San Francisco Bay Regional Water Quality Control Board

Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region

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Acronyms and Abbreviations

ARAL	USEPA Accelerated Response Action Level
bgs	Below ground surface
CalEPA	California Environmental Protection Agency (includes the Air Resources Board; Department of Pesticide Regulation; Department of Resources Recycling and Recovery or CalRecycle; Department of Toxic Substances Control; Office of Environmental Health Hazard Assessment; and State Water Resources Control Board and Regional Water Quality Control Boards.
CAP	Corrective Action Plan
COPC	Chemical of potential concern
CSM	Conceptual Site Model (sometimes called Site Conceptual Model)
CVOC	Chlorinated volatile organic compound/chemical
DTSC	Department of Toxic Substances Control
DTSC-HERO	DTSC Health and Ecological Risk Office
EC	Engineering control
ESA	Environmental Site Assessment
ESL	Water Board Environmental Screening Level
FAQ	Frequently asked question
GWIA ESLs	Groundwater-to-indoor-air ESLs
HI	Hazard Index (sum of the hazard quotients or HQs for all chemicals with similar non-carcinogenic health effects and their exposure pathways)
HQ	Hazard Quotient (ratio of non-carcinogenic health effects of the exposure under consideration over the exposure at which no adverse effects have been observed; an HQ > 1 means that an adverse effect can occur but does not necessarily mean an adverse effect will occur)
HVAC	Heating, ventilation, and air conditioning
IC	Institutional control
Johnson & Ettinger	Johnson & Ettinger Model
Low-Threat Tool	Water Board Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites – Interim Final
MassDEP	Massachusetts Department of Environmental Protection
NA	Not applicable
NAVFAC	Naval Facilities Engineering Command

NPL	National Priorities List
PCE	Tetrachloroethene (also known as tetrachloroethylene or perchloroethylene)
ppb	Parts per billion
RAP	Remedial Action Plan
RfC	Inhalation Reference Concentration (non-carcinogens)
RfD	Oral Reference Dose (non-carcinogens)
RSL	USEPA Regional Screening Level
Soil Gas Advisory	CalEPA Advisory – Active Soil Gas Investigations
SWRCB	State Water Resources Control Board
TCE	Trichloroethene (also known as trichloroethylene)
URAL	USEPA Urgent Response Action Level
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	U.S. Environmental Protection Agency
VI	Vapor intrusion
VIG	DTSC Vapor Intrusion Guidance
VIM	Vapor intrusion mitigation
VIMA	DTSC Vapor Intrusion Mitigation Advisory
VOC	Volatile organic compound/chemical
Water Board	San Francisco Bay Regional Water Quality Control Board
$\mu g/m^3$	Micrograms per cubic meter
μg/L	Micrograms per liter

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Executive Summary

The purpose of the Interim Framework for Assessment of Vapor Intrusion at TCE-Contaminated Sites in the San Francisco Bay Region ("Framework") is to provide a set of guidelines for addressing vapor intrusion (VI) of trichloroethene (TCE) and other chlorinated volatile organic compounds from the subsurface to indoor air, at all sites under the oversight of the San Francisco Bay Regional Water Quality Control Board ("Water Board"). In other words, it is intended to complement professional judgment, not to replace it. Moreover, it is intended to complement related documents provided by the Water Board such as the 2013 Environmental Screening Levels (ESLs) and the 2009 Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites. It does not establish policy or regulation and is intended as guidance for Water Board staff. Water Board staff anticipates the need to periodically update the Framework as the science evolves and when the Department of Toxic Substances Control (DTSC) issues an update to its 2011 Vapor Intrusion Guidance, on which much of this guidance is based.

The following prompted the development of this Framework:

- Updated information regarding the TCE short-term toxicity, specifically an increased risk of fetal heart defects that was included as one of the non-cancer endpoints in the derivation of widely used chronic non-cancer toxicity factors.
- USEPA Region 9 TCE guidance ("Region 9 guidance") consisting of the December 3, 2013, letter also known as "South Bay Letter" together with the follow-up memorandum from July 9, 2014, which provide USEPA-recommended interim action levels (termed "accelerated response action levels" and "urgent response action levels") for TCE in indoor air and recommendations for indoor air sampling.
- Increased awareness of the uncertainties related to the collection and interpretation of data for VI investigations.
- A recent surge in building and redevelopment activities on or near contaminated sites in the Bay Area and a need to consider vapor intrusion mitigation (VIM) as an interim measure at sites where cleanup of the subsurface VOC vapor source is progressing slowly.

This Framework summarizes the Water Board's VI approach, explains background information on the toxicity criteria for evaluating cancer and non-cancer health effects of TCE, and presents guidelines for evaluating VI mitigation. Specific features are:

- A listing of CalEPA VI guidance (Section 2.a).
- A modified stepwise approach and expanded description of evaluating multiple lines of evidence based on the DTSC's 2011 vapor intrusion guidance (Section 3).

- Interim response action levels for TCE in indoor air and interim response actions designed to reduce indoor air TCE levels consistent with the USEPA Region 9 guidance (Section 4.b.i).
- Specific recommendations for mitigation of indoor air TCE threats (Section 4.b.ii).
- TCE trigger levels for soil gas and groundwater that prompt accelerated VI investigation when exceeded. Soil-gas trigger levels for TCE are based on the same default attenuation factors from DTSC that are used for the Water Board's ESLs. Groundwater trigger levels for TCE are derived by two models similar to those used for the groundwater-to-indoor air ESLs for TCE (Section 4.c).
- Guidelines for evaluating VIM systems and determining the appropriate level of regulatory agency oversight relative to 1) the VI threat and 2) a proposed mitigation system's intrinsic reliability (Section 5).
- Discussion of VI concerns for closed landfills (Section 6).
- Discussion of the six items in the South Bay Letter and modifications to the Water Board's VI approach (Attachment A).

1. Introduction

a. Scope and Purpose

This Framework addresses vapor intrusion concerns largely driven by recent discussions regarding the short-term toxicity of trichloroethene (TCE) and uncertainties associated with vapor intrusion (VI) investigations. It presents information intended for staff of the San Francisco Bay Regional Water Quality Control Board (Water Board) regarding the following VI issues:

1. Modifications to the Water Board VI approach in response to the USEPA Region 9 December 3, 2013, letter with specific guidelines for South Bay National Priorities List (NPL) sites under joint oversight (USEPA, 2013c).
2. Integration of two approaches to investigate and evaluate vapor intrusion: the stepwise approach, which starts with review of available information and subsurface investigation and then moves towards sampling indoor air if necessary, and multiple lines of evidence approach to data evaluation.
3. Explanation of the toxicological findings that gave rise to concerns about adverse health effects resulting from short-term (three weeks or less) exposure to TCE by inhalation of indoor air.
4. Evaluation criteria for proposed vapor intrusion mitigation (VIM) systems.

Recent research indicates that adequately evaluating vapor intrusion requires more comprehensive (and more costly) datasets than commonly used in the past due to concerns about the uncertainties resulting from the spatial and temporal variability in the data and potential short-term effects of TCE. As a result, these investigations are more resource-intensive both for responsible parties and Water Board staff. This Framework is designed considering reasonable balance between requiring sufficient and appropriate data to make timely, informed decisions, and the resource burdens to responsible parties, Water Board staff, and other stakeholders in doing so. Water Board staff will continue to focus resources towards those sites presenting the greatest threats.

This Framework primarily addresses VI for chlorinated volatile organic compounds (CVOCs, e.g., TCE) not petroleum hydrocarbons. There are significant differences between CVOC vapor intrusion and petroleum vapor intrusion. For CVOCs, biodegradation typically occurs under anaerobic conditions, which is generally slower than aerobic biodegradation. In contrast, petroleum hydrocarbons are aerobically degraded (oxidized) by nearly ubiquitous microbes in both the groundwater and the vadose zone. The concentrations of petroleum hydrocarbons can be decreased by several orders of magnitude over short vertical distances (SWRCB, 2012). The USEPA document *Petroleum Hydrocarbons and Chlorinated Solvents Differ in their Potential for Vapor Intrusion* (USEPA, 2012b) provides an excellent discussion of the differences in the vapor intrusion potential of CVOCs and petroleum hydrocarbons.

VI evaluation is a critical component of a regulatory case closure process. The Framework is consistent with the overall Water Board approach to site evaluation and closure for sites contaminated with CVOCs (e.g., TCE) as described in the *Assessment Tool for Closure of Low-Threat Chlorinated Solvent Sites – Interim Final* (Low-Threat Tool; Water Board, 2009).

While vapor intrusion is the focus of this Framework, the investigation and cleanup of TCE-contaminated groundwater for protection of drinking water resources remains a priority for the Water Board.

b. Disclaimers

This Framework is an interim document prepared by Water Board staff. It is not intended to establish policy or regulation. The information presented in this document is not a final Board action. Water Board staff reserves the right to change this information at any time without public notice. This document is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation in the State of California. Based on an analysis of site-specific circumstances, Water Board staff may decide to act at variance with the guidelines in this document.

2. Background

a. Vapor Transport in the Subsurface

Evaluation of vapor intrusion can be complex because there are many different factors that influence when or if VI will occur. Major technical aspects include the characteristics of the subsurface VOC vapor source (strength and location), vadose zone geology (soil type, stratum continuity), vadose zone hydrology (moisture content, depth to groundwater, capillary fringe thickness), vadose zone chemical and biological factors that determine the level of biodegradation, building (type and condition of slab, operation of the HVAC), and climate. An excellent discussion of the technical aspects of VI is USEPA *Conceptual Model Scenarios for the Vapor Intrusion Pathway* (USEPA, 2012a).

The transport of vapors in the vadose zone is dominated by diffusion with advection only occurring in the immediate vicinity of buildings or when there is a pressure gradient (e.g., landfills) (USEPA, 2012a). Diffusion occurs from areas of greater concentration to lower concentration. Air-phase diffusion is about 10,000-times greater than water-phase diffusion. Vapor-phase diffusion in the subsurface varies with total porosity and moisture content (i.e., how much of that total porosity is water filled). McAlary (2009) showed:

> "For a given compound, the effective vapor-phase diffusion coefficient in gravel with 32.5% total porosity, 10% water-filled porosity, and 22.5% air-filled porosity is only 3.5 times higher than the diffusion coefficient in clay with 50% total porosity, 30% water-filled porosity, and 20% air-filled porosity, even though the permeability of the clay may be a million times lower."

Where the VOC vapor source is groundwater, the capillary fringe can significantly influence the attenuation of vapors. USEPA (2012a) provides a useful description of how the capillary fringe functions for vapor transport:

> "The capillary fringe is a zone immediately above the water table that acts like a sponge sucking water up from the underlying groundwater. At the base of the capillary fringe, most of the soil pores are completely filled with water. Above this zone, water content

decreases with increasing distance above the water table. The grain size of the soil particles influences the height of the capillary fringe: fine-grained soils exert greater suction on the groundwater table, resulting in a thicker capillary fringe that may be irregular across the upper surface, while coarse-grained soils exert less suction, resulting in a thinner capillary fringe that tends to be flatter along the top. The capillary fringe may reduce the emission of vapors from a dissolved groundwater source because its elevated water content limits the vapor migration (VOCs migrate much more slowly through water than through air)."

b. CalEPA Vapor Intrusion Guidance

For evaluation of the VI pathway (VI evaluation), in addition to the *Environmental Screening Levels* (ESLs; Water Board, 2013a and 2013b), the Water Board utilizes the four guidance documents issued by the Department of Toxic Substances Control (DTSC) or the California Environmental Protection Agency (CalEPA) that address VI sampling, evaluation, mitigation, remediation, and public participation. These documents and a summary of their content are listed below:

- *Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air* (Vapor Intrusion Guidance or VIG) (DTSC, 2011a) – The VIG presents the overall approach to VI evaluation, which includes 11 steps, and multiple lines of evidence. The document also includes sampling methodology for indoor air and subslab soil gas probe installation as well as site-specific inputs for Johnson & Ettinger modeling.
- *Final Vapor Intrusion Mitigation Advisory, Revision 1* (VIMA) (DTSC, 2011b) – The VIMA addresses all aspects of VIM system design and implementation.
- *Advisory – Active Soil Gas Investigations* (Soil Gas Advisory) (CalEPA, 2012) – The Soil Gas Advisory addresses sampling of soil gas by active removal of vapor and laboratory analysis.
- *Final Vapor Intrusion Public Participation Advisory* (VIPPA) (DTSC, 2012) – The VIPPA addresses public participation aspects specifically for VI issues such as public perceptions and concerns, risk communication, and other issues (e.g., privacy).

c. USEPA Region 9 Guidance and Changes to the Water Board VI Approach

On December 3, 2013, USEPA Region 9 issued a letter ("South Bay Letter"; USEPA, 2013c) to the Water Board that provides guidelines and supplemental information for VI evaluations at nine South Bay Superfund or NPL sites with subsurface TCE and PCE contamination that the Water Board oversees. The South Bay Letter includes an attachment with the guidelines and supplemental information for six specific items. Attachment A includes a discussion of the six items and adjustments to the Water Board VI approach in response to the South Bay Letter.

In response to the USEPA's South Bay Letter and subsequent discussions, the following two key changes have been incorporated into this Framework:

- TCE Action Levels for Indoor Air – As discussed in Section 4, Water Board staff now provisionally incorporates the USEPA Indoor Air TCE Action Levels to determine when interim response actions (mitigation measures) are warranted;

- Indoor Air Sampling with HVAC-Off as well as HVAC-On – The previous Water Board approach only included HVAC-On indoor air sampling. Water Board staff now incorporates HVAC-Off indoor air sampling to assess building susceptibility to soil gas entry and whether the HVAC system is providing a level of mitigation.

3. Integrating the Stepwise Approach with Multiple Lines of Evidence

The stepwise approach is described in the DTSC VIG and refers to a process of site investigation that begins with 1) assembling available information regarding the release, contaminant transport and potential exposure pathways, 2) conducting subsurface sampling, and 3) progressing towards evaluating the building and indoor air, if necessary. At the same time, evaluating multiple lines of evidence means considering more than one type of information (Table 1) before making decisions about a potential VI threat.

The following sections (3a – d) present the Water Board's approach to evaluating vapor intrusion threats. It includes a modified stepwise approach, a description of multiple lines of evidence that is expanded from the VIG (Step 2, p. 4), a summary of the key data lines of evidence, and some special considerations.

a. Modified Stepwise Approach to Vapor Intrusion Evaluation

The 11 steps in the stepwise approach generally proceed from the subsurface source toward the indoor receptor:

- Steps 1 through 5 consist of a subsurface investigation (site history, geology/hydrogeology, utility corridor assessment, and extent of contaminants defined by sampling soil, soil gas, and groundwater), and development of a conceptual site model (CSM);
- Steps 6 and 7 describe a building envelope[1] investigation and include subslab soil gas sampling, crawl space air sampling, and site-specific modeling (e.g., Johnson & Ettinger model).
- Steps 8 through 10 are focused on the indoor air investigation, including work plan development, building survey for potential indoor air sources, and indoor air and ambient air sampling during at least two rounds of sampling to determine seasonal variations. Pathway sampling (likely locations for subsurface vapor entry such as sumps, floor drains, elevator shafts or stairwells) is included during this process. Indoor air sampling for all chemicals of potential concern (COPCs) is conducted at the appropriate point during implementation of the stepwise approach or if the appropriate media-specific Water Board Trigger Level for TCE is exceeded (Section 4).
- Step 11 addresses subsurface remediation, building mitigation, institutional controls and long-term monitoring.

A modified stepwise approach is presented in Table 1 and Figure 1 that incorporates the TCE Trigger Levels (discussed in Section 4.c) used to prioritize indoor air sampling.

[1] Building envelope = ground surface/building interface.

Table 1 – Modified Stepwise Approach for Vapor Intrusion Evaluations		
	Steps in the VIG	**Description**
Subsurface Investigation and Conceptual Site Model Development	Step 1 – Identify all spills and releases	Review site history records to identify known or suspected areas of VOC use.
	Step 2 – Characterize the site	Define the lateral and vertical extent of VOCs in soil, soil gas and groundwater to locate the subsurface VOC vapor source. Characterize site geology, potential preferential pathways, and building susceptibility.
	Step 3 – Evaluate whether there is a complete exposure pathway	If the pathway is complete (i.e., there is a subsurface VOC vapor source and buildings are present above the contamination, within 100 feet of the source), develop public participation plan and begin public notification.
	Step 4 (existing building) – Determine if there is an imminent hazard	If appropriate, inspect the building and talk to occupants to determine if there are imminent hazards. Imminent hazards include noticeable odors and potentially explosive conditions (e.g., gasoline, methane) or other conditions that can be detected without instrumentation or laboratory analyses.
	Step 5 – Perform screening evaluation using default attenuation factors	Compare all data to appropriate VI ESLs and TCE Trigger Levels (Section 4). If the site fails the ESL screening evaluation, options include proceeding stepwise to a more detailed, site-specific evaluation (Steps 6 and 7) or skipping to later steps (indoor air sampling, Steps 8 through 10; or remediation and/or mitigation, Step 11). If the site fails the TCE Trigger Level evaluation, then indoor air sampling (Steps 8 through 10) should be conducted while site investigation and cleanup activities continue.
Building Envelope Investigation and Modeling	Step 6 – If site fails Step 5, collect additional site data	Collect and evaluate: (1) soil samples for physical properties (for inputs to a site-specific Johnson & Ettinger model); (2) subslab soil gas samples; or (3) crawl space air samples.
	Step 7 – Site-specific screening evaluation (modeling)	Use a Johnson & Ettinger model to derive site-specific attenuation factors. If the site fails Step 7, proceed to indoor air sampling (Steps 8 through 10) or skip to remediation and mitigation (Step 11).
Indoor Air Investigation	Step 8 (existing building) – Indoor Air Sampling Part 1: building survey, indoor air sampling work plan, contingency plan, notification	Plan indoor air sampling: 1) survey the building to identify potential vapor entry points (see Building Susceptibility in Section 3.d.ii) and sources (e.g., household products or building materials) that could confound indoor air sampling results; 2) prepare a detailed plan for indoor and outdoor air sampling (e.g., locations, methods, etc.), laboratory analytical methods and reporting limits; 3) develop a contingency plan should results indicate significant threat; and 4) prepare public notification.
	Step 9 (existing building) – Indoor Air Sampling Part 2: perform indoor air sampling	Indoor and outdoor air sampling is performed over a minimum of two seasons to include cold weather sampling. See the VIG for duration, number of sampling events, number of samples, locations, equipment, and analytes. The collection of pathway samples (likely locations for subsurface vapor entry like drains, utilities, sumps, etc.) is also discussed.
	Step 10 (existing building) – Indoor Air Sampling Part 3: Evaluate the data	Promptly interpret all data, weigh lines of evidence, characterize the risks, and evaluate risk management decisions. Prepare post-sampling public notification, giving consideration to privacy concerns.
Building Mitigation and Subsurface Remediation	Step 11a (existing building) – If site fails Step 10, conduct remediation and/or mitigation as appropriate	If there is significant current risk, implement VIM in accordance with the contingency plan. Remediate the subsurface vapor source until it no longer poses a significant threat. VIM systems are not considered a means of remediating subsurface vapor source areas.
	Step 11b (no buildings/ future construction) – Remediate contamination or implement ICs	Remediate subsurface vapor source. If this is not feasible (e.g., accessibility), then engineering controls and (ICs; e.g., land use covenant) can be used to control exposure. When new construction is proposed, remediation and/or mitigation will be required.
	Step 11c (all sites) – Institute long-term monitoring.	Evaluate the need for long-term monitoring and amount of regulatory oversight for sites with VIM systems.

b. Evaluating Multiple Lines of Evidence

Evaluation of the VI pathway is complex because there are subsurface factors as well as building and climate factors affecting the extent to which contaminant vapors move from subsurface into overlying buildings. There is considerable uncertainty associated with individual lines of evidence resulting from the spatial and temporal variability of volatile contaminant concentrations in groundwater, soil gas (including subslab soil gas), and indoor air (Holton et al. 2013; Winkler et al. 2001). Multiple lines of evidence are used to reduce these uncertainties and increase confidence in making site management decisions regarding VI.

The following considerations are intended to supplement the VIG and provide the basic principles for evaluating lines of evidence:

- **Developing and Maintaining the CSM** – The lines of evidence should be evaluated in light of the CSM, and the CSM should be revised as lines of evidence are added or conflicting lines of evidence are resolved.

- **Weighting Based on Proximity of Sampled Medium to the Receptor** – Typically, the closer the sampled medium is to the receptor, the greater those data are weighted. However, the data may also be weighted on quality and representativeness of samples or other factors.

- **Minimum Number of Data Lines of Evidence** – Reliance on a single data line of evidence generally is not considered adequate. In general, Water Board staff requires two data lines of evidence that are in agreement as the minimum number of data lines of evidence necessary for a complete VI evaluation. In situations where the data lines of evidence are not clearly in agreement, then adding another data line of evidence, continued temporal monitoring to better resolve a data line of evidence, or increasing data density is advised.

  In some circumstances, a single data line of evidence may be sufficient if supported by a robust CSM. One example is an offsite area where groundwater is the only subsurface VOC vapor source, the extent of VOCs in groundwater are adequately defined laterally and vertically, concentration trends are stable or decreasing, depth to groundwater is greater than 10 feet bgs such that there is a reduced likelihood of existing or future preferential pathways, and relevant ESLs are met. In such a case, Water Board staff would rely on direct comparison of contaminant concentrations in groundwater to the groundwater-to-indoor-air ESLs (GWIA ESLs).

- **Characteristics of Primary Data Lines of Evidence** – Each data line of evidence should be weighed based on an understanding of its limitations. For instance, soil gas concentrations typically show considerable spatial and temporal variability. Therefore, reliance on a few soil gas samples from a single sampling event would introduce significant uncertainty into a site management decision.

- **Special Considerations** – There are factors that need to be evaluated as part of every vapor intrusion evaluation including proximity to the subsurface VOC vapor source and potential preferential pathways and building susceptibility. In addition, for situations where modeling is incorporated into the evaluation, there are several aspects that need to be addressed to enable the Water Board to properly weight the modeling results as a line of evidence.

Potential lines of evidence considered by Water Board staff are listed in Table 2. The lines are not in any particular order and should not be assumed to carry equal weight.

Table 2 – Lines of Evidence for Vapor Intrusion Evaluations*

Line of Evidence	Reference for Further Information
Sources	ESL User's Guide Section 1.3 (Conceptual Site Models)
Release mechanisms	
Site history	
Routes of fate and transport	
Preferential pathways	
Potential receptors and exposure pathways	
Groundwater data	VIG, Step 5 (p. 17)
Soil gas data	Soil Gas Advisory and VIG, Step 5 (p. 17)
Subslab soil gas data	VIG, Step 6 (p. 21) and Appendix G
Passive soil gas data	VIG, p. Step 2 (p. 12) and Soil Gas Advisory Appendix A
Soil matrix data	VIG, Step 5 (p. 17) and Appendix E
Crawl space air data	VIG, Step 6 (p. 22)
Indoor air data	VIG, Steps 8 through 10, (p. 25); and Appendices K, L, and M
Outdoor (ambient) air data	VIG, Step 9 (p. 31)
Radon data	VIG, Step 7 (p. 24) and Step 9 (p. 34), NAVFAC
Building construction/susceptibility	VIG, Step 8 (p. 25)
Spatial and temporal variability of data	VIG, Step 2 (p. 6); Step 5 (p. 18); Step 6 (p. 22); and Step 8 (p. 26).
Comparison of constituent ratios between different media (e.g., soil gas versus indoor air)	VIG, Step 10 (p. 34)
Site-specific fate and transport modeling (e.g., Johnson & Ettinger model)	VIG, Step 7 (p. 22) and Appendix D; and ESL User's Guide Appendix D
Portable GC/MS for real-time sampling	VIG Step 8 (p. 27), NAVFAC (2013)
Building pressure control	NAVFAC (2013)
Compound-specific isotope analysis	VIG Step 10 (p. 34), NAVFAC (2013)

Note: *Lines of evidence do not have equal weight and are listed in no particular order.

c. Primary Data Lines of Evidence

i. Groundwater

Groundwater samples for vapor intrusion evaluations should be collected in accordance with the recommendations in the VIG. The default GWIA ESLs are based on a Johnson & Ettinger model with soil layer and parameter inputs referred to as the Fine-Coarse Scenario to match an empirically-derived attenuation factor (ESL User's Guide Section 6.3). This model is considered protective at depths at or below 10 feet bgs when other criteria are met. At shallower depths, the Fine-Coarse Scenario-derived GWIA ESLs should not be used.

Shallow groundwater raises several questions regarding the applicability of available models and screening levels. In extreme cases, fluctuations in already shallow groundwater may lead to contact with the slab. Options for sites where groundwater is shallower than 10 feet bgs, are, in order of preference: 1) develop an additional line of evidence (e.g., soil gas if there is sufficient vadose zone or proceed to indoor air sampling); 2) use the Sand Scenario-derived ESLs (ESL Detail Table E-1); or 3) develop a site-specific Johnson & Ettinger model. The latter may not be appropriate for all site conditions.

ii. Soil Gas

Soil gas samples should be collected in accordance with the Soil Gas Advisory (CalEPA, 2012) or other technically equivalent methods (e.g., for fine-grained soils, see McAlary, 2009). Water Board staff considers the soil gas line of evidence (i.e., direct measurement of vapor concentrations) as critical to most vapor intrusion evaluations, provided that the soil gas line of evidence is developed as discussed below.

There are two primary objectives for soil gas sampling: 1) assessing whether the subsurface VOC vapor source is vadose zone soil and/or groundwater; and 2) collecting appropriate near-source soil gas data for comparison to soil gas ESLs (evaluation of VI potential).

Vertical soil gas sampling is used to locate the VOC vapor source, ideally with numerous vertical profiles of soil gas (CalEPA, 2012). After the VOC vapor source is located, then additional soil gas sampling can be focused close to the source to collect data that can be used for comparison against soil gas ESLs or evaluated with a site-specific Johnson & Ettinger model. Different vertical soil gas concentration profiles develop in areas where there is ground cover (e.g., building foundations and pavement) versus uncovered areas (see Step 2 of the VIG and Section 4 of the USEPA *Conceptual Model Scenarios for the Vapor Intrusion Pathway,* (USEPA, 2012a). Near-source soil gas data are considered to better represent soil gas concentrations near the foundation of a structure than soil gas samples collected at shallow depths outside a building footprint. The VIG cautions against the use of shallow soil gas data where those data are not collected immediately above the contaminant source because they likely are biased low.

For most sites, soil gas concentrations should be monitored over time to establish trends (i.e., there is uncertainty with reliance on a single soil gas sampling event) because of temporal fluctuations of soil gas concentrations.

iii. Subslab Soil Gas

Subslab soil gas samples should be collected in accordance with the VIG. Subslab soil gas data are useful in assessing vapor concentrations closest to the building and are recommended to be collected concurrently with indoor air data to help determine whether TCE detected in indoor air is from VI or some other source (e.g., indoor TCE source or outdoor air). A sufficient number and distribution of samples should be collected recognizing that subslab soil gas concentrations typically spatially vary one or more orders of magnitude beneath the slab (Luo et al., 2009). Reliance on subslab soil gas data alone is not acceptable because bi-directional flow across the slab is possible such that in some situations subslab vapors may originate from indoor air rather than the subsurface (McHugh et al., 2006).

The Water Board does not utilize the VIG default subslab attenuation factor (0.05) because it was derived using the USEPA Vapor Intrusion Database, and significant validity concerns have been identified regarding whether it is possible to derive subslab to indoor air attenuation factors given the extreme temporal and spatial variability of both indoor air data and subslab soil gas data (Song et al., 2011; Song et al., 2014; Yao et al., 2013; Holton et al., 2013). Until the Water Board selects a default subslab attenuation factor, Water Board staff recommends collecting subslab soil gas samples concurrently with indoor air samples as discussed above.

iv. Crawl Space Air

Crawl space air samples (air in the area of a raised foundation) should be collected in general accordance with VIG methods for indoor air sampling. Samples should be collected towards the center of the building footprint where the potential threat is greatest, particularly for enclosed crawl spaces, as well as potentially near the edge of the building. The Water Board uses the VIG default crawlspace attenuation factor of 1.0 (i.e., no attenuation) to evaluate crawlspace air data. Crawl space air data may be less affected by consumer products and potentially less challenging to interpret, than indoor air.

v. Indoor Air

Indoor air and ambient air samples should be collected in accordance with the VIG. The process of indoor air sampling can be complex because it involves a building survey to identify potential confounding factors (e.g., indoor sources), multiple rounds of indoor air sampling due to significant temporal variability, concurrent ambient air sampling, potentially concurrent subslab soil gas sampling, and weighing these lines of evidence to interpret the indoor air results.

In the normal progression of the stepwise approach, Water Board staff does not recommend skipping ahead to indoor air sampling unless the TCE Trigger Levels are exceeded (Section 4) or there are other limitations (e.g., groundwater is so shallow that soil gas sampling is not possible).

Indoor air typically contains detectable levels of VOCs (USEPA, 2011a) and likely will require assessing the source of the detections (e.g., consumer products, building materials, ambient air, intruding subsurface vapors, or a combination thereof). One of the simplest techniques to distinguish between sources is comparing chemical constituent ratios detected in indoor air and subsurface media (e.g., soil gas). The U.S. Department of Health & Human Services maintains the Household Products Database,[2] which can be searched for individual chemical ingredients (e.g., TCE).

For some situations, pathway sampling and other specialized techniques may be necessary to fully assess whether the sources of the detections are ambient air, indoor air sources (e.g., consumer products or building materials), intruding subsurface vapors, or some combination thereof. Some of the specialized techniques include a portable gas chromatograph with mass spectrometer (GC/MS) for real-time sampling (considered to be one of the most reliable tools to identify and locate indoor sources), building pressure control, and compound-specific isotope analysis. The Naval Facilities Engineering Compound (NAVFAC) *Innovative Vapor Intrusion Site Characterization Methods Fact Sheet* (NAVFAC, 2013) provides an excellent introduction on these and other techniques.

d. Special Considerations

i. Proximity to Subsurface Vapor Source

The character of VI evaluations varies depending on site location relative to the subsurface vapor source. Near the original release for instance, the expectation is that VOC vapors are diffusing from contaminated vadose zone soil as well as from contaminated groundwater. All else being equal, the vapor flux from vadose zone soil is expected to be greater than groundwater because substantial contaminant mass may remain in source area soils and the capillary fringe, which has a low air-filled porosity (i.e., significant moisture content), will suppress vapor diffusion from groundwater. In this situation, both soil gas and groundwater data are necessary to evaluate VI.

Away from the release location, the vapor source will primarily be contaminated groundwater. In the central portion of the plume, due to fluctuations in groundwater levels, there may be some contamination of the vadose zone over the zone of fluctuation. In the distal portions of the plume, there may be clean groundwater overlying the plume due to recharge or downward migration of the plume. This clean groundwater will further reduce vapor flux because diffusion through liquids is much slower than through gases.

ii. Preferential Pathways and Building Susceptibility

The identification of preferential pathways and evaluation of building susceptibility is critical for any VI CSM because some site conditions can allow contaminated vapors to be transported into a building with little or no attenuation. Consequently, they represent additional lines of evidence. For sites with significant preferential pathways or building susceptibility, sampling of indoor air likely will be necessary, and subsurface data lines of evidence may be weighted much less in the overall evaluation.

The term preferential pathway is used to describe a manmade or natural pathway that provides a route of least resistance for transport of contaminated liquid or vapor. Examples of manmade

[2] http://hpd.nlm.nih.gov/index.htm.

preferential pathways include utility pipelines (e.g., storm or sanitary sewers), utility backfill (e.g., coarse porous and permeable materials), dry wells, improperly destroyed wells, large filled areas (e.g., former excavations), and foundation sub-base. Examples of natural pathways include vertical fractures in clay soils, bedding planes, sand and gravel channels, and fault and fracture zones.

Building susceptibility refers to building physical or operational features that may allow for vapors to intrude. These include, but are not limited to: cracks (holes or gaps), subgrade structures, floor drains, utility vaults or pits, sumps, elevator shafts (and pits for the pistons), basements, crawl spaces, modifications to the original foundation (e.g., repairs), staining or seeps (wet foundations). Characteristics of the HVAC system operation also are important (e.g., zones of mechanical influence, non-uniform over-pressurization). In addition, exhaust fans and furnaces can induce local pressure gradients that encourage VI. Review of site geology information, utility maps, building designs, and conducting building inspections to identify these features are an important part of VI evaluations.

iii. Use of Site-Specific Johnson & Ettinger Models

The Water Board regularly receives reports in which VI risks from contaminated groundwater or soil gas are evaluated using a Johnson & Ettinger Model (several versions are available from USEPA and DTSC[3]) with site-specific inputs. These models usually are employed when the groundwater or soil gas concentrations exceed the default ESLs which incorporate default attenuation factors that are often considered too conservative by responsible parties. The site-specific model runs in the reports reviewed thus far have invariably indicated much greater attenuation (smaller attenuation factor) which in turn supported an argument that these concentrations do not pose unacceptable risk. When such a model is based on adequate site-specific geotechnical soil parameters and includes an uncertainty parameter analysis, and is consistent with VIG Appendix D (Overview of the Johnson and Ettinger Model) and *ESL User's Guide* Appendix D (Recommendations for Site-Specific Vapor Intrusion Models) such a model may be considered as an additional line of evidence. Otherwise, models may only be partially weighted when considered together with other lines of evidence. Solutions to shortcomings commonly encountered with the reports that present the results of site-specific VI models include the following:

- **Evaluate site conditions against model assumptions** – The model assumptions are listed in the *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (Johnson & Ettinger User's Guide; USEPA, 2004). Key model assumptions are: 1) homogeneous soil properties in the horizontal plane; and 2) capillary fringe devoid of contamination. Site conditions, which typically are heterogeneous, should be evaluated against these assumptions.
- **Provide justification for the model soil layer design** – Reports documenting VI models should present the site geology and hydrogeology (e.g., depth to groundwater

[3] Water Board staff recommends the most recent (March 2014) DTSC-HERO SG-SCR and GW-SCR (one-layer) versions of the model, because HERO maintains the models (California toxicity factors, DTSC-recommended inputs, and chemical properties). Alternatively, the USEPA 2004 SG-ADV and GW-ADV (3-layer) versions can be used, but the model parameters will need to be updated.

and range of fluctuation) and provide a basis or correlation with the soil layers used in the models. Cross sections should be provided to visually depict the site geology and boring logs so that the cross sections can be checked.

- **Characterize model soil types and physical parameters by direct measurement (geotechnical laboratory analysis)** – Water Board staff supports the VIG statement that estimating soil physical properties from a visual description of subsurface soil, as annotated onto a boring log, is not an appropriate approach for the selection of model input parameters. Instead, to reduce uncertainty, direct measurement is recommended by the collection of at least three soil samples from each layer for analysis of grain size, moisture content, and other physical properties. These samples should be collected at lateral and vertical locations consistent with the subsurface VOC vapor source and the receptor being evaluated. Due to model sensitivity to soil moisture, consideration should be given to seasonal soil moisture fluctuations as well as spatial differences. For instance, soil beneath a large building or pavement may have less soil moisture than at an unpaved site. Preference should be given to soil sampling techniques that minimally disturb the soil core (e.g., Shelby tube), otherwise the sampling technique may compress the soil sample, thus increasing the bulk density and decreasing soil porosity. Soil physical property testing methods are listed in the VIG Appendix H (Soil Laboratory Measurements). The following aspects of the soil layer classification and physical parameters should be addressed in VI modeling reports.
    - Soil layer classification – The Johnson & Ettinger model uses the Soil Conservation Service (now US Department of Agriculture) Soil Texture Classification system, which differs from the Unified Soil Classification System commonly employed in the environmental remediation industry. Care should be taken that the grain size analysis results (i.e., soil texture) are classified using the same system as the model.
    - Soil physical parameters – Soil physical parameters as named in the Johnson & Ettinger model are dry bulk density, total porosity, and water-filled porosity (commonly referred to as soil moisture). The VIG recommends using the results that yield the most conservative output as inputs to the model.
- **Include an uncertainty and sensitivity analysis** – Even under optimal conditions, the Johnson & Ettinger model is generally considered to have a precision no greater than an order of magnitude (Weaver and Tillman, 2005; DTSC, 2011a). The uncertainty is due to the fact that few of the inputs are actually measured. Also, the Johnson & Ettinger modeling reports that the Water Board staff receives rarely, if ever, include calibrated site-specific data (i.e., indoor air measurements) that demonstrate the model's predictive capability. Therefore, running the model with order-of-magnitude variations of key parameters both individually and together helps decision makers by providing a range of outputs. Typically, key parameters include soil moisture (soil water-filled porosity in the model) and for groundwater models, the depth to groundwater and capillary fringe thickness. Further information is provided in the *ESL User's Guide* (Appendix D - Recommendations for Site-Specific Vapor Intrusion Models).

4. TCE Toxicity and Implications for Vapor Intrusion Approach

TCE can be present at a variety of sites. Significant releases to the environment are commonly associated with these historic uses:

- Industrial solvent (e.g., circuit board manufacturing, plating facilities).

- Metal parts cleaner (e.g., auto repair facilities with waste oil tanks).
- Degradation product of tetrachloroethene (PCE) (e.g., common dry-cleaning solvent) (Section 4.d).

As of 2011, the amount of TCE used in the United States is 255 million pounds per year and the primary purposes are: 1) an intermediate for manufacturing the refrigerant (closed system) HFC-134a (about 84%); and 2) as a solvent for metals degreasing (about 15%) (USEPA, 2014b). TCE is found in some products in homes and office settings (US Department of Human & Health Services, Household Products Database, accessed September 22, 2014).

a. 2011 Changes to TCE Toxicity Criteria

Adverse health effects are evaluated by comparison to toxicity criteria set by federal or state agencies. Typically, these criteria are based on chronic effects and they are used for risk assessments, cleanup levels and screening levels. On September 28, 2011, the USEPA Integrated Risk Information System (IRIS) published new toxicity criteria for TCE (USEPA, 2011b). The most significant changes included a substantial reduction in the numbers for non-cancer inhalation toxicity factors and a change in the non-cancer toxicity endpoints (adverse effects on specific parts or functions of the human body).

The new toxicity factors have been widely accepted by regulators in California and other states for use in risk assessments, cleanup levels and screening levels, and they were incorporated into the 2013 ESLs. While changes in the TCE ESLs for cancer effects were small, changes in the magnitude of the non-cancer numbers were substantial (Table 3). For residential indoor air based on *non-cancer effects*, the 2008 ESL was 130 micrograms per cubic meter (μg/m^3), but is now 2.1 μg/m^3. At the same time, the residential indoor air ESL based on *cancer effects* is 0.59 μg/m^3, which is still about 3.5-times lower than the ESL based on non-cancer effects. The changes in indoor air residential ESLs between 2008 and 2013 are presented in Table 3.

Table 3 – Comparison of 2008 versus 2013 Residential Indoor Air ESLs for TCE

Basis	2008 Indoor Air ESL (μg/m^3)	2013 Indoor Air ESL (μg/m^3)	Ratio (2013/2008)
Cancer	1.2	0.59*	0.49
Non-Cancer	130	2.1	0.02
Most Conservative	1.2	0.59	not applicable

Note:
* - The 2013 Residential Indoor Air Cancer ESL for TCE differs from the corresponding USEPA Residential Indoor Air Cancer RSL for TCE. The RSL uses a different formula for TCE to account for a mutagenic mechanism, whereas the ESLs use the standard formula for the cancer endpoint.

Adverse non-cancer health effects documented for TCE include hepatic, renal, neurological, immunological, reproductive and developmental damage. IRIS selected rodent studies showing adverse effects on the kidneys, the immune system and the developing fetus for the 2011 oral reference dose (RfD). The 2011 inhalation reference concentration (RfC) is also based on oral studies. The first two endpoints (kidney and immune system) are chronic (long-term) effects whereas the third (fetal heart malformation) is a developmental effect, which is necessarily the result of a short-term exposure, in this case three weeks during the first trimester of pregnancy. Congenital heart defects in humans are common, rarely debilitating, and may have multiple causes making it difficult to interpret epidemiological studies. However, both the new RfD for chronic *oral* exposure and the RfC for chronic *inhalation* exposure obtained from rodent studies suggest that the fetal heart malformation risk could increase in pregnant women exposed to TCE from contaminated drinking water as well as from inhalation of vapors (USEPA 2011b). IRIS did not provide any guidance whether the inclusion of the developmental endpoint was intended to trigger additional, accelerated actions by regulatory agencies overseeing TCE-contaminated sites. Regulatory agencies that adopted the 2011 IRIS toxicity factors have been grappling with the practical implications. Some of the agencies that have addressed the TCE short-term toxicity include USEPA Region 10 (USEPA, 2012d), USEPA Region 9 (USEPA, 2013c; discussed in Attachment A and Section 4.b); the Massachusetts Department of Environmental Health (MassDEP, 2014); and DTSC (DTSC, 2014). On August 27, 2014, the USEPA Office of Solid Waste and Emergency Response issued guidance regarding early or interim actions at Superfund sites along with information about the inhalation toxicity of TCE (USEPA, 2014d).

Given the short duration of this critical exposure period (the period when the fetal heart is formed), the implication is that a rapid response action may be warranted to protect women of reproductive age at sites with potential TCE VI risks. Furthermore, consideration should be given to protection of both remediation workers and nearby members of the public where TCE remediation is taking place due to the short duration of the critical exposure period. Factors to consider include: providing adequate ventilation; appropriate personal protective equipment for remediation workers; field monitoring equipment capable of detecting concentrations in the range of the screening levels (i.e., photoionization detector capable of detecting in the ppb range); and possible air sampling using an onsite or offsite laboratory. The DTSC *Proven Technologies and Remedies Guidance: Remediation of Chlorinated Volatile Organic Compounds in Vadose Zone Soil* (DTSC, 2010) provides further information on work zone and perimeter air monitoring.

Developmental toxicity has been linked to inhalation of TCE vapors as well as ingestion of TCE-contaminated drinking water with more substantial evidence for the latter. Therefore, while this Framework only addresses the recent changes regarding the inhalation pathway for TCE, it is recognized that in addition to actions based on the maximum contaminant level (5 µg/L) more immediate action may be necessary if an existing drinking water source is impacted or threatened by TCE at concentrations above the non-cancer ESL for drinking water (7.8 µg/L). The investigation and cleanup of TCE-contaminated groundwater for protection of drinking water resources remains a priority for the Water Board and groundwater cleanup should not be delayed.

b. USEPA-Recommended Action Levels for Indoor Air and Interim Response Actions for TCE

On July 9, 2014, USEPA Region 9 issued a memorandum to Region 9 Superfund Staff and Management entitled *EPA Region 9 Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion* (Memorandum; USEPA, 2014c). The information in the July 9, 2014, memorandum supersedes Item 1 in the USEPA Region 9 December 3, 2013 letter (see Attachment A). The Memorandum provides two sets of TCE indoor air response action levels for both residential and commercial exposure scenarios that are intended to protect women of reproductive age. It distinguishes between a hazard quotient (HQ) of 1 and an HQ of 3. The Accelerated Response Action Levels (ARALs) and Urgent Response Action Levels (URALs) are presented in Table 4.

Table 4 – USEPA Region 9 Accelerated Response Action Levels and Urgent Response Action Levels for Indoor Air

Exposure Scenario	Accelerated Response Action Level (HQ = 1)	Urgent Response Action Level (HQ = 3)
Residential	2 µg/m^3	6 µg/m^3
Commercial (8-hour workday)	8 µg/m^3	24 µg/m^3
USEPA recommends that the response time associated with the ARALs be a few weeks whereas it should be a few days for the URALs.		

The numerical values for the accelerated response action levels correspond to the chronic non-cancer screening levels (i.e., these numbers essentially are the same as the non-cancer ESLs for indoor air; see ESL Detail Table E-3). USEPA recommends that the results from time-weighted air sampling methods be compared to these levels and provides suggestions on how to determine whether expedited laboratory analysis turnaround times may be appropriate.

The *Tiered Response Actions* in the July 9, 2014, USEPA Region 9 memorandum from are:

- **TCE Indoor Air Concentration ≤ ARAL (HQ 1)** – USEPA recommends routine periodic confirmatory sampling or monitoring.
- **TCE Indoor Air Concentration > ARAL (HQ1)** – USEPA recommends early or interim response measures be evaluated and implemented quickly, within a few weeks. These include:
    - Increasing building pressurization and/or ventilation;
    - Sealing potential conduits where vapors may be entering the building;
    - Treating indoor air (carbon filtration, air purifiers);
    - Installing and operating engineered exposure controls (subslab or crawl space depressurization systems)

TCE Indoor Air Concentration > URAL (HQ3) – USEPA recommends early or interim response measures be evaluated and implemented quickly, within a few days, and that effectiveness be confirmed before additional exposure is allowed to occur. Temporary relocation may be necessary to prevent additional exposure, if other mitigation measures are not available or effective.

In all cases, the evaluation of subsurface VI for long term exposure would continue.

The USEPA Region 9 memorandum also lists recommendations for (a) sampling, (b) expediting turn-around time for TCE analytical results, and (c) implementing early or interim measures to mitigate TCE inhalation exposure.

i. Water Board Indoor Air TCE Interim Response Action Levels

> **Interim Response Action Levels** are concentrations in indoor air that prompt immediate response actions to reduce exposure.

Water Board staff has provisionally selected residential and commercial/industrial indoor air interim response action levels for TCE that are the same as the USEPA Region 9 ARALs and URALs to determine when to initiate a prompt response action. The residential and commercial/industrial indoor air TCE ARALs are 2 and 8 μg/m^3, respectively. These correspond to the ESLs based on a non-carcinogenic endpoint and a HQ of 1 (ESL Detail Table E-3). The residential and commercial/industrial indoor air TCE URALs are 6 and 24 μg/m^3, respectively, based on a HQ of 3. If there is an exceedance of these action levels, then interim response actions should be evaluated consistent with the Tiered Response Actions listed above and as discussed further in the next section. The action levels and response actions and potential expedited laboratory turnaround times should be incorporated into indoor air sampling work plans and associated contingency plans.

ii. Water Board Interim Response Actions for TCE in Indoor Air

Interim response actions are actions taken by the responsible party or occupant to reduce or eliminate exposure after indoor air sample results exceed the appropriate residential or commercial/industrial TCE ARAL or URAL. These actions include immediately encouraging the occupant to take precautions to reduce exposure. Actions for residents should include increasing ventilation, sealing potential conduits, or treating indoor air as well as other measures. Actions for commercial occupants should include increasing use of the HVAC system (i.e., increasing ventilation through greater outdoor air intake or increasing building pressurization), sealing potential conduits, or treating indoor air. Possible sources of TCE inside the building should be evaluated and removed and the building should be retested as soon as possible. If multiple lines of evidence indicate that TCE attributable to the subsurface is migrating into indoor air at concentrations exceeding the chronic exposure levels, a VIM system should be installed (Section 5). The performance standard (i.e., TCE concentration) for a VIM system should be the appropriate cancer risk ESL, which is lower than the non-cancer ESL and is expected to be protective of non-cancer effects regardless of the time to manifestation.

c. Water Board Trigger Levels for Soil Gas and Groundwater

> **Trigger Levels** are concentrations in environmental media that prompt prioritization of indoor air sampling.

The Water Board has developed concentrations for TCE in soil gas and groundwater to prioritize indoor air sampling due to concerns regarding potential TCE short-term effects and potential need for prompt action. These concentrations are called Trigger Levels and are listed in Table 5 along with TCE screening levels for soil gas and groundwater and two endpoints (cancer and non-cancer). As shown, the Trigger Levels are based on the non-cancer hazard; that is, the target concentrations are the indoor air ARALs (2 μg/m^3 and 8 μg/m^3 for residential and commercial/industrial exposure scenarios, respectively).

Table 5 – TCE ESLs and Trigger Levels for Indoor Air Sampling

Medium	Residential			Commercial/Industrial		
	Cancer Risk ESL	Non-cancer Hazard ESL	Trigger Level	Cancer Risk ESL	Non-cancer Hazard ESL	Trigger Level
Indoor Air	0.59 μg/m^3	2.1 μg/m^3	**NA**	3.0 μg/m^3	8.8 μg/m^3	**NA**
Soil Gas[*]	300 μg/m^3	1,100 μg/m^3	**1,000 μg/m^3**	3,000 μg/m^3	8,800 μg/m^3	**8,000 μg/m^3**
Groundwater - Sand Scenario[1 **]	4.9 μg/L	17 μg/L	**17 μg/L**	49 μg/L	140 μg/L	**140 μg/L**
Groundwater - Fine-Coarse Scenario[2]	130 μg/L	460 μg/L	**460 μg/L**	1,300 μg/L	3,900 μg/L	**3,900 μg/L**

Notes:

1 – Sand Scenario – Predominantly coarse soils <u>or</u> likelihood of preferential pathways (manmade or natural; see Section 3.d.ii) <u>or</u> shallow first groundwater (<10 feet bgs). See Framework text (Section 4.c.i) for basis of derivation. This scenario should be used as the default scenario if any of the criteria are met.

2 – Fine-Coarse Scenario – Continuous fine-grained soil layer at the water table <u>and</u> lower likelihood of preferential pathways <u>and</u> deep first groundwater (≥10 feet bgs). See Framework text for basis of derivation. This scenario may also be used if multiple lines of evidence indicate that a site more resembles this scenario.

* – ESLs and trigger levels for soil gas vary slightly due to changes in exposure assumptions between the USEPA ARALs and the ESLs

** – The Sand Scenario uses an updated Johnson and Ettinger model, which will be incorporated in the next ESL update

The basis of the Trigger Levels is presented below:

i. Soil Gas TCE Trigger Levels for Indoor Air Sampling

Soil gas sampling is important for initially locating and defining the VOC vapor sources as well as quantitatively evaluating VI (with properly located samples or vapor wells). Soil gas TCE Trigger Levels are used to prioritize indoor air sampling for TCE while site investigation and cleanup activities continue (i.e., skipping ahead in the stepwise approach; Figure 1). The residential and commercial/industrial soil gas TCE Trigger Levels are based on the DTSC default attenuation factors of 0.002 and 0.001 (VIG Table 2), respectively. For example, the residential soil gas TCE Trigger Level (1,000 µg/m^3) is calculated by dividing the TCE residential ARAL (2 µg/m^3) by the DTSC default attenuation factor of 0.002. The residential and commercial/industrial soil gas TCE Trigger Levels are: 1,100 and 8,000 µg/m^3, respectively. No Trigger Levels are established for subslab data because Water Board staff considers subslab data to be best used as one line of evidence to be evaluated when interpreting indoor air data.

ii. Groundwater TCE Trigger Levels for Indoor Air Sampling

Groundwater TCE Trigger Levels are used to prioritize and expedite indoor air sampling for TCE while site investigation and cleanup activities continue to address the subsurface VI threat (i.e., skip steps 6 and 7 in the stepwise approach; see Table 1). Groundwater TCE Trigger Levels were developed for residential and commercial/industrial exposure scenarios using an approach similar to the one that generated two sets of screening levels in the ESLs. The Trigger Levels are applied as follows:

- **Sand Scenario:** The Sand Scenario is applied in cases of predominantly coarse soils or large likelihood of manmade or natural preferential pathways or first groundwater is less than 10 feet bgs. The Sand Scenario TCE Trigger Levels were developed using the Johnson & Ettinger model (DTSC-HERO March 2014 GW-SCR version) with sand, a 5-foot depth to groundwater, and a target indoor air concentration equal to the RfC. The residential and commercial shallow groundwater TCE Trigger Levels are 17 and 140 µg/L, respectively. Water Board staff considers that natural (e.g., conduits created by sand lenses, fractures, or desiccation cracks), manmade (e.g., utility vaults or associated backfill) and building-specific (e.g., below-ground elevator components) preferential pathways responsible for minimal attenuation of contaminant vapors are more likely to be present and affect vapor transport in the upper 10 feet of soil.

- **Fine-Coarse Scenario:** The Fine-Coarse Scenario is applied in cases where there is continuous fine-grained soil layer at the water table and lower likelihood of preferential pathways and first groundwater is 10 feet bgs or deeper). The Fine-Coarse Scenario groundwater TCE Trigger Levels were developed using the Johnson & Ettinger model (USEPA 2004 GW-ADV version) with the Fine-Coarse Scenario soil type inputs and a target indoor air concentration equal to the RfC. The Fine-Coarse Scenario is most applicable to sites where there is a continuous, predominantly fine-grained soil at the depth of the water table resulting in a relatively thick capillary fringe. The empirical basis of the Fine-Coarse Scenario soil type and restriction of its application to depths of 10 feet bgs or deeper are described in Section 6.3 of the *ESL User's Guide*. The residential and commercial deep groundwater TCE Trigger Levels are: 460 and 3,900 µg/L, respectively.

d. Recommendations Regarding PCE

PCE can be a source of TCE if site conditions favor dechlorination. Reductive dechlorination is a major anaerobic biodegradation pathway for the chlorinated solvents (e.g., PCE and TCE) provided that the geochemical conditions are suitable (e.g., sufficient electron donors and the requisite microorganisms are present – USEPA, 2013b). During the oxidative degradation of a variety of organic compounds (e.g., naturally occurring or added organic carbon sources or petroleum hydrocarbons from comingled releases) electron donors (hydrogen or reduced compounds) are generated that then can be used for the stepwise reduction of chlorinated VOCs. The typical transformation sequence is PCE to TCE to dichloroethene (DCE) to vinyl chloride and ultimately to non-toxic end products (e.g., ethene, ethane, and carbon dioxide). The transformation process can slow or stop at DCE or vinyl chloride in some instances with vinyl chloride being the more toxic (carcinogenic) product. However, the transformation does not typically slow or stall from PCE to TCE to DCE. Therefore, for PCE release sites, TCE and the remaining degradation products should be tested and monitored. If chemicals are added to facilitate PCE degradation (i.e., enhanced in-situ biodegradation) TCE production should be monitored.

e. Public Participation for TCE/PCE Sites

Water Board staff utilizes the *Final Draft – Public Participation at Cleanup Sites* (SWRCB, 2005) to determine the appropriate level of effort for public participation at cleanup sites. The guidance describes three categories of public participation effort and how to determine the appropriate category for a site. For this purpose, "the site" should be considered as the source area and down- and cross-gradient extent of all COPCs exceeding applicable screening levels in all media. For TCE contaminated sites, the following should be considered:

- <u>Re-Evaluation of Public Participation Level for TCE/PCE Sites</u> – Many smaller cleanup sites, such as drycleaners, were considered Category 1; however, if a TCE release has migrated away from the original source property and has the potential to migrate to indoor air off-site, these sites should be re-categorized as Category 2. Many larger cleanup sites already fall under public participation Category 2 or 3 due to the significance of the contamination and the like likelihood for groundwater contamination to migrate away from the source property. Soil gas contamination can also migrate past the property boundary of the original release, thus the likely extent of contamination in all media should be considered in determining the notification area. Additional notification may be required if new data indicates that the extent of contamination is larger than the original notification area.
- <u>Conduct Additional Public Participation Activities if Re-Evaluation Results in a Public Participation Level Increase</u> – If the re-evaluation indicates that a Category 1 or 2 site should be increased to a Category 2 or 3 site, additional public participation activities should be conducted. The additional activities should mention all potential exposure pathways including VI, actions that are being taken to evaluate and remediate the site, and actions that persons can take to reduce potential exposure.
- <u>Expedite Public Notification if TCE Trigger Levels or Action Levels Are Exceeded</u> – If TCE has been detected at concentrations exceeding the trigger levels or action levels; a notification regarding TCE should be made promptly so that women of child-bearing age are informed of the potential concerns, actions that are being taken to evaluate and remediate the site, and actions they can take to reduce potential exposure.

For VI sites, there are additional concerns that may need to be taken into consideration such as privacy (indoor air sampling), risk communication, and outreach to prospective buyers and new occupants. The VIPPA (DTSC, 2012a) addresses these issues.

f. Re-Opening TCE/PCE Sites based on Vapor Intrusion and Short-Term, Developmental Toxicity Concerns

Water Board staff may re-open any site if data indicates that residual contamination poses an unacceptable risk to public safety, health, or the environment or if previously undetected contamination is discovered. For example, in the case of a property transfer, a Phase I or Phase II environmental site assessment may reveal that contamination remains at the property at concentrations that are no longer considered protective due to the new toxicity criteria. A site brought to the attention of Water Board staff will be reevaluated to determine whether it should be reopened. Water Board staff does not routinely reopen closed sites. Decisions will be made only after thorough review by the site project manager and supervisor.

5. Evaluating a VIM System

Vapor Intrusion Mitigation (VIM) and remediation are complementary approaches to addressing volatile contaminants. The purpose of remediation is to reduce the level of contamination in the environmental medium that is acting as a source of indoor air vapors (DTSC, 2011b). Interim remedial actions including aggressive source control should be conducted to the extent feasible to remove contaminant mass remaining sorbed to soil, in non-aqueous phase liquids, and in very large concentrations in groundwater. Complete cleanup (remediation) of volatile contaminants may take years to decades to meet site cleanup goals. The purpose of mitigation is to reduce contaminant entry into existing building structures or remove contaminants after they have entered a building (e.g., residence).

VIM is an engineering control[4] that is a useful tool to manage the effects of residual contaminants and to reduce short term risk during investigation and implementation of cleanup. VIM may also be used as a precautionary measure even if not required under current circumstances to reduce the potential for exposure and liability should conditions change in the future. A typical VIM system consists of a vapor barrier and a sub-barrier vapor venting system to prevent soil gas from entering a building and posing a risk to the occupants.

Because such systems are not fail-safe due to potential construction or renovation damage or operating errors, the importance of post-construction monitoring (e.g., indoor air or subslab soil gas) and reporting and regulatory or independent review is critical to demonstrate effectiveness. Water Board staff has encountered several issues associated with VIM systems that warrant special attention. These include: proposed VIM systems without adequate investigation and source remediation; improperly constructed VIM; no post-construction testing to determine whether the VIM system is operating properly and successfully; and no independent review of monitoring results after initial startup.

[4] An engineering control is a general term used to describe a variety of engineered or constructed physical barriers (e.g., soil capping, subsurface venting systems, mitigation barriers) to contain or prevent exposure to contamination on a property (USEPA, 2010).

a. Water Board Approach to VIM

The Water Board approach to VIM follows the VIMA (DTSC, 2011b), and it is also consistent with the Low-Threat Tool, which requires source control to the extent feasible (Water Board, 2009). The goal of VIM is to prevent the intrusion of subsurface contaminant vapors to indoor air and prevent human exposure at unacceptable levels from these contaminants. VIM is considered an interim measure and not meant as a substitute for remediation or as the sole remedial option for releases of volatile chemicals (DTSC, 2011b). In this way remediation and mitigation are complementary. However, for situations where the volatile chemical source is off-site or regional in nature, mitigation may be the only viable long-term response action due to impracticability of mass removal at the source (e.g., the source is inaccessible).

The following aspects must be addressed to ensure success of a VIM system: proper design, proper construction, post-construction quality assurance testing, operation and maintenance, long-term verification monitoring, reporting, financial assurance, land use controls, and ongoing regulatory review and involvement.

b. Evaluation Criteria for Approving VIM as Part of a Remedy

Water Board staff may become involved at two steps: 1) determination that VIM is likely to be effective as part of the remedy (i.e., approval of concept for the specific site); and 2) determination that a building is safe for occupancy (i.e., approval of installation and operational effectiveness). The first decision is made by Water Board staff (based on review of the work plan and design report), and the second is made by the local planning department with Water Board staff input (based on review of the completion report documenting construction in accordance with approved work plan and post-construction testing documenting the system is operating properly and successfully).

Figure 2 and Table 6 are used to help staff evaluate the threat posed by a site and the vulnerability of possible VIM systems. These factors are used to help determine the appropriate level of regulatory oversight and determine what documentation and operation and maintenance requirements for the VIM system are appropriate. This discussion is intended to help in the identification of potential problem areas and regulatory tools. This discussion is not guidance or policy. It is not intended to prohibit or allow any given VIM proposal.

The following factors describe the VI threat posed by a site:

1. **Magnitude of VI Threat** – VIM typically is more challenging at sites where the current contaminant concentrations and mass are great regardless of the reason (cleanup is just getting started, accessibility of the VOC vapor source, or VOC vapor source is offsite). This should be assessed based on multiple lines of evidence including groundwater, soil gas, and indoor air (for existing construction).

2. **Duration of VI Threat** – The length of time required until the system is no longer needed (i.e., no unacceptable risks remain) is important. Over extended periods of time and with successive property transfers, institutional knowledge and vigilance may decrease,

rendering long-term VIM system operation less dependable. Systems that would have to run in perpetuity because the source is not remediated are not preferred.

3. **Building Location Relative to Areas of Contamination** – Distance between the subsurface VOC vapor source or plume and the building can serve to reduce the overall VI threat. Additional measures may be needed for buildings that are not located on the source property.
4. **Foundation Type** – Some foundation designs, such as podium construction, can potentially reduce VI by depending on the placement of conduits (e.g., elevator shafts, stairwells, or utility penetrations). Potential conduits should be located on the exterior of the building where they can easily be monitored. VI is considered to pose a moderate threat to slab-on-grade foundations and a greater threat to basements, strip-footing foundations with crawl spaces, or other sub-grade foundations. Limited options are available for retrofitting existing buildings.

As the VI threat increases, the VIM system must be increasingly robust to address the threat or conversely, less vulnerable to system failure. Water Board staff should weigh the following factors to determine how vulnerable the system is, how much oversight is needed, and whether or not to approve a proposed VIM system:

1. **System Reliability** – In general, less maintenance results in a more reliable system. Passive systems (e.g., subslab venting systems) are considered more reliable than active systems (e.g., subslab depressurization systems), even though the latter may be more effective at the outset. Therefore, passive systems are preferred. Passive systems have the added benefit that they can be adapted to function as active system if the system is not effective as designed. Subslab liners (passive membranes or vapor barriers) are not considered as likely to completely eliminate VI over time due to the likelihood of punctures, perforations, tears, and incomplete seals (DTSC, 2011b).

2. **Management Type** – In general, greater density and more centralized ownership or management of a property correlate with increased VIM system reliability. For example, it would be relatively straightforward for a building engineer or manager of an apartment building or condominium complex to maintain a VIM system in a single building over the long term. However, for multiple individual homeowners, successful long-term maintenance of systems for each residence likely will not be reliable. Maintaining a VIM system requires recognition of the health risk posed by VI, technical ability to operate and troubleshoot the system, and a willingness and financial commitment. The potential for VIM system failure is greater when such systems are maintained by individual homeowners. Site access should also be considered. If the proposed system is on a property owned by the responsible party VIMs systems are easier to implement and maintain. Group management structures, including home owners associations may be reasonably reliable if the HOA has a dedicated manager or engineer funded by a viable responsible party, with a financial assurance mechanism. In that case, the HOA may be able to provide support similar to a commercial property. However, in redevelopment situations if there is no longer a viable responsible party, the HOA may more closely resemble a group of single family property owners. HOAs should be evaluated carefully, with consideration of how the HOA may change over time.

Table 6 – Evaluation Criteria for VIM			
VI Threat			
Criterion	**Lesser**	**Moderate**	**Greater**
Magnitude of VI Threat	Concentrations ≤ ESLs	Concentrations > ESLs	Concentrations >> ESLs
Duration of VI Threat	Short (e.g., 1-2 years)	Medium (e.g., 3-10 years)	Long (e.g., >10 years)
Building Location	Building >100 feet from plume boundary	Building near plume boundary	Building overlying plume
Foundation Type	Podium	Slab-on-grade	Basement
VI System Failure Vulnerability			
Criterion	**Less Vulnerable**	**Moderate**	**More Vulnerable**
System Reliability	Intrinsically safe building design	Passive VIM	Active VIM
Management Type	Professional management (e.g., Commercial or rental apartments)	Group management (e.g., Condominiums with home owner's association)	Dispersed (e.g., Single-family homes)
Note: Each factor (row) presents a range of possibilities that are not necessarily linked to the entry in the same column for the other factors (rows). The columns are organized qualitatively not quantitatively and are not intended to prohibit or allow any particular VIM proposal without site specific review by Water Board staff.			

c. VIM System Effectiveness

For new construction, local building departments often refer to Water Board staff for technical guidance prior to granting official building occupancy permits. This evaluation will begin with consideration of design and continue as the system is installed and tested. For existing construction, VIM should be implemented quickly and may need to be adjusted in an iterative process. If the VIM system is not effective, it likely will be necessary to augment the system or conduct additional remedial actions.

After Water Board staff evaluate whether a VIM system is an appropriate part of a remedy using the criteria above, the system must be appropriately designed, constructed, and tested before Water Board staff can find that the VIM system is effective, no unacceptable risks remain, and recommend that buildings are suitable for occupancy. All VIM systems should be designed, built, installed, operated, and maintained in conformance with standard geologic, engineering, and construction principles and practices by appropriately licensed professionals (DTSC, 2011b).

i. VIM System Design

A proposed design report should be submitted for Water Board review and concurrence before construction. The report should address the following topics consistent with the VIMA (DTSC, 2011b), with the understanding that the level of detail may vary based on the site-specific needs:

- Project background (e.g., rationale for VIM);
- Site conditions summary (e.g., types of volatile contaminants and concentrations, environmental hazards such as methane, subsurface conditions such as soil types, depth to groundwater, and presence of utility corridors);
- Existing building design report (e.g., condition of the foundation including identification of potential vapor entry points);
- Operation and maintenance plan (Section 5.c.iii);
- Design basis (e.g., assumptions and performance criteria);
- Construction methods (e.g., specifications, permits, procedures, construction quality control procedures, and post-construction testing procedures);
- Design calculations and drawings (e.g., justification that the VIM system is expected to provide an attenuation factor that will adequately reduce VI risk);
- Conceptual drawings;
- VIM approach;
- Implementation mechanisms (e.g., land use controls and soil management plan); and
- Financial assurance (especially if the responsible party does not own the property, or will not own the property after redevelopment, or if the responsible party may have limited resources)

Further details on the content of the proposed design report are provided in the VIMA.

ii. VIM System Construction and Quality Control

A completion report is required to document that the system was constructed appropriately. Elements of the report may include:

- Description of VIM system construction process, issues encountered, and any variances from the design;
- As-built drawings signed and stamped by a California licensed Engineer with a statement that the VIM system was installed to the manufacturer's specifications.
- Photo documentation of installation;
- Results of quality control testing (e.g., smoke testing and indoor air sampling of the building shell) and documentation of any rework needed; and
- Third party quality assurance/quality control inspection report.

Site visits by Water Board staff are encouraged. After review of the completion report, staff may recommend that the site does not pose a threat for the proposed use, or that additional corrective action is necessary by augmenting the VIMS or adding remedial action.

iii. Operation and Maintenance

Routine documentation of required O&M is required in accordance with an agency-approved O&M Plan that addresses the following elements:

- Responsible entities (e.g., homeowner's association or property manager)
- Performance goals and measures (e.g., vapor concentrations or pressure measurements)
- Monitoring (e.g., system operation parameters and volatile contaminant and combustible gas monitoring)
- Vapor sampling and analysis (e.g., indoor air and subslab soil gas sampling)
- Inspections (e.g., observing visible components to confirm their function)
- Contingency plan in the event of failure to meet performance goals
- Reporting
- Periodic reviews

The level of documentation and frequency of reporting will vary depending on the vulnerability of the VIM system. In addition, the frequency of reporting may be more frequent at start-up and later reduced.

iv. Institutional Controls and Administrative Safeguards

Additional aspects to consider for a VIM system include the following:

- **Institutional controls (ICs)**[5] – ICs typically are incorporated into land use covenants and include provisions for notifications, prohibitions (land uses, interference with the VIM system, land disturbing activities), access, and inspection and reporting requirements. The Water Board has an approved model Covenant and Environmental Restriction on Property that should be used when developing a site-specific land use covenant.
- **Enforcement mechanisms** – Enforcement mechanisms typically are legal instruments or agreements to ensure compliance (e.g., order or cost recovery agreement).
- **Financial assurance** – Financial assurance ensures that sufficient funds will be available to continue operation of the system and to conduct any corrective action required. Financial assurance may include a trust fund, surety bond, letter of credit, insurance, corporate guarantee, or qualification as a self-insurer by means of a financial test. The basis for the amount of financial assurance (e.g., detailed cost estimate) should be provided.
- **Access agreement** – An access agreement is necessary to allow for access for operation and maintenance, testing and construction and also to address concerns by affected parties (owners and tenants).

[5] ICs are non-engineered instruments, such as administrative and legal controls (e.g., covenants), that help minimize the potential for exposure to contamination and/or protect the integrity of the remedy (USEPA, 2012c).

- **Inter-agency coordination** – Depending on the nature of the VIM system, potentially significant coordination may be necessary and potential agencies include air management districts, building departments, fire departments, etc.
- **Building control termination process** – Eventually, subsurface remediation will reduce volatile contaminant concentrations to levels that no longer require remediation and VIM system operation can be terminated. The process for making this decision, which should be based on multiple lines of evidence, should be defined and documented in an appropriate document.

6. Vapor Intrusion Concerns on Closed Landfills

The Water Board recently has received proposals for mixed use (residential and commercial) redevelopments with VIM systems on closed landfill sites. At each of these sites, soil gas characterization indicated the presence of methane as well as concentrations of benzene and vinyl chloride exceeding ESLs. In general, Water Board staff does not recommend these proposed redevelopments due to: 1) the presence of an unremediated subsurface vapor source that is potentially under pressure (i.e., greater driving force; see VIG Step 3); and 2) reliability concerns for the VIM system due to differential settling, potential gas production due to water use getting into the waste, and potential creation or propagation of preferential vapor migration pathways.

The following issues would have to be addressed as part of Water Board staff's consideration of residential or commercial redevelopments on closed landfill sites:

- Full characterization of groundwater and soil gas, including temporal monitoring, and development of a robust CSM. This information should include understanding the zone of vapor influence around the existing waste footprint.
- Removal of all non-inert waste from the footprint of all future structures, including a setback distance around the structure footprints commensurate with the site-specific zone of vapor influence.
- Removal of as much of the subsurface VOC vapor source as practicable through technologies such as soil vapor extraction prior to development
- A VIM system consistent with the VIMA and recommendations in this Framework.
- Robust long-term monitoring of each building to potentially include external soil gas and subslab monitoring points in addition to in-building monitoring.
- Institutional controls are implemented.
- Financial assurance is maintained and updated.
- A single entity is responsible for managing, operating, and maintaining the VIM system.
- Independent review is conducted (i.e., either Water Board staff review or another certified entity like a City or County Local Enforcement Agency).

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Figures

Figure 1 - Modified Stepwise Approach with Interim Response Actions for TCE

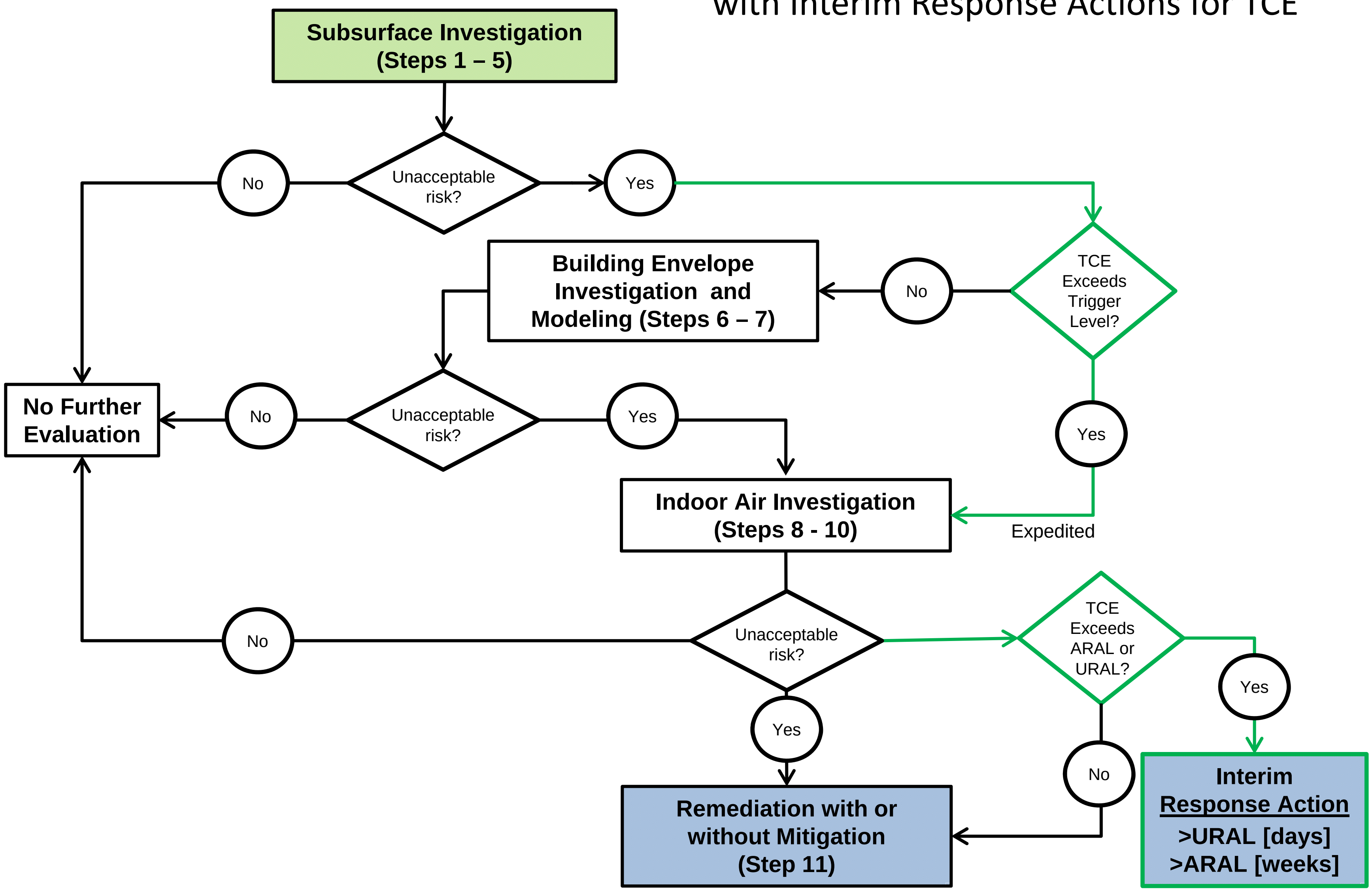
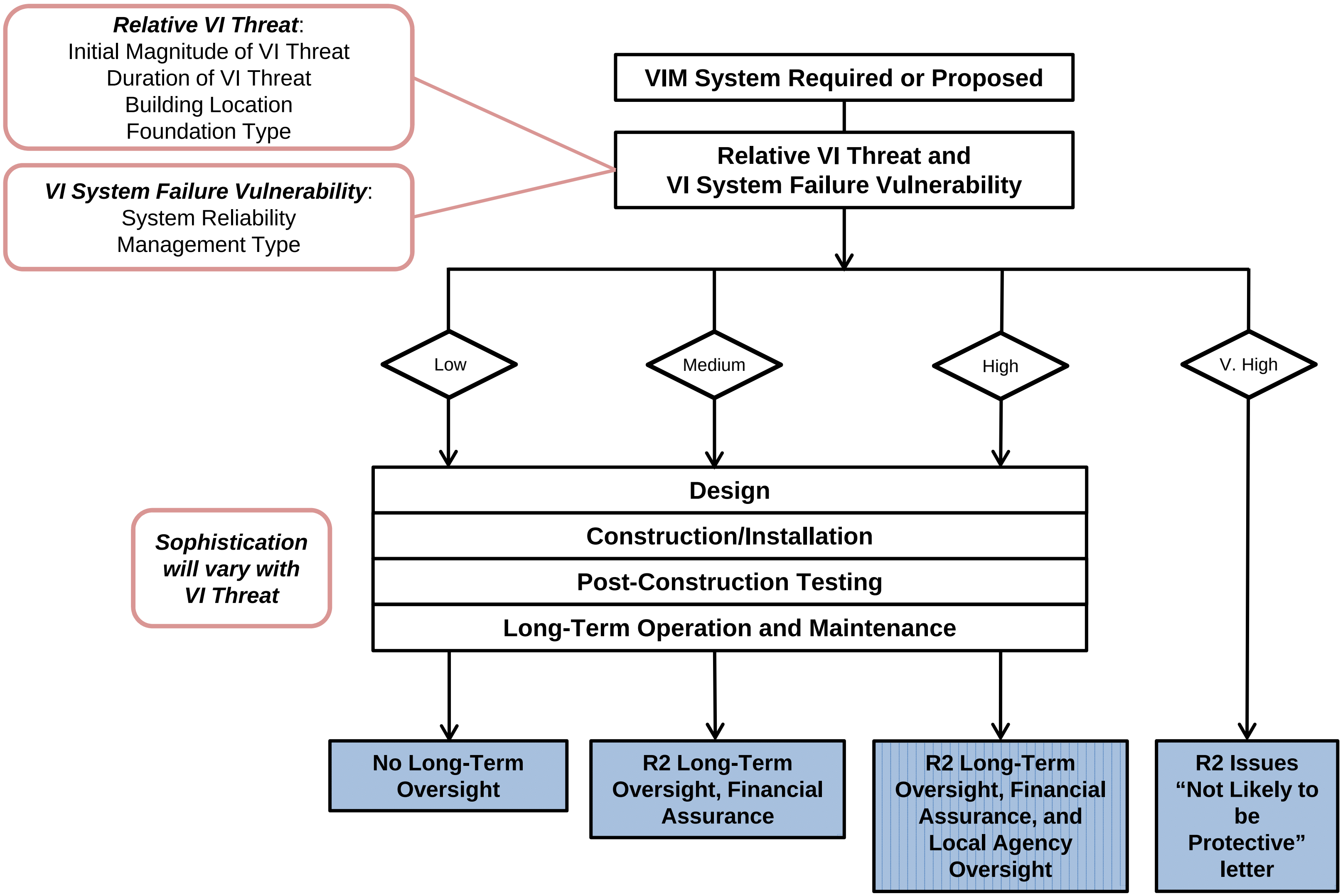


Figure 2 – VI Mitigation Oversight



Attachment A

Discussion of the Six Items in the USEPA Region 9 Letter

Discussion of the Six Items in the USEPA Region 9 Letter

On December 3, 2013, USEPA Region 9 issued a letter ("South Bay Letter"; USEPA, 2013c) to the Water Board that provides guidelines and supplemental information for VI evaluations at nine South Bay Superfund or NPL sites with subsurface TCE and PCE contamination that Water Board staff oversees. Below is a brief description of the six items and adjustments to the Water Board VI approach in response to the South Bay Letter followed by a summary.

1. Interim TCE Short-Term Response Action Levels and Guidelines

The South Bay Letter provided Interim TCE Short-Term Response Action Levels for indoor air and recommended interim response action (mitigation measures) along with guidelines on the speed of implementation (e.g., days or weeks). The numerical values corresponded to the chronic, non-cancer screening levels (based on a hazard quotient of 1). On July 9, 2014, USEPA Region 9 issued a memorandum to Region 9 Superfund Staff and Management entitled *EPA Region 9 Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion* (memorandum; USEPA, 2014c). The information in the memorandum supersedes Item 1 in the South Bay Letter. See Section 4 of the main Framework text for further information.

Water Board staff has not previously developed interim or short-term response actions or levels for indoor air or other media. The Water Board is provisionally using these recommendations. Staff now incorporates the TCE indoor air interim action levels and response actions into the Water Board VI approach.

2. PCE Indoor Air Screening Levels

The South Bay Letter recognizes that the California-modified indoor air screening levels for PCE differ from USEPA's May 2013 Regional Screening Levels and states that California Environmental Protection Agency (CalEPA) toxicity values and indoor air screening levels should be used for PCE.

The ESLs use the current CalEPA toxicity factors for PCE.

3. Residential Building Sampling Approach – Multiple Rounds of Sampling including Colder Weather and Crawl Space Sampling

The South Bay Letter requires multiple rounds of indoor air sampling, including sampling during colder weather months when the potential for VI may be higher. USEPA staff has interpreted this as at least two rounds of sampling; including one each in the warm and cool season. The South Bay Letter also calls for crawl space, basement, and pathway sampling. The term "pathway sampling" in the South Bay Letter refers to sampling likely locations for subsurface vapor entry such as sumps, floor drains, elevator shafts or stairwells, and slab cracks.

Two rounds of indoor air sampling are consistent with the Water Board VI approach: a) the VIG (Step 9, p. 30) calls for at least two rounds of indoor air sampling to detect seasonal variations (late summer/early autumn and late winter/early spring); and b) crawl space and basement sampling are identified as lines of evidence in the VIG. The utility of this type of sampling is recognized in Step 9 of the VIG.

4. Commercial Building Sampling Approach – Building HVAC-Off, HVAC-On, and Pathway Sampling

The South Bay Letter requires that, for commercial buildings, indoor air sampling to be conducted with the heating, ventilation, and air conditioning system (HVAC) both on and off, and requires pathway sampling. HVAC-off sampling addresses whether there is potential for subsurface VI into buildings without reliance on the indoor air ventilation system.

This is consistent with the Water Board approach with the exception that the VIG does not currently specify HVAC-off sampling. When conducting indoor air sampling where there is an HVAC, Water Board staff plans to incorporate both HVAC-on and HVAC-off sampling to assess building susceptibility to soil gas entry and whether the HVAC is providing a level of mitigation.

5. On-Property Study Area Building Sampling

The South Bay Letter requires that indoor air be sampled at buildings with existing VIM systems because those systems can be damaged during construction and renovation activities. This sampling requirement extends to buildings overlying subterranean parking garages because of potential preferential pathways (e.g., elevator shafts, stairwells).

This is consistent with the Water Board approach and is addressed in the following sections of the DTSC VIMA (DTSC, 2011b): 1) Section 6.2 (Construction Quality Assurance/Quality Control Testing), and 2) Section 7.2.2 (Operation and Maintenance – Performance Measures); and 3) Section 7.2.3 – Operation and Maintenance – General Guidelines for Monitoring - Indoor Air Quality Monitoring).

6. Indoor Air Sampling Required for Buildings Overlying 5 µg/L TCE in Groundwater

The South Bay Letter has been interpreted to require indoor air sampling in buildings overlying 5 µg/L TCE in groundwater. The letter states that this value is supported by the USEPA Vapor Intrusion Screening Level (VISL) calculator,[1] which uses the USEPA generic default groundwater-to-indoor air attenuation factor of 0.001, and the appropriate Henry's Law conversion, empirical data, and mathematical modeling. However, USEPA has been implementing their VI evaluations, which includes indoor air sampling, beginning with a first cut groundwater TCE concentration of 50 µg/L for residential areas and 100 µg/L for commercial areas and stepping out as needed.

The Water Board is not utilizing the 5 µg/L TCE in groundwater as a trigger for indoor air sampling. Instead, Water Board staff has developed specific Trigger Levels for TCE in soil gas

[1] The VISL calculator is periodically updated. The May 2014 version (USEPA, 2014a) uses the same generic default groundwater-to-indoor air attenuation factor of 0.001 as the previous December 2013 version cited in the South Bay Letter.

samples and groundwater samples. When these Trigger Levels are exceeded, staff will prioritize indoor air sampling while continuing with the stepwise approach integrated with multiple lines of evidence as presented in Section 3.0 of the main Framework. The toxicological basis for actions recommended by the Water Board and the development of the TCE Trigger Levels are presented in Section 4.0 of the main Framework.

Summary

Overall, the South Bay Letter supports a multiple lines of evidence approach that is consistent with the USEPA *OSWER Final Guidance for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Sources to Indoor Air (External Review Draft)* (USEPA, 2013a). In the approach, indoor air sampling is practically mandatory. This differs from the VIG stepwise approach that starts with review of available information and subsurface investigation and then moves towards indoor air, if necessary. That is, indoor air sampling is not deemed necessary unless subsurface contaminant concentrations indicate a potential risk for VI. Water Board staff continues to use the stepwise approach, but with modifications to address TCE short-term toxicity. This is further discussed in Section 3 (Integrating the Stepwise Approach with Multiple Lines of Evidence) and Section 4 (Evaluating TCE Vapor Intrusion).

The South Bay Letter also provides information on recent research and USEPA Region 9 experience that have implications for VI evaluations, such as:

- Daily indoor air concentrations resulting from subsurface VI can vary by two or more orders of magnitude in residential, passively-ventilated structures. The greatest indoor air concentrations usually occur when the outdoor air temperatures are significantly below indoor air temperatures.
- Longer-term passive samplers can help address the temporal variability of indoor air concentrations by averaging over longer periods than Summa canister samples.
- VI remains a concern at buildings with VIM systems because those systems can be damaged during construction and renovation activities.

In response to the South Bay Letter, Water Board staff has made the following modifications to the Water Board VI evaluation approach:

- **TCE Interim Action Levels for Indoor Air** – Water Board staff now provisionally incorporates the TCE indoor air interim action levels and response actions into the Water Board VI approach. See Section 4 of the main Framework for further information.
- **Indoor Air Sampling with HVAC-Off as well as HVAC-On** – The previous Water Board approach included HVAC-On indoor air sampling. Water Board staff now incorporates HVAC-Off indoor air sampling to assess building susceptibility to soil gas entry and whether the HVAC system is providing a level of mitigation.
- **TCE Trigger Levels for Soil Gas and Groundwater** – Water Board staff has developed soil gas and groundwater TCE Trigger Levels that would result in the prioritization of indoor air sampling, potentially skipping ahead in the stepwise approach. The basis and use of these Trigger Levels are discussed in Section 4.0 of the main Framework.

Attachment B

Johnson & Ettinger Model Printouts for Groundwater TCE Trigger Levels

USEPA GW-SCREEN
Version 3.0, 04/2003

DTSC Modification
March 2014

San Francisco Bay Regional Water Quality Control Board - Groundwater TCE Trigger Level: Sand Scenario

Reset to Defaults

DATA ENTRY SHEET

Scenario: **Residential**
Chemical: **Trichloroethylene**

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

YES: X

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 (μg/L)	Chemical
79016		**Trichloroethylene**

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

Results Summary					Risk-Based Groundwater Concentration	
Soil Gas Conc. (C_{source}) ($\mu g/m^3$)	Attenuation Factor (alpha) (unitless)	Indoor Air Conc. ($C_{building}$) ($\mu g/m^3$)	Cancer Risk	Noncancer Hazard	Cancer Risk $= 10^{-6}$ (μg/L)	Noncancer HQ = 1 (μg/L)
2.53E+02	4.8E-04	1.2E-01	NA	NA	4.9E+00	1.7E+01

MESSAGE: Values of Csource and Cbuilding (INTERCALCS worksheet) are based on unity and do not represent actual values.

Trigger Level

MORE ↓

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

MORE ↓

ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vandose zone soil vapor permeability, k_v (cm^2)	ENTER Vadose zone SCS soil type (Lookup Soil)	ENTER Vadose zone soil dry bulk density, ρ_b^V (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
S			S	1.66	0.375	0.054

MORE ↓

Lookup Receptor Parameters

	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)	ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Exposure Time ET (hrs/day)	ENTER Air Exchange Rate ACH $(hour)^{-1}$
Residential	1.0E-06	1	70	30	30	350	24	0.5

Used to calculate risk-based groundwater concentration.

END

CHEMICAL PROPERTIES SHEET

Trichloroethylene

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (^oC)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (^oK)	Critical temperature, T_C (^oK)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)
6.87E-02	1.02E-05	9.85E-03	25	7,505	360.36	544.20	6.07E+01	1.28E+03	4.1E-06	2.0E-03

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: **Residential**

Chemical: **Trichloroethylene**

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

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. groundwater temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Vadose zone effective diffusion coefficient, D^{eff}_V (cm^2/s)	Capillary zone effective diffusion coefficient, D^{eff}_{cz} (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)
3.39E+04	1.00E+06	5.00E-03	15	8,495	5.99E-03	2.53E-01	1.77E-04	1.11E-02	4.43E-04	2.78E-03

Diffusion path length, L_d (cm)	Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
137	15	2.53E+02	1.25	8.33E+01	1.11E-02	5.00E+03	3.32E+06	**4.81E-04**	1.22E-01	4.1E-06	2.0E-03

END

USEPA GW-SCREEN
Version 3.0, 04/2003

DTSC Modification
March 2014

San Francisco Bay Regional Water Quality Control Board - Groundwater TCE Trigger Level: Sand Scenario

Reset to Defaults

DATA ENTRY SHEET

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

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

YES [X]

OR

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

YES [ ]

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

MESSAGE: Values of Csource and Cbuilding (INTERCALCS worksheet) are based on unity and do not represent actual values.

Trigger Level

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_W (μg/L)	Chemical
79016		**Trichloroethylene**

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

MORE ↓

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

MORE ↓

ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vandose zone soil vapor permeability, k_v (cm^2)	ENTER Vadose zone SCS soil type (Lookup Soil)	ENTER Vadose zone soil dry bulk density, ρ_b^V (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)
S			S	1.66	0.375	0.054

MORE ↓

Lookup Receptor Parameters

	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)	ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Exposure Time ET (hrs/day)	ENTER Air Exchange Rate ACH (hour)$^{-1}$
Commercial	1.0E-06	1	70	25	25	250	8	1

Used to calculate risk-based groundwater concentration.

END

CHEMICAL PROPERTIES SHEET

Trichloroethylene

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (^oC)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (^oK)	Critical temperature, T_C (^oK)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)
6.87E-02	1.02E-05	9.85E-03	25	7,505	360.36	544.20	6.07E+01	1.28E+03	4.1E-06	2.0E-03

END

INTERMEDIATE CALCULATIONS SHEET

Scenario: Commercial

Chemical: Trichloroethylene

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

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

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

END

GW-ADV
Version 3.1; 02/04

Reset to

San Francisco Bay Regional Water Quality Control Board
Groundwater TCE Trigger Level - Fine-Coarse Scenario

Scenario: Residential
Chemical: Trichloroethylene

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

YES: X

OR

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

YES:

Cancer Risk GW (µg/L):	1.3E+02
Non-Cancer Hazard GW (µg/L):	4.6E+02
GW Trigger Level (µg/L):	4.6E+02

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_W (µg/L)	Chemical
79016		Trichloroethylene

MORE ↓

ENTER Average soil/ groundwater temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to water table, L_{WT} (cm)	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)	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 (cm²)
15	15	300	100	200		B	CL	S		

Totals must add up to value of L_{WT} (cell G28)

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm³)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm³/cm³)	ENTER Stratum B SCS soil type (Lookup Soil)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm³)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm³/cm³)	ENTER Stratum C SCS soil type (Lookup Soil)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm³)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm³/cm³)
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-s²)	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

Used to calculate risk-based groundwater concentration.

END

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (^oC)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (^oK)	Critical temperature, T_C (^oK)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($(\mu g/m^3)^{-1}$)	Reference conc., RfC (mg/m^3)
7.90E-02	9.10E-06	1.03E-02	25	7,505	360.36	544.20	1.66E+02	1.47E+03	4.1E-06	2.0E-03

END

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)
9.46E+08	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	4,000

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. groundwater temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Capillary zone effective diffusion coefficient, D^{eff}_{cz} (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)
3.39E+04	1.00E+06	4.00E-04	15	8,495	6.25E-03	2.64E-01	1.77E-04	6.16E-03	4.82E-04	0.00E+00	3.42E-05	1.68E-04	285

Convection path length, L_p (cm)	Source vapor conc., C_{source} (μg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m^3)	Unit risk factor, URF (μg/m^3)$^{-1}$	Reference conc., RfC (mg/m^3)
15	2.64E+02	0.10	8.33E+01	6.16E-03	4.00E+02	1.71E+220	1.72E-05	4.55E-03	4.1E-06	2.0E-03

END

San Francisco Bay Regional Water Quality Control Board
Groundwater TCE Trigger Level - Fine-Coarse Scenario

GW-ADV
Version 3.1; 02/04

Reset to

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

YES | x

OR

Scenario: Commercial
Chemical: Trichloroethylene

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

YES |

Cancer Risk GW (µg/L):	1.3E+03
Non-Cancer Hazard GW (µg/L):	3.9E+03
GW Trigger Level (µg/L):	3.9E+03

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_W (µg/L)	Chemical
79016		Trichloroethylene

MORE ↓

ENTER Average soil/groundwater temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to water table, L_{WT} (cm)	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)	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 (cm²)
15	15	300	100	200		B	CL	S		

Totals must add up to value of L_{WT} (cell G28)

MORE ↓

ENTER Stratum A SCS soil type	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm³)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm³/cm³)	ENTER Stratum B SCS soil type	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm³)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm³/cm³)	ENTER Stratum C SCS soil type	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm³)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm³/cm³)
Lookup Soil				Lookup Soil Parameters				Lookup Soil			
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-s²)	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	1	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	25	8.3	250	1.0E-06	1

Used to calculate risk-based groundwater concentration.

END

ED (25 yrs) divided by 3 (24 hours/8 hours = 3) to account for Exposure Time of 8 hours.

CHEMICAL PROPERTIES SHEET

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm\text{-}m^3/mol$)	Henry's law constant reference temperature, T_R (^oC)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B (^oK)	Critical temperature, T_C (^oK)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
7.90E-02	9.10E-06	1.03E-02	25	7,505	360.36	544.20	1.66E+02	1.47E+03	4.1E-06	2.0E-03

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)
2.63E+08	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	4,000

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} ($atm\text{-}m^3/mol$)	Henry's law constant at ave. groundwater temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Capillary zone effective diffusion coefficient, D^{eff}_{cz} (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)
6.78E+04	1.00E+06	4.00E-04	15	8,495	6.25E-03	2.64E-01	1.77E-04	6.16E-03	4.82E-04	0.00E+00	3.42E-05	1.68E-04	285

Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
15	2.64E+02	0.10	8.33E+01	6.16E-03	4.00E+02	1.71E+220	8.61E-06	2.27E-03	4.1E-06	2.0E-03

END