

User's Guide: Derivation and Application of Environmental Screening Levels

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

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Executive Summary

The purpose of this “User’s Guide: Derivation and Application of Environmental Screening Levels” is to explain how the Environmental Screening Levels (ESLs) were derived and how they should (and should not) be used. The ESLs have three main elements: an Excel workbook (including an interactive tool and supporting tables), PDF copies of the supporting tables, and the ESL User’s Guide (this document).

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

Surface Water and Groundwater:

- Protection of drinking water resources;
- Protection of aquatic habitats;
- Protection against vapor intrusion into buildings;
- Protection against nuisance conditions.

Soil and Soil Gas:

- Protection of human health (direct-exposure);
- Protection against vapor intrusion into buildings;
- Protection against leaching and subsequent degradation of groundwater;
- Protection of terrestrial biota;
- Protection against nuisance conditions.

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

risk assessment should be evaluated on a site-by-site basis for areas where significant concerns may exist.

The ESLs are considered to be protective for typical bay area sites. Under most circumstances, and within the limitations described, the presence of a chemical in soil, soil gas, or groundwater at concentrations below the corresponding ESL can be assumed to not pose a significant threat to human health, water resources, or the environment. Additional evaluation will generally be necessary at sites where a chemical is present at concentrations above the corresponding ESL. Active remediation may or may not be required depending on site-specific conditions and considerations. The ESLs may especially be beneficial for use at sites where the preparation of a more formal environmental assessment may not be warranted or feasible due to time and cost constraints.

ESL users should be aware of site-specific circumstances before applying ESLs to any given site. This includes an understanding of current/future land use type, media affected by contamination, and site-specific factors (collectively, the conceptual site model). The ESLs provide a tiered approach to environmental risk assessments. Under Tier 1, sample data are directly compared to ESLs for a more conservative conceptual site model (e.g., residential land use and potable groundwater); these are the Tier 1 ESLs. Under Tier 2, selection of specific ESLs is further refined with respect to site-specific considerations such as land use and groundwater use potential. This provides an intermediate but still relatively rapid and cost-effective option for preparing more site-specific risk assessments. The use of exposure scenarios and assumptions that depart significantly from those used to develop the ESLs constitutes a site-specific Tier 3 evaluation.

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

The ESLs are “evergreen,” and are updated periodically to incorporate changes as appropriate, including revised toxicity criteria and exposure assessment parameters. Users should use the current version of the ESLs that is posted at the Regional Water Board web site and identify the version for the record in all relevant communications.

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Acronyms and Abbreviations

API	American Petroleum Institute
ASTM	ASTM International, formerly known as the American Society for Testing and Materials
ATSDR	U.S. Department of Public Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry
AWQC	Aquatic Water Quality Criteria
bgs	below ground surface
BTEX	Benzene, toluene, ethylbenzene and xylenes
C_{soil}	Leaching based soil concentration (mg/kg)
C_{gw}	Target groundwater screening level ($\mu\text{g/L}$)
Cal/EPA	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.
Cal/OSHA	Division of Occupational Safety and Health, Department of Industrial Relations, State of California
CCC	Criterion for Continuous Concentration
CCM	Criterion for Maximum Concentration
CDPH	California Department of Public Health
CEQA	California Environmental Quality Act
CHHSL	California Human Health Screening Level
CMR	Code of Massachusetts Regulations
CSM	Conceptual Site Model (sometimes called Site Conceptual Model)

CTR	California Toxics Rule
DAF	Dilution-Attenuation Factor
DCE	Dichloroethene
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DEP	[Massachusetts] Department of Environmental Protection
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
EPA	[U.S.] Environmental Protection Agency
ESL	Environmental Screening Level
FVC	Final Chronic Value
H	Henry's law constant (atm·m ³ /mol)
H'	dimensionless Henry's law constant
HDOH	Hawai'i Department of Health
HI	Hazard index
HQ	Hazard Quotient
HVAC	Heating, ventilation, and air conditioning
ITRC	Interstate Technology & Regulatory Council
K _{oc}	Organic carbon partition coefficient (cm ³ /g)

LC ₅₀	Lethal concentration (50th percentile)
LOEL	Lowest Observed Effect Level
MADEP	Massachusetts Department of Environmental Protection
MCL	Maximum Containment Level
MOEE	Ontario Ministry of Environment and Energy
MtBE	Methyl tertiary butyl ether (aka tert-methyl butyl ether)
NAPL	Non aqueous phase liquid (aka product)
NIOSH	National Institute for Occupational Safety and Health
NOEL	No Observed Effect Level
ODEQ	Oregon Department of Environmental Quality
OEHHA	Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration (federal)ct
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene
PEL	Permissible Exposure Limit
PHG	Public Health Goal
PPRTV	Provisional Peer-Reviewed Toxicity Value
PRG	Preliminary Remediation Goals
RAGS	Risk Assessment Guidance for Superfund (U.S. EPA)

RfC	Inhalation Reference Concentration (noncarcinogens)
RfD	Oral Reference Dose (noncarcinogens)
REL	Recommended Exposure Limit
RSL	(U.S. EPA) Regional Screening Level
RWQCB	Regional Water Quality Control Board
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SGC	Silica gel cleanup
SNARL	Suggested No-Adverse-Response Level
STLC	Soluble Threshold Limit Concentration (for liquids)
SWRCB	State Water Resources Control Board
TBA	Tertiary butyl alcohol
TCE	Trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
THQ	Target Hazard Quotient
TMDL	Total Maximum Daily Load
TPH	Total petroleum hydrocarbons
TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group
TR	Target Risk
TTLC	Total Threshold Limit Concentration (for solids)
ULR	Urban Land Redevelopment
USDHHS	U.S. Department of Health and Human Services
U.S. DOE	U.S. Department of Energy
U.S. EPA	U.S. Environmental Protection Agency

U.S. FWS U.S. Fish and Wildlife Service

VF Infinite Source Volatilization Factor (m^3/kg)

VOC Volatile organic compound/chemical

1 Introduction

Preparation of detailed environmental risk assessments for sites contaminated by releases of hazardous chemicals can be a time-consuming and costly effort that requires expertise in multiple disciplines, including toxicology, geology, ecology, chemistry, physics, and engineering. For small businesses and property owners with limited financial resources, preparation of such risk assessments can be cost-prohibitive.

The Environmental Screening Levels (ESLs) are conservative values for soil, groundwater, soil gas, and surface water that can be directly compared to environmental data collected at a site, thus saving time and money. Screening levels for over 100 commonly detected chemicals are presented in a series of lookup tables arranged in a format that allows the user to take into account site-specific factors to help define environmental concerns at a given property. The lookup tables may be accessed via an interactive Excel workbook or a stand-alone PDF file.

With certain limitations, risks to human health and the environment can be considered not to be of regulatory concern at sites where concentrations of chemicals of concern do not exceed the respective ESLs. The presence of chemicals at concentrations above the ESLs does not necessarily indicate that a significant risk exists at the site. It does generally indicate that additional evaluation of potential environmental concerns is warranted.

1.1 Comparison to Existing Screening Levels

The ESLs address a greater range of media and endpoints than do other commonly-used screening levels, and reflect the broader scope of environmental concerns outlined in the *San Francisco Bay (Region 2) Water Quality Control Plan* (Basin Plan) (SFBRWQCB, undated). Differences and similarities between the ESLs and screening levels prepared by the other programs are summarized below.

1.1.1 California Human Health Screening Levels

The California Human Health Screening Levels (CHHSLs), developed by the Office of Environmental Health Hazard Assessment (OEHHA), are concentrations of more than 50 common contaminants in soil and/or soil gas that Cal/EPA considers to be below thresholds of concern for risks to human health. The CHHSLs are listed in *Use of California Human Health Screening Levels in Evaluation of Contaminated Properties* (Cal/EPA, 2005). The CHHSLs were developed by OEHHA in *Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (OEHHA, 2004).

The CHHSLs do not address potential groundwater or surface water protection concerns and address only two of five environmental concerns potentially related to contaminated soil, as detailed in the following table:

Table 1-1. Environmental Concerns Addressed

	ESLs	CHHSLs
Groundwater Quality		
Drinking Water	Yes	No
Vapor Intrusion to Buildings	Yes	No
¹ Aquatic Receptors	Yes	No
² Ceiling Levels	Yes	No
Soil Quality		
Direct Exposure	Yes	Yes
Vapor Intrusion to Buildings	No	No
Leaching to Groundwater	Yes	No
Terrestrial Receptors	Yes	No
² Ceiling Levels	Yes	No
Soil Gas		
Vapor Intrusion into Buildings	Yes	Yes

1. Groundwater discharge to surface water.
2. Nuisances (odor, etc.), general resource degradation.

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

1.1.2 U.S. EPA Regional Screening Levels

The U.S. EPA Regional Screening Levels or RSLs (formerly PRGs; U.S. EPA, 2013d) address human health concerns associated with direct exposure to chemicals in soil, but do not address ecological concerns. Exposure routes and receptors not addressed by the RSLs, but included in the ESLs are listed below:

- direct-exposure screening levels for construction and trench workers' exposure to subsurface soils;
- groundwater screening levels for vapor intrusion;
- groundwater screening levels for the protection of aquatic habitats/surface water quality
- soil screening levels for urban area ecological concerns;
- soil and groundwater ceiling levels to address potential presence of NAPL and nuisance odor concerns
- soil and groundwater screening levels for Total Petroleum Hydrocarbons (TPH)

1.1.3 Risk Evaluation at Sites in the City of Oakland

In 2000, the City of Oakland, working collaboratively with local, state, and federal regulatory agencies, established a comprehensive program to facilitate the assessment and cleanup of contaminated properties in Oakland. The City's approach includes guidance for developing site-specific cleanup levels based on the geology, hydrogeology and climate conditions found in Oakland, as well as permit-based institutional controls. The original version included Oakland-specific screening levels but these have since been removed.

Site-specific cleanup levels based on the input values recommended by the City of Oakland are appropriate for use at Oakland sites, under the conditions and limitations discussed in our memo dated August 3, 2001 (SFBRWQCB, 2001). Because many input values are specific to Oakland, this approach may not be appropriate for other areas within the Regional Water Board's jurisdiction.

Oakland-specific input values and current information about the City of Oakland's approach are available on the City's website.¹

1.1.4 Hazardous Waste Regulations

California Total Threshold Limit Concentrations (TTLC) criteria and Soluble Threshold Limit Concentration (STLC) criteria should not, in most cases, be used to screen soil and groundwater or set cleanup levels. The TTLC and STLC criteria are intended for use in classifying the waste material for disposal in a Class I, II, or III landfill (Title 22, Section 66699 - Persistent and Bioaccumulative Toxic Waste). Where TTLC or STLC criteria are exceeded, the waste generally must be sent to a Class I hazardous waste landfill. The criteria, developed in the 1980s, are only loosely based on human health and environmental considerations. STLC values generally reflect drinking water or surface water goals of the time, and some are clearly out of date. TTLC values were derived by simply multiplying the STLC value by 10 for organic chemicals or 100 for metals.

In most cases, TTLC values exceed the most conservative ESLs presented in this document. However, in certain instances TTLC values may be less than risk-based ESLs. It is not anticipated that the TTLC and STLC values will be revised in the near future.

1.1.5 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, 2003). 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 exposure limits 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

¹ www.oaklandbrownfields.org

offsite releases. OSHA limits are derived for an occupational setting, where the chemical in question is used in the industrial process and where workers and others who might be exposed to the chemical have knowledge of the chemical's presence, receive appropriate health and safety training, and may be provided with protective gear to minimize exposures. OSHA limits are derived for adult, healthy workers and are not intended to protect children, pregnant women, the elderly, or people with compromised immune systems.

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 levels that protect the full range of people who might be exposed to contaminants in soil and groundwater, including sensitive receptors. This goes beyond adult, healthy workers for which OSHA limits are intended. OSHA limits are not intended to evaluate risks posed by involuntary exposures to the general public, where site residents and occupants generally do not expect to be exposed to chemicals from a vapor intrusion pathway, do not receive training on such exposure, and have no protective gear to minimize exposures.

1.2 Evaluation and Management of Contaminated Sites

ESLs are a tool to facilitate rapid evaluation of a contaminated site located in the San Francisco Bay area (Region 2). They provide an initial estimate of the likelihood that a contaminant at its present concentration will have a negative effect on the environment, human or ecological receptors, or present or future drinking water resources. In addition, ESLs provide a starting point for a site-specific risk assessment (“Tier 2” or “Tier 3”). Although not intended for use as cleanup numbers, ESLs often play a role in discussions of cleanup goals and whether cleanup activities have yielded satisfactory results. ESLs do not include guidance for managing contaminated properties that do not meet site-specific cleanup goals after reasonable remediation efforts. For some of those sites, a well-designed risk management strategy may be an integral component of case closure. To facilitate case closure for certain types of properties with low levels of residual contaminants, the approaches described in the State Board’s Low-Threat Underground Storage Tank Case Closure Policy or the San Francisco Bay Regional Water Board’s Assessment Tool for Closure of Low-Threat Chlorinated

Solvent Sites may be preferable. Figure 1.1 shows how to select guidance appropriate for a given site.

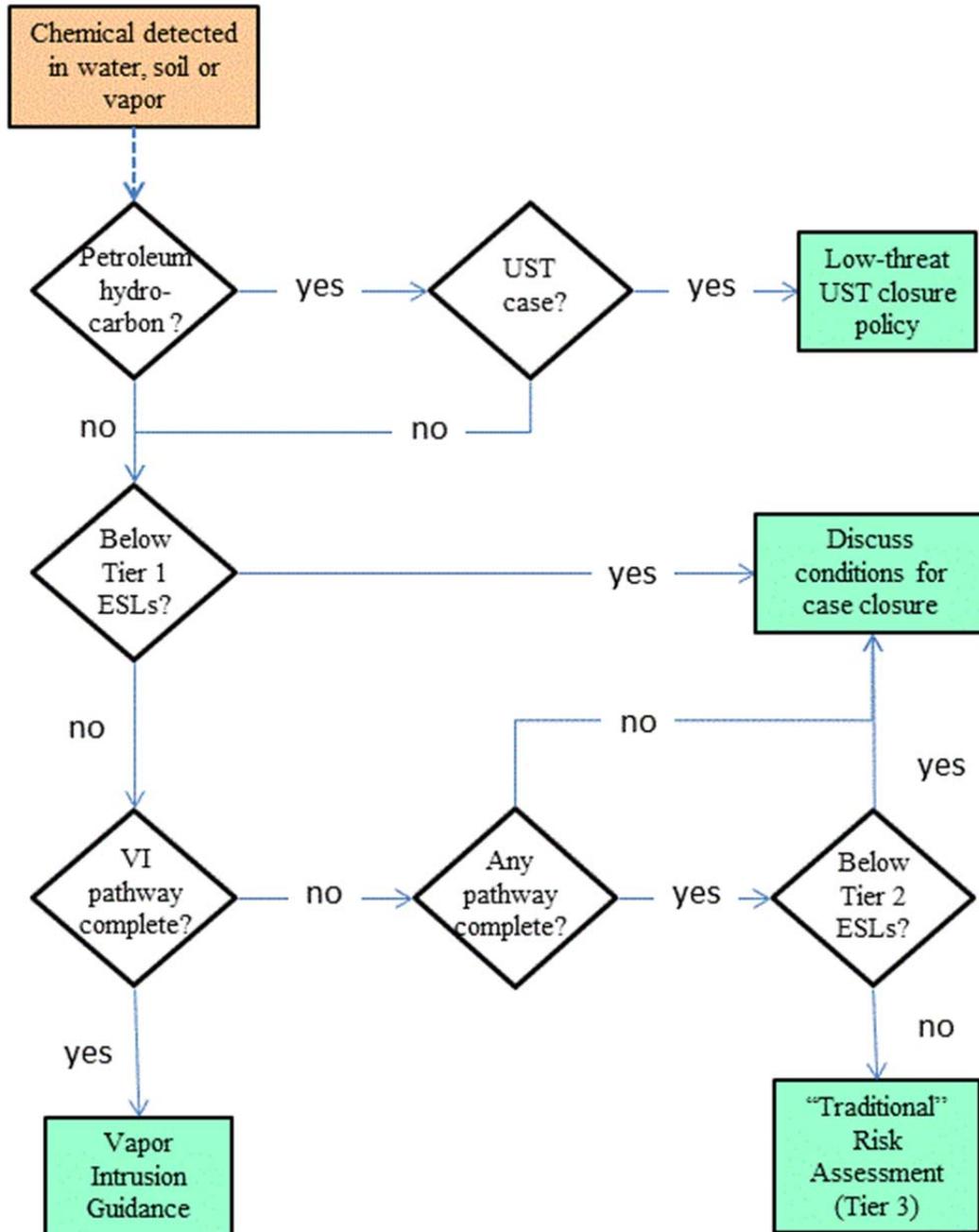


Figure 1-1. Flowchart for selection of appropriate guidance

1.2.1 Low-Threat Underground Storage Tank Case Closure Policy

The principal purpose of the *Low-Threat Underground Storage Tank Case Closure Policy*² (SWRCB, 2012) is to increase the efficiency of the cleanup process for Underground Storage Tank (UST) sites and to facilitate closure at UST sites that do not appear to be a long-term threat to human health, the environment, or the waters of the state. In order to become eligible for low-threat closure, a site must meet eight general criteria as well as media-specific criteria for groundwater, vapor intrusion to indoor air, soil (direct contact) and outdoor air. The general criteria are:

- a. The unauthorized release is located within the service area of a public water system;
- b. The unauthorized release consists only of petroleum;
- c. The unauthorized (“primary”) release from the UST system has been stopped;
- d. Free product has been removed to the maximum extent practicable;
- e. A conceptual site model that assesses the nature, extent, and mobility of the release has been developed;
- f. Secondary source has been removed to the extent practicable;
- g. Soil or groundwater has been tested for methyl tert-butyl ether (MtBE) and results reported in accordance with Health and Safety Code Section 25296.15; and
- h. Nuisance as defined by Water Code Section 13050 does not exist at the site.

A number of sites contaminated with petroleum hydrocarbons will fail one or more of these criteria or will not be a good candidate for closure under the Low-Threat Policy. Assessment of petroleum-related releases can be difficult due to the complexity of the mixtures involved. Further guidance is provided in Chapter 7 “Cumulative Risk” and Chapter 8 “Screening Levels for Total Petroleum Hydrocarbons.”

² http://www.waterboards.ca.gov/water_issues/programs/ust/lt_cls_plcy.shtml

1.2.2 Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites

Chlorinated hydrocarbon solvents, used in the past for degreasing, microchip manufacturing and dry cleaning, are frequent contaminants at sites in the Region and present multiple challenges for cleanup. Because of their density, these compounds tend to sink to the bottom of an aquifer, but they also pose a vapor intrusion risk from soil, soil gas, and as dissolved phase in groundwater.

Depending on site conditions chlorinated solvents may attenuate very slowly through dilution or attenuation, or they may give rise to more toxic (carcinogenic) degradation products (daughter compounds). Toxicity criteria for the parent and daughter compounds are subject to frequent updates.

Recognizing these and other challenges for cleanup, the San Francisco Regional Water Board's Groundwater Committee developed an *Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites*³ (SFBRWQCB, 2009). This tool describes nine criteria that must be met to show that the negative effect of the remaining contamination on the environment, human and/or ecological receptors and present or future drinking water resources is minimal. The criteria fall into three groups: (1) site characterization, (2) source control and mitigation and (3) demonstration that future land and water use is not adversely affected.

1.2.3 Developing Strategies for Closure

If the initial screening indicates that remediation and/or additional monitoring is necessary, goals and timelines for the proposed activities should be discussed with the overseeing regulatory agency. For planning purposes, it can be helpful to work backwards from the desired outcome. In order to obtain case closure the responsible party must show that any remaining contamination left in place does not pose an unacceptable threat to human health, the environment or water resources. Elements of the closure strategy may include an environmental covenant or a site management plan.

³http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/sitecleanup/Low_Threat_Closure_Assessment_Tool.pdf

1.3 Conceptual Site Models

For all environmental sites, it is important to concisely summarize information that is currently known about the site and how it relates to the goals for the site (U.S. EPA, 1996; see p. 4 and p. 15-20). This summary is referred to as the Conceptual Site Model (CSM). The CSM synthesizes various forms of information, including site history and use, local and regional geology, hydrogeology, analytical chemistry data, monitoring data, nearby land use and groundwater use. The CSM provides the interpretation of the data to provide a coherent story explaining what the contaminants are, which media are affected, and who may be impacted. An effective CSM helps all parties to understand the critical features of a site. The CSM is expected to change or evolve as more information becomes available. In an initial screening level assessment (Tier 1) the CSM may be very simple; as more information becomes available the CSM should be refined in an iterative manner. A complex CSM may be presented as a stand-alone document including copies of all figures, tables, and other information that illustrate and support the understanding of the conditions of the site. It is helpful to include a current summary of the CSM in each document for a case to provide context as new information is added.

1.3.1 Elements of a CSM

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

1. **A description of the nature and extent of contaminants at the site.** This is often portrayed as a diagram that shows known or suspected sources of contaminants and concentrations of known contaminants. Figure 1-2 is an example that shows the extent of tetrachloroethene (PCE) contamination at a site. The figures or discussion should address all media that are known or suspected to be contaminated. It is helpful to include a summary of the site history, including operations at the site that are known or suspected to have caused the release. Cross sections showing the delineation of the vertical extent of contamination may be included. A calculation of residual contaminant mass in each media may be included.

2. **A description of how contaminants are moving or changing in space and time.** This should address whether the extent of known contamination is growing, migrating, or attenuating and should include a discussion of geology and hydrogeology. For new sites, this section may be brief, but for older and more complex sites, this section should summarize relevant site-specific issues such as preferential pathways (natural and man-made), vertical groundwater gradients, and evidence of biodegradation. If biodegradation is occurring at a site, the degradation byproducts should be discussed. Boring logs, well logs, maps of subsurface utilities and other figures, as appropriate, may be used to support this evaluation. Plots of chemical concentration versus distance or time may be useful to illustrate contaminant migration or attenuation. If remediation has been conducted at the site, the effectiveness of the remediation should be evaluated. The cross section shown in Figure 1-3 is an example that illustrates contaminants moving downward through a thin zone of an aquitard.

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 as shown in Figure 1-4 (see Chapter 2). For more detailed evaluations, a site specific description of the actual receptors – both human and environmental – should be included and the presence of sensitive receptors such as schools or day care centers highlighted. Exposure pathways and receptors which may be present at the site but are not considered by the ESLs should be noted, such as consumption of backyard produce grown in contaminated soil or ingestion of contaminated surface water by endangered species. An example of a detailed site specific evaluation of receptors and exposure pathways is shown in Figure 1-5.

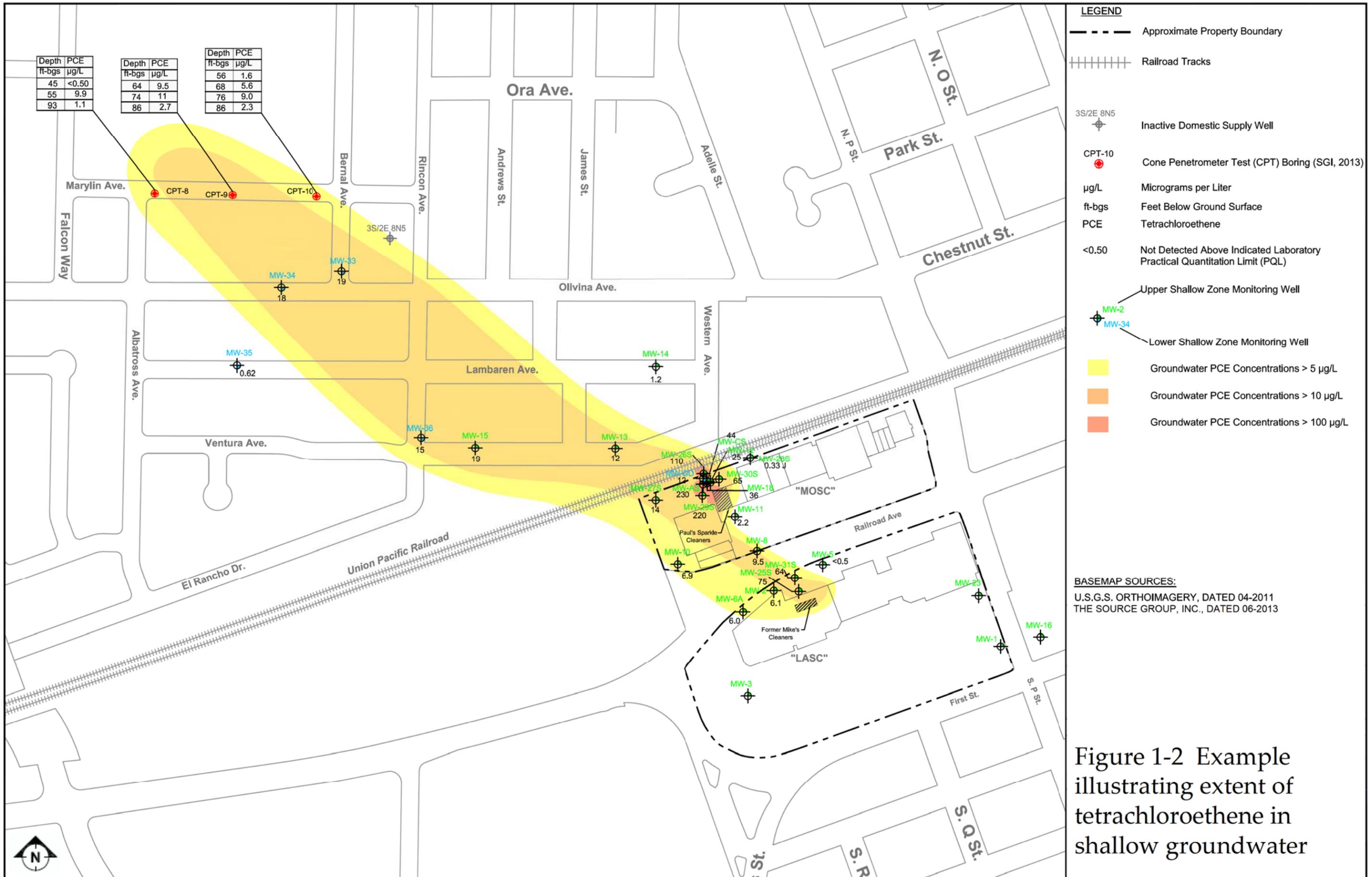


Figure 1-2 Example illustrating extent of tetrachloroethene in shallow groundwater

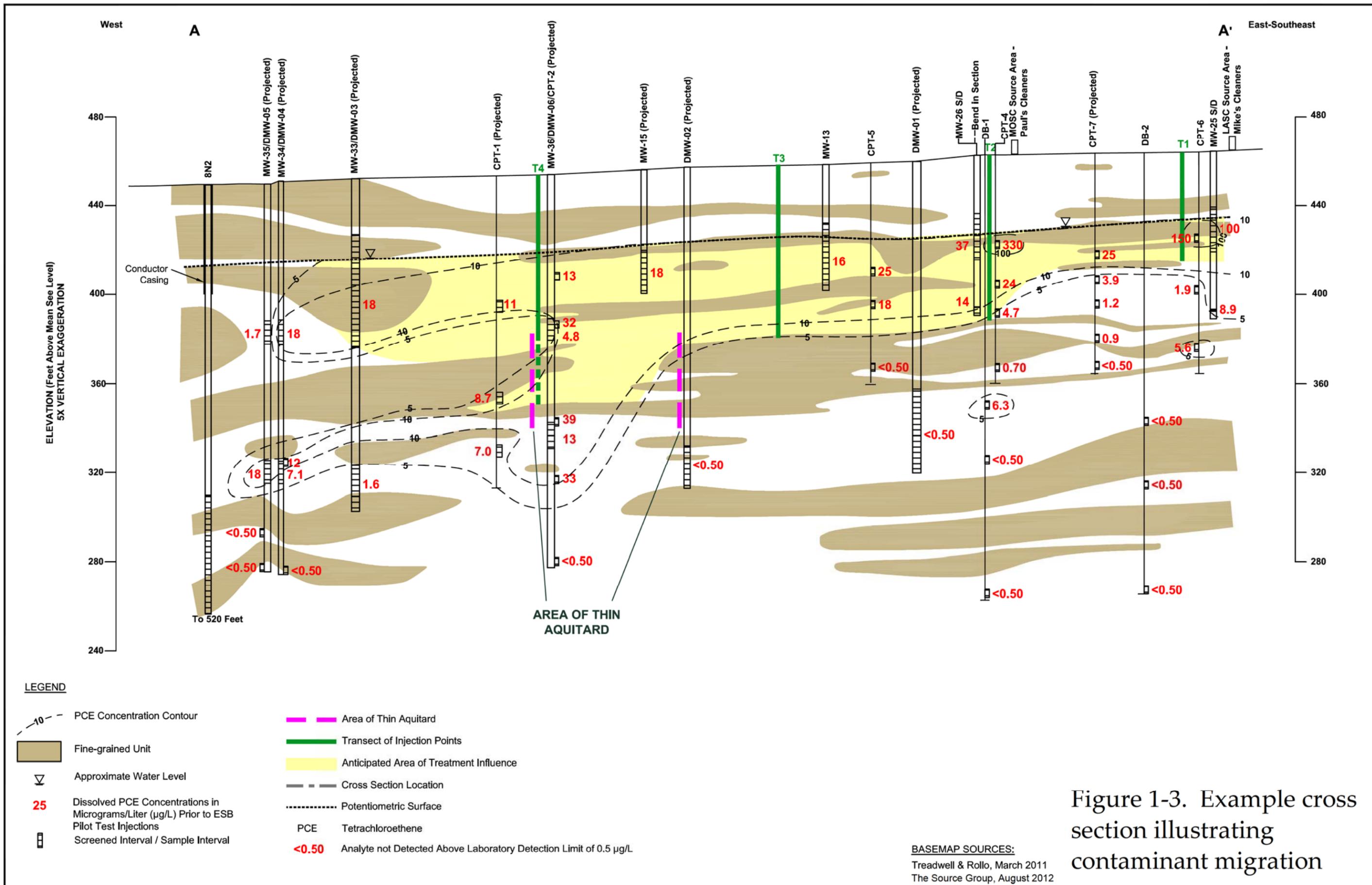
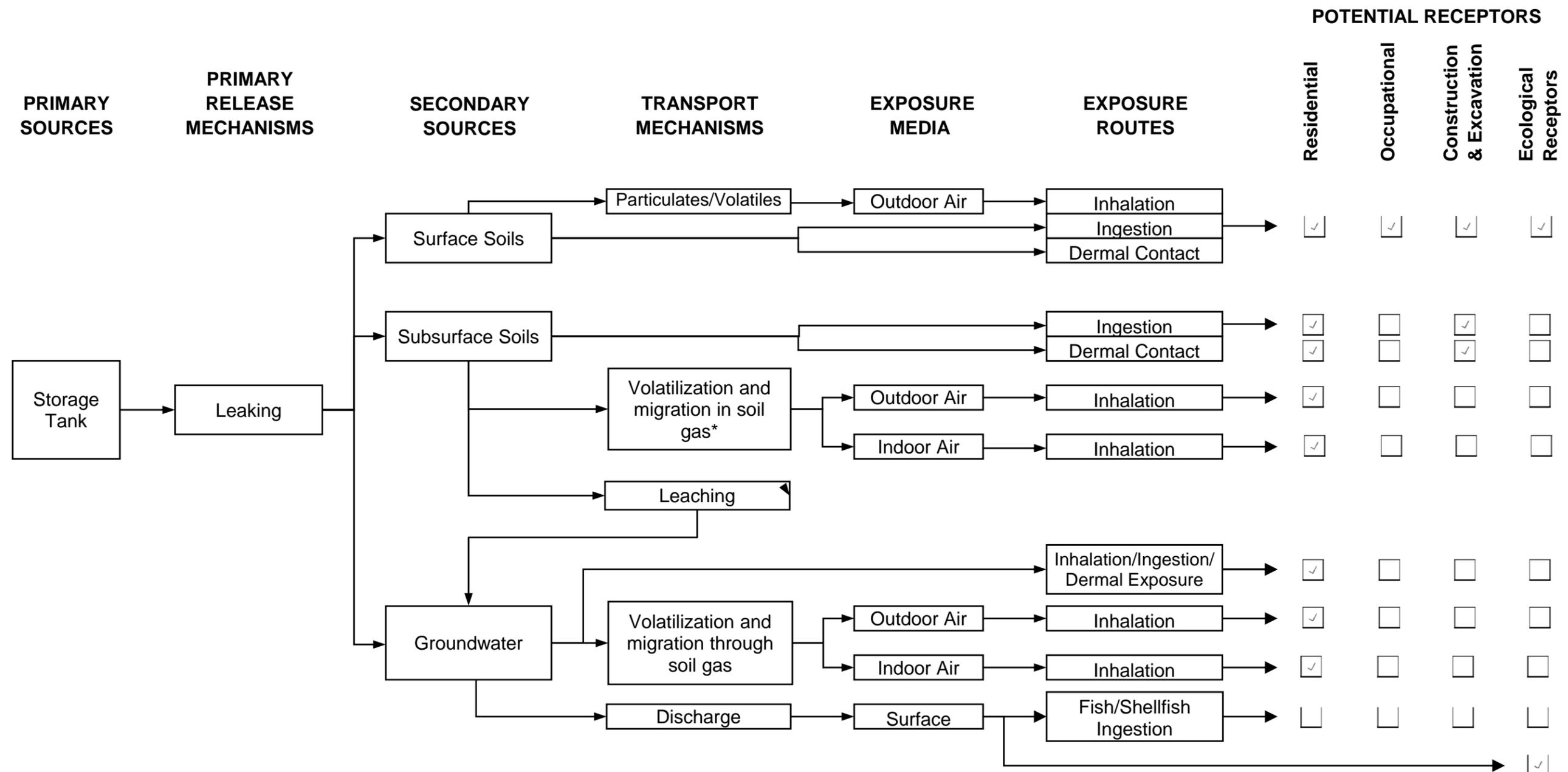


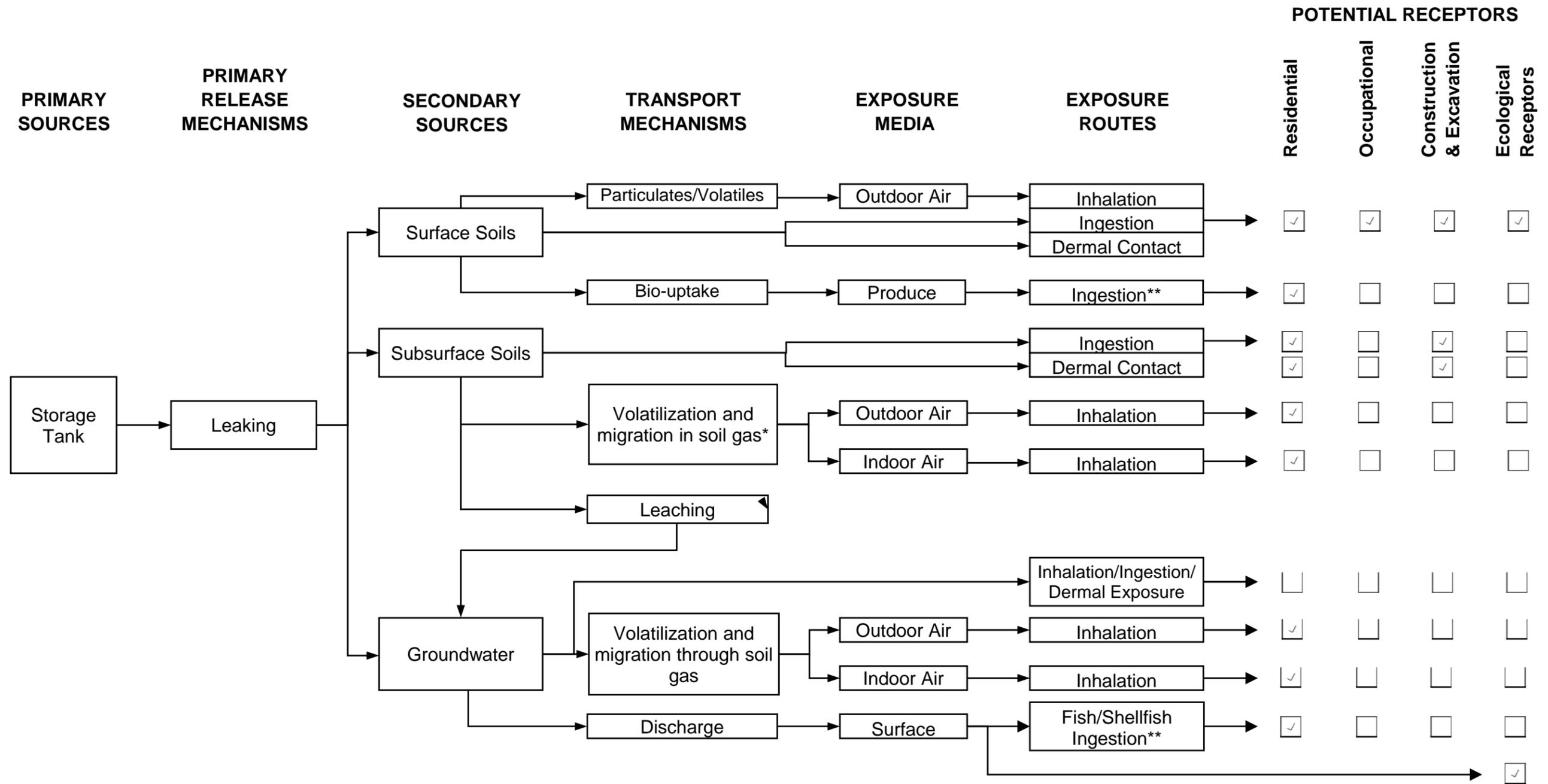
Figure 1-3. Example cross section illustrating contaminant migration

BASEMAP SOURCES:
Treadwell & Rollo, March 2011
The Source Group, August 2012



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

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



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

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

Figure 1-5. Example of site specific receptors and exposure pathways

1.4 Limitations

The ESLs presented in the lookup tables, and in particular the Tier 1 ESLs, are not regulatory cleanup standards. Use of the ESLs as cleanup levels should be evaluated in view of the overall site investigation results and the cost/benefit of performing a more detailed environmental risk assessment. The ESLs are intended to be conservative for use at the vast majority of sites in developed areas. As discussed in Chapter 3, use of the Environmental Screening Levels may not be appropriate for final assessment of all sites. Examples include:

- Sites that warrant a detailed, fully documented environmental risk assessment
- Sites with high rainfall and subsequent high surface water infiltration rates [i.e., infiltration >720 mm (28 inches) per year].
- Sites where inorganic chemicals are potentially mobile in leachate due to soil or groundwater conditions different from those assumed in development of the lookup tables
- Conservation areas where chemical concentrations pose heightened threats to ecological habitats where the presence of endangered or protected species is possible
- Sites affected by tides, rivers, streams, etc. where there is a potential for erosion and accumulation of chemicals in aquatic habitats

Examples of other site characteristics that may warrant a more detailed environmental risk assessment are discussed in Chapter 2. In such cases, the information provided in this document may still be useful for identification of potential environmental concerns and development of strategies for preparation of a more site-specific risk assessment.

ESLs for chemicals that are biodegradable in the environment may be overly conservative if used as cleanup levels at older release sites, depending on site conditions and degree of weathering. For example, direct exposure soil ESLs for total petroleum hydrocarbons (TPH) are based on fresh (unweathered) petroleum mixture compositions (see Chapter 8).

Soil ESLs do not consider potential water- or wind-related erosion and deposition of chemicals in sensitive ecological habitats. They also do not consider issues potentially related to anticipated Total Maximum Daily Load regulations (TMDLs). This may especially be of concern for metals and pesticides that are only moderately toxic to humans but highly toxic to aquatic and terrestrial biota. The Regional Water Board *Erosion and Sediment Control Field Manual* (SFBRWQCB, 1999a) provides practical information on the mitigation of erosion and runoff concerns.

The field of vapor intrusion continues to evolve, with more recent guidance moving towards the evaluation of multiple lines of evidence (e.g., groundwater data, soil gas data, and indoor air data for assessing whether the pathway is complete as well as assessing risks, possibly with multiple sampling rounds). The soil gas ESLs are based on default attenuation factors that are considered to be conservative. The groundwater-to-indoor air ESLs are based on specific modeled scenarios that may not be appropriate for sites with fractured bedrock, gravels, and/or where building designs, ventilation systems and local environmental conditions otherwise lead to higher-than-expected vapor flow rates through foundations. See Section 3.5 and Chapter 6 for further information, and consult with the overseeing regulatory agency.

Rather than attempting to include every imaginable concern, the ESLs focus on concerns deemed most important at the time of the current update. Examples of human and ecological concerns that have not been considered in the current version of the ESLs include the ingestion of produce grown on contaminated soil or irrigated with contaminated water or the effects of contaminated soil on burrowing animals.

2 Tiered Approach to Environmental Risk Assessment

The ESLs are intended to be used in a tiered approach, as shown schematically in Figure 2-1. A single Tier 1 ESL lookup table incorporates default site scenarios and represents a conservative level of risk assessment. By comparing sample data to ESLs decisions can be made regarding the need for additional site investigation, remedial action or a more detailed risk assessment. A detailed understanding of the derivation of the screening levels is not required for Tier 1, but a basic version of a Conceptual Site Model (CSM) is helpful.

A Tier 2 risk assessment requires development of a more detailed CSM to serve as a guide to identifying potential receptors and relevant exposure pathways. This process allows the user to refine the selection of screening levels to only those that are relevant to current or future likely site scenarios or conditions. This provides an intermediate but still relatively rapid and cost-effective option for preparing more site-specific risk assessments.

For a Tier 3 assessment, the user may elect to use alternate models and modeling assumptions to develop site-specific screening or final cleanup goals or quantitatively evaluate the risk posed to human and/or ecological receptors by the contaminated media. Consideration of the methodologies and potential environmental concerns discussed in this document is still encouraged in Tier 3. This will help increase the comprehensiveness and consistency of Tier 3 risk assessments as well as expedite their preparation and review.

Environmental concerns considered in the ESLs are summarized in Table 1-1. The degree to which any given concern will drive environmental risk at a site depends on the potential for exposure and the toxicity and mobility of the chemical. The risk-based calculations used for Tier 1 and Tier 2 tables are identical; the primary difference is the use of a detailed CSM in Tier 2.

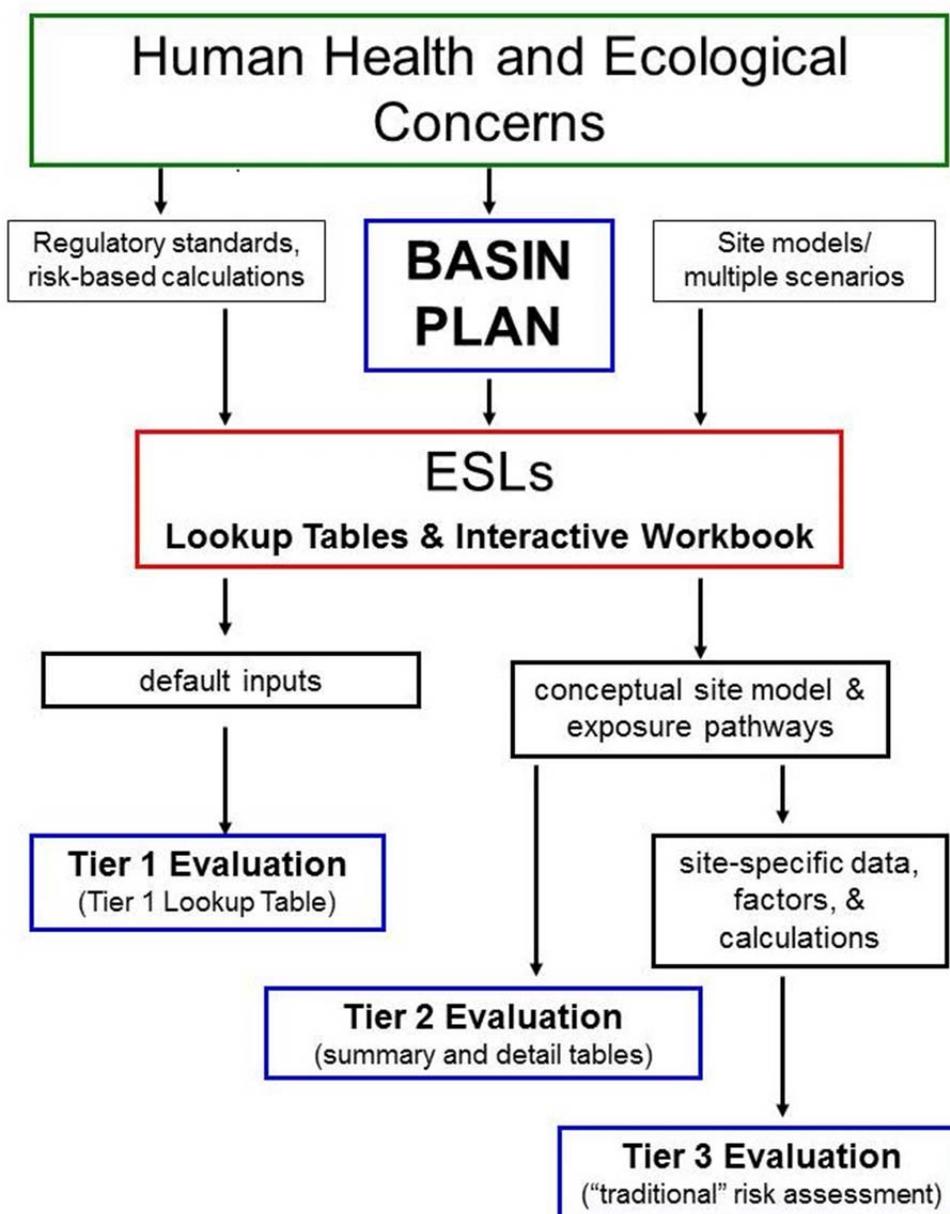


Figure 2-1. Tiered process for selecting screening levels

In the example shown in Figure 2-2 the presumed scenario is that the land use is or will be residential, the contaminant is found in shallow soil (< 3m bgs) and ground water is a potential drinking water resource. The Tier 1 ESLs for PCE in soil (0.55 mg/kg) and groundwater (5 µg/L) are based on protection of groundwater as a potential drinking water resource. In the absence of other contaminants or unusual site conditions, consistent sampling results below these ESLs indicate that further action may not be required; however, it is

recommended to check with the appropriate regulatory agency. See Section 2.4 for a more detailed discussion.

Environmental Screening Levels for Specific Concerns

Tetrachloroethene

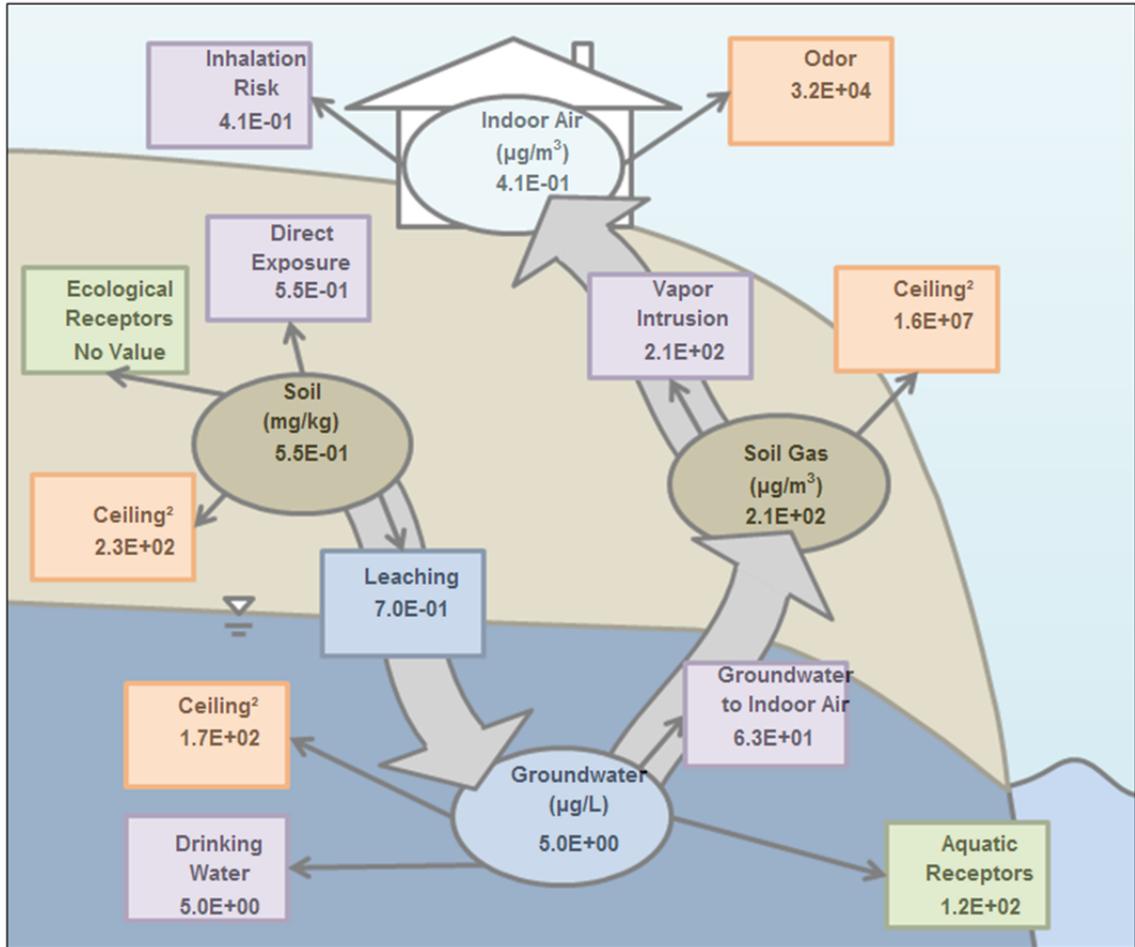


Figure 2-2. Summary of Individual Screening Levels Used to Select Tier 1 Soil and Groundwater ESLs for Tetrachloroethene

2.1 Framework for a Tiered Environmental Risk Assessment

Since a Tier 1 evaluation uses default exposure scenarios, it is most useful for screening out sites where the concentration of a single contaminant is below its ESL for a given medium or concentrations of a limited number of contaminants

are well below their respective ESLs. (For multiple contaminants refer to Chapter 7, "Cumulative Risk.") Exceedance of a Tier 1 ESL typically indicates the need for a Tier 2 assessment.

A Tier 2 evaluation may serve as a stand-alone environmental risk assessment that provides a good summary of environment concerns at a site and assess the threats to human health and the environment posed by chemical releases. The evaluation can be prepared as a component of a site investigation or remedial action report or as a separate document. The information listed below should be addressed to provide a basic conceptual site model in a report that presents the risk assessment. The level of detailed required for each topic will vary depending on site-specific considerations.

1. Summary of Past, Current, and Anticipated Future Site Activities and Uses
 - Describe past and current site uses and activities
 - Describe foreseeable future site uses and activities
2. Summary of Site Investigation
 - Identify all types of affected media
 - Identify all sources of chemical releases
 - Identify all chemicals of concern
 - Identify magnitude and extent of concentrations that exceed ESLs to extent feasible and applicable (include maps of site with isoconcentration contours for soil and groundwater)
 - Identify nearby groundwater extraction wells, bodies of surface water and other potentially sensitive ecological habitats
 - Ensure data are representative of site conditions
3. Appropriateness of Tier 2 Lookup Tables and Resulting ESLs
 - Do Tier 2 ESLs exist for all chemicals of concern?
 - Does the site have a high public profile and warrant a fully documented, detailed environmental risk assessment?
 - Do soil and groundwater conditions at the site differ significantly from those assumed in development of the lookup tables?

- Do chemical concentrations pose a threat to sensitive ecological habitats?
 - Other issues as applicable to the site
4. Soil and Groundwater Description
- State the regulatory beneficial use of groundwater beneath the site; discuss the actual, likely beneficial use of groundwater based on measured or assumed quality of the groundwater and the hydrogeologic nature of the soil or bedrock containing the groundwater
 - Characterize the soil type(s) and location of contaminated soil, such as soil stratigraphy, soil texture and permeability, depth to and thickness of contaminated soil, as applicable to the lookup tables
5. Exposure Point Concentrations
- Identify maximum concentrations of chemicals present in the media of concern
 - Describe how alternative exposure point concentrations were determined, if proposed, and provide supporting data.
 - Discuss the need to evaluate groundwater data with respect to surface water standards for potential bioaccumulation of chemicals in aquatic organisms due to the size of the plume, the proximity of the plume to a body of surface water and the potential for minimal dilution of groundwater upon discharge to surface water
 - Discuss how background concentrations of chemicals were determined, if considered for use in the risk assessment
6. Selection of Tier 2 ESLs and Comparison to Site Data
- Summarize how Tier 1 ESLs were selected with respect to the information provided above and additional assumptions as applicable.
 - Compare site data to the selected summary Tier 1 ESLs and discuss general results.
 - Show the results of evaluation of cumulative effects, usually in the form of summed risk ratios and hazard ratios.
 - If desired or recommended, compare site data to detailed ESLs for

individual environmental concerns and discuss specific, potential environmental concerns present at site.

7. Conclusions

- Describe the extent of soil and groundwater where measured concentrations are greater than Tier 2 ESLs, using maps and cross sections as necessary.
- Discuss if a condition of potential risk to human health and the environment exists at the site.
- Discuss if a more site-specific risk assessment is warranted at the site.
- Present a summary of recommended future actions proposed to address environmental concerns at the site.

The above list is not intended to be exhaustive or representative of an exact outline required for all Tier 2 risk assessments. Requirements for completion of an adequate site investigation and Tier 2 environmental risk assessment should be discussed with the overseeing regulatory agency.

2.2 Use of Lookup Tables

Site characteristics that play an important role in evaluating potential environmental concerns or developing site-specific cleanup goals include the following:

- Physical characteristics of the site
- Beneficial use of the groundwater immediately underlying the site or otherwise potentially threatened by the release
- Current and anticipated future use of the site

Summary Tables A through D reflect various combinations of site characteristics, listed below:

- Summary Table A – Shallow soils, potential drinking water resource threatened
- Summary Table B – Shallow soils, potential drinking water resource not threatened

- Summary Table C – Deep soils, potential drinking water resource threatened
- Summary Table D – Deep soils, potential drinking water resource not threatened

In addition, Summary Table E addresses indoor air and soil gas, and Summary Table F addresses surface water bodies. A complete listing of the ESL tables is provided in Appendix A.

Summary Tables A through D each provide separate soil screening levels for residential, unrestricted, and commercial/industrial land-use scenarios. Soils at depths of less than 10 feet or 3 meters bgs are considered “shallow soils” (see Section 3.2). For each chemical listed in the summary tables, screening levels were selected to address each applicable environmental concern under the specified combination of site characteristics, and the lowest of the individual screening levels for each concern was selected. This ensures that the ESLs presented in the summary tables are protective of all potential environmental concerns and provides a tool for rapid screening site data.

Each ESL in Summary Tables A through F addresses the environmental concerns stated or implied in the Basin Plan. These concerns include the following:

Groundwater Quality

- Protection of human health
- Current or potential drinking water resource
- Emission of subsurface vapors to building interiors
- Protection of aquatic receptors (discharges to surface water)
- Protection against nuisance and odors concerns, and general resource degradation

Soil Quality⁴

- Protection of human health

⁴ The term soil refers to any unconsolidated material found in the subsurface, including organic material mixed with inorganic products of weathering, saprolite (decomposed rock), sediment, fill material, etc.

- Direct/indirect exposure to soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);
- Protection of groundwater quality (leaching of chemicals from soil);
- Protection of terrestrial (nonhuman) receptors;
- Protection against nuisance and odors concerns, and general resource degradation.

Soil Gas

- Protection of human health
- Migration of subsurface vapors to building interiors.

Where Tier 2 ESLs are exceeded, the detailed lookup tables can be used to identify the specific environmental concerns that may be present at the site. The step-by-step use of the lookup tables is summarized below and discussed in more detail in the following sections. The process is also described in more detail below:

Step 1: Check ESL applicability and updates

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

Step 2: Identify all chemicals of potential concern

An appropriate Tier 2 assessment must be based on the results of a thorough site investigation. Determine the extent of chemicals in soil or groundwater and areas of potential environmental concern at the site and offsite, as required. Soil data should be reported on a dry-weight basis. A summary of the site investigation results should be included in the Tier 2 assessment report in order for it to be reviewed as a stand-alone document. A general outline of site investigation information that should be included in a Tier 2 risk assessment is provided in Section 2.1.

Step 3: Select appropriate Summary and Detail Table(s)

Determine the designated beneficial use groundwater beneath the site (refer to the Basin Plan). In general, all groundwater should initially be treated as a current or potential source of drinking water. Next, determine the depth at which

the chemicals of concern in are found soil. Direct contact with chemicals in soil is may not be a complete exposure pathway in situations where there has been a subsurface release and 10 ft or more of clean soil overlies the affected area. Use this site information to select the most appropriate summary or detail table.

Step 4: Determine land use

ESLs for soil, soil gas, and indoor air are selected based on the present and anticipated future use of the site. Two options are provided in the summary tables, Residential Land Use or Commercial/Industrial Land Use Only. Screening levels for residential land used are considered to be appropriate for unrestricted use of a property. 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.

Step 5: Select appropriate ESLs

Select the appropriate ESLs based on the most relevant land use(s). ESLs for groundwater are provided in each summary table and are not dependent on land use or depth of chemicals in soil. Screening levels for soil gas and indoor air are provided in Summary Table E, and for surface water are provided in Summary Table F.

Step 6: Compare site data to ESLs

For Tier 2 assessments, compare the maximum-detected concentrations of chemicals of concern to the ESLs; the use of statistical methods to estimate more site-specific exposure point concentrations and evaluate environmental risks is not appropriate. It *may* be appropriate to use an alternate exposure point concentration, such as the lesser of the maximum-detected concentration and the 95 percent upper confidence limit of the arithmetic mean of sample data for a more detailed Tier 3 assessment.

Guidance for the estimation of exposure point concentrations, use of non-detect data, and other issues is provided in the documents *Preliminary Endangerment Assessment Guidance Manual* (DTSC, 2013b; available for public review and comment until October 2014), *Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (DTSC, 1996c), *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (U.S. EPA, 2002c), and the ProUCL Version

5.0.00 User Guide and Technical Guide (U.S. EPA, 2013c), among other sources. As discussed in these documents, care should be exercised when including data collected outside of areas affected by a release in the estimation of exposure point concentrations. For commercial/industrial areas, soil data may be averaged within known or anticipated outdoor work areas, if needed. For vapor intrusion concerns, groundwater concentrations should not be averaged over an area greater than the floor space area of existing or anticipated buildings. For soil contaminants in an anticipated residential development, concentrations should not be averaged over an area greater than the area of existing or anticipated residential lot.

Step 7: Compare chemical concentrations to background levels

If information on the background concentrations of the chemicals of interest at the site is available, compare the background concentrations to the selected ESLs. If site-specific background concentrations of chemicals of concern are greater than risk-based ESLs, the background concentrations may be substituted; this should be pointed out in the Tier 1 assessment report.

Step 8: Evaluate the need for additional investigation or corrective actions

Based on a comparison of available site data to the ESLs, evaluate the need for additional action at the site. Additional actions may include additional site investigation, remedial action, or preparation of a more site-specific risk assessment. Summarize this evaluation in the Tier 2 assessment report and workplans for additional corrective actions, as needed.

Step 9: Submit report

Submit the appropriate reports. Decisions regarding additional actions should always be made in conjunction with guidance from the overseeing regulatory agency.

2.3 Content and Use of the ESL Workbook and Interactive Tool (Formerly Called ESL Surfer)

The ESL Workbook is an Excel file that includes two parts: the Interactive Tool (formerly ESL Surfer) and the summary and lookup tables described above. The Interactive Tool allows users to input site-specific information and retrieve screening levels for the selected chemical and site scenario. Using the default

(more conservative) inputs produces a Tier 1 assessment; using less conservative inputs produces a Tier 2 assessment. The Interactive Tool includes separate pages (workbook sheets) for instructions, definitions, entry of the selected chemical and site-specific information, details on the resulting screening levels, and a summary of information on the chemical selected. The lookup tables provide the raw data used by the Interactive Tool. Use of the ESL Workbook requires Excel 2003 or later.

2.4 Example Selection of ESLs for Tetrachloroethene (PCE)

Figure 2-2 illustrates the selection of Tier 1 soil and groundwater ESLs for tetrachloroethene (PCE). The example assumes PCE is present in shallow soils (≤ 3 meters below ground surface) and an unrestricted land-use scenario. Groundwater immediately underlying the site is assumed to be a potential source of drinking water. The Tier 1 ESLs are shown in the circles.

The Tier 1 ESL for PCE in shallow soil (0.55 mg/kg) is selected as the lowest of the individual screening levels for direct exposure (0.55 mg/kg), protection of terrestrial/ecological receptors (230 mg/kg), gross contamination (230 mg/kg) and leaching (0.7 mg/kg).

The process for selection of a Tier 1 ESL for PCE in groundwater is similar. Individual screening levels for drinking water (5.0 $\mu\text{g/L}$), vapor intrusion (6.3 $\mu\text{g/L}$), protection of aquatic habitat (120 $\mu\text{g/L}$) and ceiling levels (170 $\mu\text{g/L}$) are compared and the lowest of these (5 $\mu\text{g/L}$) is selected for inclusion in the Tier 1 lookup tables. In this example, the vapor intrusion screening level for drinking water concerns drives potential risks and is selected as the Tier 2 ESL.

Selection of ESLs for PCE in deeper soils is similar, except that potential effects on terrestrial biota are not considered. Screening levels for groundwater protection concerns remain the same.

The process described above was carried out for each of the chemicals included in the Tier 2 lookup tables under each combination of groundwater beneficial use, soil depth and land use. The results are summarized in Tables A through D (soil) and Table F (groundwater). As can be seen from a review of these tables,

the selection of Tier 2 ESLs is typically driven by groundwater protection or indoor-air concerns. ESLs for chemicals that are relatively immobile in soils are typically driven by direct-exposure concerns. In contrast, selection of ESLs for heavy metals is typically driven by ecological concerns or ceiling levels for general resource degradation. For chemicals that have particularly strong odors, selection of ESLs may be driven in part by nuisance concerns or ceiling levels. The consideration of ceiling levels becomes especially important in the selection of ESLs for relatively immobile chemicals in deep soils.

2.5 Limitations of Tiers 1 and 2

Use of the Environmental Screening Levels is optional. Independent environmental risk assessments may be undertaken for any site. In some cases, site conditions may negate the use of Tier 1 evaluation and require preparation of a Tier 2 or Tier 3 evaluation (see Section 1.4). Reliance on only the Tier 1 ESLs to identify potential environmental concerns may not be appropriate for some sites. Examples of site conditions that may warrant a more site-specific or detailed evaluation include the following:

- VOCs are present in vadose-zone soil over a vertical distance greater than three meters
- Screening levels for soil are driven by potential leaching concerns and groundwater data are available for evaluating actual groundwater concentrations
- Inorganic chemicals cannot be assumed to be immobile in soil and thus present a potential threat to groundwater quality
- Screening levels for pesticides in soil are based on leaching concerns and potential effect on aquatic habitats, but the site is not located near a body of surface water
- Depth to groundwater is greater than 10 meters below site-related chemicals in soil
- Future erosion of shallow soils could lead to transport of site chemicals to sensitive ecological habitats
- Field observations or site conditions are not consistent with the assumptions and models used to derive the ESLs

- The site requires a detailed discussion of potential risks to human health
- Physical conditions differ drastically from those assumed in development of the ESLs
- Chemical concentrations pose heightened threats to sensitive ecological habitats, such as sites that are adjacent to wetlands, streams, rivers, lakes, ponds, marine shorelines, or the site otherwise contains or borders on areas where protected or endangered species may be present

Potential migration to sediment is also not addressed. The need for a detailed ecological risk assessment should be evaluated on a site-by-site basis for areas where these concerns may be present. Notification to the Natural Resource Trustee Agencies (including the state Department of Toxics Substances Control and Department of Fish and Game and the federal Fish and Wildlife Service, Department of the Interior and National Oceanic and Atmospheric Administration) may also be required, particularly if the release of a hazardous substance may affect surface waters.

Evaluation of landfills and sites where mining wastes are present may require the preparation of a detailed, site-specific assessment of groundwater and surface water concerns due to the possible increased mobility of metals and other chemicals and potential presence of explosive gases. Soil leaching models incorporated into the Tier 1 ESLs assume typical physical-chemical conditions in soil and groundwater and relatively immobility of heavy metals and organic chemicals with very high sorption factors. This assumption may not hold true at many landfill and mine sites, where extreme pH and Eh conditions could lead to substantial mobility of these compounds. In these and related cases, more rigorous field and laboratory studies may be required to adequately assess risk to human health and the environment.

Surface water and groundwater screening levels for several pesticides that are highly toxic to aquatic organisms are conservative, and thus the screening levels for leaching concerns are also conservative. Chlorinated pesticides are only moderately mobile in the environment, thus the soil and groundwater screening levels are likely to be conservative for sites not located near a body of surface

water. The need to apply the screening levels to soil and groundwater data should be evaluated on a site-by-site basis. Less conservative screening levels for evaluation of human-toxicity concerns only may be appropriate at many sites.

Tier 2 assessments are intended to be relatively easy and cost-effective. They require a more thorough understanding of the site and preparation of a detailed CSM to identify only those potential receptors and exposure routes relevant to the site. Through this process, Tier 1 screening levels that are based on receptors or pathways not relevant to a specific site can be eliminated. Since Tier 1 screening levels represent the most stringent value for a given chemical, eliminating screening levels based on receptors and/or exposure pathways not relevant to current or anticipated site uses may lead to site conditions being considered low-risk at the Tier 2 stage where site levels exceed only some of the Tier 1 ESLs. In other words, application of values most relevant to site-specific conditions reduces the need to prepare and justify an independent, detailed risk assessment when Tier 1 ESLs cannot or should not be fully applied.

For example, the ESLs for cobalt in soil (0.33 mg/kg for residential use and 1.6 mg/kg for industrial use) are based on the protection of human health. However, if the Tier 2 assessment shows that humans will not be exposed to soil at the site under consideration because it is or will be completely covered with buildings and pavement, soil values for cobalt that slightly exceed the ESLs are unlikely to affect the overall recommendations for the site. Similarly, the screening level for leaching concerns may not need to be considered at sites where groundwater monitoring data indicate that leaching from soil to groundwater is minimal and does not pose an adverse risk; or it may not be necessary to use an ESL that is based on drinking water if groundwater beneath a site will not be used as a drinking water source in the foreseeable future (due to low yield, for example). This greatly reduces the time and cost incurred by both the regulated entity and the overseeing regulatory agency in finalizing the risk assessment.

General examples of scenarios that warrant replacing unnecessarily restrictive Tier 1 screening levels with more appropriate Tier 2 screening levels based on a CSM and site-specific exposure pathways include the following:

Groundwater

Drinking Water

- Exclusion of drinking water concerns based on natural groundwater quality or geologic characteristics of groundwater containing unit

Vapor Intrusion

- Use of depth-specific screening levels from Detail Table E-1
- Use of indoor air data to more directly evaluate potential concerns

Surface Water

- Exclusive use of freshwater or saltwater screening levels
- Consideration of alternative surface water screening levels
- Consideration of groundwater monitoring data and observed plume migration over time

Ceiling Levels

- Use of alternative ceiling levels and/or site-specific observations and considerations

General

- Consideration of method detection limits, laboratory reporting limits or natural background concentrations of a chemical in place of the risk-based ESL

Soil Screening Levels

Direct Exposure:

- Exclusion of direct-exposure concerns based on site-specific conditions

Groundwater Protection (leaching effects)

- Use of groundwater monitoring data to evaluate leaching concerns and groundwater quality (most appropriate where main mass of

chemical is in contact with groundwater)

- Use of laboratory soil leaching test to evaluate potential migration to groundwater

Ecological Concerns

- Reconsideration of need to include ecological screening levels in highly developed or industrialized areas

Ceiling Levels

- Use of alternative ceiling levels and/or site-specific observations and considerations

Soil Gas Screening Levels

- Use of sub-slab or indoor air data to more directly evaluate potential health risk concerns

2.6 Tier 3 Assessments

For a Tier 3 assessment, alternative models and assumptions are used and fully justified to develop a detailed, comprehensive environmental risk assessment. A detailed review of the preparation of Tier 3 environmental risk assessments is beyond the scope of this document. A few potentially useful methods and some general cautions are highlighted below. Example references for the preparation of Tier 3 risk assessments are provided at the end of this section.

2.6.1 Alternate Evaluation Methods for Protection of Groundwater

Relatively simple Dilution Attenuation Factors (DAFs) that address mixing of leachate with groundwater can be calculated using equations provided in the U.S. EPA *Soil Screening Guidance: Technical Background Document* (U.S. EPA, 1996b), among 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 cm/year (3 inches/year or approximately 15 percent of total, average rainfall), and hydraulic conductivities of 2 m/day and 15 m/day, respectively). DAFs could be much higher for areas with fast moving groundwater and/or little infiltration of precipitation and lower in areas with

slow moving groundwater and/or greater infiltration of precipitation. Potentially less conservative DAFs that also address adsorption, volatilization and other factors can be calculated using more rigorous models such as SESOIL.

2.6.2 Tier 3 Reference Documents

Potentially useful reference documents for preparation of Tier 3 environmental risk assessments include the following:

Human Health Risk Assessment

U.S. EPA

- Exposure Factors Handbook: 2011 Edition (U.S. EPA, 2011a)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A) (U.S. EPA, 1989b)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals) (U.S. EPA, 1991a)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives) (U.S. EPA, 1991b)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) (U.S. EPA, 2001)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) (U.S. EPA, 2004b)
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (U.S. EPA, 2009)
- Soil Screening Guidance: Technical Background Document (U.S. EPA, 1996b)

DTSC

- CalTOX, A Multimedia Total Exposure Model For Hazardous-Waste Sites (DTSC, 1994)

- Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance) (DTSC, 2011d)
- 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, 2011a).
- Human Health Risk Assessment Note 2 – Interim, Issue: Remedial Goals for Dioxins and Dioxin-like Compounds for Consideration at California Hazardous Waste Sites (DTSC, 2009)
- Human Health Risk Assessment Note 3, Issue: DTSC recommended methodology for use of U.S. EPA Regional Screening Levels (RSLs) in the Human Health Risk Assessment process at hazardous waste sites and permitted facilities. (DTSC, 2013a)
- Human Health Risk Assessment Note 4, Issue: Screening Level Human Health Risk Assessments. (DTSC, 2011b)
- Preliminary Endangerment Assessment Guidance Manual (DTSC, 2013b)
- Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities (DTSC, 1996a)
- Standard Provisional Guide for Risk-Based Corrective Action (ASTM, 1995)

Ecological Risk Assessment

- Risk Assessment Guidance for Superfund: Volume II Environmental Evaluation Manual (U.S. EPA, 1989a);
- Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (U.S. EPA, 1997)
- Guidance for Ecological Risk Assessments at Hazardous Waste Sites and Permitted Facilities (DTSC, 1996b).

The above list of references is not intended to be comprehensive. Additional risk assessment guidance should be referred to as needed.

3 Environmental Concerns and Development of Lookup Tables

Compilation and presentation of the environmental screening levels (ESLs) presented in this document are modeled after similar documents published by the Ontario Ministry of Environment and Energy (MOEE, 1996), the Massachusetts Department of Environmental Protection (MADEP, 1994), and the Netherlands (Vetger, 1993). Screening levels for the following environmental concerns are presented:

Groundwater

- Protection of human health
 - Current or potential drinking water resource
 - Vapor intrusion into buildings
- Protection of aquatic habitats (discharges to surface water)
- Protection against nuisance concerns (odors, etc.) and general resource degradation

Soil⁵

- Protection of human health from direct/indirect exposure to soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air)
- Protection of groundwater quality (leaching of chemicals from soil)
- Protection of terrestrial (nonhuman) habitats
- Protection against nuisance concerns (odors, etc.) and general resource degradation

Soil Gas

- Protection of human health from emission of subsurface vapors to building interiors

⁵ The term soil refers to any unconsolidated material found in the subsurface, including organic material mixed with inorganic products of weathering, saprolite (decomposed rock), sediment, fill material, etc.

Detailed screening levels for each concern are organized as described in Table 3-1.

Table 3-1. Organization of Detail Tables

Beneficial Use Of Groundwater ¹	Depth of Chemicals Detected in Soil	
	Shallow Soil (≤ 3m bgs)	Deep Soil (> 3m bgs)
Current or Potential Source of Drinking Water	Soil: Tables A-1, A-2 Soil Gas: Table E-2 Water: Table F-1	Soil: Tables C-1, C-2 Water: Table F-1
NOT a Current or Potential Source of Drinking Water	Soil: Tables B-1, B-2 Soil Gas: Table E-2 Water: Table F-1b	Soil: Tables D-1, D-2 Water: Table F-1a

¹ Shallowest saturated zone beneath the subject site and deeper zones as appropriate.

The A- through D-series Detail Tables present individual screening levels compiled for soil under unrestricted (A-1, B-1, C-1, D-1) and commercial/industrial (A-2, B-2, C-2, D-2) land use scenarios. The E-series Detail Tables summarize screening levels compiled specifically for indoor-air concerns. Screening levels for groundwater and surface water are summarized in the F-series Detail Tables. Detail Tables G through L provide supporting screening levels and other information for the earlier tables.

A discussion of screening levels compiled for surface water and groundwater is provided in Chapter 4. A detailed discussion of screening levels compiled for soil is provided in Chapter 5. Chapter 6 discusses screening levels compiled for indoor air and related vapor intrusion screening levels for groundwater and soil gas.

3.1 Groundwater Beneficial Use

The Basin Plan states, “Unless otherwise designated by the Regional Board, all groundwater is considered suitable, or potentially suitable, for municipal or domestic water supply.” All groundwater beneath a given site should be initially treated as a potential source of drinking water. For initial screening purposes, the

default assumption (Tier 1) is that all shallow groundwater will ultimately discharge to a body of surface water and potentially affect aquatic organisms. Soil and groundwater ESLs have therefore been developed to protect both drinking water resources and aquatic habitats.

The Basin Plan recognizes that site-specific factors, such as low yield or poor water quality,⁶ may render groundwater unsuitable for potential drinking water purposes (“non-potable” groundwater). Summary Tables B and D are intended for use at such sites. The ESLs presented in these tables consider the potential discharge of groundwater to surface water but do not consider potential effects on sources of drinking water. The ESLs also consider issues such as the presence of free product and aesthetic or odor problems. 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.

In general, soil and groundwater screening levels are more stringent for sites that threaten a potential source of drinking water. This is particularly true for chemicals that are highly mobile in the subsurface and easily leached from soil. For chemicals that are especially toxic to aquatic life – such as several long-chain hydrocarbons, pesticides and certain heavy metals – screening levels may be driven by surface water/aquatic habitat protection concerns, even for sites that threaten drinking water resources.

3.2 Shallow Versus Deep Soils

A depth of three meters (approximately 10 feet) delineates shallow soils, where a potential exists for regular direct exposure of residents or commercial/industrial workers, from deep soils, where only periodic exposure during construction and utility maintenance work is considered likely. This is consistent with guidance presented in *Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (DTSC, 1996c), and is regarded as the maximum depth at which deeper soil is likely to be intermixed with surface soil during typical redevelopment activities. The potential for deeper soils to be

⁶ Specific criteria are detailed in State Board Resolution No. 88-63, Adoption of Policy Entitled “Sources of Drinking Water.”

http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/1988/rs1988_0063.pdf

brought to the surface in the future should be evaluated on a site-by-site basis, based on planned redevelopment or maintenance activities.

The environmental concerns noted in Table 1-1 were considered in development of ESLs for shallow soils. For deep soils, regular exposure of residents or commercial/industrial workers and effects on terrestrial ecological receptors to soil contamination were not considered. As a result, ESLs for relatively non-mobile chemicals are generally less stringent for deep soils than corresponding ESLs for shallow soils. For chemicals that are easily leached from soil or potentially volatilized to the air, protection of groundwater and vapor intrusion typically are the primary concerns. As a result, the corresponding shallow and deep soil ESLs are identical.

If chemicals are detected in shallow and deep soil, it may be appropriate to use a separate set of screening levels for each zone. The advantages and disadvantages of remediating deep soils to shallow soil criteria should be evaluated on a site-by-site basis. This may help avoid concerns regarding future disturbance and reuse of deeper soils.

3.3 Land Use

Land uses are categorized based on the assumed magnitude of potential human exposure. The Residential Land Use category is intended for sites where unrestricted future land-use is sought. This includes sites to be used for residences, hospitals, day-care centers and other sensitive purposes (DTSC, 2002). ESLs listed under this category incorporate assumptions regarding long-term, frequent exposure of children and adults in a residential setting. In contrast, Commercial/Industrial Use assumes that only working-age adults will be present at the site on a regular basis. Direct-exposure assumptions incorporated into the soil ESLs are less conservative than assumptions used for residential land use.

Land use should be selected with respect to the current and foreseeable future use of the site in question. Reference to adopted General Plan zoning maps and local redevelopment plans is an integral part of this process. Discussions with local planners may help identify reasonably foreseeable changes to land use. Use

of the lookup tables for sites with other land uses should be discussed with and approved by the overseeing regulatory agency.

3.4 Threat to Surface Water Habitats

Screening levels for freshwater, marine, and estuarine water bodies are presented in Summary Table F. These screening levels consider the same set of environmental concerns as groundwater (excluding vapor intrusion and use as drinking water), with the addition of screening levels for the potential bioaccumulation of chemicals in aquatic organisms and subsequent human consumption of these organisms. In San Francisco Bay, the areas north of the Dumbarton Bridge and west of the Richmond-San Rafael Bridge are considered to be marine. The areas south of the Dumbarton Bridge and east of the Richmond-San Rafael Bridge to the upstream extent of tidal influences are considered to be estuarine. Tidally-influenced portions of creeks, rivers, and streams flowing into the Bay between these areas should also be considered to be estuarine. Screening levels for estuarine environments are the more stringent of screening levels for marine or freshwater environments.

As discussed in Section 3.1, it is assumed that groundwater at all sites could discharge into a body of surface water. This could occur due to the natural, downgradient migration of groundwater or to human activities such as discharge of extracted groundwater into a storm drain. For several pesticides and heavy metals, including dieldrin, endrin and endosulfan, aquatic habitat goals are more stringent than drinking water toxicity goals for humans. This is reflected in the groundwater screening levels.

The groundwater screening levels for potential effects on aquatic habitats do not consider dilution of groundwater upon discharge to a body of surface water. Benthic organisms situated below or at the groundwater/surface water interface are assumed to be exposed to the full concentration of chemicals measured in groundwater. Use of a generic dilution factor to adjust the surface water protection screening levels with respect to dilution of groundwater upon discharge to surface water or in groundwater mixing zones adjacent to shorelines areas is therefore not appropriate for development of conservative screening levels. Consideration of dilution/attenuation factor and alternative groundwater

screening levels for the protection of surface water quality may be appropriate on a site-specific basis as part of a Tier 3 assessment.

Consideration of surface water standards for bioaccumulation concerns in groundwater investigations and cleanup actions may be warranted at sites where large groundwater plumes threaten to cause long-term effects on important aquatic habitats. The bioaccumulation standards will generally not need to be considered at sites with small, isolated plumes located some distance from a body of surface water. Although these plumes may possibly migrate offsite and discharge into a body of surface water, potential effects may be mitigated as the concentrations are diluted when the discharge mixes with surface water. The need for a more detailed study of potential groundwater effects on surface water with respect to bioaccumulation of chemicals in aquatic organisms should be evaluated on a site-by-site basis. This may result in more stringent soil cleanup levels to prevent additional leaching, and require development of a more comprehensive ecological risk assessment.

The soil and groundwater screening levels presented in the lookup tables do not directly address the protection of sediment quality. Site-specific concerns could include the accumulation of chemicals in sediment over time due to long-term discharges of groundwater. This may be especially true for highly sorptive, lipophilic chemicals, including heavy petroleum products.

Potential erosion and runoff of surface soils may also need to be considered, particularly in instances where metals and pesticides are present in surface soil and the site is situated near a surface water body. The need for a more detailed assessment of the potential for chemicals to accumulate in sediment – and potentially affect ecological receptors – should be evaluated on a site-by-site basis and discussed with the overseeing regulatory agency.

3.5 Vapor Intrusion

VOCs can volatilize from soil or groundwater and migrate into overlying buildings where human receptors can be exposed. Effects on indoor air can vary from building to building, and even within buildings. Soil gas and groundwater screening levels were developed for this purpose and incorporated into the ESLs.

Detailed technical discussion of subsurface vapor intrusion into buildings is provided in several documents, including:

- *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (U.S. EPA, 2004a);
- *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance)*⁷ (DTSC, 2011d);
- *Vapor Intrusion Pathway: A Practical Guideline* (ITRC, 2007a);
- *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios* (ITRC, 2007b);
- *Petroleum Hydrocarbons and Chlorinated Hydrocarbons Differ In Their Potential for Vapor Intrusion* (U.S. EPA, 2011b; and,
- *Conceptual Model Scenarios for the Vapor Intrusion Pathway* (U.S. EPA, 2012a).

At this time, two important U.S. EPA guidance documents are in the public draft stage: *OSWER Final Guidance for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Sources to Indoor Air (External Review Draft)* (U.S. EPA, 2013b) and *Guidance for Addressing Petroleum Vapor Intrusion At Leaking Underground Storage Tank Sites (External Review Draft)* (U.S. EPA, 2013a). Petroleum vapor intrusion is also addressed in the *Low-Threat Underground Storage Tank Case Closure Policy* (SWRCB, 2012). Furthermore, the ITRC is preparing a petroleum vapor intrusion guidance document, and that is anticipated for release in 2014.

Detailed discussion of the mitigation of vapor intrusion is provided in the *Final Vapor Intrusion Mitigation Advisory, Revision 1* (DTSC, 2011e), including the distinction between remediation and mitigation, mitigation methods, operation and maintenance, and long-term management considerations.

Our understanding of vapor intrusion continues to evolve as new information becomes available. Currently emerging guidance from U.S. EPA (2013b) and ATSDR (2013) stress the preference for concurrent collection of indoor air,

⁷ For the ESLs, the DTSC 2011 *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance)* is referred to as the DTSC *Vapor Intrusion Guidance*.

ambient air, and subsurface air data to evaluation of vapor intrusion concerns. Approaches to site investigations and evaluation of vapor intrusion concerns presented in the ESLs and other guidance documents should not be taken as stringent requirements that must be applied at all sites. Appropriate investigation and risk assessment needs should be determined on a site-by-site basis and in consultation with the overseeing regulatory agency. Ultimate requirements could be less or more stringent than those presented here and in other guidance documents.

3.5.1 Stepwise Approach to Vapor Intrusion Evaluation

The Regional Water Board utilizes the stepwise approach described in the DTSC *Vapor Intrusion Guidance* (DTSC, 2011d). This approach encourages the collection of subsurface data before the collection of indoor air data and the evaluation of multiple lines of evidence, if possible. Some important aspects of the document include:

- Evaluation of potential acute hazards (e.g., methane);
- Preference for direct measurement of soil gas;
- Importance of defining the extent of soil gas contamination and determining the source (vadose zone soil and/or groundwater);
- Appropriate use of temporal monitoring for soil gas;
- Description of situations where use of groundwater-only data may be acceptable;
- Quality expectations for soil gas and groundwater data;
- Sampling approach, sample collection, laboratory chemical analysis, and data evaluation for indoor air and sub-slab soil gas samples;
- Site-specific vapor intrusion model evaluation and collection of bulk soil samples for geotechnical laboratory analysis.

3.5.2 Data Collection for Use in Vapor Intrusion Evaluations

For the collection of soil gas, sub-slab soil gas, groundwater, and indoor air data for vapor intrusion evaluations, the Regional Water Board utilizes the following guidance:

- *Advisory – Active Soil Gas Investigations* (DTSC, 2012) – This document provides technical details on the collection and analysis of soil gas samples.
- *Vapor Intrusion Guidance* (DTSC, 2011d) – This document provides: (1) groundwater sampling aspects for vapor intrusion evaluations; and (2) technical details on the approach, collection and laboratory analysis of sub-slab soil gas samples and indoor air samples, and data evaluation. The document also includes information about the collection of bulk soil samples and other field measurements for parameters used in site-specific vapor intrusion model evaluations.

3.6 Implied Land-Use Restrictions under Tier 1

Although tying screening levels or cleanup levels to site-specific land use and exposure conditions can save considerable investigation and remediation costs, the use of cleanup levels less stringent than those appropriate for unrestricted land use may result in restrictions on future use of the property. For example, if a site is remediated using ESLs representing commercial/industrial land use, then the site may not be suitable for residential use in the future without additional evaluation and/or cleanup. In most cases, this will require that an environmental covenant be recorded to restrict future use of the property. As stated in the 2003 amendments to the Porter-Cologne Water Quality Control Act:

“... if the state board or the regional board finds that the property is not suitable for unrestricted use ... then the state board and regional boards may not issue a closure letter, or make a determination that no further action is required ... unless a land restriction is recorded... .”

The use of ESLs for deep soils at a site assumes that the affected soil will remain isolated below the ground surface by overlying soil. For single-family residential areas, future disturbance of soil at a depth greater than three meters is generally considered to be unlikely (DTSC, 1996c); therefore, use of the ESLs for soil below this depth (“deep soil”) without restrictions may be reasonable (see Section 2.5). However, during the redevelopment of properties for commercial/industrial or high-density residential use, excavation and removal of soils from depths in

excess of 5 or even 10 meters may occur, potentially completing the exposure pathway.

Residual concentrations of chemicals in soil left in place at a commercial/industrial site should be compared to both commercial/industrial and residential ESLs (or other suitable criteria for unrestricted land use). If concentrations are less than ESLs for unrestricted land use after cleanup, this should be clearly demonstrated in a technical report.

4 Groundwater and Surface Water Screening Levels

This chapter discusses individual concerns considered in the development of screening levels for groundwater and surface water, which are contained in the F-series detail tables. As explained in Section 3.1, for initial screening purposes, it is assumed that all groundwater can potentially discharge to a body of surface water.

The groundwater ESL for sites that threaten drinking water resources reflects the lowest screening level for domestic use of groundwater (included drinking and other household uses); aquatic habitat protection (discharges to surface water); vapor intrusion into indoor air; and a ceiling level for taste, odor, or other nuisance concerns. For sites where use of groundwater as a drinking water resource is not a concern, the ESLs do not consider risk from household use of groundwater and ceiling levels based on taste (odor may be considered a nuisance).

Screening levels for surface water were compiled in a similar manner as for groundwater, with the exception that vapor intrusion into indoor air was not considered. For freshwater surface water bodies (Table F-2a), the ESL reflects the lowest of screening levels for drinking water toxicity, aquatic habitat protection, bioaccumulation/human consumption, and nuisance concerns. For marine surface water bodies (Table F-2b), the ESL reflects the lower of screening levels for aquatic habitat protection, bioaccumulation/human consumption, and nuisance concerns. For estuarine systems (Table F-2c), the ESL reflects the lower of screening levels for aquatic habitat protection, bioaccumulation/human consumption, and nuisance concerns. The estuary aquatic habitat goal is the lower of the screening levels for freshwater and marine surface water bodies (Detail Table F-4a).

As discussed below, groundwater screening levels for potential discharges to aquatic habitats only consider goals for surface water quality. Aquatic habitat goals for freshwater, marine, and estuarine surface water bodies also consider the potential bioaccumulation of chemicals in aquatic organisms and subsequent

consumption by humans. Use of the bioaccumulation goals as additional screening levels for groundwater should be evaluated on a site-by-site basis.

4.1 Screening Levels for Drinking Water

A summary of drinking water standards and guidelines is provided in Detail Table F-3. The Basin Plan directs that primary and secondary Maximum Contaminant Levels (MCLs)⁸ be used as an upper bound when setting cleanup goals for groundwater designated for use as a domestic or municipal supply. All groundwater basins in the San Francisco Bay Region are designated as existing or potential sources of drinking water. The default ESLs, (also called MCL Priority) use the most conservative of California primary or secondary MCLs for all chemicals with established MCLs to represent the Basin Plan water quality objectives. For chemicals with no established MCL and for all risk based ESLs, the smallest of these three criteria were used:

1. **Risk based goals:** calculated as described below
2. **Other health based criteria:** selected according to the following hierarchy: Office of Environmental Health Hazard Assessment (OEHHA) Public Health Goal if available, California Department of Public Health Notification Levels⁹ if available, or California Department of Public Health Archived Advisory Levels¹⁰
3. **Ceiling values** (I-series detail tables): considering taste, odor, the solubility of the chemical and an upper limit to prevent gross contamination

Calculated risk-based goals for drinking water account for potential exposures from use of groundwater as a source of household drinking water as well as exposures resulting from inhalation of chemicals volatilized to indoor air due to common domestic activities such as bathing/showering, cooking, dishwashing/laundry, and flushing the toilet. Volatilization of chemicals into indoor air during household use of water is not the same as vapor intrusion, but

⁸ <http://www.cdph.ca.gov/certlic/drinkingwater/pages/chemicalcontaminants.aspx>

⁹ <http://www.cdph.ca.gov/certlic/drinkingwater/Documents/Notificationlevels/notificationlevels.pdf>

¹⁰ <http://www.cdph.ca.gov/certlic/drinkingwater/Documents/Notificationlevels/archivedadvisorylevels.pdf>

may occur concurrently with exposure to chemicals that volatilize from groundwater and migrate through soil into indoor air. Screening levels for vapor intrusion are discussed in Chapter 6.

ESLs for non-cancer endpoints are evaluated based on childhood exposures that take into account differences in daily intake rates, body weights, and exposure duration for children from 1 to 6 years of age. The combination of greater intake rates and lower body weights for children results in more conservative risk-based concentrations than an adult-only assumption.

Risk-based goals are calculated using the following equations and are generally consistent with the U.S. EPA Regional Screening Table User Guide (U.S. EPA, 2013d) except that dermal exposure is not presently included in the drinking water ESLs:

Table 4-1. Calculation of drinking water risk-based goals

Household Use of Water – Noncarcinogenic Effects	
Ingestion (equation 1a)	$C_{\text{water}} = \frac{\text{THQ} \times \text{ED}_c \times 365 \frac{\text{days}}{\text{year}} \times \text{BW}_c \times 1000 \frac{\mu\text{g}}{\text{mg}}}{\text{EF}_r \times \text{ED}_c \times \frac{1}{\text{RfD}_o} \times \text{IRW}_c}$
Inhalation of Volatilized Chemicals (equation 1b)	$C_{\text{water}} = \frac{\text{THQ} \times \text{ED}_c \times 365 \frac{\text{days}}{\text{year}} \times 1000 \frac{\mu\text{g}}{\text{mg}}}{\text{EF}_r \times \text{ED}_c \times \text{ET}_r \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1}{\text{RfC}} \times \text{K}}$
Total (equation 1c)	$\frac{1}{\text{Ingestion of Water}} + \frac{1}{\text{Inhalation of Vapors}}$

Household Use of Water – Carcinogenic Effects

Ingestion (equation 2a)

$$C_{\text{water}} = \frac{\text{TR} \times 365 \frac{\text{days}}{\text{year}} \times 70 \text{ years} \times 1000 \frac{\mu\text{g}}{\text{mg}}}{\text{SF}_o \times \text{EF}_r \times \text{IFW}_{\text{adj}}}$$

Where: (equation 2b)

$$\text{IFW}_{\text{adj}} = \left(\frac{\text{ED}_c \times \text{IRW}_c}{\text{BW}_c} + \frac{(24 \text{ years} \times \text{IRW}_a)}{\text{BW}_a} \right)$$

Inhalation of Volatilized Chemicals (equation 2c)

$$C_{\text{water}} = \frac{\text{TR} \times 365 \text{ days/year} \times 70 \text{ years}}{\text{EF}_r \times \text{K} \times \text{ET}_r \times \left(\frac{1}{24 \text{ hr}} \right) \times \text{ED}_r \times \text{IUR}}$$

Total (equation 2d)

$$\frac{1}{\text{Ingestion - Water}} + \frac{1}{\text{Inhalation - Volatiles}}$$

Parameter	Definition (units)	Value
C_{water}	Chemical concentration in water ($\mu\text{g}/\text{L}$)	Chemical-specific
TR	Target risk level	1×10^{-6}
THQ	Target hazard quotient	1
BW_c	Body weight, child (kg)	15
BW_a	Body weight, adult (kg)	70
AT_r	Averaging time, resident, noncarcinogen (days)	$\text{ED}_r \times 365$
AT_{nc}	Averaging time, noncarcinogens, child exposure (days)	$\text{ED}_c \times 365$
EF_r	Exposure frequency, resident (day/yr)	350
ET_r	Exposure time, resident (hours/day)	24
ED_c	Exposure duration, child (years)	6
ED_r	Exposure duration, resident (years)	30
ED_{0-2}	Exposure duration, 0-2 years age (years)	2
ED_{2-6}	Exposure duration, 2-6 years age (years)	4
ED_{6-16}	Exposure duration, 6-16 years age (years)	10
ED_{16-30}	Exposure duration, 16-30 years age (years)	14
AT_c	Averaging time carcinogen (days)	$365 \text{ days/year} \times 70 \text{ years}$
IFW_{adj}	Resident drinking water ingestion rate (L-yr/kg-day)	1.086
IRW_c	Water ingestion rate, child (L/day)	1
IRW_a	Water ingestion rate, adult (L/day)	2
RfC	Inhalation reference concentration (mg/m^3)	Chemical-specific (Table J-2)

IUR	Inhalation Unit Risk ($\mu\text{g}/\text{m}^3$) ⁻¹	Chemical-specific (Table J-2)
SF _o	Cancer slope factor for oral exposure (mg/m^3) ⁻¹	Chemical-specific (Table J-2)
RfD _o	Reference dose for oral exposure ($\text{mg}/\text{kg}\text{-day}$)	Chemical-specific (Table J-2)
K	Volatilization factor (L/m^3)	0.5 (Andelman, 1990)

Note that averaging times such as AT_c (averaging time for carcinogen exposure) or AT_r (averaging time for the residential scenario) can be defined either in days or in years depending on the guidance document. If the averaging time is given in years, the number must be multiplied by 365 for use in these formulas.

4.2 Screening Levels for Aquatic Habitat Protection

4.2.1 Freshwater, Marine, and Estuarine Habitats

Detail Tables F-4a through F-4d list aquatic habitat goals that were considered in the ESLs. Separate goals were compiled for freshwater, marine, and estuarine habitats. In the San Francisco Bay Area, the areas north of the Dumbarton Bridge and west of the Richmond-San Rafael Bridge are considered to be marine. The areas south of the Dumbarton Bridge and east of the Richmond-San Rafael Bridge to the upstream extent of tidal influences are considered to be estuarine. Tidally-influenced portions of creeks, rivers, and streams flowing into the Bay between these areas should also be considered to be estuarine. Screening levels for estuarine environments are the more stringent of screening levels for marine or freshwater environments. Goals were selected based on the following order of preference and availability (abbreviations are explained at the end of the list):

- CTR CCC
- U.S. EPA CCC
- Lowest of U.S. EPA Ecotox AWQC and FVC Threshold Value (or the Tier II value cited in the Ecotox guidance if no AWQC or FVC) or 50 percent U.S. EPA Chronic LOEL
- U.S. DOE Chronic PRG
- 50 percent MOEE Chronic AWQC or LOEL
- 10 percent CTR CMC
- 10 percent U.S. EPA CMC (or 10 percent Acute LOEL if no CMC)
- Other aquatic water quality criteria (5 percent LC₅₀)
- Drinking water screening level

Acronyms:

AWQC: Aquatic Water Quality Criteria

CCC: Criterion for Continuous Concentration

CMC: Criterion for Maximum Concentration

CTR: California Toxics Rule (as presented in CVRWQCB 2003 and U.S. EPA 2000)

FVC: Final Chronic Value

LC₅₀: median Lethal Concentration

LOEL: Lowest Observed Effect Level

MOEE: Ontario Ministry of Environment and Energy

PRG: Preliminary Remediation Goals

U.S. EPA: U.S. Environmental Protection Agency

U.S. DOE: U.S. Department of Energy (chronic values only)

Goals provided in each reference are generally based on dissolved-phase concentrations of the chemicals in water. However, goals for selenium are based on total recoverable, rather than dissolved, concentrations.

Chronic and acute freshwater goals were used as screening levels if the goals for salt water (marine) were not available. Conversely, salt-water goals were used as screening levels if the goals for fresh water were not available. Other exceptions to the prioritization scheme include the use of chemical-specific U.S. DOE PRGs in place of U.S. EPA chronic LOELs when the LOEL was developed for a general group of compounds rather than a specific chemical. Surface water goals for selenium are based on the California Toxics Rule as promulgated in *40 CFR Part 131: Water Quality Standards, Establishment of Numerical Criteria for Priority Toxic Pollutants for the State of California* (U.S. EPA, 2000).

The primary sources of data for chronic and acute surface water criteria specific to California are the Basin Plan (SFBRWQCB, 2013), the California Toxics Rule and *A Compilation of Water Quality Goals* (CVRWQCB, 2003). Other sources include the following: U.S. EPA's *Ecotox Thresholds* (U.S. EPA, 1996a), U.S. EPA's *National Recommended Water Quality Criteria* (U.S. EPA, 2002a), U.S. Department of Energy's *Preliminary Remediation Goals for Ecological Endpoints* (USDOE, 1997), and MOEE's *Rationale for The Development and Application of Generic Soil, Groundwater and Sediment Criteria* (MOEE, 1996).

Surface water standards for potential bioaccumulation of chemicals in aquatic organisms and subsequent human consumption of these organisms are presented in Detail Table F-4d. Both California and Federal standards are given.

4.2.2 Groundwater Screening Levels for Aquatic Habitats

As discussed in Chapter 3, it is assumed that all groundwater can discharge into a body of surface water. Goals for aquatic habitat protection in San Francisco Bay are based on the lower of the goals for marine or freshwater environments. For settings where discharge to surface water is not occurring, target surface water goals and corresponding groundwater goals can be adjusted on a site-specific basis.

The groundwater screening levels for potential effects on aquatic habitats do not consider dilution of groundwater upon discharge to surface water. Benthic organisms may be exposed to the full concentration of chemicals in groundwater prior to mixing with surface water. Potential dilution of groundwater upon discharge to surface water or in groundwater mixing zones adjacent to shorelines areas is therefore not appropriate for development of conservative screening levels. Adjustment of the groundwater screening levels with respect to potential dilution may be appropriate on a site-specific basis.

The U.S. EPA Ecotox goal for barium (3.9 µg/L) was not considered as a screening level and not included in the lookup table for groundwater due to low confidence in the goal and comparison to reported natural background concentrations of this metal in Bay Area groundwater (some locations exceed 100 µg/L). Background concentrations of boron, copper, lead, mercury, selenium, thallium, and zinc have also been reported in excess of the groundwater screening levels presented in Detail Tables F-1 and F-2. This issue is being further evaluated by the Regional Water Board.

Surface water standards for potential bioaccumulation of chemicals in aquatic organisms and subsequent human consumption were not considered in the selection of groundwater screening levels for aquatic habitats. Consideration of the standards may be appropriate for sites where the discharge of groundwater containing these chemicals may affect aquatic habitats; this should be evaluated on a site-by-site basis.

4.3 Surface Water and Groundwater Ceiling Levels

The I-series detail tables summarize ceiling levels for surface water and groundwater. Ceiling values for surface water and groundwater that are considered to be a current or potential source of drinking water are based on the lowest of the chemicals taste and odor threshold, one-half the solubility, and a maximum of 50,000 µg/L for any chemical based on general resource degradation concerns (Detail Tables I-1 and I-3, after MADEP 1994). Taste and odor thresholds for drinking water were selected in the following order of preference and availability:

- California Department of Public Health(CDPH) Secondary MCLs
- U.S. EPA Secondary MCLs
- CDPH taste and odor Notification Levels or Archived Action Levels
- Taste and odor levels developed by Amooore and Hautala (as presented in CVRWQCB, 2003)
- Odor thresholds presented in Massachusetts DEP (MADEP, 1994) and MOEE (MOEE, 1996) guidance documents
- Odor thresholds from other sources

With the exception of the MADEP and MOEE odor thresholds, data for each of the listed sources are summarized in the document *A Compilation of Water Quality Goals* (CVRWQCB, 2005).

Ceiling levels for surface water and groundwater resources that are NOT considered to be a current or potential source of drinking water were selected in a similar manner, with the exception that the drinking water taste and odor thresholds were replaced with general nuisance thresholds (Detail Tables I-2 and I-4). Nuisance thresholds are intended to reflect the concentration at which a chemical in water poses unacceptable odor problems. Thresholds presented in the MADEP and MOEE guidance documents were used as the primary sources of data. Taste and odor levels developed by Amooore and Hautala (in CVRWQCB, 2000) were referred to for chemicals that lack odor thresholds in the MOEE guidance. It is apparent that similar sources were used to develop both the MOEE and the Amooore and Hautala databases. In keeping with the MOEE and MADEP guidance documents, a 10-fold dilution/attenuation of chemical

concentrations in groundwater upon discharge to surface water was assumed (non-drinking water resources, nuisance thresholds only). The nuisance threshold for MtBE presented in Detail Table I-2 of 180 µg/L is based on the concentration at which the majority of subjects could smell MtBE in water (OEHHA, 1999a). This was selected as a nuisance screening level for MtBE in surface water. Assuming a dilution factor of 10 yields an odor threshold of 1,800 µg/L for groundwater.

4.4 Other Groundwater Screening Levels

Additional screening levels for groundwater provided in *A Compilation of Water Quality Goals* include U.S. EPA and National Academy of Sciences Suggested No-Adverse-Response Level (SNARL) goals for toxicity other than cancer risk and Agricultural Water Quality goals developed by the United Nations (CVRWQCB, 2003). The SNARL goals largely duplicate risk-based screening levels for drinking water presented in Detail Table F-3. Agricultural Water Quality goals for 12 metals are provided in Detail Table F-5. These goals were not considered in the lookup tables but may need to be evaluated on a site-specific basis. The agricultural goals are higher than screening levels for both drinking water and surface water protection for seven of the 12 metals listed. Agricultural goals for copper, cobalt, selenium, and zinc are higher than goals for aquatic habitat protection but are lower than goals for drinking water (i.e., drinking water goals may not be adequately protective for irrigation use). The agricultural goal for molybdenum is lower than both the drinking water goal and the surface water goal for this metal. The development of these goals was not reviewed for preparation of the ESLs.

5 Soil Screening Levels

Exposure to chemicals present in soil can occur through inadvertent ingestion, inhalation of airborne dust and chemicals volatilized from soil, and dermal absorption resulting from contact with soil (collectively, direct exposure). Residents and commercial or industrial workers may regularly be exposed to soils or dust derived from these soils. When evaluating potential exposure, a depth of three meters (approximately 10 feet) is typically used to delineate between shallow soils, where regular exposure to residents and/or workers is assumed, and deeper soils, where only periodic contact during construction and utility maintenance work is assumed. A depth of three meters is consistent with guidance presented in the *Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (DTSC, 1996a). Regular exposure to soils below the water table is generally considered only for construction workers.

Chemicals present in shallow soil are typically presumed to have the greatest potential for direct exposure under current site conditions or following construction activities during which excavation and grading activities can result in soil mixing. The potential for deeper soils to be brought to the surface during redevelopment activities should be evaluated on a site-by-site basis. Environmental concerns considered for shallow-soil versus deep-soil ESLs are summarized in the table below (Table 5-1).

Table 5-1. Environmental Concerns Considered in Soil ESLs

Category	Human Health (Direct Exposure)	Human Health (Indoor-Air)	*Groundwater Protection (Drinking Water Resource Threatened)	*Groundwater Protection (Drinking Water Resource not Threatened)	Ecological Concerns (Terrestrial Receptors)	Ceiling Levels
Table A						
Residential Land Use	X		X	X	X	X
Commercial/Industrial Land Use Only	X		X	X	X	X
Table B						
Residential Land Use	X			X	X	X
Commercial/Industrial Land Use Only	X			X	X	X
Table C						
Residential Land Use	X		X	X		X
Commercial/Industrial Land Use Only	X		X	X		X
Table D						
Residential Land Use	X			X		X
Commercial/Industrial Land Use Only	X			X		X

*Groundwater protection concerns not related to drinking water include discharge to surface water, indoor-air, and ceiling levels (nuisance concerns, etc.).

5.1 Soil Screening Levels for Direct Exposure

The following sections present the technical basis used to calculate direct-exposure ESLs for residential and non-residential land uses. Non-residential land uses encompass all commercial and industrial land uses and focus on two very different receptors – a commercial/industrial worker and a construction worker. ESLs calculated for residential land-uses are based on both child and adult exposure. ESLs for non-residential land uses are based solely on exposures to adults. Due to the wide range of activities and exposure levels a non-residential receptor may be exposed to during various work-related activities, it is important to ensure that the default exposure assumptions are representative of site-specific conditions.

5.1.1 Residential Receptors

Residential land use assumes a resident occupies a dwelling within the site boundaries for 30 years (representing the 90th percentile of the length of time someone lives in a single location). Exposure to soil is expected to occur during home maintenance activities, yard work or landscaping, and outdoor play. Intake is assumed to occur via direct ingestion, dermal absorption, and inhalation of airborne dust and chemicals volatilized from soil. For the residential scenario, both adults and children were evaluated. Children often exhibit behavior such as greater hand-to-mouth contact that can result in greater exposure to soils than those associated with a typical adult. In addition, children have a lower body weight relative to the predicted intake.

Equations 3a-d and 4a-f are used to calculate ESLs for a resident exposed to noncarcinogenic and carcinogenic endpoints, respectively. Default exposure assumptions are provided for use when site-specific data are not available.

Direct Contact Soil Exposures – Noncarcinogenic Effects – Residential Land Use

Incidental Ingestion of Soil (equation 3a)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_{\text{nc}} \times \text{BW}_c}{\text{EF}_r \times \text{ED}_c \times \frac{1}{\text{RfD}_o} \times \text{IRS}_c \times 10^{-6} \text{ kg/mg}}$$

Inhalation of Particles and Vapors from Soil (equation 3b)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_{\text{nc}}}{\text{EF}_r \times \text{ED}_c \times \frac{1}{\text{RfC}} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 3c)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_n \times \text{BW}_c}{\text{EF}_r \times \text{ED}_c \times \frac{1}{\text{RfD}_o \times \text{GIABS}} \times \text{SA}_c \times \text{AF}_c \times \text{ABS}_d \times 10^{-6} \text{ kg/mg}}$$

Total (equation 3d)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Direct Contact Soil Exposures - Carcinogenic Effects - Residential Land Use

Incidental Ingestion of Soil (equation 4a)

$$C_{\text{soil}} = \frac{\text{TR} \times 365 \text{ days/year} \times 70 \text{ years}}{\text{SF}_o \times \text{EF}_r \times \text{IFS}_{\text{adj}} \times 10^{-6} \text{ kg/mg}}$$

Where: (equation 4b)

$$\text{IFS}_{\text{adj}} \left(\frac{\text{mg} \cdot \text{yr}}{\text{kg} \cdot \text{day}} \right) = \left(\frac{\text{ED}_c \times \text{IRS}_c}{\text{BW}_c} + \frac{(\text{ED}_r - \text{ED}_c) \times \text{IRS}_a}{\text{BW}_a} \right)$$

Inhalation of Particles and Vapors from Soil (equation 4c)

$$C_{\text{soil}} = \frac{\text{TR} \times 365 \text{ days/year} \times 70 \text{ years}}{\text{EF}_r \times \text{ET}_r \times \frac{1 \text{ day}}{24 \text{ hrs}} \times 1,000 \text{ } \mu\text{g/mg} \times \text{ED}_r \times \text{IUR} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 4d)

$$C_{\text{soil}} = \frac{\text{TR} \times 365 \text{ days/year} \times 70 \text{ years}}{\frac{\text{SF}_o}{\text{GIABS}} \times \text{EF}_r \times \text{SFS}_{\text{adj}} \times \text{ABS}_d}$$

Where: (equation 4e)

$$\text{SFS}_{\text{adj}} \left(\frac{\text{mg} \cdot \text{yr}}{\text{kg} \cdot \text{day}} \right) = \left(\frac{\text{ED}_c \times \text{AF}_c \times \text{SA}_c}{\text{BW}_c} + \frac{(\text{ED}_r - \text{ED}_c) \times \text{AF}_a \times \text{SA}_a}{\text{BW}_a} \right)$$

Total (equation 4f)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Parameter	Definition (units)	Value
C _{soil}	Chemical concentration in soil (mg/kg)	Chemical-specific
TR	Target risk level	1 x 10 ⁻⁶
THQ	Target hazard quotient	1

BW _c	Body weight, child (kg)	15
BW _a	Body weight, adult (kg)	70
AT _n	Averaging time, noncarcinogens (days)	ED x 365
AT _{nc}	Averaging time, noncarcinogens, child exposure (days)	ED _c x 365
ET _r	Exposure time, resident (hours/day)	24
EF _r	Exposure frequency, resident (day/yr)	350
ED _c	Exposure duration, child (years)	6
ED _r	Exposure duration, residential (years)	30
IRS _c	Soil ingestion rate, resident, child (mg/day)	200
IRS _a	Soil ingestion rate, resident, adult (mg/day)	100
RfC	Inhalation reference concentration (µg/m ³)	Chemical-specific (Table J-2)
IUR	Inhalation Unit Risk (µg/m ³) ⁻¹	Chemical-specific (Table J-2)
SA _c	Exposed dermal surface area, child (cm ² /day)	2,800
SA _a	Exposed dermal surface area, adult (cm ² /day)	5,700
AF _c	Soil adherence factor, child (mg/cm ²)	0.2
AF _a	Soil adherence factor, adult resident (mg/cm ²)	0.07
ABS	Skin absorption factor (unitless)	Chemical-specific (Table J-2)
SF _o	Cancer slope factor for oral exposure (mg/kg-day) ⁻¹	Chemical-specific (Table J-2)
RfD _o	Reference dose for oral exposure (mg/kg-day)	Chemical-specific (Table J-2)
VF	Volatilization factor (m ³ air/kg soil)	Chemical-specific (Table J-1); see note below
PEF	Particulate emission factor (m ³ /kg)	1.3 x 10 ⁹
IFS _{adj}	Adjusted resident ingestion rate, soil	114 mg-year/kg-day
SFS _{adj}	Adjusted resident dermal factor, soil	361 mg-year/kg-day
GIABS	Gastro-intestinal absorption factor	Chemical-specific

Note: The soil-to-air infinite source volatilization factor (VF) is chemical-specific and must be calculated for each chemical at the appropriate temperature using the methodology outlined in the U.S. EPA Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (U.S.EPA, 2002c), equation 4-8. The equations are also summarized in the RSLs User's Guide (U.S.EPA, 2013d) and include the following variables: the Air Dispersion Term (Q/C_{vol}), the apparent diffusivity (D_A), the exposure time in seconds (T), and the dry soil bulk density (ρ_b). Calculation of the chemical -specific D_A requires in addition the following variables: diffusivity in air (D_{ia}), diffusivity in water (D_{iw}), air-filled soil porosity (θ_a), water filled soil porosity (θ_w), soil particle density (ρ_s), the dimensionless Henry's law constant at the appropriate temperature (H'), and the chemical's soil-water partition coefficient (K_d).

5.1.2 Commercial/Industrial Receptors

The commercial/industrial scenario represents a variety of workers, from those who spend most of their workday indoors to those who frequently work outdoors, but not workers involved in trench digging or excavation activities. A commercial/industrial worker is assumed to be a long-term receptor exposed during the course of a work day as either a full time employee of a company operating on-site. The commercial/industrial exposure scenario includes a dermal component (e.g., direct contact with soil); thus, the screening levels for this receptor are expected to protect other reasonably anticipated indoor and outdoor workers at a commercial/industrial facility. However, screening levels developed for the commercial/industrial worker may not be protective of a construction worker due to the latter's increased soil contact rate during construction activities. The following equations are used to develop ESLs for combined pathways of exposure for both carcinogenic and noncarcinogenic endpoints. Default exposure assumptions are provided for use when non sites-specific information is available.

Direct Contact Soil Exposures - Noncarcinogenic Effects - Commercial/Industrial

Incidental Ingestion of Soil (equation 5a)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_{\text{nci}} \times \text{BW}_a}{\text{EF}_{\text{ci}} \times \text{ED}_{\text{ci}} \times \frac{1}{\text{RfD}_o} \times \text{IRS}_{\text{ci}} \times 10^{-6} \text{ kg/mg}}$$

Inhalation of Particulates and Volatiles from Soil (equation 5b)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_{\text{nci}}}{\text{EF}_{\text{ci}} \times \text{ED}_{\text{ci}} \times \frac{8 \text{ hr}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1}{\text{RfC}} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 5c)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_{\text{nci}} \times \text{BW}_a}{\text{EF}_{\text{ci}} \times \text{ED}_{\text{ci}} \times \frac{1}{\text{RfD}_o} \times \text{SA}_{\text{ci}} \times \text{AF}_{\text{ci}} \times \text{ABS}_d \times 10^{-6} \text{ kg/mg}}$$

Total (equation 5d)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Direct Contact Soil Exposures – Carcinogenic Effects – Commercial/Industrial

Incidental Ingestion of Soil (equation 6a)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c \times \text{BW}_a}{\text{SF}_o \times \text{EF}_{ci} \times \text{ED}_{ci} \times \text{IRS}_{ci} \times 10^{-6} \text{ kg/mg}}$$

Inhalation of Particulates and Volatiles from Soil (equation 6b)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c}{\text{IUR} \times 1,000 \mu\text{g/mg} \times \text{EF}_{ci} \times \text{ED}_{ci} \times \frac{8 \text{ hr}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hr}} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 6c)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c \times \text{BW}_a}{\frac{\text{SF}_o}{\text{GIABS}} \times \text{EF}_{ci} \times \text{ED}_{ci} \times \text{AF}_{ci} \times \text{SA}_{ci} \times \text{ABS}_d \times 10^{-6} \text{ mg/kg}}$$

Total (equation 6f)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Parameter	Definition (units)	Value
C _{soil}	Chemical concentration in soil (mg/kg)	Chemical-specific
TR	Target risk level	1 x 10 ⁻⁶
THQ	Target hazard quotient	1
BW _a	Body weight, adult (kg)	70
AT _{nci}	Averaging time, noncarcinogens, commercial/industrial (days)	ED _{ci} x 365 days/year
EF _{ci}	Exposure frequency, commercial/industrial (day/yr)	250
ED _{ci}	Exposure duration, commercial/industrial (years)	25
ET _{ci}	Exposure time, commercial/industrial (hours)	8
IRS _{ci}	Soil ingestion rate, commercial/industrial (mg/day)	100
IUR	Inhalation unit risk (μg/m ³) ⁻¹	Chemical-specific (Table J-2)
RfC	Inhalation reference concentration (μg/m ³)	Chemical-specific (Table J-2)
SA _{ci}	Exposed dermal surface area, commercial/industrial (cm ² /day)	3,300
AF _{ci}	Soil adherence factor, commercial/industrial (mg/cm ²)	0.2

ABS	Skin absorption factor (unitless)	Chemical-specific (Table (J-2))
AT _c	Averaging time carcinogen (days)	365 days/year x 70 years
SF _o	Cancer slope factor for oral exposure (mg/m ³) ⁻¹	Chemical-specific (Table J-2)
RfD _o	Reference dose for oral exposure (mg/kg-day)	Chemical-specific (Table J-2)
VF	Volatilization factor (m ³ /kg)	Chemical-specific (Table J-1)
PEF	Particulate emission factor (m ³ /kg)	1.3 x 10 ⁹
GIABS	Gastro-intestinal absorption factor	Chemical-specific

5.1.3 Construction Worker

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. If multiple construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial exposures to surface and subsurface soils during excavation, maintenance and building construction projects. A construction worker is assumed to be exposed to chemicals in soil via incidental ingestion, dermal contact, and inhalation due to volatilization and fugitive dust. While a construction worker receptor is assumed to have a higher soil ingestion rate than a commercial/industrial worker due to the type of activities performed during construction projects, the exposure frequency and duration are typically of shorter duration due to the short-term nature of construction projects. However, chronic toxicity information was used when developing screening levels for a construction worker receptor. This approach is more conservative than using sub-chronic toxicity data because it combines the relatively short exposure duration of construction-related exposures with chronic toxicity criteria. Equations 8 and 9 are used to develop ESLs for cumulative exposure to carcinogenic and noncarcinogenic chemicals by all exposure pathways. Default exposure assumptions are provided for use when non site-specific information is available (U.S. EPA 2002c).

Direct Contact Soil Exposures – Noncarcinogenic Effects – Construction Worker

Incidental Ingestion of Soil (equation 7a)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_n \times \text{BW}_a}{\text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \frac{1}{\text{RfD}_o} \times \text{IRS}_{\text{cw}} \times 10^{-6} \text{ kg/mg}}$$

Inhalation of Particulates and Volatiles from Soil (equation 7b)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_n}{\text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \frac{8 \text{ hr}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1}{\text{RfC}} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 7c)

$$C_{\text{soil}} = \frac{\text{THQ} \times \text{AT}_n \times \text{BW}_a}{\text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \frac{1}{\text{RfD}_o \times \text{GIABS}} \times \text{SA}_{\text{cw}} \times \text{AF}_{\text{cw}} \times \text{ABS}_d \times 10^{-6} \text{ kg/mg}}$$

Total (equation 7d)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Direct Contact Soil Exposures – Carcinogenic Effects – Construction worker

Incidental Ingestion of Soil (equation 8a)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c \times \text{BW}_a}{\text{SF}_o \times \text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \text{IRS}_{\text{cw}} \times 10^{-6} \text{ kg/mg}}$$

Inhalation of Particulates and Volatiles from Soil (equation 8b)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c}{\text{IUR} \times 1,000 \mu\text{g/mg} \times \text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hr}} \times \left(\frac{1}{\text{VF}} + \frac{1}{\text{PEF}} \right)}$$

Dermal Contact with Soil (equation 8c)

$$C_{\text{soil}} = \frac{\text{TR} \times \text{AT}_c \times \text{BW}_a}{\frac{\text{SF}_o}{\text{GIABS}} \times \text{EF}_{\text{cw}} \times \text{ED}_{\text{cw}} \times \text{SFS}_{\text{adj}} \times \text{SA}_{\text{cw}} \times \text{AF}_{\text{cw}} \times \text{ABS}_d \times 10^{-6} \text{ kg/mg}}$$

Total (equation 8d)

$$\frac{1}{\frac{1}{\text{Res Soil Ing}} + \frac{1}{\text{Res Soil Inhal}} + \frac{1}{\text{Res Soil Dermal}}}$$

Parameter	Definition (units)	Value
C _{soil}	Chemical concentration in soil (mg/kg)	Chemical-specific
TR	Target risk level	1 x 10 ⁻⁶
THQ	Target hazard quotient	1
BW _a	Body weight, adult (kg)	70
AT _n	Averaging time, noncarcinogen	ED _{cw} x 365
AT _c	Averaging time carcinogen (days)	70 years x 365 days/year
EF _{cw}	Exposure frequency, construction worker (day/yr)	250
ED _{cw}	Exposure duration, construction worker (years)	1
ET _{cw}	Exposure time, construction worker (hours)	8
IRS _{cw}	Soil ingestion rate, construction worker (mg/day)	330
IUR	Inhalation unit risk (µg/m ³) ⁻¹	Chemical-specific (Table J-2)
RfC	Inhalation reference concentration (µg/m ³)	Chemical-specific (Table J-2)
SA _{cw}	Exposed dermal surface area, construction worker (cm ² /day)	5,800
AF _{cw}	Soil adherence factor, commercial/industrial (mg/cm ²)	0.51
ABS	Skin absorption factor (unitless)	Chemical-specific (Table J-2)
GIABS	Gastro-intestinal absorption factor (unitless)	Chemical-specific
SF _o	Cancer slope factor for oral exposure (mg/m ³) ⁻¹	Chemical-specific (Table J-2)
RfD _o	Reference dose for oral exposure (mg/kg-day)	Chemical-specific (Table J-2)
VF	Volatilization factor (m ³ /kg)	Chemical-specific (Table J-1)
PEF	Particulate emission factor (m ³ /kg)	1.4 x 10 ⁶

Screening levels for human health/direct-exposure concerns for shallow soils are summarized in Detail Tables K-1 (residential land use exposure scenario) and K-2 (commercial/industrial exposure scenario). Direct-exposure screening levels for deep soils are summarized in Detail Table K-3 (construction/utility worker exposure scenario). Only the construction/utility trench worker exposure scenario includes periodic contact with chemicals in deep soils.

5.2 Soil Screening Levels for Protection of Groundwater

Detail Table G contains soil screening levels for protection of groundwater. These screening levels are intended to address potential leaching of chemicals from vadose-zone soils and subsequent migration to groundwater. The soil screening levels are back-calculated based on target groundwater screening levels, which are summarized in Detail Tables F-1a and F-1b and discussed in Chapter 2. In Detail Tables F-1a and F-1b, the Groundwater to Indoor Air ESL input for the Detail Table G calculations is selected solely from the default soil type Fine-Coarse Mix in a residential scenario. For the All Sand soil type or different land

use, a manual calculation of the Soil Leaching to Groundwater ESL is necessary. Instructions for the manual calculation are included in Appendix B.

The majority of the screening levels were calculated based on an empirical equation presented in guidance published by the Massachusetts DEP (MADEP, 1994):

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

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

where:

- DAF = SESOIL-based dilution/attenuation factor;
- H = Henry's Law Constant (atm-m³/mol);
- K_{oc} = organic carbon partition coefficient (cm³/g);
- C_{soil} = leaching based soil concentration (mg/kg);
- C_{gw} = target groundwater screening level (μg/L).

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

SESOIL models the generation and downward migration of leachate in the vadose zone. The AT123D application models the mixing of leachate with groundwater immediately below the contaminated area. A more detailed discussion of the derivation and application of the SESOIL/AT123D algorithm as modified by the Massachusetts DEP and adopted for use by the MOEE is provided in MOEE (1996) and MADEP (1994). The algorithm is based on a three-meter thick vadose zone characterized by one meter of contaminated soil sandwiched between two one-meter thick layers of clean soil. The lower layer immediately overlies groundwater. All vadose-zone soil is conservatively assumed to be very permeable sand that freely allows the migration of leachate to groundwater. The organic carbon content of the soil is assumed to be 0.1 percent. Mixing with groundwater is modeled over a 10-meter by 10-meter

area. Use of a thicker sequence of contaminated soil would not significantly alter the results of the model given the assumed 1-meter depth to groundwater.

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

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

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

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

SESOIL modeling carried out by the Hawai'i Department of Health (HDOH, 1995) suggests that chemicals with sorption coefficients greater than 30,000 cm³/g will be immobile in the surface under normal soil conditions and not likely to affect groundwater. HDOH ran the SESOIL models conservatively assuming an annual rainfall of 400 cm/year (158 inches/year), an infiltration rate of 144 cm/year (57 inches/year) and permeable soil overlying fractured bedrock.

Based on modeling studies as well as field experience in general, screening levels for chemicals with sorption coefficients greater than 30,000 cm³/g were set at the theoretical soil saturation level for that chemical if higher than the screening level generated by use of the SESOIL algorithm. Exceptions to this approach are pentachlorophenol and bis(2-ethylhexyl)phthalate, both of which have a higher solubility than other highly sorptive chemicals. Leaching-based screening levels for these chemicals were developed using only the SESOIL algorithm described above.

The majority of PCBs releases identified in the Bay Area are 1242- to 1260-range Aroclors. The default K_{oc} of 33,000 cm³/g presented in Detail Table J-1 was considered to be adequately conservative for this range and used in the leaching model. For less chlorinated PCB mixtures, a site-specific evaluation of potential leaching concerns and possible vapor emission concerns is required.

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

A leaching-based soil screening level was developed for perchlorate (ClO_4^-). Perchlorate is a salt, and is not sorptive, volatile or biodegradable under normal conditions. Use of the SESOIL/AT123D algorithm was therefore not considered appropriate. As an alternative, the simple, chemical partitioning model presented in the U.S. EPA Soil Screening Level Guidance document (U.S. EPA 1996b) was used:

$$C_{\text{soil}} = C_{\text{water}} \times \left((K_{\text{oc}} \times f_{\text{oc}}) + \left(\frac{\theta_{\text{w}} + (\theta_{\text{a}} \times H')}{\rho_{\text{b}}} \right) \right) \times \text{DAF} \quad (\text{Equation 10a})$$

where:

- C_{soil} = soil screening level for leaching concerns (mg/kg);
- C_{water} = target dissolved-phase concentration of chemical (mg/L);
- K_{oc} = sorption coefficient;
- f_{oc} = fraction organic carbon in soil;
- θ_{w} = water-filled porosity;
- θ_{a} = air-filled porosity;
- H' = dimensionless Henry's Law constant;
- ρ_{b} = soil bulk density (g/cm^3);
- DAF = Dilution/Attenuation Factor

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

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

The default water-filled porosity in the models is 0.15 and the default soil bulk density is 1.5. Laboratory-based tests are recommended for more site-specific analysis of potential leaching of perchlorate from soil.

5.3 Soil Screening Levels for Urban Terrestrial Habitats

ESLs for the protection of terrestrial plants and animals are included for shallow soils in both the Residential and Commercial/Industrial land-use scenarios. The screening levels were taken directly from guidance developed by the Ontario

Ministry of the Environment and Energy (MOEE, 1996). Screening levels were available for heavy metals and some high-molecular-weight organic compounds and pesticides.

The MOEE guidance is primarily a compilation of criteria published by environmental agencies in Canada and elsewhere and is an update to previous guidance (MOEE, 1991; CCME, 1994). Ecological effects-based soil values developed by the Dutch government (Vegter, 1993; van den Berg, 1993) were in particular reviewed for inclusion in the MOEE guidance. The Netherlands C values referenced are intended to represent the concentration of a chemical in soil at which the No Observed Effects Concentration for 50 percent of the target species would be exceeded. Earlier versions of the Canadian and Dutch guidance are presented in *Evaluation of Soil Contamination* (U.S. FWS, 1990).

The MOEE intended use of the screening levels over a broad range of land-use scenarios, including residential land use, agricultural and parkland. For the purposes of consideration in the Tier 1 lookup tables the screening levels are considered to be adequate only for general screening purposes in and around developed, urban areas.

The screening levels are not intended for use in areas where a significant risk to endangered or threatened species may exist or where there is a potentially significant threat to terrestrial ecological receptors that extends beyond the general boundary of a subject site. This could include sites that are adjacent to wetlands, streams, rivers, lakes, ponds, marine shorelines, or sites that otherwise contain or border on areas where protected or endangered species may be present. Potential migration to sediment is also not addressed. The need for a detailed risk assessment should be evaluated on a site-by-site basis for areas where significant ecological concerns may exist. Notification to the Natural Resource Trustee Agencies (including the state Department of Toxics Substances Control and California Department of Fish and Wildlife and the U.S. Fish and Wildlife Service, Department of the Interior and National Oceanic and Atmospheric Administration) may also be required, particularly if the release of a hazardous substance may affect surface water bodies.

5.4 Ceiling Levels

Ceiling levels are presented in each of the ESL summary tables for soil. These screening levels are intended to be protective against odor and other nuisance and aesthetic concerns, as well as restrict the presence of potentially mobile, free product and limit the overall degradation of soil quality. The selection of soil ceiling levels was based on methods originally published by the Massachusetts DEP (MADEP, 1994) and also used by the MOEE (MOEE, 1996), as described in the Detail Table H series.

Odor Thresholds presented in the Detail Table H series are intended to represent the concentration of a chemical in air at which 50 percent of the population can detect a chemical odor. An Odor Index for a chemical is calculated by dividing the chemical's vapor pressure (in Torr, at 20-30 degrees Celsius) by its odor threshold (in ppm-volume, see Detail Tables H-2 and H-3). This provides a relative ranking of chemicals for potential nuisance concerns. As summarized in Detail Tables H-2 and H-3, ceiling levels were then selected based a comparison of a chemical's vapor pressure and odor index to a table of generic screening levels presented in Detail Table H-1. For chemicals that are liquids under ambient conditions, the ceiling level was selected as the lowest of the generic level from Detail Table H-1 and the chemical's theoretical saturation level in soil. This was intended to prevent the presence of mobile, free product in the subsurface.

6 Indoor Air and Vapor Intrusion Screening Levels

This chapter presents the derivation of risk-based screening levels for ambient and indoor air, as well as soil gas and groundwater screening levels for vapor intrusion. Vapor intrusion is the migration of VOCs through the vadose zone and into an occupied building. The screening levels discussed here address both human health and odor concerns. Risk-based ESLs for ambient and indoor air are calculated using the methodology outlined in RAGS Part F (U.S. EPA, 2009a); Section 6.1(below) provides the details. Odor-based ESLs for ambient and indoor air based on 50 percent odor-recognition thresholds are found in Summary Table E and Detail Tables H-2 and H-3. Soil gas and groundwater ESLs for evaluating the potential for vapor intrusion were calculated using attenuation factors derived from the Johnson and Ettinger model (Johnson and Ettinger, 1991) as programmed into Microsoft Excel by U.S. EPA (see Sections 6.2 and 6.3, respectively). As used here, the Johnson and Ettinger model implementation by U.S. EPA in Microsoft Excel is referred to as “the U.S. EPA Vapor Intrusion Model.”

6.1 Indoor and Ambient Air Screening Levels

Indoor and ambient air screening levels are calculated using the following equations (note that the units for both C_{air} and RfC are $\mu\text{g}/\text{m}^3$):

Noncarcinogenic Effects - Resident (equation 11a)

$$C_{\text{air}} = \left(\frac{\text{THQ} \times \text{AT}_n}{\left(\frac{1}{RfC} \right) \times \text{ET}_r \times \frac{1}{24 \text{ hr}} \times \text{EF}_r \times \text{ED}_r} \right)$$

Carcinogenic Effects - Resident (equation 11b)

$$C_{\text{air}} = \frac{\text{TR} \times \text{AT}_c}{\text{IUR} \times \text{ED}_r \times \text{EF}_r \times \text{ET}_r \times \left(\frac{1}{24 \text{ hr}} \right)}$$

Noncarcinogenic Effects - commercial/industrial (equation 12a)

$$C_{\text{air}} = \left(\frac{\text{THQ} \times \text{AT}_n}{\left(\frac{1}{\text{RfC}} \right) \times \text{ET}_{\text{ci}} \times \frac{1}{24 \text{ hr}} \times \text{EF}_{\text{ci}} \times \text{ED}_{\text{ci}}} \right)$$

Carcinogenic Effects - commercial/industrial (equation 12b)

$$C_{\text{air}} = \frac{\text{TR} \times \text{AT}_c}{\text{IUR} \times \text{ED}_{\text{ci}} \times \text{EF}_{\text{ci}} \times \text{ET}_{\text{ci}} \times \left(\frac{1}{24 \text{ hr}} \right)}$$

Parameter	Definition (units)	Value
C_{air}	Chemical concentration in air ($\mu\text{g}/\text{m}^3$)	Chemical-specific Table E-3)
TR	Target risk level	1×10^{-6}
THQ	Target hazard quotient	1
IUR	Inhalation unit risk ($\mu\text{g}/\text{m}^3$) ⁻¹	Chemical specific (Table J-2)
RfC	Reference concentration for inhalation exposure ($\mu\text{g}/\text{m}^3$)	Chemical specific (Table J-2)
ET	Exposure time (hr/day)	24 – residential exposure 8 – occupational exposure
EF	Exposure frequency (days/year)	350 – residential exposure 250 – occupational exposure
ED_r	Exposure duration, resident (years)	30
ED_{ci}	Exposure duration, commercial/industrial worker (years)	25
AT_c	Averaging time – carcinogenic exposure (days)	70×365 days/year
AT_n	Averaging time – noncarcinogenic exposure (days)	$\text{ED} \times 365$ days/year

The calculated indoor-air screening levels are provided in Detail Table E-3.

6.2 Soil Gas Screening Levels

Vapor attenuation from the subsurface to indoor air is dependent on a number of factors, including diffusion, advection, sorption and degradation reactions.

Additional attenuation occurs when vapors enter a building and are diluted via mixing with indoor air. These mechanisms can be expressed quantitatively as an

attenuation factor (AF) defined as the ratio of the indoor air concentration (C_{IA}) to the measured subsurface vapor concentration (C_{SV}) (U.S. EPA, 2008):

$$AF = \frac{C_{IA}}{C_{SV}} \quad \text{(equation 13)}$$

Attenuation factors for soil gas to indoor air were derived from the DTSC Vapor Intrusion Guidance (DTSC, 2011d). Appendix B of the Vapor Intrusion Guidance includes “preliminary screening attenuation factors” based on the U.S. EPA Vapor Intrusion Model (U.S. EPA, 2003). Appendix B derives attenuation factors for both existing and future structures, with existing-structure attenuation factors being two times more stringent than future-structure attenuation factors, due to improved “tightness” of newer building foundations. The soil gas-to-indoor air screening levels rely on the existing-structure attenuation factors listed below:

Table 6-1. Default Attenuation Factors Used in the ESLs

Land use	Soil gas to indoor air attenuation factor (alpha)
Residential	0.002 (or 1:500)
Commercial / industrial	0.001 (or 1:1,000)

Soil gas-to-indoor air screening levels, obtained by dividing the indoor air screening levels by the attenuation factor, can be found in Detail Table E-2.

Users should only compare the soil gas ESLs to soil gas data, provided that the subsurface contamination is laterally and vertically delineated. Further information is presented in Section 3.5 of this User’s Guide and in Step 5 of the DTSC *Vapor Intrusion Guidance* (DTSC, 2011d).

The ESLs include no sub-slab soil gas screening levels, due to uncertainty regarding the appropriate sub-slab-to-indoor air attenuation factor. The DTSC *Vapor Intrusion Guidance* borrows an attenuation factor of 0.05 (or 1:20) from U.S. EPA’s vapor intrusion database (U.S. EPA, 2008). U.S. EPA derived this attenuation factor from a statistical analysis of paired measurements of indoor air and sub-slab soil gas (95th percentile value). However, the database includes sites across the country, many of which have conditions different from what are found

in the San Francisco Bay region (e.g., basements and long, cold winters that emphasize the advective flow component of vapor intrusion). Until there is a better technical basis for the attenuation factor, it is premature to derive sub-slab ESLs. We recommend that users seeking to evaluate sub-slab sampling results derive a site-specific attenuation factor using a current version of the U.S. EPA Vapor Intrusion Model.

6.3 Groundwater-to-Indoor Air Screening Levels

Vapor attenuation from groundwater to indoor air is dependent on a number of factors, including those previously mentioned for soil gas, as well as attenuation in the capillary fringe, immediately above the water table. These mechanisms can be expressed quantitatively as an attenuation factor (AF) defined as the ratio of the indoor air concentration (C_{IA} , $\mu\text{g}/\text{m}^3$) to the measured groundwater concentration (C_{GW} , $\mu\text{g}/\text{L}$) (U.S. EPA, 2008):

$$\text{AF} = \frac{C_{IA}}{C_{GW}} \times \frac{\text{m}^3}{1,000\text{L}} \quad (\text{equation 14})$$

Attenuation factors for groundwater-to-indoor air are derived using the GW-ADV version of the U.S. EPA Vapor Intrusion Model (U.S. EPA, 2004a). Two different groundwater-to-indoor air screening levels have been developed, and their use is based on knowledge of site-specific soil types. The different soil types and their application are described below:

- **Fine-Coarse Mix** – These default screening levels are based on a past evaluation of paired groundwater and indoor air data from typical Bay Area sites where the soils have a significant proportion of fines. This is the default soil type that should be used for Bay Area sites, unless the site soils (from water table to ground surface) consist of predominantly sand or gravel, or if fractured bedrock or significant preferential pathways are present. These screening levels should only be used at sites where the depth to groundwater is at least 10 feet. These screening levels may not be protective at sites with shallower groundwater. At sites with shallower groundwater, soil gas sampling should be performed to assess vapor intrusion potential (see Section 3.5).

- **All Sand** – These screening levels are based on having 10 feet of sand above the water table. It is anticipated that this soil type may only apply to limited sites, such as bay margin fill sites (e.g., former Naval Station Treasure Island, former Hunters Point Naval Shipyard) and possibly Livermore Valley or Southern Santa Clara Valley.

A copy of each soil type's DATAENTER worksheet showing the soil/groundwater parameters, soil properties, building parameters, and exposure parameters is included in Appendix C. Toxicity factors are from Detail Table J-2 of the ESL Workbook. In addition, a table of input parameters for each soil type is included.

The groundwater-to-indoor-air screening levels should not be used if the source of the VOCs is in the vadose zone. Further information is presented in Section 3.5 of this User Guide and in Step 5 of the DTSC *Vapor Intrusion Guidance*.

6.4 Consideration of Odor in Indoor Air and Soil Gas

Odor-based ESLs for indoor air are based on the 50 percent odor-recognition thresholds (the level at which half of the population can detect the odor) as published in the ATSDR Toxicological Profiles¹¹ and other references (MOE, 1996, MADEP, 1994, USDHHS, 2001). The results are found in Summary Table E and Detail Tables H-2 and H-3. For soil gas, the odor thresholds were multiplied by an attenuation factor of 0.002 (or 1:500) to calculate a ceiling level. This attenuation factor is the same as the attenuation factor for residential exposure discussed in Section 6.2.

6.5 Site-Specific Vapor Intrusion Models

For cases where a site-specific model is used to evaluate vapor intrusion, recommendations for content and organization that will facilitate review by the Regional Water Board are included in Appendix D.

¹¹ <http://www.atsdr.cdc.gov/toxprofiles/index.asp>

7 Cumulative Risk

The ESLs are intended as a screening tool for sites with low levels of contaminants, and are tabulated for one chemical and one medium (water, soil or indoor air) only. The numbers for human health risk produced by the workbook and shown in the lookup tables reflect a target risk (Risk) of 10^{-6} for chemicals that act predominantly as carcinogens or a target hazard quotient (HQ) of 1 when the noncarcinogenic effect(s) are the predominant concern. When multiple chemicals are present or receptors are exposed to more than one contaminated medium, the applicability of the ESLs should be carefully evaluated. The conclusion that a site does not pose a significant danger of adverse effects on human health is reasonable only if one or a small number of contaminants are present at concentrations that are significantly below the ESLs. If multiple contaminants are present and one or more of the concentrations approach the respective ESLs, the cumulative risk (and hazard) must be evaluated.

7.1 Evaluating Cumulative Risks and Hazards at Sites with Multiple Chemicals of Concern

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

At sites where several chemicals are present at concentrations greater than their respective ESLs, cumulative cancer risk and noncarcinogenic hazard can be calculated as follows:

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

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

(equation 15)

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

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

(equation 16)

A hazard index of 1 or less is generally considered to be without potential adverse health effects. A hazard index greater than 1 suggests further evaluation. Previous ESLs and the November 2013 U.S. EPA RSLs provide screening levels calculated for an HQ that is smaller than 1 for sites with multiple contaminants. This will be briefly discussed in the next section.

In some cases, the Excel “Hazard-Risk Calculator” provided by OEHHA on the Cal/EPA Brownfields site may be helpful for initial estimates:

<http://www.calepa.ca.gov/Brownfields/SB32.htm>.

7.2 Additional Consideration for Assessing Cumulative Risk and Hazard

Calculating cumulative risk and hazard is typically part of a Tier 3 evaluation. In particular, segregation of hazard indices by effect and mechanism of action can be complex and time-consuming because it is necessary to identify all of the major effects and target organs for each chemical and then to classify the chemicals according to target organ(s) or mechanism of action. This analysis is not simple and should be performed by a toxicologist. If the segregation is not carefully done, an underestimate of true hazard could result.

Previous ESL versions had two sets of screening levels for noncarcinogens in the tables with the Direct Exposure Soil Screening Levels (K-series tables), one corresponding to an HQ of 1 and the other reflecting an HQ of 0.2 for the purpose of simplifying the quick evaluation of a “typical site” with five contaminants. Similarly, the RSLs now feature a second set of screening reflecting a target HQ of 0.1. However, the availability of an alternate table may detract from the need to evaluate multiple contaminants detected at concentrations above or near ESLs in a comprehensive manner. For example, using a screening-level table based on a target hazard quotient of less than 1 may appear to shift the emphasis from carcinogenic to noncarcinogenic effects when both should be evaluated.

Below are some steps that might be included in comprehensive evaluation of a site contaminated with several chemicals:

- Identify the chemical(s) that drive(s) the risk or hazard. The drivers can be chemicals that are present in higher concentrations, are more toxic than others, or are more likely to reach and harm the receptor(s) because of physical properties such as volatility.
- If multiple chemicals are present in significant concentrations, evaluate both total risk and total hazard.
- Consider the distribution of the contamination (for example, whether there are “hotspots”) and where the contamination is located relative to current or future receptors.
- Make sure that all relevant exposure pathways are considered at sites where more than one medium is contaminated. For example, a receptor may be exposed through contact with contaminated soil and inhalation of a volatile chemical moving into living or work spaces from contaminated soil or groundwater. The combined risk or hazard of these pathways should not exceed 10^{-6} or 1, respectively.

Questions regarding the selection of contaminants of potential concern, possible subtraction of a background level, and other issues should be discussed with the overseeing regulatory agency in a timely manner.

8 Screening Levels for Total Petroleum Hydrocarbons

Total Petroleum Hydrocarbons (TPH) refers to a non-specific laboratory analysis that provides a measure of petroleum hydrocarbon concentrations over a particular carbon range without identifying individual compounds. The amount of TPH detected in environmental samples is a useful indicator of petroleum contamination at a site. This chapter describes the development of ESLs for TPH as a tool for evaluating the risk to human health and the environment posed by petroleum releases at sites that do not meet the conditions of the *Low-Threat Underground Storage Tank Closure Policy* (see Section 1.2.1).

The majority of ESLs are developed for individual chemicals; however, TPH is an exception because it is composed of many constituents. Petroleum fuels are complex mixtures of many different compounds with varying properties. Some petroleum compounds, like benzene, naphthalene, and benzo[a]pyrene, have been sufficiently studied to understand their toxicity and physical and chemical properties, and ESLs are developed for these individual chemicals. However, the vast majority of petroleum compounds have not been sufficiently studied to enable development of screening levels on an individual chemical basis; and, given the number of compounds in petroleum mixtures, this would not be practical.

The following sections provide (1) basic information on petroleum hydrocarbons and mixtures; (2) a fraction approach for deriving TPH health-risk based ESLs; (3) TPH ESLs for water; and (4) brief descriptions of various issues associated with TPH.

8.1 Petroleum Hydrocarbons and Mixtures

8.1.1 Summary of Petroleum Chemistry and Composition

Petroleum hydrocarbons are chemicals composed of hydrogen and carbon that originate from crude oil. Most crude oil contains tens of thousands of compounds, including hydrocarbons and non-hydrocarbons (Stout, et al., 2002).

The non-hydrocarbons include organic chemicals with heteroatoms (mostly sulfur in crude oils and oxygen in weathered fuels), and metals.

The hydrocarbons can be divided into two broad families based on molecular structure and chemical bonding patterns: aliphatic and aromatic. Aliphatics are nonpolar because electrons are shared fairly evenly. In other words, there is no electron excess (partial negative charge) or deficit (partial positive charge) for the interaction with polar molecules such as water. They can further be divided into several classes including straight-chain, saturated aliphatics (alkanes); branched alkanes (isoalkanes); cyclic alkanes (cycloalkanes); and various unsaturated aliphatics (alkenes and alkynes). Examples of aliphatics include n-hexane (C₆, straight-chain or linear alkane) and cyclohexane (C₆, cyclic alkane).

Aromatic hydrocarbons are moderately polar because they have “clouds” of loosely attached “delocalized” electrons which facilitate interactions among the aromatics as well as between the aromatic and polar molecules. Aromatic hydrocarbons consist of one or more ring(s) and can have aliphatic attachments. Examples include benzene (C₆, a single ring aromatic or monoaromatic hydrocarbon), toluene (C₇, methylbenzene) and naphthalene (C₁₀), which has a fused, double ring and is the smallest polycyclic aromatic hydrocarbon (PAH). Aliphatic (nonpolar) and aromatic (polar) hydrocarbons have physical, chemical and biological properties that are distinct from each other. For instance, n-hexane (C₆ aliphatic) is much more volatile than benzene (C₆ aromatic), and benzene has a 200-times greater solubility in water than n-hexane. Therefore, the properties of petroleum mixtures vary with the percent of aliphatic versus aromatic compounds, the size of the molecules, the presence of non-hydrocarbons,¹² and the presence of polar breakdown products (metabolites).

For the development of TPH ESLs, petroleum is subdivided into three TPH mixtures commonly measured and reported at environmental cleanup sites, which are described below.

- TPH gasoline (TPHg) – Automotive gasolines are complex mixtures of C₄ to C₁₂ hydrocarbons (Potter and Simmons, 1998) consisting of

¹² The presence of non-hydrocarbons (e.g., sulfur compounds) is not included in the derivation of health-risk based TPH ESLs.

about 50 to 80 percent aliphatics (dominantly branched) and about 20 to 50 percent aromatics (ATSDR, 1995b). In addition to hydrocarbons, these mixtures commonly include additives and blending agents to boost performance. Finished gasolines typically contain more than 150 separate compounds although as many as 1,000 compounds have been identified in some blends (ATSDR, 1995b).

- TPH diesel (TPHd) – Diesel is a middle distillate mixture of C8 to C21 hydrocarbons (Potter and Simmons, 1998), consisting of about 65 percent aliphatics and 35 percent aromatics (ATSDR, 1995a). Some other examples of middle distillates include kerosene, home heating fuel, and jet fuel (e.g., JP4).
- TPH motor oil (TPHmo) – Motor oil is a heavy distillate mixture characterized by high molecular weight hydrocarbons with a carbon range of C18 to C34+, consisting of about 80 percent aliphatic and 20 percent aromatics (Potter and Simmons, 1998).

The term “residual fuel” refers to the complex mixture of high molecular weight constituents remaining following distillation and collection of the lower molecular weight distillation constituents. Examples of residual fuels include Bunker C oil and fuel oil no. 6. ESLs are not developed for the residual fuels (see Section 8.2.4). The term “residual fuel” does not refer to TPH products remaining in soil as a result of natural weathering or following cleanup activities.

8.1.2 Weathering and Fate of Petroleum Releases

Following a release to the environment, the composition of petroleum mixtures changes due to movement and weathering (dissolution or leaching, partitioning, volatilization, biodegradation, and for surface releases, photodegradation). These processes affect the aliphatics and aromatics differently. Aliphatics tend to be more volatile whereas the aromatics tend to be more soluble. In addition, the smaller molecular weight compounds tend to be more mobile than the heavier molecular weight compounds. Degradation of petroleum occurs both in the presence and absence of oxygen (Potter and Simmons, 1998), although degradation rates are much lower in the absence of oxygen. Susceptibility to degradation is greatest for the n-alkanes, then progressively decreases in order of isoalkanes, alkenes, monoaromatics, PAHs, and finally cycloalkanes. Further information on the differential weathering characteristics of aliphatic and

aromatic hydrocarbons is presented in Potter and Simmons (1998) and Stout, et al. (2002).

8.2 Fraction Approach to Evaluating TPH

The Total Petroleum Hydrocarbon Criteria Working Group (Edwards, et al., 1997) estimated the number of individually identified hydrocarbon components of various petroleum-derived fuels and crude oil at approximately 250. Only a relatively small number of these 250 hydrocarbons have been sufficiently studied to understand their toxicity and fate and transport characteristics.

For the ESLs, petroleum releases to environmental media are evaluated in terms of both indicator chemicals and TPH. Typical indicator chemicals include *n*-hexane, benzene, toluene, ethylbenzene, xylenes, naphthalene, and benzo[a]pyrene. The monocyclic aromatics benzene, toluene, ethylbenzene and the three xylene isomers are commonly referred to as “BTEX”. Depending on the petroleum mixture released, other indicator chemicals may also be appropriate and should be discussed with the overseeing regulatory agency. These might include additives (e.g., MtBE) or blending agents.

Surrogates are used to represent noncarcinogenic toxicity of TPH. This approach is generally consistent with guidance from U.S. EPA (U.S. EPA, 1986) and DTSC (DTSC, 1996c) and similar to how TPH has been evaluated by the TPHCWG and MADEP.

8.2.1 TPH Fractions

Previous approaches to representing the toxicity of TPH for the computation of health risk-based ESLs used a single surrogate as the source for toxicity factors for each TPH mixture (e.g., gasoline, diesel, motor oil). The current approach employs the use of fractions to develop weighted-average toxicity factors and physical constants, which are then used to derive human health risk-based screening levels for TPH. The approach is similar to that used by the State of Hawaii Department of Health (HDOH, 2011).

The fractions and surrogates are selected based on the U.S. EPA *Final Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons* (Complex Hydrocarbon Mixtures PPRTV; U.S. EPA, 2009d). The hydrocarbon fractions are divided by molecular structure into aliphatics and aromatics, and then each structure is subdivided into three carbon ranges (low, medium, and high), for a total of six fractions. Figure 8-1 presents the fractions and illustrates their intersection with the three TPH mixtures, for petroleum fuels. For example, TPHd has components of four fractions: C9 to C18 aliphatics, C19 to C32 aliphatics, C9 to C16 aromatics, and C17 to C32 aromatics, with lesser amounts of C5-C8 aliphatics.

The above TPH carbon range distinctions with respect to different types of petroleum fuels do not necessarily apply to the vapors associated with the fuels. As would be expected, TPH vapors associated with petroleum fuels will be dominated by the most volatile carbon range components of the fuel. This may or may not correspond with the overall carbon range makeup of the fuel itself. Vapor-phase compounds associated with gasolines are typically dominated by C5-C8 aliphatics and BTEX, similar to the fuel itself, with only minor amounts of C9-C12 aliphatics (e.g., Hartman, 1998, API, 2010). Vapor-phase compounds associated with diesel and other middle distillate fuels are also typically dominated by variable proportions of C5-C8 aliphatics and C9-C12+ aliphatics, with only minor amounts of aromatics, even though the former may comprise a very minor amount of the fuel itself (e.g., see Brewer, et al., 2013).

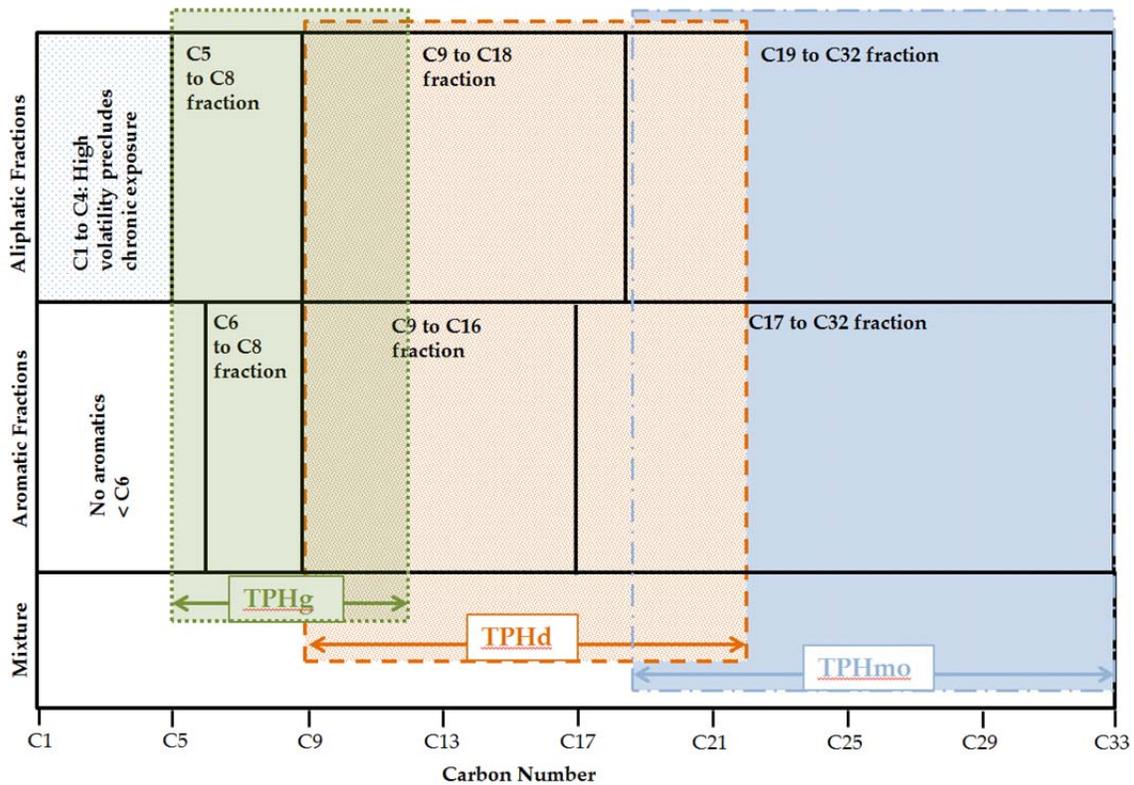


Figure 8-1. Intersection of TPH Fractions and Mixtures

Table 8-1 presents the U.S. EPA-recommended surrogates for these fractions and the corresponding noncarcinogenic oral reference dose (RfD) and inhalation reference concentration (RfC) values. Detailed information, including U.S. EPA review of the toxicity studies, is available in the Complex Hydrocarbon Mixtures PPRTV as well as six accompanying PPRTVs (U.S. EPA, 2009b, 2009c, 2009e, 2009f, 2009g and 2012b), one PPRTV for each hydrocarbon/mixture recommended as a surrogate.

Table 8-1. Surrogates and Toxicity Factors for each TPH Fraction

TPH Fraction	Toxicity Factors	
	RfD (mg/kg-day)	RfC (mg/m ³)
Aliphatics C5 to C8	3.0E-01	6.0E-01
	n-Hexane	Commercial hexane
Aliphatics C9 to C18	1.0E-02	1.0E-01
	Aliphatic hydrocarbon stream C9-C17	Aliphatic hydrocarbon stream C9-C17
Aliphatics C19 to C32	3.0E+00	Not volatile
	White mineral oil	
Aromatics C6 to C8	Not used	
Aromatics C9 to C16	3.0E-02	1.0E-01
	High-flash aromatic naphtha	High-flash aromatic naphtha
Aromatics C17 to C32	4.0E-02	Not volatile
	Fluoranthene	

Source: U.S. EPA, 2009d

8.2.2 TPH Weighted-Average Toxicity Factors and Constants

Each TPH fraction is weighted based on its relative proportion in the particular fuel mixture (e.g., gasoline, diesel, motor oil). For the RfDs, the fraction weighting is based on weight percent composition in the fuel mixture. Table 8-2 presents the TPH fraction composition for the . For the RfCs, the fraction weighting is based on percent vapor composition above the fuel for gasoline and diesel only, as motor oil is considered to be nonvolatile (Table 8-3).

Table 8-2. Fraction Composition for Petroleum Fuel Mixtures

TPH Fraction	TPHg	TPHd	TPHmo
Aliphatics C5 to C8	45%	0%	0%
Aliphatics C9 to C18	12%	45%	0%
Aliphatics C19 to C32	0%	35%	7.5%
Aromatics C6 to C8	Not used		
Aromatics C9 to C16	16%	21%	0%
Aromatics C19 to C32	0%	0%	25%

TPH fraction composition for petroleum fuel mixtures based on Park and San Juan, 2000 for TPHg and TPHd; after Potter and Simmons, 1998 for TPHmo

Table 8-3. Fraction Composition for Petroleum Vapors

TPH Fraction	TPHg	TPHd	TPHmo
Aliphatics C5 to C8	99%	25%	0%
Aliphatics C9 to C18	0.5%	75%	0%
Aliphatics C19 to C32	0%	0%	0%
Aromatics C6 to C8	Not used		
Aromatics C9 to C16	0.5%	0%	0%
Aromatics C19 to C32	0%	0%	0%

TPH fraction composition for petroleum vapors based on HDOH (2011)

Each fraction/surrogate's toxicity factor and the composition are used to develop a weighted-average toxicity factor (RfD or RfC) for each TPH mixture using the following formula adapted from Oregon Department of Environmental Quality guidance (ODEQ, 2003):

$$\text{Weighted RfD (or RfC)} = \frac{1}{\left(\frac{\% \text{ Fraction 1}}{\text{RfD Fraction 1}} + \frac{\% \text{ Fraction 2}}{\text{RfD Fraction 2}} + \dots\right)}$$

(equation 17)

An average Henry's Law Constant for TPHg and TPHd, which is pertinent to inhalation of particulates and vapors (one component of the soil direct contact exposure model), was also calculated. The physical constants used and calculated volatilization factors are presented in Appendix E. The resulting

health-risk based TPH ESLs are presented in Detail Tables E-3 (Indoor Air), F-3 (Drinking Water) and K series (Soil Direct Contact).

8.2.3 Other Mixtures and Site-Specific TPH Screening Levels

TPH screening levels for petroleum fuels other than gasoline, diesel or motor oil can be derived using the fractions/surrogates approach, provided that there is information on the fraction composition (weighting).

Site-specific TPH screening levels can be derived if adequate testing is performed to estimate the current fraction composition of the TPH. Representative samples could be collected and analyzed using fractionation methods, such as described by MADEP (2004a and 2004b) or Washington DOE (1997). The compositional percentages can then be used with the fraction-specific toxicity factors to calculate the site-specific, weighted-average toxicity factors (and physical constants), and then used in the appropriate health risk-based ESL equations to generate site-specific screening levels. Details should be discussed with the overseeing regulatory agency prior to implementing a site-specific approach.

8.3 TPH ESLs for Water

8.3.1 Drinking Water

Detail Table F-3 presents a summary of Drinking Water TPH Screening Levels that consider the following criteria:

- California MCLs;
- Other criteria (such as OEHHA Public Health Goals, CDPH Action Levels or Notification Levels);
- Risk-based goals; and
- Ceiling levels (Detail Table I-1) – Ceiling levels are based on the lowest of (1) half of the solubility (intended to indicate the potential presence of non-aqueous phase liquid or NAPL), (2) taste and odor threshold, or (3) an upper limit.

Regulatory drinking water standards (e.g., MCLs or public health goals) have not been developed for TPH. Consequently, for groundwater that is a current or

potential source of drinking water, the only applicable criteria are risk-based goals and ceiling levels. The lowest criterion is the ceiling level of 100 µg/L, based on taste and odor and referenced in *A Compilation of Water Quality Goals* (CVRWQCB, 2003). This criterion is applied to all three TPH mixtures.

For groundwater that is not a source of drinking water, only the groundwater ceiling levels apply (Detail Table I-2). The source of the nuisance odor threshold values for the TPH mixtures are the Massachusetts Contingency Plan GW-3 Standards (MADEP, 2013) without the dilution factor of 10. The source of the solubility data is Shiu, et al. (1990).

8.3.2 Protection of Aquatic Receptors (Surface Water and Groundwater)

Surface water criteria for the protection of aquatic receptors are presented in Detail Tables F-2a (Surface Water Screening Levels Freshwater Habitats), F-2b (Surface Water Screening Levels Marine Habitats), and F-2c (Surface Water Screening Levels Estuary Habitats), F-4a (Summary of Selected Aquatic Habitat Goals), F-4b (Summary of California EPA Continuous and Maximum Aquatic Habitat Goals), F-4c (Summary of US EPA and Other Published Aquatic Habitat Goals), and F-4d (Surface Water Quality Standards for Bioaccumulation and Human Consumption of Aquatic Organisms). Derivation of freshwater and saltwater ESLs is described below.

Freshwater:

- TPH gasoline – The ESL of 500 ug/L was derived based on ecological toxicity testing at the Presidio under Board Order 96-070 (SFBRWQCB, 1998; Montgomery Watson, 1999). Note that the testing did not include silica gel cleanup.
- TPH diesel and TPH motor oil – The ESL of 640 ug/L was derived based on ecological toxicity testing species at the San Francisco International Airport under Board Order 99-045 (SFBRWQCB, 1999b). Note that the testing did not include silica gel cleanup.

Saltwater:

- TPH gasoline – The ESL of 3,700 ug/L was derived based on ecological toxicity testing at the San Francisco International Airport under Board Order 99-045 (SFBRWQCB, 1999b). Note that the testing did not include silica gel cleanup.
- TPH diesel and TPH motor oil – The criteria used for the ESL is the same as freshwater.

8.3.3 Groundwater (Protection of Surface Water Aquatic Receptors)

The surface water ESLs assume that groundwater may discharge to surface water. Therefore, surface water criteria are also applicable to groundwater near the shoreline.

8.4 Other TPH Topics

8.4.1 Laboratory Analysis for TPH

Laboratory analysis for TPH is commonly carried out in accordance with EPA Method 8015C Nonhalogenated Organics by Gas Chromatography (U.S. EPA, 2007). This method utilizes a gas chromatograph (GC) equipped with a flame ionization detector (FID). The analysis is performed over a specified carbon range and quantified against a fuel standard (e.g., C6 to C12 for gasoline).

8.4.2 Degradation, Polar Intermediates, and Silica Gel Cleanup

At most fuel release sites the hydrocarbons are quickly altered due to breakdown by light or microorganisms, a process known as weathering. The rate at which this occurs varies depending on site conditions such as moisture content, oxygen levels, or the nature of resident microbial populations. The transformation of hydrocarbons into carbon dioxide is a stepwise process that produces many intermediates such as alcohols, aldehydes, ketones, acids and esters, all of which contain oxygen. Oxygen alters the electron distribution of the parent hydrocarbon to facilitate interaction with water. Therefore, these metabolites are also known as “polar intermediates.”

The presence of polars in environmental samples from petroleum release sites led to concerns several decades ago that some of the polars originate from the decay of fresh biological material rather than petroleum hydrocarbons. Silica gel cleanup (SGC; EPA Method 3630C) was proposed as a remedy for this and another potential artifact resulting from suspended particles. However, according to current knowledge, most polars at petroleum release sites are polar intermediates from the breakdown of petroleum hydrocarbons. Suspended solids can be removed by less expensive methods (e.g., filtration or decanting). Moreover, because unmodified silica gel is a nonspecific adsorbent and SGC requires additional sample manipulation, adding this procedure may introduce other artifacts, such as removing aromatics. Thus, routine addition of a SGC step to TPH sample analysis cannot be justified at this time.

For decisions regarding the assessment, management and cleanup of petroleum release sites it would be desirable to have a better understanding of how the polar intermediates affect human health, environmental receptors and water quality. Since it is not likely that every metabolite of every component of petroleum mixtures such as gasoline will be identified and characterized with respect to fate and transport, toxicity and other properties that determine its adverse effects, it is important to handle site investigation in a way that results in adequate protection. It is clear that hydrocarbons cannot be converted to carbon dioxide in a single step (i.e. intermediates will be produced) and it is also known that certain oxygen-containing metabolites tend to be more toxic than the nonpolar parent compound. In addition to the added oxygen, which makes a molecule more reactive, the shortened chain length may also increase the toxicity in the case of the larger aliphatics. Moreover microorganisms could potentially produce higher levels of those metabolites that are particularly toxic to humans or environmental receptors because some microorganisms may have a higher tolerance for certain toxic compounds. In addition, polar metabolites could change exposure scenarios because of their different transport properties. For example, the water-solubilities of 1-hexanol (5,900 mg/L) and 2-hexanol (14,000 mg/L) are significantly greater than that of n-hexane (approximately 10 mg/L) and benzene (1,800 mg/L).

The elimination of polar metabolites through routine application of SGC would artificially and unreasonably lower the toxicity estimates for some sites with

biodegrading petroleum mixtures. Inclusion of polars provides some protection from their likely adverse effects by assuming that the toxicity of the metabolites present in a TPH sample is, on average, similar to that of the parent hydrocarbons. Even compounds with low toxicity can have adverse effects at high enough exposure levels (high concentrations). Moreover, the toxicity of biodegrading petroleum mixtures (hydrocarbons and polar metabolites) to aquatic receptors is of particular concern at release sites that are near the San Francisco Bay or other bodies of surface water. With respect to adverse effects on water quality, it should be noted that, while there are sparse data on the toxicity of polars, even fewer studies have investigated potential connections between odor or nuisance issues and polar metabolites at petroleum release sites. Therefore, routine addition of a SGC step to the analysis of samples from petroleum sites is not only largely unjustified, but also may not be adequately protective. The 1999 internal Regional Water Board memorandum on the subject is misleading and is not consistent the rationale presented here and with the Regional Water Board's practice. The 1999 memorandum is superseded by this User's Guide. Regional Water Board staff will evaluate petroleum sites that do not fall under the *Low-Threat Underground Storage Tank Case Closure Policy* (Section 1.2.1) on a case-by-case basis. At some sites, comparison of samples treated with SGC and duplicates analyzed without such treatment may yield useful information. However, if the intention is to present the analysis from a single set of data, the use of SGC should be discussed with the overseeing regulatory agency in advance of the sampling.

8.4.3 Cumulative Risk/Hazard and Risk Drivers at TPH Sites

Although the toxicity of the majority of compounds in TPH mixtures is poorly understood, cancer risks and non-cancer hazards have been identified for the few constituents that have been studied. Aliphatics tend to have non-cancer health effects, whereas the well-studied aromatics tend to have dominantly carcinogenic risks. Some compounds, such as benzene and ethylbenzene, contribute to both risk and hazard. The fraction approach described above focusses on the non-cancer hazards. Cancer hazards are typically evaluated through indicator compounds such as the BTEX carcinogens benzene and ethylbenzene, as well as naphthalene and other PAHs, for which carcinogenicity has been documented.

In contrast to the approach described above, the 2013 U.S. EPA RSLs provide screening levels for six TPH fractions. Some of these TPH RSLs are based on cancer risk and others on noncarcinogenic hazard. When evaluating the total risk and hazard posed by a petroleum release, care must be taken to include a reasonable estimate of the carcinogenic and noncarcinogenic effects of the TPH contamination in the total for each. In addition, the best (most protective; Section 8.4.2) estimate should be used when computing the cumulative risk or hazard. It is not appropriate to assume that the human health risk at all petroleum sites is always driven by individual aromatic compounds. Data collected in Hawaii (HDOH, 2012) show that TPH can drive the vapor intrusion risk in some instances.

8.4.4 Waste Oil Releases

At sites where releases of waste oils have occurred, it is prudent to test the soil and groundwater for chlorinated solvents, heavy metals, and PCBs. Because of the potential for chlorinated solvents, soil gas testing should also be considered. The testing program should be discussed with the overseeing regulatory agency.

8.4.5 Methane and Acute Hazards

Petroleum products, like crude oil and organic matter from various sources, can produce methane as a result of biodegradation under anaerobic conditions and in the presence of methanogenic microorganisms. Although not considered toxic, methane can present a hazard at release sites. The ESLs do not address acute hazards such as asphyxiation and fire and explosions. The DTSC Vapor Intrusion Guidance and the two U.S. EPA draft guidance documents on vapor intrusion (2013a and 2013b) address acute hazards, and the U.S. EPA guidance includes some information about methane.

9 Additional Considerations

9.1 Chemicals Not Listed In Lookup Tables

The lookup tables list more than 100 chemicals, representing those most commonly found at sites where releases of chemicals have occurred. ESLs for chemicals not listed in the lookup tables may be developed using available supporting information, including information presented in this User's Guide, and submitted to the overseeing regulatory agency for review.

9.2 Detection Limits and Reporting Limits

Method detection limits¹³ and laboratory reporting limits¹⁴ for individual chemicals were not directly considered in development of the lookup tables. In some cases, ESLs may be less than typical method detection limits. Examples include the risk-based ESLs for dioxin in soil. An evaluation of data quality objectives early in the investigation will help ensure that specific detection limits are appropriate for the project. 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.

9.3 Soil Data Reporting: Dry Weight Basis

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

¹³ The method detection limit is defined as the minimum concentration that can be measured and reported with 99 percent confidence that the concentration is greater than zero, but the exact concentration cannot be reliably quantified.

¹⁴ The laboratory reporting limit is the lowest amount of an analyte in a sample that can be quantitatively determined with stated, acceptable precision and accuracy. Typically the reporting limit is a multiple of the method detection limit.

9.4 Background Metal Concentrations

Concentrations of naturally occurring metals were not considered in development of the ESLs, but should be considered on a site by site basis. The natural background concentration of a chemical in soil or groundwater can vary substantially between sites, or even between soil types within a single site. Site-specific or regional background concentrations can be substituted for risk-based concentrations at sites where naturally occurring background concentrations exceed the ESLs. Background concentrations may be evaluated by collecting on-site samples, located upgradient of the suspected release, or by reference to local data collected from past studies. 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 for distinguishing concentrations of chemicals in soil and groundwater from background is provided in the Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities (DTSC, 1996c; DTSC, 1997).

Arsenic and chromium are often naturally present in Bay Area soils at concentrations above risk-based screening levels. Background concentrations of arsenic in Bay Area soils typically exceed the 0.39 mg/kg risk-based screening level for direct-exposure concerns (Duvergé, 2011). Alternative screening levels based on site-specific or regional established background levels may represent a more appropriate screening level in such instances. For sites where metals are known to be present due to site-related activities, cleanup levels may be based on a site-specific or region-specific determination of appropriate background. Cleanup of naturally-occurring chemicals to less than background concentrations is not generally required.

9.5 Degradation Products

Considering the degradation of a chemical (“parent compound”) to toxic breakdown products (“daughter products”) is an important part of site investigations. Examples include the breakdown of PCE to vinyl chloride via trichloroethylene (TCE) and *cis*-1,2-DCE, all of which are more toxic than the parent compound, and the breakdown of MtBE to TBA. Living organisms break

down organic molecules in several steps and the intermediates may be relatively toxic. The rates of formation of toxic metabolites and their degradation depend on the nature of the contamination and the site conditions (such as oxygen levels or the nature of resident microbial populations). In most cases, both the parent compound and daughter products are present together.

Some regulatory agencies incorporate an assumption that the parent chemical will be eventually be completely transformed to the daughter products (MADEP, 1994, MOE, 1996). Thus, they lower the initially derived screening levels for the parent compounds to account for the more toxic daughter products. The ESLs do not use this approach because complete degradation is not always observed. It is more appropriate to use the method discussed in Chapter 7 to evaluate the cumulative risk from the combination of compounds.

It should be pointed out that at some sites degradation of chlorinated solvents in groundwater is minimal, but concentrations of daughter products in soil gas may be greater. This emphasizes the need to collect soil gas data at sites where vapor intrusion is of potential concern.

9.6 Multiple Species of One Chemical

Some contaminants can be present in more than one chemical form in the environment or change from one form to another when site conditions change or when they partition between different media. In these cases, every attempt should be made to determine the concentration of the most toxic species for comparison to risk-based screening levels. In the case of cyanides, the ESLs are based on the most toxic form, HCN. For chromium, risk-based ESLs are calculated for chromium-3 and chromium-6. However, the MCL for chromium in drinking water is currently a MCL of 50 µg/L for total chromium, which is well above the risk-based level for the more toxic form, chromium-6. A change of the California MCL is being discussed, and testing for chromium-6 is recommended regardless of the current regulatory status.

9.7 Congeners

Congeners are compounds with similar structure such as the dioxins and dioxin-like compounds. They are usually found as part of complex mixtures in the

environment. To facilitate evaluation of sites contaminated with dioxins, toxic equivalents or TEQs have been developed. These factors allow for the conversion of concentrations of less toxic congeners so that they can be added to the concentration of the most toxic congener, in this case 2,3,7,8-TCDD or tetrachlorodibenzo[b,e][1,4]dioxin, the only congener for which ESLs are listed. TEQs for dioxins are listed in the DTSC *Human Health Risk Assessment Note 2* (DTSC, 2009).

9.8 Lead

Direct-exposure screening levels for lead are 80 mg/kg for residential land use and 320 mg/kg for commercial/industrial land use. These screening levels are based on the CHHSL (OEHHA, 2009), which is calculated as the concentration in soil that could result in an increase of 1 microgram per deciliter ($\mu\text{g}/\text{dL}$) in blood lead, irrespective of background exposures. The toxic endpoint is based on the relationship between blood-lead levels and cognitive ability, and an increase of 1 $\mu\text{g}/\text{dL}$ in blood lead is calculated as having no more than a 2.5 percent probability of decreasing intelligence quotient (IQ) by more than 1 point in a child or fetus at the 90th percentile of the blood lead distribution in the general population. DTSC provides the LeadSpread tool (DTSC, 2011c) for evaluation potential adverse health effects resulting from exposure to lead in the environment.

9.9 Arsenic Bioavailability

Arsenic can exist in multiple chemical forms which differ in their bioavailability. The ESLs do not distinguish between these forms and consider all arsenic fully bioavailable.

9.10 Age-Adjustment Factors

Exposure parameters and formulas for the calculation of human health risks may be modified to include age-adjustment factors as appropriate and as our understanding of likely scenarios and impacts evolves. Some of the residential ESLs are calculated using adjusted factors that divide the 30 years of a typical residential exposure into six years as a child and 24 years as an adult. The ESLs

do not currently include multiple age-adjustment factors for the early years (0 – 16 years of age). Equations that can account for multiple developmental stages can be found in the calculations for mutagens in the RSLs (U.S. EPA, 2013d).

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Appendix A

Index of ESL Lookup Tables

Index of ESL Lookup Tables

Tier 1 Table

Summary Tables

A	Shallow Soil (<3 m bgs), Groundwater is a Current or Potential Source of Drinking Water
B	Shallow Soil (<3 m bgs), Groundwater is not a Current or Potential Source of Drinking Water
C	Deep Soil (>3 m bgs), Water is a Current or Potential Source of Drinking Water
D	Deep Soil (>3 m bgs), Water is not a Current or Potential Source of Drinking Water
E	Shallow Soil Gas and Indoor Air
F	Surface Water

Detail Tables

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A-2	Shallow Soil Screening Levels (<3 m bgs) Commercial / Industrial Land Use (Potentially Contaminated Groundwater is a Current or Potential Drinking Water Resource)
B-1	Shallow Soil Screening Levels (<3 m bgs) Residential Land Use (Groundwater is not a Current or Potential Drinking Water Resource)
B-2	Shallow Soil Screening Levels (<3 m bgs) Commercial / Industrial Land Use (Groundwater is not a Current or Potential Drinking Water Resource)
C-1	Deep Soil Screening Levels (>3 m bgs) Residential Land Use (Groundwater is a Current or Potential Drinking Water Resource)
C-2	Deep Soil Screening Levels (>3 m bgs) Commercial / Industrial Land Use (Groundwater is a Current or Potential Drinking Water Resource)
D-1	Deep Soil Screening Levels (>3 m bgs) Residential Land Use (Groundwater is not a Current or Potential Drinking Water Resource)
D-2	Deep Soil Screening Levels (>3 m bgs) Commercial / Industrial Land Use (Groundwater is not a Current or Potential Drinking Water Resource)
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L	Target Organs and Chronic Health Effects

Appendix B

Manual Calculation of ESL for Soil Leaching to Groundwater

MANUAL CALCULATION OF ESL FOR SOIL LEACHING TO GROUNDWATER

(When Tier I ESL Input for soil type is set to “All Sand”)

Issue: Currently, for scenarios where the Tier I ESLs input toggle for soil type is set to “All Sand,” the soil leaching to groundwater ESL is not correctly calculated. This is because the Workbook selection process for the target groundwater screening level does not allow for selection from the All Sand soil type columns on Table E-1 for the vapor intrusion groundwater screening level.

Resolution: The resolution process includes manual selection of the target groundwater screening level, calculation the soil leaching to groundwater ESL, and manual review to determine the Final Soil ESL.

Background on Soil Leaching to Groundwater ESL Calculation: Soil screening levels for groundwater protection concerns are summarized in Detail Table G and Summary Tables A through D. These screening levels are intended to address potential leaching of chemicals from vadose-zone soils and subsequent impact to groundwater. The soil leaching ESLs are back- calculated based on target groundwater screening levels. Target groundwater screening levels are summarized in Detail Tables F-1a and F-1b.

The formula for calculating this ESL is presented in Section 6.5 of the User’s Guide. That formula is:

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

Where:

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

DAF = SESOIL-based dilution/attenuation factor;

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

Procedure:

1. Select the DAF for the target chemical from Detail Table G.

2. Select the lowest groundwater value for C_{gw} from (a) either Detail Table F-1a (Groundwater is a Drinking Water Resource) or Detail Table F-1b (Groundwater is Not a Drinking Water Resource) based on the drinking water resource Tier I ESL input and (b) Detail Table E-1 (based on appropriate soil type/land use Tier I ESL inputs).
3. Multiply DAF by C_{gw} by 0.001 mg/ μ g to convert units, as indicated above.
4. In the Workbook, review the Specific Concerns worksheet and re-evaluate the Final Soil ESL with the manually calculated soil leaching to groundwater ESL.

Appendix C

**Model Parameters for
Groundwater-to-Indoor Air ESLs:
Tables of Inputs and Copies of DataEnter Sheets for
Fine-Coarse Mix and All Sand Soil Types**

Appendix C Table 1
Parameters for Fine-Coarse Mix - Residential
GW-to-Indoor Air ESLs
U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

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

Appendix C Table 1
Parameters for Fine-Coarse Mix - Residential
GW-to-Indoor Air ESLs
U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
Soil-Bldg Pressure Differential (ΔP)	g/cm-s ²	40	DTSC VIG Table 3.
Enclosed Space Floor Length (L_B)	cm	1,000	U.S. EPA <i>User's Guide</i> , p. 54.
Enclosed Space Floor Width (W_B)	cm	1,000	U.S. EPA <i>User's Guide</i> , p. 54.
Enclosed Space Height (H_B)	cm	244	Slab-on-grade scenario. U.S. EPA <i>User's Guide</i> , p. 40.
Floor-Wall Seam Crack Width (w)	cm	0.1	U.S. EPA <i>User's Guide</i> , p. 55.
Indoor Air Exchange Rate (ER)	1/hour	0.5	DTSC VIG Table 3.
Average Vapor Flow Rate into Bldg (Q_{soil})	L/min	5	DTSC VIG Table 3.
Exposure Parameters			
Averaging Time for Carcinogens (AT_C)	yr	70	DTSC <i>Human Health Note 1</i> (DTSC, 2011).
Averaging Time for Noncarcinogens (AT_{NC})	yr	30	DTSC <i>Human Health Note 1</i> (DTSC, 2011).
Exposure Duration (ED)	yr	30	DTSC <i>Human Health Note 1</i> (DTSC, 2011).
Exposure Frequency (EF)	d/yr	350	DTSC <i>Human Health Note 1</i> (DTSC, 2011).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL <i>User's Guide</i>
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL <i>User's Guide</i>
Toxicity Factors - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
Chemical Properties - No change to the values used in the VLOOKUP.			

Abbreviations/Acronyms:

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

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

Appendix C Table 1
Parameters for Fine-Coarse Mix - Residential
GW-to-Indoor Air ESLs
U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
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g - gram.

L - liter.

min - minute.

s - second.

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

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

U.S. EPA - United States Environmental Protection Agency.

USEPA *User's Guide - User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (USEPA, 2004).

yr - year.

Note:

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

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U.S. EPA. 2004. *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* . February 22.

Appendix C Table 2
Parameters for All Sand - Residential
GW-to-Indoor Air ESLs

U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
Soil/Groundwater and Soil Layer Parameters			
Average Soil/Groundwater Temperature (T)	Celsius	15	From U.S. EPA <i>User's Guide</i> Figure 8.
Depth Below Grade to Bottom of Enclosed Floor (L_F)	cm	15	DTSC <i>VIG</i> Table 3.
Depth Below Grade to Water Table (L_{WT})	cm	300	All Sand model-specific.
Thickness of Soil Stratum A (h_A)	cm	300	All Sand model-specific.
Soil Type Used to Estimate Soil Vapor Permeability	na	Sand (S)	USDA SCS soil texture classification. See note (1).
Soil Stratum Directly Above Water Table	na	A	All Sand model-specific. The capillary fringe is 17 cm thick.
Stratum A SCS Soil Type	na	Sand (S)	All Sand model-specific.
Stratum A Soil Dry Bulk Density (ρ_b^A)	grams/cm ³	1.50	U.S. EPA (1996)
Stratum A Soil Total Porosity (n^A)	cm ³ /cm ³	0.43	U.S. EPA (1996)
Stratum A Soil Water-Filled Porosity (Θ_w^A)	cm ³ /cm ³	0.15	U.S. EPA (1996)
Building Parameters			
Enclosed Space Floor Thickness (L_{crack})	cm	15	Same as L_F (DTSC <i>VIG</i> Table 3)
Soil-Bldg Pressure Differential (ΔP)	g/cm-s ²	40	DTSC <i>VIG</i> Table 3.
Enclosed Space Floor Length (L_B)	cm	1,000	U.S. EPA <i>User's Guide</i> , p. 54.
Enclosed Space Floor Width (W_B)	cm	1,000	U.S. EPA <i>User's Guide</i> , p. 54.
Enclosed Space Height (H_B)	cm	244	Slab-on-grade scenario. U.S. EPA <i>User's Guide</i> , p. 40.
Floor-Wall Seam Crack Width (w)	cm	0.1	U.S. EPA <i>User's Guide</i> , p. 55.
Indoor Air Exchange Rate (ER)	1/hour	0.5	DTSC <i>VIG</i> Table 3.
Average Vapor Flow Rate into Bldg (Q_{soil})	L/min	5	DTSC <i>VIG</i> Table 3.

Appendix C Table 2
Parameters for All Sand - Residential
GW-to-Indoor Air ESLs
U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
Exposure Parameters			
Averaging Time for Carcinogens (AT _C)	yr	70	DTSC Human Health Note 1 (DTSC, 2011).
Averaging Time for Noncarcinogens (AT _{NC})	yr	30	DTSC Human Health Note 1 (DTSC, 2011).
Exposure Duration (ED)	yr	30	DTSC Human Health Note 1 (DTSC, 2011).
Exposure Frequency (EF)	d/yr	350	DTSC Human Health Note 1 (DTSC, 2011).
Target Risk for Carcinogens (TR)	unitless	1.0E-06	ESL User's Guide
Target Hazard Quotient for Noncarcinogens (THQ)	unitless	1	ESL User's Guide
Toxicity Factors - See Table J-2 of the ESL Workbook. Note that IUR in Table J-2 is the same as URF in the model.			
Chemical Properties - No change to the values used in the VLOOKUP.			

Abbreviations/Acronyms:

cm - centimeter.

d - day.

DTSC - California Department of Toxic Substances Control.

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

g - gram.

L - liter.

min - minute.

s - second.

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

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

U.S. EPA - United States Environmental Protection Agency.

USEPA *User's Guide* - *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (USEPA, 2004).

Appendix C Table 2
Parameters for All Sand - Residential
GW-to-Indoor Air ESLs
 U.S. EPA Vapor Intrusion Model, GW-ADV, February 2004

Parameter	Units	Value	Notes
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yr - year.

Note:

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

References:

- DTSC. 2011a. *Human Health Risk Assessment Health Note 1* . Office of Human and Ecological Risk (HERO). May 20.
- DTSC. 2011b. *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance)* . October.
- U.S. EPA. 1996. *Soil Screening Guidance: Technical Background Document* . EPA-540-R95-128. Washington, D.C. Office of Solid Waste and Emergency Response. May.
- U.S. EPA. 2004. *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* . February 22.

GW-ADV
Version 3.1; 02/04

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

FINE-COARSE MIX

YES

OR

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

YES

Reset to

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

ENTER
Initial groundwater conc., C_w ($\mu\text{g/L}$)

127184

Chemical
Tetrachloroethylene

MORE ↓

ENTER
Average soil/groundwater temperature, T_s ($^{\circ}\text{C}$)

ENTER
Depth below grade of enclosed space floor, L_f (cm)

ENTER
Depth below grade to water table, L_{WT} (cm)

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

ENTER
Soil stratum directly above water table, (Enter A, B, or C)

ENTER
SCS soil type directly above water table

ENTER
Soil stratum A SCS soil type (used to estimate soil vapor permeability)

OR

ENTER
User-defined stratum A soil vapor permeability, k_v (cm^2)

15

15

300

100

200

B

CL

S

MORE ↓

ENTER
Stratum A SCS soil type
Lookup Soil

ENTER
Stratum A soil dry bulk density, ρ_b^A (g/cm^3)

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

ENTER
Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)

ENTER
Stratum B SCS soil type
Lookup

ENTER
Stratum B soil dry bulk density, ρ_b^B (g/cm^3)

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

ENTER
Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)

ENTER
Stratum C SCS soil type
Lookup

ENTER
Stratum C soil dry bulk density, ρ_b^C (g/cm^3)

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

ENTER
Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)

S

1.50

0.430

0.15

CL

1.5

0.43

0.3

MORE ↓

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

ENTER
Soil-bldg. pressure differential, ΔP (g/cm-s^2)

ENTER
Enclosed space floor length, L_B (cm)

ENTER
Enclosed space floor width, W_B (cm)

ENTER
Enclosed space height, H_B (cm)

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

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

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

15

40

1000

1000

244

0.1

0.5

5

MORE ↓

ENTER
Averaging time for carcinogens, AT_C (yrs)

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

ENTER
Exposure duration, ED (yrs)

ENTER
Exposure frequency, EF (days/yr)

ENTER
Target risk for carcinogens, TR (unitless)

ENTER
Target hazard quotient for noncarcinogens, THQ (unitless)

70

30

30

350

1.0E-06

1

END

Used to calculate risk-based groundwater concentration.

DATA ENTRY SHEET

GW-ADV
Version 3.1; 02/04

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

ALL SAND

Reset to Defaults

YES

OR

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

YES

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_w ($\mu\text{g/L}$)	Chemical		ENTER Soil stratum directly above water table, (Enter A, B, or C)	ENTER SCS soil type directly above water table	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
127184		Tetrachloroethylene		A	S	S	
ENTER Average soil/ groundwater temperature, T_s ($^{\circ}\text{C}$)	ENTER Depth below grade to bottom of enclosed space floor, L_f (cm)	ENTER Depth below grade to water table, L_{WT} (cm)	ENTER Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)		
15	15	300	300				

MORE
↓

ENTER Stratum A SCS soil type Lookup Soil Parameters	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum B SCS soil type Lookup Soil Parameters	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum C SCS soil type Lookup Soil Parameters	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
S	1.50	0.430	0.15								

MORE
↓

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

MORE
↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

END

Used to calculate risk-based groundwater concentration.

Appendix D

Recommendations for Site-Specific Vapor Intrusion Models

RECOMMENDATIONS FOR SITE-SPECIFIC VAPOR INTRUSION MODELS

Regional Water Board staff frequently reviews reports that include the results of site-specific vapor intrusion model runs using the Johnson and Ettinger model (Johnson and Ettinger, 1991) as programmed into Microsoft Excel by U.S. EPA. For this document, the term U.S. EPA Vapor Intrusion Model will be used to refer to the Johnson and Ettinger model implementation by U.S. EPA in Microsoft Excel.

An overview of the U.S. EPA Vapor Intrusion Model is provided in the DTSC *Vapor Intrusion Guidance* Appendix D (DTSC, 2011d). Detailed information on the model is provided in the *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (User's Guide; U.S. EPA, 2004a) and the *Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model* (Johnson, 2002). For models/results submitted to our agency, we recommend that such reports include the following, to facilitate our review, and that sufficient technical justification be provided for variances.

Rationale for Modeling:

- **Model Version** – Typically, the versions of the US EPA Vapor Intrusion Model used are the screening version (SCR) or advanced version (ADV). The SCR version allows for only one soil layer whereas the ADV version allows for up to three soil layers and more input parameters. All versions are available from the U.S. EPA website vapor intrusion portal, but use of these models requires incorporation of default parameters from DTSC Vapor Intrusion Guidance Table 3 (DTSC, 2011d) and modification of the toxicity factors to match the ESLs (Table J-2). Screening level versions are available from DTSC website.
- **Modifications to the Spreadsheet/Model** – Modifications to the spreadsheet should be summarized and a copy of the Microsoft Excel Workbook included for checking purposes. The most common modification is re-programming to run multiple chemicals at one time and total the cumulative risk/hazard.

- **Chemicals of Potential Concern** – These typically include all volatile chemicals detected at the site. See the U.S. EPA User's Guide (U.S. EPA, 2004a) for a discussion of which chemicals are considered to be volatile.
- **Exposure Point Concentrations** – Typically, either the maximum concentrations are modeled or the model is run for each sample. If the site has enough samples and is sufficiently characterized, then use of a statistical average may be appropriate.
- **Soil Layer Design** – The rationale for the number, texture, and thickness of the soil layers and depth to groundwater used in the model should be presented and adequately supported. Note that the U.S. EPA Vapor Intrusion Model employs the U. S. Department of Agriculture (USDA), Soil Conservation Service (SCS) Soil Texture Classification system, which differs from the soil classification commonly used for soil logging in the environmental remediation industry (the Unified Soil Classification System). If site-specific soil samples are collected for geotechnical laboratory analysis, the online USDA soil texture calculator (<http://soils.usda.gov/technical/aids/investigations/texture/>) can be used to classify soils into the SCS system. Further information is presented in the U.S. EPA User's Guide (U.S. EPA, 2004a).
- **Building Parameters** – Default input values for these parameters are provided in the DTSC Vapor Intrusion Guidance Table 3 (DTSC, 2011d) and/or the U.S. EPA User's Guide (U.S. EPA, 2004a).
- **Exposure Parameters** – Default exposure factors are provided in the Direct Exposure Model Factors worksheet in the ESL workbook.
- **Toxicity Factors** – The model toxicity factors should be consistent with Table J-2 of the ESLs. Note that Table J-2 presents the RfC in units of ug/m³ versus mg/m³ in the VLOOKUP worksheet of the U.S. EPA Vapor Intrusion Model.

References

- DTSC. 2011d. *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Vapor Intrusion Guidance)*. October.
- Johnson, P. 2002. *Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model*. American Petroleum Institute, No. 17. May.
- U.S. EPA. 2004a. *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*. February 22.

Appendix E

Physical-Chemical Inputs for Volatile TPH Fractions

Physical-Chemical Inputs for the Volatile TPH Fractions

TPH fraction	Equivalent Carbon Range	Equivalent carbon midpoint	Diffusivity in Air D_a (cm ² /s)	Diffusivity in Water D_w (cm ² /s)	Henry's Law Constant H (atm-m ³ /mol)	Dimensionless Henry's Law constant H'	Soil-water partition coefficient Kd (cm ³ /g)
Aliphatics C5-C8	EC5 - EC8	6.5	8.0E-02	1.0E-05	1.3E+00	5.4E+01	3.0E+01
Aliphatics C9-C18	EC>8 - EC16	12.5	7.0E-02	1.0E-05	1.7E+00	7.1E+01	3.0E+01
Aromatics C6 to C8	EC6 - EC9	7.0	7.0E-02	1.0E-05	2.9E-02	1.2E+00	3.0E+01
Aromatics C9-C16	EC9 - EC<22	15.0	7.0E-02	1.0E-05	4.4E-04	1.8E-02	3.0E+01

These parameters are used in the calculation of Apparent Diffusivity (D_a), which is in turn needed to calculate the Volatilization Factor (VF).

For the D_a and VF equations and non-chemical-specific inputs, see U.S. EPA (2002) Supplemental Soil Guidance for Developing Soil Screening Levels for Superfund Sites

Equivalent carbon - see Gustafson et al. (1997)

D_a , D_w , and Koc values from MADEP (2002). For Koc, used the C11-C22 aromatics value.

Henry's Law Constant calculated using Equations 26 (aliphatics) or 27 (aromatics) (Gustafson, et al., 1997), at 25 degrees Celsius.