe: ____________________________________________________

☐ Groundwater well data representative of conditions below the building, including seasonal depth to groundwater

☐ Basis for concluding there is no contamination within the capillary fringe of groundwater below the building (for groundwater to indoor air modeling).

☐ Exposure point concentrations are based on data from multiple sampling rounds
Exposure point concentrations are based on sampling locations representative of conditions directly below the building (e.g. average concentrations from samples within the building footprint) and not averaged concentrations from samples across an entire site.

Calibration of models using measured indoor air concentrations for current risk assessment at existing buildings.

The subslab to indoor air attenuation factor should be locked at 0.03 to account for building aging and modification over time at existing or future buildings (User’s Guide Section 5.4.2).

Calibration of the source to slab component of models using multi-depth soil gas sampling (including subslab samples).

Uncertainty and Sensitivity Analysis

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

Written reports that contain:

- Conceptual site model (CSM) - Written description of soil types and continuity of strata (layers). Discussion of adequacy of geologic and hydrogeologic characterization considering the depositional environment and fill history. Particular focus should be the soil types and layer continuity immediately beneath the building (see Yao et al. 2017 for further information);
- Name of the VI model used and version (including any reprogramming to run more than one chemical at a time, etc.);
- Identification of the exposure scenario (e.g., residential versus commercial/industrial);
- Discuss how preferential pathways are accounted for in the proposed model;
- Discuss how the model was calibrated;
- List or table of any multi-depth soil gas and indoor air sample concentrations used to calibrate the model;
- List or table of inputs;
- Confirm the toxicity criteria used in the model (if any) are consistent with the California Code of Regulations (see DTSC 2019a) and the ESLs.
- List or table of key outputs that should include the attenuation factors for all chemicals and model runs;
- Copies of each model worksheet; and
- Copy of the model file to enable an independent evaluation.

References are listed in the ESL User’s Guide.

For questions regarding a specific site, contact the Water Board case manager. For questions about the form, contact the ESL Team at ESLs.ESLs@waterboards.ca.gov.