Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil

November 2004
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Integrated Risk Assessment Section

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Table of Contents

1. Introduction

One of the activities required by SB 32, the California Land Environmental Restoration and Reuse Act (Escutia, Chapter 764, Statues of 2001), is for the California Environmental Protection Agency (Cal/EPA), "in cooperation with the Department of Toxic Substances Control, the State Water Resources Control Board, and the Office of Environmental Health Hazard Assessment," to publish a list of screening numbers for specific contaminants. A "screening number" is defined in this statute as meaning "the concentration of a contaminant published by the agency as an advisory number." The screening numbers are "for the protection of public health and safety." Cal/EPA is also to "report on the feasibility of establishing screening numbers to protect water quality and ecological resources."

The task of producing a list of screening numbers based on "protection of public health and safety" has been assigned to the Office of Environmental Health Hazard Assessment (OEHHA). The contaminants on this list have been selected by a process defined in the Health and Safety Code Section 57008, which is reprinted in Appendix A. The selected chemicals are listed in Table 1. Some of these contaminants are identified on specific lists in Title 22 of the California Code of Regulations (CCR) while the Department of Toxic Substances Control (DTSC) and the State Water Resources Control Board (SWRCB) identified others as chemicals that are common soil contaminants at sites where these agencies are the regulatory authority for remediation requirements.

The screening numbers required by SB 32 are not intended for use by regulatory agencies that have authority to require remediation of contaminated soil. SB 32 states: "A screening number is solely an advisory number, and has no regulatory effect, and is published solely as a reference value that may be used by citizen groups, community organizations, property owners, developers, and local government officials to estimate the degree of effort that may be necessary to remediate a contaminated property. A screening number may not be construed as, and may not serve as, a level that can be used to require an agency to determine that no further action is required or a substitute for the cleanup level that is required to be achieved for a contaminant on a contaminated property. The public agency with jurisdiction over the remediation of a contaminated site shall establish the cleanup level for a contaminant pursuant to the requirements and the procedures of the applicable laws and regulations that govern the remediation of that contaminated property and the cleanup level may be higher or lower than a published screening number." In addition, these screening numbers should not be used to infer actual health risk of a site. They are base on general assumptions and, therefore, useful to get a general understanding of potential problems with a site, but cannot be used to assess the actual health risks. Actual health risks can be better estimated with a site-specific health risk assessment based on OEHHA, Cal/EPA or U.S. Environmental Protection Agency (EPA) guidelines, which is also useful to derive site-specific contaminant cleanup levels.

The sites where these screening numbers may be used for advisory purposes include "sites subject to remediation under the Carpenter-Presley-Tanner Hazardous Substances Account Act (Chapter 6.8, commencing with Section 25300, of Division 20) and the Porter-Cologne Water Quality Control Act (Division 7, commencing with Section 13000, of the Water Code)." However, SB 32 does not limit application of published screening numbers to these sites.

Table 1. Chemicals Identified for Initial Determination of Screening Numbers

Volatile Organic Chemicals[1]	**Nonvolatile Acidic Organic Compounds**
Benzene[2]	Pentachlorophenol
Carbon Tetrachloride[2]	2,4-Dichlorophenoxyacetic
1,2-Dichloroethane (1,2-DCA) [2]	2,4,5-Trichlorophenoxypropionic
cis-1,2-Dichloroethylene (cis-1,2-DCE) [2]	**Nonvolatile Inorganic Compounds**
trans-1,2-Dichloroethylene (trans-1,2-DCE) [2]	Antimony and/or antimony compounds
Ethylbenzene[2]	Arsenic and/or arsenic compounds
Methyl *tert*-butyl ether (MTBE) [2]	Asbestos
Naphthalene[2]	Barium and/or barium compounds
Tetrachloroethylene[2]	Beryllium and/or beryllium compounds
Toluene	Cadmium and/or cadmium compounds
1,1,1-Trichloroethane (1,1,1-TCA) [2]	Chromium (VI) compounds
Trichloroethylene (TCE)	Chromium and/or chromium (III) compounds
Vinyl chloride[2]	Cobalt and/or cobalt compounds
Xylene[2]	Copper and/or copper compounds
Nonvolatile Neutral Organic Compounds	Fluoride salts
Aldrin	Lead and/or lead compounds
Benzo(a)pyrene[2]	Mercury and/or mercury compounds
Chlordane	Molybdenum and/or molybdenum compounds
DDT	Nickel and/or nickel compounds
DDE	Perchlorate
DDD	Selenium and/or selenium compounds
Dieldrin	Silver and/or silver compounds
1,4-Dioxane[2]	Thallium and/or thallium compounds
Dioxin (2,3,7,8-TCDD)	Vanadium and/or vanadium compounds
Endrin	Zinc and/or zinc compounds
Heptachlor	**Organometallic Compounds**
Kepone	Organic lead
Lindane (hexachlorocyclohexane)	
Methoxychlor	
Mirex	
Polychlorinated biphenyls (PCBs)	
Toxaphene	

[1] The criteria for classifying a chemical as volatile are Henry's law constant more than 10^{-5} atmos-m^3/mole and molecular weight less than 200 g/mole. (Smucker, 2002).
[2] A chemical not listed in Title 22 of the *California Code of Regulations*, but selected by DSTC or SWRCB to be included.

Section 57008, which was added to the HSC by SB 32, requires Cal/EPA to publish a list of screening numbers for protection of human health and safety and lists several activities that must be completed before the list is published (See HSC §57008(b)):

(2) The agency, in cooperation with the Department of Toxic Substances Control, the State Water Resources Control Board, and the Office of Environmental Health Hazard Assessment, shall publish a list of screening numbers for contaminants listed in paragraph (2) of subdivision (a) for the protection of human health and safety, and shall report on the feasibility of establishing screening numbers to protect water quality and ecological resources. The agency shall determine the screening numbers using the evaluation set forth in Section 25356.1.5 and the results of the peer review, and shall use the most stringent hazard criterion established pursuant to Subpart E of the National Oil and Hazardous Substances Pollution Contingency Plan (40 C.F.R. 300.400 et seq.), as amended. The agency shall set forth separate screening levels for unrestricted land uses and a restricted, nonresidential use of land. In determining each screening number, the agency shall consider all of the following:

(A) The toxicology of the contaminant, its adverse effects on human health and safety, biota, and its potential for causing environmental damage to natural resources, including, but not limited to, beneficial uses of the water of the state, including sources of drinking water.

(B) Risk assessments that have been prepared for the contaminant by federal or state agencies pursuant to environmental or public health laws, evaluations of the contaminant that have been prepared by epidemiological studies and occupational health programs, and risk assessments or other evaluations of the contaminant that have been prepared by governmental agencies or responsible parties as part of a project to remediate a contaminated property.

(C) Cleanup levels that have been established for the contaminant at sites that have been, or are being, investigated or remediated under Chapter 6.8 (commencing with Section 25300) of Division 20, or cleaned up or abated under Division 7 (commencing with Section 13000) of the Water Code or under any other remediation program administered by a federal or local agency.

(D) Screening numbers that have been published by other agencies in the state, in other states, and by federal agencies.

(E) The results of external scientific peer review of the screening numbers made pursuant to Section 57004.

SB 32 contains a requirement for methodology that is to be used in determining screening numbers. The statute states "The agency shall determine the screening numbers using the evaluation set forth in Section 25356.1.5 and the results of the peer review, and shall use the most stringent hazard criterion established pursuant to Subpart E of the National Oil and Hazardous Substances Pollution Contingency Plan (40 C.F.R. 300.400 et seq.), as amended."

OEHHA interprets this sentence to require use of methodology that is consistent with the most stringent U.S. EPA "Superfund" methodology for exposure assessment and hazard evaluation in determining screening numbers. This methodology has recently been reviewed by OEHHA (2001).

2. Summary of OEHHA's Review of Published Screening Numbers

For each contaminant on the list in Table 1, OEHHA staff reviewed documentation on "the toxicology of the contaminant, its adverse effects on human health and safety, biota, and its potential for causing environmental damage to natural resources, including, but not limited to, beneficial uses of the water of the state, including sources of drinking water." This information includes documents on the websites of OEHHA (www.oehha.ca.gov) and U.S. EPA (www.epa.gov). As part of this activity, OEHHA scientists have reviewed "Risk assessments that have been prepared for the contaminant by federal or state agencies pursuant to environmental or public health laws, evaluations of the contaminant that have been prepared by epidemiological studies and occupational health programs, and risk assessments or other evaluations of the contaminant that have been prepared by governmental agencies." This information is reviewed in documents listed in Appendix F.

In preparing this document, OEHHA staff did not formally consider "Cleanup levels that have been established for the contaminant at sites that have been, or are being, investigated or remediated under Chapter 6.8 (commencing with Section 25300) of Division 20, or cleaned up or abated under Division 7 (commencing with Section 13000) of the Water Code or under any other remediation program administered by a federal or local agency." This information will be included in the Cal/EPA report described in HSC §57009 (see Appendix A). Information in the report on cleanup levels will be considered if Cal/EPA publishes it before publication of final screening numbers.

OEHHA scientists have reviewed screening numbers published by agencies of the U.S. government, the government of the State of California and by agencies in other states. The screening numbers published by the federal government are the risk-based concentrations (RBCs) developed by U.S. EPA Region 3 (2000) and the preliminary remediation goals (PRGs) developed by U. S. EPA Region 9 (Smucker, 2002). The screening levels published by an agency of the State of California are the risk-based screening levels (RBSLs) and environmental screening levels (ESLs) published by the California Regional Water Quality Control Board (RWQCB) Region 2 (RWQCB, 2001, 2003). The ESL document (RWQCB, 2003) is an update of the RBSL document (RWQCB) in which the designation of the screening values was changed to "environmental screening levels" because a number of values were based on adverse environmental effects and not on direct human health impacts. OEHHA scientists have also reviewed cleanup levels published in the Model Toxics Control Act Cleanup Regulation of the State of Washington and a compilation of screening levels published by states other than California prepared by the California Center for Land Recycling (CCLR, 2003).

In reviewing RBCs published by U.S. EPA Region 3 (U.S. EPA Region 3, 2000) and the PRGs published U.S. EPA Region 9 (Smucker, 2002), OEHHA scientists noted that differences were attributable to differences in exposure algorithms used to calculate these screening levels or to differences in toxicity criteria used for calculating individual screening levels. RBSLs and ESLs published by the San Francisco Bay RWQCB were found to differ from U.S. EPA Region 9 PRGs primarily as a result of RBSL and ESL calculations including exposure resulting from inhalation of indoor air contaminated by chemicals in soil gas beneath buildings and including a factor for multiple chemical exposures that are not in the PRG calculation. Because inclusion of inhalation of chemicals from soil gas is potentially a more stringent approach to hazard evaluation, it is an appropriate methodology for screening number calculation as required by HSC §57008.

3. Public Workshops and Comments on OEHHA's Proposed Methodology for Calculating Advisory Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil

On March 12, 2004, OEHHA published the draft report *Proposed Methodology for Calculating Advisory Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (OEHHA, 2004)**.** On the same day, OEHHA published a notice in the California Regulatory Notice Register requesting public comments on the proposed methodology. The comment period began on March 12, 2004 and ended on April 16, 2004. The notice also announced two public workshops, one in the northern part of the state and the other in the southern part of the state, to brief interested parties on the scientific and policy bases for the development of the proposed screening numbers and to receive public comments. The first workshop was held in Sacramento on April 6, 2004 and the second was held in Los Angeles on April 7, 2004.

OEHHA staff have considered all written comments received during the comment period. These comments are in Appendix E together with OEHHA's responses. Based on consideration of comments and discussions that occurred during the two workshops, OEHHA has modified the previously published methodology for calculating soil-screening numbers. The major modifications are as follows:

- Screening numbers for volatile organic chemicals, calculated in units of mg per kg dry soil using the Johnson and Ettinger model for soil gas intrusion into indoor air, have been removed. This was done for two reasons. First, soil-screening numbers previously calculated are strongly dependant on site-specific parameters such as soil organic carbon content, and second, OEHHA believes the soil gas levels are the most appropriate basis for screening numbers based on soil gas intrusion into indoor air.

- For a commercial/industrial land use scenario, soil gas-screening numbers for VOCs are now based on an air-exchange rate of one per hour. This change was made because screening numbers are intended to be advisory at sites where new buildings may be constructed. New commercial/industrial buildings would be required to meet current building codes with air exchange rates of one per hour or higher. As recommended in the comments of DTSC and SWRCB staff, an air exchange rate of 0.5 per hour is used for a residential land use scenario.

- In the Johnson and Ettinger model for soil gas intrusion, the ratio of soil gas concentration to indoor air concentration for VOCs has been recalculated using the value for Q_{soil} currently recommended by U.S. EPA, 5 L/min. This change in methodology changes screening number for VOCs by a few percent from previously calculated values (OEHHA, 2004).

- Both the residential and commercial/industrial soil-screening numbers for lead were recalculated using LeadSpread 7, the current version of the DTSC spreadsheet for estimating lead exposure from soil lead. The default values of parameters, *i.e.*, values in the spreadsheet when it is downloaded at http://www.dtsc.ca.gov/ScienceTechnology/ledspred.html were used in calculations.

4. Methodology for Calculating Soil-Screening Numbers Based on Protection of Public Health and Safety

a. Selection of Environmental Transport and Exposure Assessment Methodology

In a survey of risk assessment methodologies used in programs within the boards and departments of Cal/EPA, OEHHA (2001) found that DTSC follows the exposure assessment methodology developed and published by U.S. EPA to support its "Superfund" program. The RWQCBs allow the same methodology to be used in evaluating their sites.

To estimate exposure to soil-bound contaminants other than lead and lead compounds, standard U.S. EPA "Superfund" algorithms were used. For an unrestricted land use scenario (possibly residential), screening numbers were calculated using Equations 4.1 and 4.2 from the U.S. EPA Region 9 PRG document (Smucker, 2002). These equations are reproduced in Appendix C as Equations C-1 and C-2, respectively. When the calculated screening number was greater than 10^5 mg/kg, the screening number for the chemical was set equal to 10^5 mg/kg.

To calculate screening numbers for a commercial/industrial land use scenario, Equations 4.3 and 4.4 from the PRG document were used (Equations C-2 and C-3 in Appendix C). For lead and lead compounds, screening numbers were calculated using the software LeadSpread 7 (DTSC, 2003). The residential lead screening level was calculated to be protective of at least 99 percent of children, and the commercial/industrial screening number was calculated to be protective of at least 99 percent of adult workers. When the calculated screening number was greater than 10^5 mg/kg, the screening number for the chemical was set equal to 10^5 mg/kg.

For purposes of calculating screening numbers based on contamination of indoor air by chemicals in soil gas, OEHHA scientists used the November 2002 version of the Johnson and Ettinger model with soil parameters that describe a dry coarse-grained soil of low organic carbon content and with other parameters recommended by U.S. EPA (2003). Because improved methodology for estimating impacts of vapor intrusion may be published in the near future, it may be appropriate to modify screening numbers for volatile contaminants as improved methodology becomes available.

For every volatile chemical, soil-gas-screening numbers were calculated to be protective of non-cancer chronic toxicity resulting from exposure to chemicals in indoor air contaminated by chemicals in soil gas. This was done by calculating the value of α, the ratio of indoor air chemical concentration to soil gas chemical concentration calculated by the Johnson and Ettinger model. A target indoor air concentration equal to the chronic reference concentration for air was divided by α to calculate the soil-gas-screening number. For details of these calculations, see Appendix B. For the volatile chemicals that are assessed as carcinogens by DTSC, the target indoor air concentration was calculated as the level giving an estimated lifetime cancer risk of 10^{-6}. This target level was divided by the calculated value of α to give the soil-gas-screening number. Values of α for VOCs are listed in Table 2 and Table 3.

At the request of staff of DTSC and SWQCB, OEHHA calculated screening numbers for soil gas beneath buildings constructed with engineered fill below sub-slab gravel and also calculated a second set of screening numbers for buildings constructed without a layer of engineered fill below the gravel. The second set of soil-gas-screening numbers is intended largely for sites with buildings that are typically older and that were constructed without a layer of compacted, fine-grained cohesive soil below sub-slab gravel.

To calculate α for older buildings constructed without a layer of engineered fill below sub-slab gravel, parameters describing a four-inch-thick porous material of low water and organic carbon content were entered into the model. To describe typical current building construction, parameters describing this gravel layer were used along with parameters describing a twelve-inch-thick layer of engineered fill (bulk density of 1.8 g/cm^3, organic carbon content of 0.002 %, total porosity of 0.3 cm^3/cm^3 and water-filled porosity of 0.15 cm^3/cm^3). For details of these calculations and all parameters used, see Appendix B.

The residential exposure scenario and the commercial/industrial scenario differ in the duration of exposure (30 years versus 25 years) and the frequency of exposure (350 days per year versus 250 days per year). The exposure to soil-bound chemicals during a work shift in the commercial/industrial scenario is identical to adult exposure to soil-bound chemicals in the residential scenario. Similarly, exposure to contaminated indoor air during a work shift is calculated assuming a pulmonary ventilation rate of 20 cubic meters of air per work shift, and the exposure to contaminated indoor air for an adult in the residential scenario is calculated assuming a pulmonary ventilation rate of 20 cubic meters of air per day (U.S. EPA, 2001).

In response to a recommendation of one UC peer review panel member, OEHHA scientists considered whether exposure to chemicals in garden crops grown on contaminated soil should be included in the calculation of screening numbers. OEHHA staff developed a list of reasons for (Pros) and reasons against (Cons) including this pathway (see Appendix D). Based on this analysis, exposure from garden crops was not included in the screening number calculation. Primarily these screening numbers are intended for the purpose of estimating the cost of cleanup at sites where the DTSC or the SWRCB have authority over site assessment and remediation. Both agencies, in most cases, do not consider the potential of exposure to contaminants in garden crops grown on contaminated soil as part of their remediation decisions for these sites. The one exception is for lead, which has specific methodologies developed and currently used for estimating exposure through the consumption of garden crops.

Table 2. Values of α, the Ratio of Indoor Air Concentration to Soil Gas Concentration, Resulting from Soil Gas beneath a Building Constructed with Engineered Fill below Sub-slab Gravel (Calculated Using the Johnson and Ettinger Model for Estimating Vapor Intrusion of Chemicals in Soil Gas)

Chemical	**Calculated Value of α Using:**	
	Residential air exchange rate (0.50/hr)	**Commercial/industrial air exchange rate (1.0/hr)**
Benzene	9.94 E-04	4.97 E-04
Carbon Tetrachloride	9.23 E-04	4.61 E-04
1,2-Dichloroethane	1.10 E-03	5.48 E-04
cis-1,2-Dichloroethylene	8.90 E-04	4.45 E-04
trans-1,2-Dichloroethylene	8.67 E-04	4.34 E-04
Ethylbenzene	9.01 E-04	4.50 E-04
Mercury (elemental)	4.70 E-04	2.35 E-04
Methyl tert-Butyl Ether	1.09 E-03	5.43 E-04
Naphthalene	7.72 E-04	3.86 E-04
Tetrachloroethylene	8.77 E-04	4.39 E-04
Tetraethyl Lead[1]	2.27 E-04	1.13 E-04
Toluene	9.87 E-04	4.93 E-04
1,1,1-Trichloroethane	9.23 E-04	4.61 E-04
Trichloroethylene	9.30 E-04	4.65 E-04
Vinyl Chloride	1.11 E-03	5.53 E-04
m-Xylene	8.62 E-04	4.31 E-04
o-Xylene	9.87 E-04	4.93 E-04
p-Xylene	9.15 E-04	4.57 E-04
	Average value of α = 8.79 E-04	Average value of α = 4.39 E-04
	Standard deviation = 2.16 E-04	Standard deviation = 1.11 E-04

[1] Tetraethyl lead does not meet the molecular weight criterion for classification as a volatile chemical stated by Smucker (2002). However, it is included in the analysis because the Henry's law constant for tetraethyl lead is much greater than 10^{-5} atmos-m^3/mole.

Table 3. Values of α, the Ratio of Indoor Air Concentration to Soil Gas Concentration, Resulting from Soil Gas beneath a Building Constructed without Engineered Fill below Sub-slab Gravel (Calculated Using the Johnson and Ettinger Model for Estimating Vapor Intrusion of Chemicals in Soil Gas)

Chemical	**Calculated Value of α Using:**	
	Residential air exchange rate (0.50/hr)	**Commercial/industrial air exchange rate (1.0/hr)**
Benzene	2.32 E-03	1.16 E-03
Carbon Tetrachloride	2.31 E-03	1.15 E-03
1,2-Dichloroethane	2.34 E-03	1.17 E-03
Cis-1,2-Dichloroethylene	2.30 E-03	1.15 E-03
trans-1,2-Dichloroethylene	2.29 E-03	1.15 E-03
Ethylbenzene	2.30 E-03	1.15 E-03
Mercury (elemental)	2.11 E-03	1.05 E-03
Methyl tert-Butyl Ether	2.34 E-03	1.17 E-03
Naphthalene	2.26 E-03	1.13 E-03
Tetrachloroethylene	2.29 E-03	1.15 E-03
Tetraethyl Lead[1]	1.77 E-03	8.84 E-04
Toluene	2.32 E-03	1.16 E-03
1,1,1-Trichloroethane	2.31 E-03	1.15 E-03
Trichloroethylene	2.31 E-03	1.15 E-03
Vinyl Chloride	2.34 E-03	1.17 E-03
m-Xylene	2.29 E-03	1.15 E-03
o-Xylene	2.32 E-03	1.16 E-03
p-Xylene	2.30 E-03	1.15 E-03
	Average value of α = 2.27 E-03	Average value of α = 1.13 E-03
	Standard deviation = 1.34 E-04	Standard deviation = 6.76 E-05

[1] Tetraethyl lead does not meet the molecular weight criterion for classification as a volatile chemical stated by Smucker (2002). However, it is included in the analysis because the Henry's law constant for tetraethyl lead is much greater than 10^{-5} atmos-m^3/mole.

b. Selection of Toxicity Criteria for Calculating Soil-Screening Numbers

In the survey of risk assessment methodologies used in programs within the boards and departments of Cal/EPA, OEHHA (2001) found that, in most cases, toxicity criteria developed by Cal/EPA are used when available and that U.S. EPA toxicity criteria are used if Cal/EPA criteria are not available. Consequently, screening numbers are calculated using Cal/EPA toxicity criteria when available, and are calculated using U.S. EPA toxicity criteria when Cal/EPA toxicity criteria are not available. Carcinogenic potency factors and chronic reference levels published by OEHHA and U.S. EPA for chemicals in Table 1 are listed in Table 4

Table 4. Toxicity Criteria Used for Calculating Cost-of-Cleanup Screening Numbers

Chemical	Carcinogenic Potency Factor (Source[1])		Reference Level[2] (Source[1])		
	CPF_o[3] $(mg/kg\text{-}d)^{-1}$	CPF_i[4] $(mg/kg\text{-}d)^{-1}$	RfD_o[5] (mg/kg-d)	RfD_i[6] (mg/kg-d)	REL[7] ($\mu g/m^3$)
Organic Acidic Chemicals					
2,4-D			1.00E-02 (I)	1.00E-02 (E)	
2,4,5-T			8.00E-03 (I)	8.00E-03 (E)	
Pentachlorophenol	0.081 (O)	0.018 (O)	3.00E-02 (I)	3.00E-02 (E)	
Organic Neutral Chemicals					
Aldrin	17 (O)	17 (O)	3.00E-05 (I)	3.00E-05 (E)	
Benzo(a)pyrene	12 (O)	3.9 (O)			
Chlordane	1.3 (O)	1.2	5.00E-04 (I)	2.00E-04 (E)	
DDD	0.24 (O)	0.24 (O)			
DDE	0.34 (O)	0.34 (O)			
DDT	0.34 (O)	0.34 (O)	5.00E-04 (I)	5.00E-04 (E)	
Dieldrin	16 (O)	16 (O)	5.00E-05 (I)	5.00E-05 (E)	
1,4-Dioxane	0.027 (O)	0.027 (O)		8.57E-01 (O)*	3.00E+03 (O)
Dioxin (2,3,7,8-TCDD)	130,000 (O)	130,000 (O)		1.14E-08 (O)*	4.00E-05 (O)
Endrin			3.00E-04 (I)	3.00E-04 (E)	
Heptachlor	4.1(O)	4.1 (O)	5.00E-04 (I)	5.00E-04 (E)	
Lindane	1.1 (O)	1.1 (O)	3.00E-04 (I)	3.00E-04 (E)	
Kepone	16 (O)	16 (O)			
Methoxychlor			5.00E-03 (I)	5.00E-03 (E)	
Mirex	18 (O)	18 (O)	2.00E-04 (I)	2.00E-04 (E)	
PCBs	5 (O)	2 (O)			
Toxaphene	1.2 (O)	1.2 (O)			

Chemical	Carcinogenic Potency Factor (Source[1])		Reference Level[2] (Source[1])		
	CPF_o[3] (mg/kg-d)$^{-1}$	**CPF_i[4] (mg/kg-d)$^{-1}$**	**RfD_o[5] (mg/kg-d)**	**RfD_i[6] (mg/kg-d)**	**REL[7]($\mu g/m^3$)**
Inorganic Chemicals					
Antimony and compounds			4.00E-04 (I)		
Arsenic	9.45 (O)	12 (O)	3.00E-04 (I)	8.57E-06 (O)*	3.00E-02 (O)
Barium and compounds			7.00E-02 (I)	1.43E-04 (I)	
Beryllium and compounds		8.4 (O)	2.00E-03 (O)	2.00E-06 (O)*	7.00E-03 (O)
Beryllium oxide	7 (O)	8.4 (O)			
Beryllium sulfate	3,000 (O)	3,000 (O)			
Cadmium and compounds	0.38 (O)	15 (O)	5.00E-04 (I)	5.71E-06 (O)*	2.00E-02 (O)
Chromium III			1.50E+00 (I)		
Chromium VI		510 (O)	3.00E-03 (I)	2.20E-06 (I)	
Cobalt			2.00E-02 (I)	5.70E-07 (I)	
Copper and compounds			4.00E-02 (H)		
Fluoride			6.00E-02 (I)	3.71E-03 (O)*	1.30E+01 (O)
Lead and lead compounds					
Lead acetate	0.28(O)	0.28(O)		2.57E-05 (O)*	9.00E-02(O)

Chemical	Carcinogenic Potency Factor (Source[1])		Reference Level[2] (Source[1])		
	CPF_o[3] (mg/kg-d)$^{-1}$	CPF_i[4] (mg/kg-d)$^{-1}$	RfD_o[5] (mg/kg-d)	RfD_i[6] (mg/kg-d)	REL[7] (μg/m^3)
Mercury and compounds			3.00E-04 (I)	2.6 E-05 (O)*	9.0 E-02 (O)
Molybdenum			5.00E-03 (I)		
Nickel and compounds		0.91 (O)	2.00E-02 (I)		
Nickel subsulfide	1.7 (O)	1.7 (O)			
Perchlorate	TBD (O)				
Selenium			5.00E-03 (I)	5.71E-03 (O)*	2.00E+01 (O)
Silver and compounds			5.00E-03 (I)		
Thallium and compounds			6.60E-05 (I)		
Vanadium and compounds			7.00E-03 (H)		
Zinc			3.00E-01 (I)		
Volatile Chemicals					
Benzene	0.1 (O)	0.1 (O)	3.00E-03 (I)	1.71E-02 (O)*	6.00E+01 (O)
Carbon tetrachloride	0.15 (O)	0.15 (O)	7.00E-04 (I)	1.14E-02 (O)*	4.00E+01 (O)
1,2-Dichloroethane	0.047 (O)	0.073 (O)	3.00E-02 (I)		
cis-1,2-Dichloroethylene			1.00E-02 (I)	1.00E-02 (I)	
trans 1,2-Dichloroethylene			2.00E-02 (I)	2.00E-02 (I)	
Ethylbenzene			1.00E-01 (I)	5.71E-01 (O)*	2.00E+03 (O)

Chemical	Carcinogenic Potency Factor (Source[1])		Reference Level[2] (Source[1])		
	CPF_o[3] $(mg/kg\text{-}d)^{-1}$	CPF_i[4] $(mg/kg\text{-}d)^{-1}$	RfD_o[5] (mg/kg-d)	RfD_i[6] (mg/kg-d)	REL[7] ($\mu g/m^3$)
Methyl tert butyl ether	0.0018 (O)	0.00091 (O)		2.28 E+00 (O)	8.0 E+03 (O)
Naphthalene	0.12 (O)	0.12 (O)	2.00E-02 (I)	2.57E-03 (O)	9.00E+00 (O)
Tetrachloroethylene	0.54 (O)	0.021 (O)	1.00E-02 (I)	1.00E-02 (O)	3.5 E+01 (O)
Tetraethyl lead			1.00E-07 (I)	1.00E-07 (I)	
Toluene			2.00E-01 (I)	8.57E-02 (O)	3.00E+02 (O)
Trichloroethane, 1,1,1-			2.80E-01 (I)	6.30E-01 (I)	
Trichloroethylene	0.013 (O)	0.007 (O)	3.00E-04 (I)	1.71E-01 (O)	6.00E+02 (O)
Vinyl chloride	0.27 (O)	0.27 (O)	3.00E-03 (I)	2.86E-02 (I)	
Xylenes			2.00E-01 (O)	2.00E-01 (O)	7.00E+02 (O)

[1] (O) OEHHA, (I) US EPA IRIS, (O)* Computed from OEHHA REL, (H) Set equal to tabled oral RfD, US EPA (1997)
[2] Reference dose for chronic toxicity other than cancer from long-term exposure
[3] Carcinogenic potency factor for exposure by the oral route
[4] Carcinogenic potency factor for exposure by the inhalation route
[5] Reference dose for chronic exposure by the oral route
[6] Reference dose for chronic exposure by the inhalation route
[7] Reference exposure level developed by Air Toxics and Epidemiology Section of OEHHA

Screening numbers based on cancer risk were calculated for all chemicals in Table 4 that are listed as "known to the state to cause cancer" (CCR, Title 22, §12000) or have recently been included in cancer risk calculations in assessments used by DTSC or RWQCB for remediation decisions. Screening numbers based on cancer risk were also calculated for MTBE because potential carcinogenic risk has been used in setting cleanup requirements for MTBE contamination by DTSC. The algorithms, parameters and methodologies used in these calculations are described in Appendix B and Appendix C

5. Soil-Screening Numbers

a. Non-Volatile Chemicals

For non-volatile chemicals, soil-screening numbers for an "unrestricted" land use scenario, the residential scenario, are listed in column 2 of Table 5. Algorithms used in these calculations are the U.S. EPA algorithms for a residential scenario (Equations C-1 and C-2 for carcinogens and non-carcinogens, respectively, in Appendix C). Soil-screening numbers for a commercial/industrial scenario calculated using U.S. EPA's algorithms for a commercial/industrial scenario (Equations C-3 and C-4 for carcinogens and non-carcinogens, respectively, in Appendix C) are listed in column 4 of Table 5.

Table 5. Soil-Screening Numbers (mg/kg soil) for Nonvolatile Chemicals Based on Total Exposure to Contaminated Soil: Inhalation, Ingestion and Dermal Absorption

Chemical	**Soil-Screening Number (mg per kg of dry soil)**			
	Residential Scenario		**Commercial/Industrial Scenario**	
Organic Acidic Chemicals		Basis[1]		Basis[1]
2,4-D	6.9E+02	(nc)	7.7E+03	(nc)
2,4,5-T	5.5E+02	(nc)	6.1E+03	(nc)
Pentachlorophenol	4.4E+00	(ca)	1.3E+01	(ca)
Organic Neutral Chemicals				
Aldrin	3.3E-02	(ca)	1.3E-01	(ca)
Benzo(a)pyrene	3.8E-02	(ca)	1.3E-01	(ca)
Chlordane	4.3E-01	(ca)	1.7E+00	(ca)
DDD	2.3E+00	(ca)	9.0E+00	(ca)
DDE	1.6E+00	(ca)	6.3E+00	(ca)
DDT	1.6E+00	(ca)	6.3E+00	(ca)
Dieldrin	3.5E-02	(ca)	1.3E-01	(ca)
1,4-Dioxane	1.8E+01	(ca)	6.4E+01	(ca)
Dioxin (2,3,7,8-TCDD)	4.6E-06	(ca)	1.9E-05	(ca)
Endrin	2.1E+01	(nc)	2.3E+02	(nc)
Heptachlor	1.3E-01	(ca)	5.2E-01	(ca)
Lindane	5.0E-01	(ca)	2.0E+00	(ca)

Chemical	Soil-Screening Number (mg per kg of dry soil)			
	Residential Scenario		Commercial/Industrial Scenario	
Kepone	3.5E-02	(ca)	1.3E-01	(ca)
Methoxychlor	3.4E+02	(nc)	3.8E+03	(nc)
Mirex	3.1E-02	(ca)	1.2E-01	(ca)
PCBs	8.9E-02	(ca)	3.0E-01	(ca)
Toxaphene	4.6E-01	(ca)	1.8E+00	(ca)
Inorganic Chemicals				
Antimony and compounds	3.0E+01	(nc)	3.8E+02	(nc)
Arsenic[2]	7.0E-02	(ca)	2.4E-01	(ca)
Barium and compounds	5.2E+03	(nc)	6.3E+04	(nc)
Beryllium and compounds	1.5E+02	(nc)	1.7E+03	(nc)
Beryllium oxide[3]	9.1E-02	(ca)	4.1E-01	(ca)
Beryllium sulfate[3]	2.1E-04	(ca)	9.5E-04	(ca)
Cadmium and compounds	1.7E+00	(ca)	7.5E+00	(ca)
Chromium III	1.0E+05	(nc,max)	1.0E+05	(nc,max)
Chromium VI	1.7E+01	(ca)	3.7E+01	(ca)
Cobalt	6.6E+02	(nc)	3.2E+03	(nc)
Copper and compounds	3.0E+03	(nc)	3.8E+04	(nc)
Fluoride	4.6E+03	(nc)	5.7E+04	(nc)
Lead and lead compounds	1.5E+02	(nc)	3.5E+03[5]	(nc)
Lead acetate[3]	2.3E+00	(ca)	1.0E+01	(ca)
Mercury and compounds	1.8E+01	(nc)	1.8E+02	(nc)
Molybdenum	3.8E+02	(nc)	4.8E+03	(nc)
Nickel and compounds	1.6E+03	(nc)	1.6E+04	(nc)
Nickel subsulfide[3]	3.8E-01	(ca)	1.1E+04	(ca)
Perchlorate[4]	postponed	(nc)	postponed	(nc)
Selenium	3.8E+02	(nc)	4.8E+03	(nc)
Silver and compounds	3.8E+02	(nc)	4.8E+03	(nc)
Thallium and compounds	5.0E+00	(nc)	6.3E+01	(nc)
Vanadium and compounds	5.3E+02	(nc)	6.7E+03	(nc)
Zinc	2.3E+04	(nc)	1.0E+05	(nc)

[1] (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a reference level in Table 3 for chronic toxic effects other than cancer, (max) denotes the screening number is based on the maximum concentration allowed, 100,000 mg/kg, and not toxicity.

[2] The screening numbers for arsenic are for contamination resulting from human activity. Concentrations of naturally occurring arsenic may be far above the screening number. When levels of arsenic at a site are a concern, the agency with authority over remediation decisions should be consulted.

[3] These metal salts are significantly (greater than 10-fold) more toxic than the values for the metals in general. If it is known that this chemical was used at the site, the screening number for this chemical should be used instead of the screening number for the metal and its compounds.

[4] Calculation of a screening number for the chemical has been postponed until the toxicity criterion currently being developed by OEHHA is published as a final document

[5] This screening number is based on the methods described in this document. However, this particular screening number is above the Total Threshold Limit Concentration for lead, 1,000 mg/kg, as defined in Title 22 of the *California Code of Regulations.* Because of the regulatory implications during remediation of a site, it is recommended that the actual screening level used be below 1,000 mg/kg.

b. Volatile Chemicals

For volatile chemicals, soil-gas-screening numbers are listed in Table 6 and Table 7. These screening numbers are based on inhalation of indoor air contaminated by soil gas and are calculated using the Johnson and Ettinger model (USEPA, 2003). Assumptions and parameters used in these calculations are listed in Appendix B. OEHHA recommends using soil gas analyses for screening purposes whenever site history or soil analysis indicates that any of the volatile chemicals listed in Tables 6 (7) is present.

When screening numbers, based on calculation methods used for non-volatile chemicals in Table 5, were developed for these volatile chemicals, the screening numbers were much higher in every case. While such a comparison is not provided here, the comparison is made in the draft document, *"Proposed Methodology for Calculating Advisory Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil"* (*Table 5*, OEHHA, 2004). This comparison was based on the partitioning of a chemical among the three soil phases that is incorporated in the Johnson and Ettinger model.

Table 6. Soil-Gas-Screening Numbers for Volatile Chemicals below Buildings Constructed with Engineered Fill below Sub-slab Gravel

Chemical	**Soil-Gas-Screening Number (µg per liter of soil gas)**			
	Residential Scenario		**Commercial/Industrial Scenario**	
Benzene	8.5 E-02	(ca)*	2.8 E-01	(ca)
Carbon Tetrachloride	6.3 E-02	(ca)	2.1 E-01	(ca)
1,2-Dichloroethane	1.1 E-01	(ca)	3.6 E-01	(ca)
cis-1,2-Dichloroethylene	4.1 E+01	(nc)*	1.2 E+02	(nc)
trans-1,2-Dichloroethylene	8.4 E+01	(nc)	2.4 E+02	(nc)
Ethylbenzene	postponed	(ca)	postponed	(ca)
Mercury (elemental)	2.0 E-01	(nc)	5.6 E-01	(nc)
Methyl *tert*-Butyl Ether	8.6 E+00	(ca)	2.9 E+01	(ca)
Naphthalene	9.3 E-02	(ca)	3.1 E-01	(ca)
Tetrachloroethylene	4.7 E-01	(ca)	1.6 E+00	(ca)
Tetraethyl Lead	1.6 E-03	(nc)	4.5 E-03	(nc)
Toluene	3.2 E+02	(nc)	8.9 E+02	(nc)
1,1,1-Trichloroethane	2.5 E+03	(nc)	7.0 E+03	(nc)
Trichloroethylene	1.3 E+00	(ca)	4.4 E+00	(ca)
Vinyl Chloride	2.8 E-02	(ca)	9.5 E-02	(ca)
m-Xylene	8.5 E+02	(nc)	2.4 E+03	(nc)
o-Xylene	7.4 E+02**	(nc)	2.1 E+03**	(nc)

Chemical	Soil-Gas-Screening Number (µg per liter of soil gas)			
	Residential Scenario		Commercial/Industrial Scenario	
p-Xylene	8.0 E+02	(nc)	2.2 E+03	(nc)

* (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a reference level in Table 3 for chronic toxic effects other than cancer.
** Recommended soil-gas-screening number for xylenes. The representative value for xylenes is based on the calculated lowest health-protective one amongst the three isomers.

Table 7. Soil-Gas-Screening Numbers for Volatile Chemicals below Buildings Constructed without Engineered Fill below Sub-slab Gravel

Chemical	Soil-Gas-Screening Number (µg per liter of soil gas)			
	Residential Scenario		Commercial/Industrial Scenario	
Benzene	3.6 E-02	(ca)*	1.2 E-01	(ca)
Carbon Tetrachloride	2.5 E-02	(ca)	8.5 E-02	(ca)
1,2-Dichloroethane	5.0 E-02	(ca)	1.7 E-01	(ca)
cis-1,2-Dichloroethylene	1.6 E+01	(nc)*	4.4 E+01	(nc)
trans-1,2-Dichloroethylene	3.2 E+01	(nc)	8.9 E+01	(nc)
Ethylbenzene	postponed	(ca)	postponed	(ca)
Mercury (elemental)	4.5 E-02	(nc)	1.3 E-01	(nc)
Methyl *tert*-Butyl Ether	4.0 E+00	(ca)	1.3 E+01	(ca)
Naphthalene	3.2 E-02	(ca)	1.1 E-01	(ca)
Tetrachloroethylene	1.8 E-01	(ca)	6.0 E-01	(ca)
Tetraethyl Lead	2.1 E-04	(nc)	5.8 E-04	(nc)
Toluene	1.4 E+02	(nc)	3.8 E+02	(nc)
1,1,1-Trichloroethane	9.9 E+02	(nc)	2.8 E+03	(nc)
Trichloroethylene	5.3 E-01	(ca)	1.8 E+00	(ca)
Vinyl Chloride	1.3 E-02	(ca)	4.5 E-02	(ca)
m-Xylene	3.2 E+02	(nc)	8.9 E+02	(nc)
o-Xylene	3.2 E+02**	(nc)	8.8 E+02**	(nc)
p-Xylene	3.2 E+02	(nc)	8.9 E+02	(nc)

* (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a reference level in Table 3 for chronic toxic effects other than cancer.
** Recommended soil-gas-screening number for xylenes. The representative value for xylenes is based on the calculated lowest health-protective one amongst the three isomers.

6. Application of Screening Numbers to Sites Where More Than One Chemical Contaminant Has Been Identified

For sites with more than one non-carcinogenic chemical contaminant, the hazard index should be calculated. For non-carcinogenic chemical species $S_1, S_2, \ldots, S_n$ with soil concentrations or soil gas concentrations $C_1, C_2, \ldots, C_n$ and soil-screening numbers or soil-gas-screening numbers $SN_1, SN_2, \ldots, SN_n$, the non-carcinogenic hazard index is

$$Hazard\ Index = C_1/SN_1 + C_2/SN_2 + \ldots + C_n/SN_n.$$

For sites with more than one carcinogenic chemical contaminant, the carcinogenic cancer risk index should be calculated. For carcinogenic chemical species $S_1, S_2, \ldots, S_n$ with soil concentrations or soil gas concentrations $C_1, C_2, \ldots, C_n$ and soil-screening numbers or soil-gas-screening numbers $SN_1, SN_2, \ldots, SN_n$, the cancer risk index is also calculated using the expression

$$Risk\ Index = C_1/SN_1 + C_2/SN_2 + \ldots + C_n/SN_n.$$

For sites with multiple contaminants, the risk index for carcinogenic chemicals and the hazard index for non-carcinogenic chemicals should be individually compared to 1 for advisory purposes in estimating costs of cleanup. When either value is above 1, having all the carcinogenic or non-carcinogenic contaminants be individually below their respective screening number may not be sufficient to avoid the cost of remediation.

In an example of how to do this calculation, it is assumed there is a proposed residential site where nine listed chemical contaminants are found in the soil. There are five chemicals listed as non-carcinogens and four chemicals listed as carcinogens. Six of the chemicals are non-volatile and three chemicals are volatile. Soil concentration levels have been obtained for the non-volatile chemicals and soil gas level concentrations have been obtained for the volatile chemicals.

The information from the example is displayed in Table 8. The non-carcinogenic chemicals are listed separately from the carcinogenic chemicals since the carcinogenic endpoint is considered to be a different endpoint from the non-carcinogenic endpoints. The volatile and nonvolatile chemicals are listed together for both the non-carcinogenic and carcinogenic chemicals because volatility of the chemical does not affect the calculation of the Hazard Index or Risk Index.

In this example, the Risk Index suggests that the carcinogenic chemical contaminants at this site do not pose a carcinogenic risk and would not be cause for remediation. The Hazard Index is above 1, so there may be a need for site remediation of the non-carcinogenic chemical contaminants. Because the Hazard Index is not much greater than 1, the extent of remediation may be small. Only one chemical, silver compounds, really drives the assessment. If this one contaminant can be easily removed from the site, remediation may be inexpensive and quick. On the other hand, if it is a contaminant over the whole site and to a significant depth, remediation may be extensive and costly. In that case, the results may be discussed with the appropriate regulatory agencies to determine if a more specific and detailed evaluation is needed to determine if or what type of remediation needs to be done.

It needs to be emphasized here that the Hazard Index and the Risk Index obtained by this method do not indicate the site does or does not pose a human health hazard. The results are an indication whether further investigation may be warranted at the site and to provide some basis on the level of effort and cost that may be needed to remediate the site.

Table 8. Calculation of the Hazard Index and Carcinogenic Risk Index Using a Hypothetical Example

Chemical	Volatility	Measured Soil Concentration or Soil Gas Concentration	Screening Soil Number or Screening Soil Gas Number	Index
Noncarcinogens		**C**	**SN**	**C/SN**
Antimony and compounds	NV	2.1E+00	3.0E+01	0.070
cis-1,2-Dichloroethylene	V	1.3E+01	4.1E+01	0.265
Methoxychlor	NV	6.4E+00	3.4E+02	0.019
Silver and compounds	NV	5.1E+02	3.8E+02	1.342
Toluene	V	1.8E+00	3.2E+02	0.005
Hazard Index				**1.751**
Carcinogens				
Chlordane	NV	3.1E-02	4.3E-01	0.072
PCBs	NV	4.0E-04	8.9E-02	0.005
Tetrachloroethylene	V	2.4E-01	4.7E-01	0.421
Toxaphene	NV	9.3E-03	4.6E-01	0.020
Risk Index				**0.608**

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Appendix A: Text of Sections 57008, 57009 and 57010 added to the California Health and Safety Code by The California Land Environmental Restoration and Reuse Act (Escutia), Chapter 764, 2001)

57008. (a) For purposes of this section, the following definitions apply:

(1) "Agency" means the California Environmental Protection Agency.

(2) "Contaminant" means all of the following:

(A) A substance listed in Tables II and III of subparagraphs (A) and (B) of paragraph (2) of subdivision (a) of Section 66261.24 of Title 22 of the California Code of Regulations.

(B) The five halogenated hydrocarbon industrial solvents that, in the experience of the State Water Resources Control Board and the Department of Toxic Substances Control are most commonly found as contaminants at sites subject to remediation under the Carpenter-Presley-Tanner Hazardous Substances Account Act (Chapter 6.8 (commencing with Section 25300) of Division 20) and the Porter-Cologne Water Quality Control Act (Division 7 (commencing with Section 13000) of the Water Code).

(C) Ten hazardous substances not included under subparagraphs (A) and (B) that, in the experience of the Department of Toxic Substances Control and the State Water Resources Control Board, are most commonly found as contaminants at sites subject to remediation under the Carpenter-Presley-Tanner Hazardous Substances Account Act (Chapter 6.8 (commencing with Section 25300) of Division 20) and the Porter-Cologne Water Quality Control Act (Division 7 (commencing with Section 13000) of the Water Code).

(3) "Screening number" means the concentration of a contaminant published by the agency as an advisory number pursuant to the process established in subdivisions (b) and (c). A screening number is solely an advisory number, and has no regulatory effect, and is published solely as a reference value that may be used by citizen groups, community organizations, property owners, developers, and local government officials to estimate the degree of effort that may be necessary to remediate a contaminated property. A screening number may not be construed as, and may not serve as, a level that can be used to require an agency to determine that no further action is required or a substitute for the cleanup level that is required to be achieved for a contaminant on a contaminated property. The public agency with jurisdiction over the remediation of a contaminated site shall establish the cleanup level for a contaminant pursuant to the requirements and the procedures of the applicable laws and regulations that govern the remediation of that contaminated property and the cleanup level may be higher or lower than a published screening number.

(b) (1) During the same period when the agency is carrying out the pilot study required by Section 57009 and preparing the informational document required by Section 57010, the agency shall initiate a scientific peer review of the screening levels published in Appendix 1 of Volume 2 of the technical report published by the San Francisco Regional Water Quality Control Board entitled "Application of Risk-Based Screening Levels and Decision-Making to Sites with Impacted Soil and Groundwater (Interim Final-August 2000)." The agency shall conduct the scientific peer review process in accordance with Section 57004, and shall limit the review to those substances specified in paragraph (2) of subdivision (a). The agency shall complete the peer review process on or before December 31, 2004.

(2) The agency, in cooperation with the Department of Toxic Substances Control, the State Water Resources Control Board, and the Office of Environmental Health Hazard Assessment, shall publish a list of screening numbers for contaminants listed in paragraph (2) of subdivision (a) for the protection of human health and safety, and shall report on the feasibility of establishing screening numbers to protect water quality and ecological resources. The agency shall determine the screening numbers using the evaluation set forth in Section 25356.1.5 and the results of the peer review, and shall use the most stringent hazard criterion established pursuant to Subpart E of the National Oil and Hazardous Substances Pollution Contingency Plan (40 C.F.R. 300.400 et seq.), as amended. The agency shall set forth separate screening levels for unrestricted land uses and a restricted, nonresidential use of land. In determining each screening number, the agency shall consider all of the following:

(A) The toxicology of the contaminant, its adverse effects on human health and safety, biota, and its potential for causing environmental damage to natural resources, including, but not limited to, beneficial uses of the water of the state, including sources of drinking water.

(B) Risk assessments that have been prepared for the contaminant by federal or state agencies pursuant to environmental or public health laws, evaluations of the contaminant that have been prepared by epidemiological studies and occupational health programs, and risk assessments or other evaluations of the contaminant that have been prepared by governmental agencies or responsible parties as part of a project to remediate a contaminated property.

(C) Cleanup levels that have been established for the contaminant at sites that have been, or are being, investigated or remediated under Chapter 6.8 (commencing with Section 25300) of Division 20, or cleaned up or abated under Division 7 (commencing with Section 13000) of the Water Code or under any other remediation program administered by a federal or local agency.

(D) Screening numbers that have been published by other agencies

in the state, in other states, and by federal agencies.
(E) The results of external scientific peer review of the screening numbers made pursuant to Section 57004.

(c) (1) Before publishing the screening numbers pursuant to subdivision (b), the agency shall conduct two public workshops, one in the northern part of the state and the other in the southern part of the state, to brief interested parties on the scientific and policy bases for the development of the proposed screening numbers and to receive public comments.

(2) Following publication of the screening numbers pursuant to subdivision (b), the agency shall conduct three public workshops in various regions of the state to discuss the screening numbers and to receive public comments. The agency shall select an agency representative who shall serve as the chairperson for the workshops, and the agency shall ensure that ample opportunity is available for public involvement in the workshops. The deputy secretary for external affairs shall actively seek out participation in the workshops by citizen groups, environmental organizations, community-based organizations that restore and redevelop contaminated properties for park, school, residential, commercial, open-space or other community purposes, property owners, developers, and local government officials.

(d) Following the workshops required by subdivision (c), the agency shall revise the screening numbers as appropriate. The agency shall, from time to time, revise the screening numbers as necessary as experience is gained with their use and shall add screening numbers for contaminants to the list as information concerning remediation problems becomes available.

(e) The agency shall publish a guidance document for distribution to citizen groups, community-based organizations, property owners, developers, and local government officials that explains how screening numbers may be used to make judgments about the degree of effort that may be necessary to remediate contaminated properties, to facilitate the restoration and revitalization of contaminated property, to protect the waters of the state, and to make more efficient and effective decisions in local-level remediation programs.

(f) Nothing in this section affects the authority of the Department of Toxic Substances Control, the State Water Resources Control Board, or a regional water quality control board to take action under any applicable law or regulation regarding a release or threatened release of hazardous materials.

SEC. 3. Section 57009 is added to the Health and Safety Code, to read:

57009. For purposes of this section, the following terms have the following meanings:

(1) "Agency" means the California Environmental Protection Agency.
(2) "Contaminated property" means a property located in the study area that is, or may be, subject to remediation pursuant to Chapter 6.10 (commencing with Section 25401) of Division 20 .
(3) "Pilot screening numbers" means the levels published in Appendix 1 of Volume 2 of the technical report, except that, for purposes of the study required by this section, the levels published in Appendix 1 may be used only as informational screening numbers, as provided in paragraph (3) of subdivision (a) of Section 57008 , and in a manner consistent with the technical report.
(4) "Study area" means the Los Angeles, Santa Ana, and San Diego regions, as established pursuant to Section 13200 of the Water Code.
(5) "Technical report" means the technical report published by the San Francisco Regional Water Quality Control Board entitled "Application of Risk-Based Screening Levels and Decision-Making to Sites with Impacted Soil and Groundwater (Interim Final-August 2000)" and any updates to the technical report.
(b) The agency shall conduct a study to evaluate the usefulness of pilot screening numbers in encouraging remediation at contaminated properties in the study area. The agency shall conduct the study in accordance with the requirements of subdivision (c) and shall develop information that bears on all of the following issues:
(1) The extent to which the pilot screening numbers are an adequate basis for estimating the degree of effort that may be necessary to remediate contaminated properties.
(2) Whether the availability of the pilot screening numbers as information provides an adequate basis for seeking funding from public or private sector sources to evaluate the feasibility of remediating a contaminated property and restoring it to productive use.
(3) The stages in the remediation process for which the pilot screening numbers are of the most use.
(4) The types of information derived from site investigations that are most useful, when combined with the pilot screening numbers, in making decisions concerning the feasibility of remediation of contaminated properties.
(5) Whether the availability of pilot screening numbers as information enables a person interested in the remediation of a contaminated property to determine, within an acceptable range, the relationship between the estimated cost of remediation of the property and the economic and social benefits that may derive from the property if it is restored to any of its reasonably foreseeable uses.
(c) The agency shall carry out the study required by subdivision (b) in the study area over the period commencing on March 1, 2002, until March 1, 2004. On or before June 30, 2004, the agency shall do

all of the following:
(1) Prepare a brief document that explains what are screening numbers, what is the relationship of screening numbers to regulatory cleanup levels, and how screening numbers may be used to make judgments concerning the feasibility of restoring a contaminated property to productive use, and the degree of effort that may be required to remediate the property.
(2) Post the explanatory document prepared pursuant to paragraph (1), the technical report, and updates to the technical report, on the Internet Web sites maintained by the Department of Toxic Substances Control and by the California regional water quality control boards that have jurisdiction in the study area.
(3) Identify 25 contaminated properties in the study area that are remediated during the test period of March 1, 2002, until March 1, 2004, to determine the effects of the availability of the pilot screening numbers as information on the course of remediation and revitalization of contaminated properties and on assisting persons involved with the remediation to make meaningful decisions concerning the feasibility and effectiveness of remediation activities and assess whether the pilot screening numbers were more or less stringent than the required cleanup levels.
(d) The agency may not include in the pilot study more than 25 remediated contaminated properties in the study area.
(e) The study required by this section does not create any legal or regulatory authorization to use the pilot screening numbers. The pilot screening numbers are only available as information.
(f) The agency shall evaluate the information developed by the study required by this section, use the information as appropriate to carry out the requirements of Section 57008 , and, to the extent the information is timely, provide the information and the evaluation to the contractor preparing the study required by Section 57010.
(g) The agency shall post the information developed by the study required by this section and the information required under paragraph (2) of subdivision (c) on its Internet Web site.
(h) Nothing in this section affects the authority of the Department of Toxic Substances Control, the State Water Resources Control Board, or a regional water quality control board to take action under any applicable law or regulation regarding a release or threatened release of hazardous materials.
SEC. 4. Section 57010 is added to the Health and Safety Code, to read:
57010. (a) On or before January 1, 2003, the California Environmental Protection Agency shall publish an informational document to assist citizen groups, community-based organizations, interested laypersons, property owners, local government officials, developers, environmental organizations, and environmental

consultants to understand the factors that are taken into account, and the procedures that are followed, in making site investigation and remediation decisions under the Carpenter-Presley-Tanner Hazardous Substances Account Act (Chapter 6.8 (commencing with Section 25300) of Division 20) and under the Porter-Cologne Water Quality Control Act (Division 7 (commencing with Section 13000) of the Water Code).

(b) The agency shall make the informational document required by this section available to any person who requests it at no charge and shall also post the public information manual on the agency's Internet Web site. The agency shall update both the printed informational document and the Web site at appropriate intervals as new legislation or revised policies affect the administration of the Carpenter-Presley-Tanner Hazardous Substances Account Act (Chapter 6.8 (commencing with Section 25300) of Division 20) and the Porter-Cologne Water Quality Control Act (Division 7 (commencing with Section 13000) of the Water Code).

SEC. 5. It is the intent of the Legislature that funds be appropriated to the California Environmental Protection Agency in the annual Budget Act or in another measure to implement paragraph (2) of subdivision (b) and subdivisions (c) to (e), inclusive, of Section 57008 of, and Section 57009 of, the Health and Safety Code. The agency shall expend existing peer review funds appropriated to review hazardous substance exposure levels to complete the peer review process set forth in paragraph (1) of subdivision (b) of Section 57008 and to make the results of the peer review public, and shall expend existing funds appropriated for public informational purposes to implement Section 57010. After the agency, or any board, office, or department within the agency, has expended the funds authorized by this section, the agency, or any board, office, or department within the agency, is not required to take any further action to implement Sections 57008 and 57009 of the Health and Safety Code, until the Legislature appropriates funds in the annual Budget Act or in another measure for those purposes.

Appendix B: Derivation of Risk-Based Soil-Gas-Screening Numbers

1. Introduction

The California Environmental Protection Agency (Cal/EPA) was required to develop soil-screening numbers for a number of chemicals of interest to the State of California by the California Land Environmental Restoration and Reuse Act (Escutia, Chapter 764, Statues of 2001). The task of producing a list of screening numbers based on "protection of public health and safety" has been assigned to the Office of Environmental Health Hazard Assessment (OEHHA). The Soil to Indoor Air Pathway is of major significance when dealing with volatile chemicals. Johnson and Ettinger (1991) developed a screening-level model for estimating the transport of contaminant vapors from a subsurface source into indoor air space. The model relates indoor air concentrations to soil gas concentrations. To facilitate the use of the Johnson and Ettinger model, US EPA published a spreadsheet version of the model. The spreadsheet can be used to calculate generic health-protective soil gas concentrations among others. When compared to site data those soil gas concentrations indicate whether or not a risk-based soil gas level is exceeded at the site. Therefore, a risk-based soil gas level can be used as a first-tier screening tool to identify sites needing further assessment.

A number of empirical studies have proven that calculating and using bulk soil-screening concentrations is a process involving significant uncertainty. This uncertainty is related to the modeling of the chemical partitioning among the soil air, soil water, and soil particle phase and results in underestimation or overestimation of the calculated soil-screening numbers depending on the chemical and/or soil properties. That is why the US EPA (2003e) recommends collecting soil gas data from the site of interest to be compared to calculated health protective soil gas levels.

This appendix presents the development of risk-based soil-gas-screening numbers for the soil to indoor air pathway. The resulting values will be incorporated as a component of the generic screening procedure for a number of chemicals of interest to the State of California.

2. Limitations of the Derived Screening Numbers

There are several limitations of the use of soil-gas-screening numbers.

2.1. Policy-Related

- These values should be used as screening numbers to assess the need of further site investigation. They are not clean-up levels.
- These values are based on the protection of human health from inhalation of indoor air, and may not be protective to wildlife, consumption of wildlife or other agricultural food products, and to domestic pets.

- The protection of human health considers the migration of vapors/gases from soil to the indoor air only and does not address impact due to other indoor sources, such as vapors/gases from showering with contaminated water.
- Volatilization from groundwater is not considered in this document.

2.2. Model-Related

A number of limitations for the use of the Johnson and Ettinger model are also described in US EPA (2003e). A brief list of those limitations is provided below:

- The presence or suspected presence of residual or free-product non-aqueous phase liquids (LNAPL (Light Non-Aqueous Phase Liquid), DNAPL (Dense Non-Aqueous Phase Liquid), fuels, solvents, etc. in the subsurface.
- The presence of heterogeneous geologic materials between the vapor source and building. The Johnson and Ettinger model does not apply to geologic materials that are fractured, contain macropores or other preferential pathways, or are composed of karst.
- Sites where significant lateral flow of vapors occurs.
- Very shallow groundwater where the building foundation is wetted by the groundwater.
- Very small building air exchange rates (e.g., $<0.25/h$).
- Buildings with crawlspace structures or other significant openings to the subsurface (e.g., earthen floors, stone buildings, etc.).
- The calculated screening number component may not be applicable to future buildings with properties different from the ones considered by the Johnson and Ettinger model.
- Sites where significant biodegradation exists or is expected to exist.
- The model considers only source located below the receptor building. A source located at some distance and brought below the building as a plume cannot be modeled by the Johnson and Ettinger model alone and requires coupling with additional models.

3. Steps to Calculate the Soil-Gas-Screening Number

The derivation of the soil gas to indoor air value by the Johnson and Ettinger model may be described by the following three consecutive steps (Fig. B-1):

1. Calculation of Target Indoor Air Concentration.
2. Calculation of the Soil Gas to Indoor Air Attenuation Factor α.
3. Calculation of the Soil Gas Level immediately below foundation corresponding to the calculated Target Indoor Air Concentration.

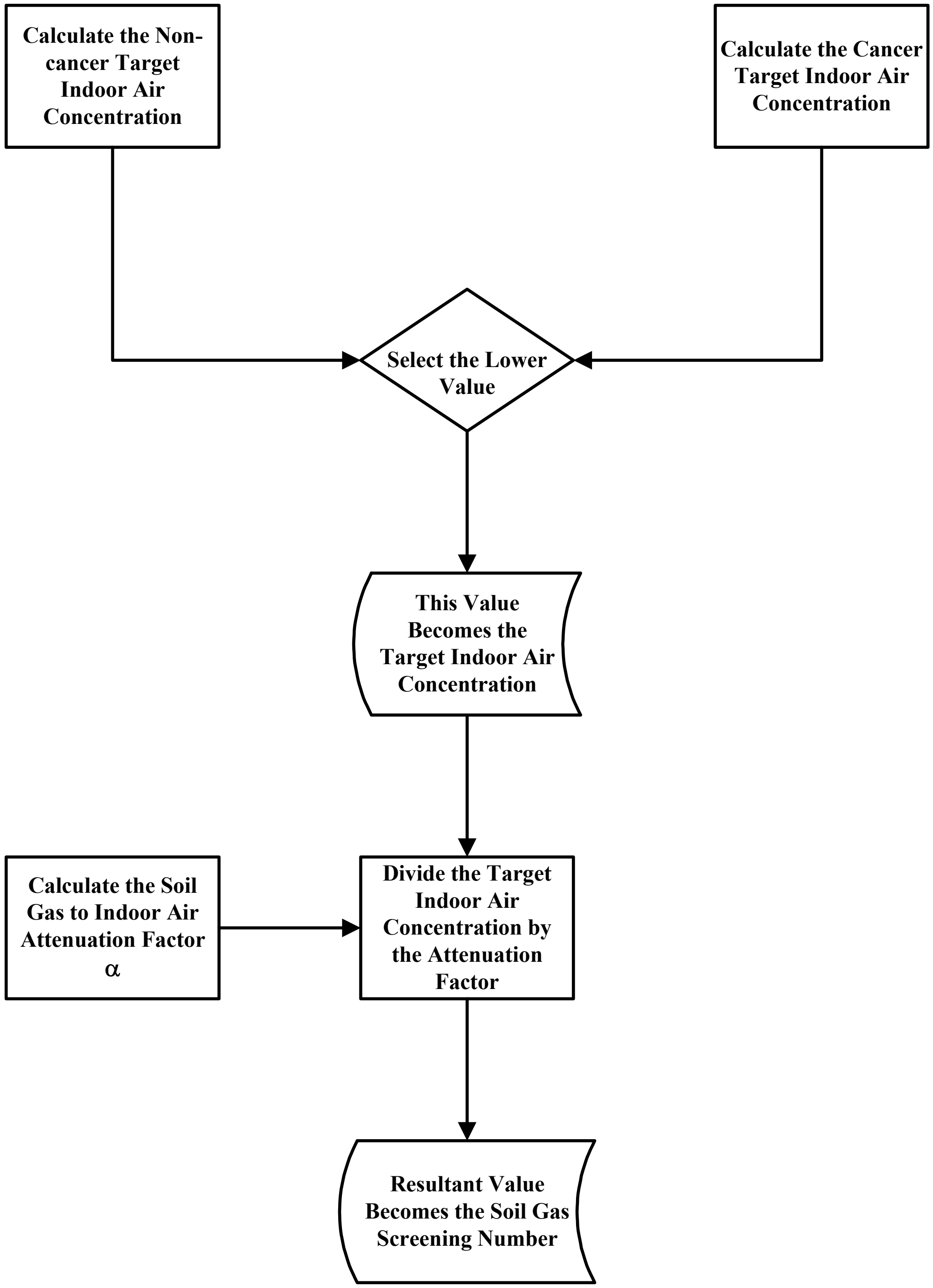

Figure B-1 Calculation of the Soil-Gas-Screening Number

3.1 Calculation of Target Indoor Air Concentration

3.1.1. Theory

The Target Indoor Air Concentration (C_{ia}) denoted also as $C_{building}$ in the US EPA (2003e) spreadsheet is based on either a cancer or non-cancer end-point. The endpoint is determined by the lowest Target Indoor Air Concentration calculated using equations B-1 and B-2. Exposure assumptions and chemical-specific toxicity values used to calculate both target concentrations are discussed in the following section of this appendix.

Cancer Target Indoor Air Concentration

$$C_{ia-c} = \frac{TR \times AT_c \times 365\ days/year}{URF \times EF \times ED} \qquad \text{Eq. B-1}$$

C_{ia-c}	Cancer Target Indoor Air Concentration, $\mu g/m^3$
TR	Target Risk Level, unitless
AT_c	Averaging Time for Carcinogens, yr
URF	Unit Risk Factor, $(\mu g/m^3)^{-1}$, chemical-specific
EF	Exposure Frequency, days/yr
ED	Exposure Duration, yr

Non-Cancer Target Indoor Air Concentration

$$C_{ia-nc} = \frac{THQ \times AT_{nc} \times 365\ days/year}{EF \times ED \times 1/REL(RfC)} \qquad \text{Eq. B-2}$$

C_{ia-nc}	Non-Cancer Target Indoor Air Concentration, $\mu g/m^3$
THQ	Target Hazard Quotient, unitless
AT_{nc}	Averaging Time for Non-Carcinogens, yr
REL (RfC)	Reference Exposure Level (or Reference Concentration), $\mu g/m^3$, chemical-specific
EF	Exposure Frequency, days/yr
ED	Exposure Duration, yr

3.1.2. Toxicity Values

All calculations were based on Cancer Target Risk Level of 1×10^{-6} and Non-Cancer Target Hazard Quotient of 1, widely used in the development of screening numbers by many regulatory agencies, including US EPA and Cal/EPA.

Cal/EPA database (OEHHA, 2004) was the preferred source of carcinogenic unit risks. If no cancer toxicity value was available in the Cal/EPA database, the US EPA's Integrated Risk Information System (IRIS) (US EPA, 2003b) was searched. Cal/EPA database was also searched for chronic Reference Exposure Levels (RELs). IRIS was also searched for non-carcinogenic reference concentrations (RfCs), if no RELs were found in the Cal/EPA database. The following two sources were searched, in order of preference, if IRIS values were also not available: provisional toxicity values recommended by EPA's National Center for Environmental Assessment (NCEA) and EPA's Health Effects Assessment Summary Tables (HEAST) (US EPA, 2003c). Whenever inhalation toxicity data (unit risks and/or RfCs) were not available from all of the above referenced sources, they were extrapolated using toxicity data for oral exposure (cancer slope factors and/or reference doses, respectively) from these same sources using the same preference order. All collected toxicity values and the selected for use in the modeling procedure ones are presented in Table B-1.

Table B-1. U.S. EPA and OEHHA Toxicity Values*

CHEMICALS	**OEHHA TOXICITY VALUES**		**US EPA TOXICITY VALUES**	
	URF, $(\mu g/m^3)^{-1}$	**Chronic REL**, $\mu g/m^3$	**URF**, $(\mu g/m^3)^{-1}$	**RfC**, mg/m^3
Benzene	**2.9 E-05**	6.0 E+01	2.2 E-06	3.0 E-02
Carbon Tetrachloride	**4.2 E-05**	4.0 E+01	1.5 E-05	NA
1,2-Dichloroethane	**2.1 E-05**	NA	2.6 E-05	NA
cis-1,2-Dichloroethylene	NA	NA	NA	**3.5 E-02**
trans-1,2-Dichloroethylene	NA	NA	NA	**7.0 E-02**
Ethylbenzene	NA	**2.0 E+03**	NA	1.0 E+00
Mercury, elemental	NA	**9.0 E-02**	NA	3.0 E-04
Methyl tert-Butyl Ether	**2.6 E-07**	8.0 E+03	NA	3.0 E+00
Naphthalene	**3.4 E-05**	9.0 E+00	NA	3.0 E-03
Tetrachloroethylene	**5.9 E-06**	3.5 E+01	2.86 E-06	NA
Tetraethyl Lead	NA	NA	NA	**3.5 E-07****
Toluene	NA	**3.0 E+02**	NA	4.0 E-01
1,1,1-Trichloroethane	NA	NA	NA	**2.2 E+00**
Trichloroethylene	**2.0 E-06**	6.0 E+02	1.1 E-04	3.5 E-02
Vinyl Chloride	**7.8 E-05**	NA	4.4 E-06	1.0 E-01
m-Xylene	NA	**7.0 E+02**	NA	1.0 E-01
o-Xylene	NA	**7.0 E+02**	NA	1.0 E-01
p-Xylene	NA	**7.0 E+02**	NA	1.0 E-01

Notes
* Selected toxicity values shown in bold
** Extrapolated from Oral Reference Dose (RfD)
NA Not Available
URF Unit Risk Factor
REL Reference Exposure Level
RfC Reference Concentration

3.1.3. Exposure Parameters

All exposure parameters were selected following US EPA (2001b). Some exposure parameter values for residential and industrial/commercial land uses differ and are shown in Table B-2. The same values were selected for all other parameters for both land uses.

Table B-2. Exposure Parameters Used Under Residential and Industrial/Commercial Land Uses

PARAMETER	LAND USE	
	Residential	Industrial/Commercial
Averaging Time for Carcinogens (AT_c), yr	70	70
Averaging Time for Non-Carcinogens (AT_{nc}), yr	30	25
Exposure Frequency (EF), days/yr	350	250
Exposure Duration (ED), yr	30	25

3.2 Calculation of Soil Gas to Indoor Air Attenuation Factor α

3.2.1. Model Theory*

3.2.1.a. Under the assumption that mass transfer is a steady-state process, Johnson and Ettinger (1991) give the solution for the attenuation coefficient (α) as:

$$\alpha = \frac{\left[\left(\frac{D_T^{eff} A_B}{Q_{building} L_T}\right) \times \exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right)\right]}{\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_{building} L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]\right]} \qquad \textit{Eq. B-3}$$

α	Steady-state attenuation factor, unitless
D_T^{eff}	Total overall effective diffusion coefficient, cm^2/s, see Section 3.2.1.b.
A_B	Area of the enclosed space below grade, cm^2. The value of A_B includes the area of the floor in contact with the underlying soil and the total wall area below grade, see Table B-7
$Q_{building}$	Building ventilation rate, cm^3/s, see Section 3.2.1.g.
L_T	Source-building separation, cm, see Table B-4
Q_{soil}	Volumetric flow rate of soil gas into the enclosed space, cm^3/s, see Section 3.2.1.h., see Table B-7
L_{crack}	Enclosed space foundation or slab thickness, cm, equals L_F, see Table B-4
A_{crack}	Area of total cracks, cm^2, see Table B-7

* Section based on US EPA (2003e)

D_{crack}	Effective diffusion coefficient through the cracks, cm^2/s (assumed equivalent to D_i^{eff} of soil layer *i* in contact with the floor).

3.2.1.b. The overall effective diffusion coefficient for systems composed of *n* distinct soil layers between the source of contamination and the enclosed space floor is:

$$D_T^{eff} = \frac{L_T}{\sum_{i=0}^{n} L_i / D_i^{eff}} \qquad \textit{Eq. B-4}$$

D_T^{eff}	Total overall effective diffusion coefficient, cm^2/s
L_i	Thickness of soil layer *i*, cm
D_i^{eff}	Effective diffusion coefficient across soil layer *i*, cm^2/s, see Section 3.2.1.c.
L_T	Distance between the source of contamination and the bottom of the enclosed space floor, also denoted as Source-building separation in US EPA (2003e) spreadsheet, cm, see Table B-4

3.2.1.c. The effective diffusion coefficient within the unsaturated zone may also be estimated as:

$$D_i^{eff} = D_a\left(\theta_{a,i}^{3.33} / n_i^2\right) + \left(D_w / H'_{TS}\right)\left(\theta_{w,i}^{3.33} / n_i^2\right) \qquad \textit{Eq. B-5}$$

D_i^{eff}	Effective diffusion coefficient across soil layer i, cm^2/s
D_a	Diffusivity in air, cm^2/s, chemical-specific, see Table B-5
$\theta_{a,i}$	Soil air-filled porosity of layer *i*, cm^3/cm^3, see Table B-6
n_i	Soil total porosity of layer *i*, cm^3/cm^3, see Table B-6
D_w	Diffusivity in water, cm^2/s, chemical-specific, see Table B-5
$\theta_{w,i}$	Soil water-filled porosity of layer *i*, cm^3/cm^3, see Table B-6
H'_{TS}	Henry's law constant at the system temperature, dimensionless, chemical-specific, see Section 3.2.1.d.

3.2.1.d. The dimensionless form of the Henry's law constant at the system temperature (i.e., at the average soil/groundwater temperature) may be estimated using the Clapeyron equation by:

$$H'_{TS} = \frac{exp\left[-\frac{\Delta H_{v,TS}}{R_c}\left(\frac{1}{T_S} - \frac{1}{T_R}\right)\right] H_R}{RT_S} \qquad \textit{Eq. B-6}$$

H'_{TS}	Henry's law constant at the system temperature, dimensionless
$\Delta H_{v,TS}$	Enthalpy of vaporization at the system temperature, cal/mol, chemical-specific, see Section 3.2.1.e.
T_S	System temperature, °K

T_R	Henry's law constant reference temperature, ^{o}K
H_R	Henry's law constant at the reference temperature, atm-m^3/mol
R_C	Gas constant (= 1.9872 cal/mol -^{o}K)
R	Gas constant (= 8.205 E-05 atm-m^3/mol-^{o}K)

3.2.1.e. The enthalpy of vaporization at the system temperature can be calculated from Lyman et al. (1990) as:

$$\Delta H_{v,TS} = \Delta H_{v,b}\left[\frac{(1 - T_S/T_C)}{(1 - T_B/T_C)}\right]^n \qquad \textit{Eq. B-7}$$

$\Delta H_{v,TS}$ Enthalpy of vaporization at the system temperature, cal/mol
$\Delta H_{v,b}$ Enthalpy of vaporization at the normal boiling point, cal/mol, chemical-specific, see Table B-5
T_S System temperature, ^{o}K
T_C Critical temperature, ^{o}K, see Table B-5
T_B Normal boiling point, ^{o}K, see Table B-5
n Constant, unitless, see Table B-3

3.2.1.f. US EPA (2003e) provides a table showing the value of *n* as a function of the ratio T_B/T_C.

Table B-3. Value of *n* as a function of T_B/T_C

T_B/T_C	*n*
< 0.57	0.30
0.57 – 0.71	0.74 (T_B/T_C) – 0.116
> 0.71	0.41

3.2.1.g. The building ventilation rate ($Q_{building}$) may be calculated as:

$$Q_{building} = (L_B\ W_B\ H_B\ ER)/3{,}600 \qquad \textit{Eq. B-8}$$

$Q_{building}$	Building ventilation rate, cm^3/s
L_B	Length of building, cm, see Table B-7
W_B	Width of building, cm, see Table B-7
H_B	Height of building, cm, see Table B-7
ER	Air exchange rate, (1/h), see Table B-7
3,600	Conversion factor seconds per hour

3.2.1.h. There are a few ways to estimate the soil gas advection rate $\boldsymbol{Q_{soil}}$. US EPA (2003e) recommends assigning a default value of 5 L/min for this parameter.

3.2.2. Model Scenario

OEHHA followed the Johnson and Ettinger model to calculate the attenuation factor α. A one-story slab on grade building (Figure B-2) was modeled according to the common construction practices in California. A sandy soil type was assumed to consider soils with maximum soil vapor permeability. To describe typical current building construction, the following layers were modeled (from top to bottom):

- a minimum of three and a half inches (≈ 9 cm) thick concrete layer slab on the top,
- a minimum of four inches (10 cm) thick crushed rock or gravel, and sand mixture installed below the concrete layer,
  and,
- a minimum of twelve inches (30 cm) layer of engineered fill used to stabilize the building.

To calculate α for older buildings constructed without a layer of engineered fill below sub-slab gravel, only parameters for the first two layers were entered into the model.

The Johnson and Ettinger model assumes:

- That the concrete slab starts at the ground surface level to maximize the exposed foundation area (most slabs in California are built on the ground surface),
- Only the contamination limited by the foundation area.

The contamination was assumed to start immediately below the installed clean engineered fill material (gravel in the case without engineered fill) to maximize the exposure.

The resulting values for the Johnson and Ettinger model-based spreadsheet parameters are shown in Table B-4 and best illustrated on Figure B-2.

Table B-4. Scenario Parameters and Corresponding Values

SCENARIO PARAMETER	**CORRESPONDING VALUE**, Inch (cm)	
	With Engineered Fill	**Without Engineered Fill**
Depth Below Grade to Bottom of Enclosed Space Floor, L_F	3.5 (≈ 9)	3.5 (≈ 9)
Depth Below Grade to Top of Contamination, L_t	19.5 (49)	7.5 (19)
Source-building separation, L_T	16 (40)	4 (10)
Depth Below Grade to Bottom of Contamination, L_b*	0 (0)	0 (0)

Notes
* Given the potential for a wide variety of contamination thicknesses, the contamination thickness was assumed to be unknown.

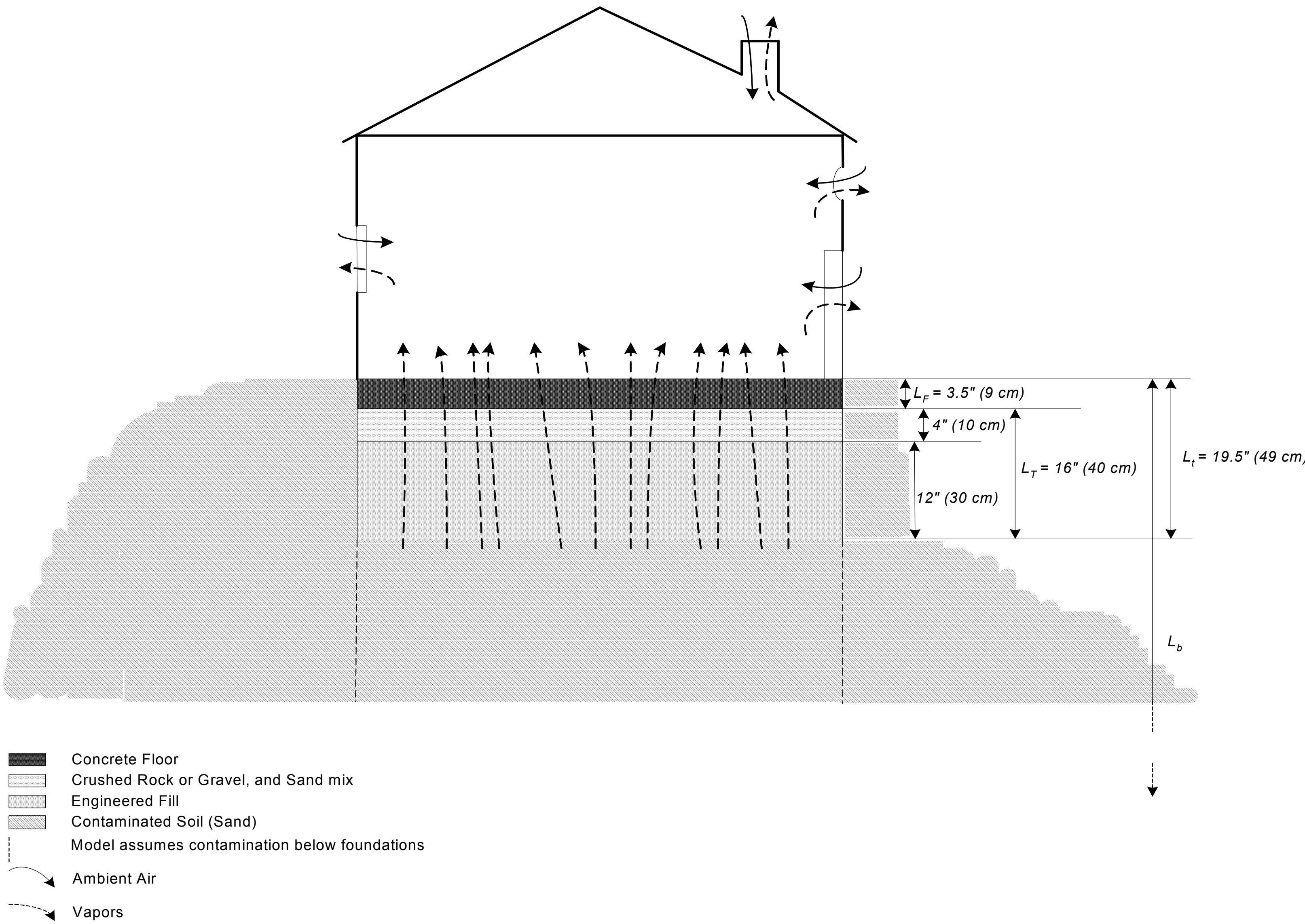

Figure B-2. Soil to Indoor Air Vapor Migration Scenario with Engineered Fill

3.2.3. Johnson and Ettinger Model Input Parameters

The derivation of soil gas to indoor air attenuation factor α includes three groups of inputs parameters, namely physical-chemical properties, soil properties, and building parameters. These input parameters were developed considering soil-physics science, available studies of building characteristics, and expert opinion (US EPA, 2003e).

3.2.3.1. Physical-Chemical Properties

The source of **physical-chemical data** used in the calculation is primarily EPA's Superfund Chemical Data Matrix (SCDM) database (US EPA, 2003d). For non-available data, widely available sources were also consulted. All used chemical-specific parameters and their corresponding values for the chemicals of interest are presented in Table B-5.

Table B-5. Physical – Chemical Properties

Chemical	**D_a** (cm^2/s)	**D_w** (cm^2/s)	**H** (atm-m^3/mol)	**T_R** (^OC)	**T_B** (^OK)	**T_C** (^OK)	**$\Delta H_{v,b}$** (cal/mol)
Benzene	8.80E-02	9.80E-06	5.54E-03	25	353.24	562.16	7,342
Carbon Tetrachloride	7.80E-02	8.80E-06	3.03E-02	25	349.90	556.60	7,127
1,2-Dichloroethane	1.04E-01	9.90E-06	9.77E-04	25	356.65	561.00	7,643
cis-1,2-Dichloroethylene	7.36E-02	1.13E-05	4.07E-03	25	333.65	544.00	7,192
trans-1,2-Dichloroethylene	7.07E-02	1.19E-05	9.36E-03	25	320.85	516.50	6,717
Ethylbenzene	7.50E-02	7.80E-06	7.86E-03	25	409.34	617.20	8,501
Mercury, elemental	3.07E-02	6.30E-06	1.07E-02	25	629.88	1,750.00	14,127
Methyl tert-Butyl Ether	1.02E-01	1.05E-05	6.23E-04	25	328.30	497.10	6,678
Naphthalene	5.90E-02	7.50E-06	4.82E-04	25	491.14	748.40	10,373
Tetrachloroethylene	7.20E-02	8.20E-06	1.84E-02	25	394.40	620.20	8,288
Tetraethyl Lead*	1.32E-02	6.40E-06	8.26E-01	25	475.15	712.72	9,757
Toluene	8.70E-02	8.60E-06	6.62E-03	25	383.78	591.79	7,930
1,1,1-Trichloroethane	7.80E-02	8.80E-06	1.72E-02	25	347.24	545.00	7,136
Trichloroethylene	7.90E-02	9.10E-06	1.03E-02	25	360.36	544.20	7,505
Vinyl Chloride	1.06E-01	1.23E-05	2.69E-02	25	259.25	432.00	5,250
o-Xylene	8.70E-02	1.00E-05	5.18E-03	25	417.60	630.30	8,661
p-Xylene	7.69E-02	8.44E-06	7.64E-03	25	411.52	616.20	8,525
m-Xylene	7.00E-02	7.80E-06	7.32E-03	25	412.27	617.05	8,523

Notes

D_a Diffusivity in air
D_w Diffusivity in water
H Henry's law constant at reference temperature
T_R Henry's law constant reference temperature

T_B Normal boiling point
T_C Critical temperature
$\Delta H_{v,b}$ Enthalpy of vaporization at the normal boiling point
* T_C and $\Delta H_{v,b}$ for tetraethyl lead were estimated. Please refer to Section 5.

3.2.3.2. Soil Properties

The construction fill (shown as L_T on Figure B-2) was modeled to comprise of two separate soil layers, namely gravel and engineered fill (for the "with engineered fill scenario") as discussed in section 3.2.2. Given the lack of values for gravel corresponding parameters in US EPA (2003e), OEHHA conservatively assumed that the upper layer was only comprised of sand. Accordingly, the values for all parameters shown in Table B-6 are the default values provided by the US EPA (2003e), and shown in the VLOOKUP spreadsheet of the Johnson and Ettinger model. The lower layer (stabilizing engineered fill material) was assumed to be 12 inches thick as this thickness meets building codes' minimum requirements, and to consist of compacted silty clay - a material complying with the engineered fill requirements – to be cohesive, fine grained and of low organic content. While the degree of compaction and the soil parameters' values are determined on a case-by-case manner, it can be assumed that the engineered fill is compacted to a density of 125± 3 lbs per cubic foot at 20% (v/v) water content (Personal communication from Dr. Ram Ramanujam, Hazardous Substances Engineer, Department of Toxic Substances Control, November 5, 2004). Such material has a bulk density of 1.8 g dry weight per cubic centimeter and a total porosity of approximately 0.30 cm^3/cm^3. The value of 0.15 cm^3/cm^3 for the Vadose Zone Soil Water-Filled Porosity was assumed after personal communication with Dr. Roger Brewer, San Francisco Bay Regional Water Quality Control Board, November 10, 2004.

Table B-6. Input Parameters and Values Assigned to the Sand and Engineered Fill Layers

PARAMETERS	SAND LAYER	ENGINEERED FILL LAYER
Layer Thickness, Inches (cm)	4 (10)	12 (30)
Vadose Zone Soil Dry Bulk Density , g/cm^3	1.66	1.8
Vadose Zone Soil Total Porosity, unitless	0.375	0.30
Vadose Zone Soil Air-Filled Porosity, cm^3/cm^3	0.321	0.15
Vadose Zone Soil Water-Filled Porosity, cm^3/cm^3	0.054	0.15
Soil Organic Carbon Fraction, unitless	0.002	0.002

Notes
* Based on US EPA (2003e) and VLOOKUP spreadsheet.

The highest California average annual soil temperature of 22^0 C (72^0 F) provided in US EPA (2003e) was used to calculate the attenuation factor α.

3.2.3.3. Building Parameters

A list of reasonably conservative values for the model-related building parameters is provided in Table B-7 below. The rationale for each parameter value selection is provided in Section 6.

Table B-7. Building Input Parameters and Values

INPUT PARAMETER	VALUE
Soil-Building Pressure Differential, $g/cm\text{-}s^2$	40
Indoor Air Exchange Rate, hr^{-1}	0.50 –Residential, 1.00 – Industrial/Commercial
Enclosed Space Height, cm	244
Enclosed Space Floor Length , cm	1,000
Enclosed Space Floor Width, cm	1,000
Floor Wall Seam Crack Width, cm	0.1
Floor Wall Seam Perimeter, cm	4,000
Area of Enclosed Space Below Grade, cm^2	1,000,000
Crack Depth Below Grade, cm	9
Diffusion Path Length, cm	40 (10)*
Convection Path Length, cm	9
Soil Gas Advection Rate, L/m	5
Crack-To-Total Area Ratio, unitless	Spreadsheet-calculated
Crack Radius, cm	Spreadsheet-calculated
Area of Crack, cm^2	Spreadsheet-calculated

Notes:
* Without Engineered fill scenario

3.2.3.4. Spreadsheets Application

The advanced soil contamination spreadsheet version (SL-ADV Version 3.0; 02/03) was used to calculate the Soil Gas to Indoor Air Attenuation Factor α. Three soil strata were modeled: stratum A represents the assumed sand soil encompassing the foundation; stratum B represents the mixture of gravel and sand; and stratum C represents the engineered fill. Examples of the Attenuation Factor calculation are provided at the end of this document as Figure B-3 (residential scenario with engineered fill) and Figure B-4 (industrial/commercial scenario without engineered fill).

3.3 Calculation of the Soil-Gas-Screening Number

The steady-state vapor-phase concentration of the contaminant at the bottom of the engineered fill (C_{source}) is calculated given the Johnson and Ettinger derived α and health-based target indoor air concentration as:

$$C_{source} = C_{building} / \alpha \times 1{,}000 \qquad \textit{Eq. B-9}$$

C_{source} Soil Gas Level at the Source, µg/L
$C_{building}$ Target Indoor Air Concentration, µg/m^3, see Section 3.1.
α Steady-State Attenuation Factor, unitless, see Section 3.2.
1,000 Conversion factor from µg/m^3 to µg/L

This concentration, denoted as C_{source} in the spreadsheet, represents the risk-based soil-gas-screening number.

4. Results

Modeling results for Target Indoor Air Concentrations, Attenuation Factors and Soil-Gas-Screening Numbers for all chemicals of interest are shown in Tables B-8, B-9, B-10, and B-11 below.

OEHHA used the US EPA (2001b) exposure parameters for workers, namely a 70 year Averaging Time for Carcinogens, a 25 year Averaging Time for Non-Carcinogens, 25 years for Exposure Duration, and 250 days per year for Exposure Frequency. Also, an air exchange rate of 1.00 was used to comply with the common industrial hygiene requirements for industrial/commercial buildings. The results are shown in the tables below.

4.1. Building Constructed with Engineered Fill below Sub-slab

4.1.1. Soil-Gas-Screening Numbers under the Residential Land Use

Table B-8. Target Indoor Air Concentrations, Attenuation Factors and Soil-Gas-Screening Numbers under the Residential Land Use

CHEMICALS	**TARGET INDOOR AIR CONCENTRATIONS,** µg/m^3	α, Unitless	**COMPUTED SOIL-GAS-SCREENING NUMBER**, µg/L
Benzene	8.40 E-02	9.94 E-04	8.45 E-02
Carbon Tetrachloride	5.79 E-02	9.23 E-04	6.27 E-02
1,2-Dichloroethane	1.16 E-01	1.10 E-03	1.05 E-01
cis-1,2-Dichloroethylene	3.65 E+01	8.90 E-04	4.10 E+01
trans-1,2-Dichloroethylene	7.30 E+01	8.67 E-04	8.42 E+01
Ethylbenzene	postponed	postponed	postponed
Mercury, elemental	9.40 E-02	4.70 E-04	2.00 E-01

CHEMICALS	TARGET INDOOR AIR CONCENTRATIONS, μg/m^3	α, Unitless	COMPUTED SOIL-GAS-SCREENING NUMBER, μg/L
Methyl tert-Butyl Ether	9.35 E+00	1.09 E-03	8.58 E+00
Naphthalene	7.20 E-02	7.72 E-04	9.33 E-02
Tetrachloroethylene	4.12 E-01	8.77 E-04	4.70 E-01
Tetraethyl Lead	3.65 E-04	2.27 E-04	1.61 E-03
Toluene	3.13 E+02	9.87 E-04	3.17 E+02
1,1,1-Trichloroethane	2.29 E+03	9.23 E-04	2.48 E+03
Trichloroethylene	1.22 E+00	9.30 E-04	1.31 E+00
Vinyl Chloride	3.11 E-02	1.11 E-03	2.80 E-02
m-Xylene	7.30 E+02	8.62 E-04	8.47 E+02
o-Xylene	7.30 E+02	9.87 E-04	7.40 E+02[1]
p-Xylene	7.30 E+02	9.15 E-04	7.98 E+02

Notes

α Attenuation Factor

[1] Representative Screening Numbers for mixed xylenes. The representative value for mixed xylenes is based on the calculated lowest one amongst the three isomers.

4.1.2. Soil-Gas-Screening Numbers under the Industrial/Commercial Land Use

Table B-9. Target Indoor Air Concentrations, Attenuation Factors, and Soil-Gas-Screening Numbers under the Industrial/Commercial Land Use

CHEMICALS	TARGET INDOOR AIR CONCENTRATIONS, μg/m^3	α, Unitless	COMPUTED SOIL-GAS-SCREENING NUMBER, μg/L
Benzene	1.41 E-01	4.97 E-04	2.84 E-01
Carbon Tetrachloride	9.73 E-02	4.61 E-04	2.11 E-01
1,2-Dichloroethane	1.95 E-01	5.48 E-04	3.56 E-01
cis-1,2-Dichloroethylene	5.11 E+01	4.45 E-04	1.15 E+02
trans-1,2-Dichloroethylene	1.02 E+02	4.34 E-04	2.35 E+02
Ethylbenzene	postponed	postponed	postponed
Mercury, elemental	1.31 E-01	2.35 E-04	5.57 E-01
Methyl tert-Butyl Ether	1.57 E+01	5.43 E-04	2.89 E+01
Naphthalene	1.20 E-01	3.86 E-04	3.11 E-01
Tetrachloroethylene	6.93 E-01	4.39 E-04	1.58 E+00
Tetraethyl Lead	5.11 E-04	1.13 E-04	4.52 E-03
Toluene	4.38 E+02	4.93 E-04	8.88 E+02
1,1,1-Trichloroethane	3.21 E+03	4.61 E-04	6.96 E+03
Trichloroethylene	2.04 E+00	4.65 E-04	4.39 E+00
Vinyl Chloride	5.24 E-02	5.53 E-04	9.48 E-02
m-Xylene	1.02 E+03	4.31 E-04	2.37 E+03
o-Xylene	1.02 E+03	4.93 E-04	2.07 E+03[1]

CHEMICALS	TARGET INDOOR AIR CONCENTRATIONS, μg/m^3	α, Unitless	COMPUTED SOIL-GAS-SCREENING NUMBER, μg/L
p-Xylene	1.02 E+03	4.57 E-04	2.23 E+03

Notes

α Attenuation Factor.

1 Representative Screening Numbers for mixed xylenes. The representative value for mixed xylenes is based on the calculated lowest one amongst the three isomers.

4.2. Building Constructed without Engineered Fill below Sub-slab

4.2.1. Soil-Gas-Screening Numbers under the Residential Land Use

Table B-10. Target Indoor Air Concentrations, Attenuation Factors and Soil-Gas-Screening Numbers for Existing Buildings under the Residential Land Use

CHEMICALS	TARGET INDOOR AIR CONCENTRATIONS, μg/m^3	α, Unitless	COMPUTED SOIL-GAS-SCREENING NUMBER, μg/L
Benzene	8.40 E-02	2.32 E-03	3.62 E-02
Carbon Tetrachloride	5.79 E-02	2.31 E-03	2.51 E-02
1,2-Dichloroethane	1.16 E-01	2.34 E-03	4.96 E-02
cis-1,2-Dichloroethylene	3.65 E+01	2.30 E-03	1.59 E+01
trans-1,2-Dichloroethylene	7.30 E+01	2.29 E-03	3.19 E+01
Ethylbenzene	postponed	postponed	postponed
Mercury, elemental	9.40 E-02	2.11 E-03	4.45 E-02
Methyl tert-Butyl Ether	9.35 E+00	2.34 E-03	4.00 E+00
Naphthalene	7.20 E-02	2.26 E-03	3.19 E-02
Tetrachloroethylene	4.12 E-01	2.29 E-03	1.80 E-01
Tetraethyl Lead	3.65 E-04	1.77 E-03	2.06 E-04
Toluene	3.13 E+02	2.32 E-03	1.35 E+02
1,1,1-Trichloroethane	2.29 E+03	2.31 E-03	9.91 E+02
Trichloroethylene	1.22 E+00	2.31 E-03	5.28 E-01
Vinyl Chloride	3.11 E-02	2.34 E-03	1.33 E-02
m-Xylene	7.30 E+02	2.29 E-03	3.19 E+02
o-Xylene	7.30 E+02	2.32 E-03	3.15 E+02[1]
p-Xylene	7.30 E+02	2.30 E-03	3.17 E+02

Notes

α Attenuation Factor

1 Representative Screening Numbers for mixed xylenes. The representative value for mixed xylenes is based on the calculated lowest one amongst the three isomers.

4.2.2. Soil-Gas-Screening Numbers under the Industrial/Commercial Land Use

Table B-11. Target Indoor Air Concentrations, Attenuation Factors, and Soil-Gas Screening Numbers for Existing Buildings under the Industrial/Commercial Land Use

CHEMICALS	**TARGET INDOOR AIR CONCENTRATIONS**, μg/m^3	α, Unitless	**COMPUTED SOIL-GAS-SCREENING NUMBER**, μg/L
Benzene	1.41 E-01	1.16 E-03	1.22 E-01
Carbon Tetrachloride	9.73 E-02	1.15 E-03	8.46 E-02
1,2-Dichloroethane	1.95 E-01	1.17 E-03	1.67 E-01
cis-1,2-Dichloroethylene	5.11 E+01	1.15 E-03	4.44 E+01
trans-1,2-Dichloroethylene	1.02 E+02	1.15 E-03	8.87 E+01
Ethylbenzene	postponed	postponed	postponed
Mercury, elemental	1.31 E-01	1.05 E-03	1.25 E-01
Methyl tert-Butyl Ether	1.57 E+01	1.17 E-03	1.34 E+01
Naphthalene	1.20 E-01	1.13 E-03	1.06 E-01
Tetrachloroethylene	6.93 E-01	1.15 E-03	6.03 E-01
Tetraethyl Lead	5.11 E-04	8.84 E-04	5.78 E-04
Toluene	4.38 E+02	1.16 E-03	3.78 E+02
1,1,1-Trichloroethane	3.21 E+03	1.15 E-03	2.79 E+03
Trichloroethylene	2.04 E+00	1.15 E-03	1.77 E+00
Vinyl Chloride	5.24 E-02	1.17 E-03	4.48 E-02
m-Xylene	1.02 E+03	1.15 E-03	8.87 E+02
o-Xylene	1.02 E+03	1.16 E-03	8.79 E+02[1]
p-Xylene	1.02 E+03	1.15 E-03	8.87 E+02

Notes

α Attenuation Factor.

1 Representative Screening Numbers for mixed xylenes. The representative value for mixed xylenes is based on the calculated lowest one amongst the three isomers.

5. Development of Attenuation factor α and Soil-Gas-Screening Number for Tetraethyl Lead

Tetraethyl lead is the only chemical from the list of chemicals of interest not included into the Johnson and Ettinger model-based spreadsheet (US EPA, 2003e). While physical-chemical parameters for the rest of chemicals under consideration were readily available in the VLOOKUP spreadsheet table, the tetraethyl lead values for the chemical-specific parameters were obtained from different scientific literature sources or calculated.

Using the parameters in the table below, the tetraethyl lead Henry's Law Constant for soil temperature was corrected according to the method shown in US EPA (2001a). The Attenuation Factor α was calculated by applying the corresponding tetraethyl lead's values for a number of parameters into the Johnson and Ettinger model-based spreadsheet provided by US EPA (2003e). A list of parameters, their values for tetraethyl lead, and the corresponding literature source are provided in the table below:

Table B-12. Chemical-Physical and Toxicity Parameters for Tetraethyl Lead (CAS No. 78-00-2)

Parameter	Value	Source
Diffusivity in Air, (D_a), cm^2/s	0.0132	DEP (2002)
Diffusivity in Water, (D_w) cm^2/s	0.0000064	DEP (2002)
Pure Component Water Solubility, (S), mg/L	0.29 (at 25° C)	SYRRES (2003)
Henry's Law Constant, (H'), unitless	3.38 E+01	US EPA (2003a)
Henry's Law Constant at Reference Temperature, (H), atm-m^3/mol	8.26 E-01	US EPA (2003a)
Henry's Law Constant Reference Temperature, (T_R), °C	25	US EPA (2001a)
Normal Boiling Point, (t_b), °C	≈ 202	US EPA (2003a)
Normal Boiling Point, (T_B), °K	475.15*	US EPA (2003a)
Critical Temperature, (T_C), °K	712.72**	US EPA (2001a)
Antoine coefficient, (B), °C	1,566.7**	US EPA (2001a)
Antoine coefficient, (C), °C	195	US EPA (2001a)
Gas constant, (R_C), cal/mol-°K	1.9872	US EPA (2001a)
Compressibility factor difference at T_B, (Zg-Zl), unitless	0.95	US EPA (2001a)
Known temperature at vapor pressure Pv, (t_{Pv}), °C	25	US EPA (2001a)
Known vapor pressure at temperature t_{Pv}, (Pv), mmHg	0.508	US EPA (2003a)
Enthalpy of Vaporization at the normal boiling point, $\Delta H_{v,b}$, (cal/mol)	9,757.15**	US EPA (2001a)
Unit Risk Factor, (URF), $(\mu g/m^3)^{-1}$	NA	US EPA (2003b)
Reference Concentration, (RfC), mg/m^3	3.5 E-07***	US EPA (2003b)
Physical State at soil temperature, (S, L, G)	L	NLM (2002)

Notes

NA Not Available
S,L,G Soil, Liquid, Gas
* Converted to °K from °C.
** Calculated as shown in the text below.
*** Extrapolated from the Oral Reference Dose (RfD): RfC (mg/m^3) = RfD $(mg/kg/d)^{-1}$ X 1/IR $(m^3/d)^{-1}$ X BW (kg). IR – adult inhalation rate of 20 m^3 per day. BW – adult body weight of 70 kg.

The **critical temperature**, can be approximated from the normal boiling point by:

$$T_C \approx 3T_B / 2 \qquad \textit{Eq. B-10}$$

The **enthalpy of vaporization** at the normal boiling point may also be approximated by:

$$\Delta H_{v,b} = \frac{2.303\ BR_C\ T_B^{\ 2}\left(Z_g - Z_l\right)}{\left(t_b + C\right)^2} \qquad \textit{Eq. B-11}$$

where:

$\Delta H_{v,b}$ Enthalpy of vaporization at the normal boiling point, cal/mol

B	Antoine coefficient, ^{o}C
R_C	Gas constant (= 1.9872 cal/mol- ^{o}K)
T_B	Normal boiling point, ^{o}K
$(Z_g\text{-}Z_l)$	Compressibility factor difference, unitless (= 0.95 at T_B)
t_b	Normal boiling point, ^{o}C
C	Antoine coefficient, ^{o}C.

The **Antoine coefficients *B***, and ***C*** are constants used to describe the vapor pressure curve of a volatile chemical as a function of temperature. The *C* coefficient can be obtained from Table B-13 below.

Table B-13. Antoine Coefficient C for Organic Compounds

Boiling Point (^{o}C)	C (^{o}C)	Boiling Point (^{o}C)	C (^{o}C)
<-150	264 –0.034 t_b	140	212
-150 to - 10	240 –0.19 t_b	160	206
-10	238	180	200
0	237	200	195
20	235	220	189
40	232	240	183
60	228	260	177
80	225	280	171
100	221	≥300	165
120	217		

Notes:

tb Normal boiling point, ^{o}C

The Antoine coefficient C for tetraethyl lead is 195 ^{o}C. The value of the Antoine coefficient *B* can now be estimated with the value of the *C* coefficient, the normal boiling point, and one pair of vapor pressure/temperature data:

$$B = \frac{(t_b + C)(t_{Pv} + C)}{t_b - t_{Pv}} \log\left(\frac{760}{P_v}\right) \qquad \textit{Eq. B-12}$$

where:

B	Antoine coefficient, ^{o}C
t_b	Normal boiling point, ^{o}C
C	Antoine coefficient, ^{o}C
t_{Pv}	Known temperature at vapor pressure Pv, ^{o}C
760	Vapor pressure at the normal boiling point, mmHg
Pv	Known vapor pressure at temperature (t_{Pv}), mmHg.

Typically, literature values for vapor pressure (Pv) are at a temperature (t_{Pv}) of 20 ^{o}C or 25 ^{o}C. Combining this vapor pressure/temperature pair with that of the normal boiling point yields a linear approximation of the vapor pressure/temperature relationship. Although this relationship is not linear, the approximation given by the equation requires only two pairs of data. Overall, use of this equation yields a maximum error of less than 50%.

All collected and calculated tetraethyl lead parameter values were incorporated to the LOOKUP spreadsheet table of the US EPA advanced soil contamination spreadsheet SL-ADV-040903.xls. The spreadsheet was run as explained in Section 3.2.3.4. The resulting tetraethyl lead values for Attenuation factors α, Target Indoor Air Concentrations, and Soil-Gas Screening Concentrations are provided in Tables B-8 and B-10 under Residential Scenario, and in Tables B-9 and B-11 under Industrial/Commercial Scenario.

6. Rationale for Selection of Values for the Input Parameters. Discussion of the Uncertainty in the Derived Soil-Gas Screening Numbers

Aside from uncertainties in the structure of the Johnson and Ettinger model, a number of uncertainties are inherent to the range of values assigned to its parameters. The rationale for their selection and the corresponding justification are provided in the text below.

6.1. Toxicity Values

There are a number of assumptions made when developing carcinogen and non-carcinogen toxicity values for chemicals of interest. Although these assumptions are associated with uncertainties, OEHHA used the most recent toxicity information available in the corresponding Cal/EPA and US EPA database sources.

6.2. Exposure Parameters

OEHHA applied US EPA recommended and widely recognized exposure parameter values for both scenarios, Residential and Industrial/Commercial.

6.3. Scenario Parameters

OEHHA used the common California building requirements to develop the attenuation factor estimate. Those combined with the values for the rest of parameters are expected to result in reasonably conservative yet health-protective soil-gas screening numbers.

6.4. Chemical Properties

OEHHA used the internal database within Johnson and Ettinger spreadsheet for all chemicals but tetraethyl lead. The literature sources for tetraethyl lead's chemical properties are provided in Table B-12.

6.5. Soil Properties

The uncertainty of the key Johnson and Ettinger model parameters and the sensitivity of the model to those parameters are described in US EPA (2003e). The *soil moisture parameter* is of critical importance for the attenuation factor value. Reasonably conservative US EPA recommended values for the sand layer were selected for the Soil Water-Filled Porosity, Soil Air-Filled Porosity, Soil Total Porosity, and Soil Dry Bulk Density. Values recommended by qualified staff of other Cal/EPA agencies were used for the engineered fill parameters. The highest California *average annual soil temperature of* 22^0 *C* (72^0 *F)* provided in US EPA (2003e) was selected to maximize the vapor migration.

6.6. Building Properties

Some building-related parameters, i.e., Q_{soil}, *building crack ratio, building air-exchange rate, and building mixing height* bring moderate to high uncertainty and demonstrate moderate to high model sensitivity, while others, i.e., *foundation area and foundation slab thickness* are characterized by low uncertainty and sensitivity (US EPA, 2003e).

For *Soil-Building Pressure Differential* (ΔP)**,** US EPA (2003e) recommends default value of 4 Pa (40 g/cm-s^2). It should be noted that US EPA assumes the average soil temperature to be 12^0 C. The highest average soil temperature in California, however, is 22^0 C. This will result in a different soil-building pressure differential. The issue becomes even more complex when factors such as availability (use) of the heating, ventilation and air conditioning (HVAC) system operation, and other environmental seasonal factors, e.g., wind loading, are considered. No relevant studies or data are currently available for the State of California. Therefore, the US EPA recommended default value was used in this modeling.

The *Indoor Air Exchange Rate (ER)* varies depending on season and climatic region. US EPA used the results from 22 studies summarized in Hers et al. (2002) to explore a number of building air exchange data distributions. A default value of 0.5 hr^{-1} for air exchange rate was selected to represent the lower end of these distributions. Due to the lack of California-specific data, this value was also used in the OEHHA modeling. In accordance to the existing industrial health and safety requirements, an exchange ratio of 1.00 was selected for the Industrial/Commercial Scenario.

The Johnson and Ettinger model assumes that subsurface volatiles migrating into the building are completely mixed within the building volume, which is determined by the building area and mixing height. For a single-story house, the variation in mixing height can be approximated by the room height or *Enclosed Space Height* (H_B). There are little data available that provide for direct inference of mixing height. The default value recommended by US EPA (2003e) is 244 cm. In the absence of different California-specific data, this value was chosen for the assumed slab-on-grade scenario.

Enclosed Space Floor Length (L_B)*, cm, and Enclosed Space Floor Width* (W_B) are two parameters used to estimate the Building Area and Subsurface Foundation Area. US EPA considered a Michigan guidance document indicating that the 111.5 m^2area approximately corresponds to the 10^{th}percentile floor space area for a residential single-family dwelling, based on statistics compiled by the U.S. Department of Commerce (DOC) and U.S. Housing and Urban Development (HUD) (US EPA, 2003e). As a result, a default value of 10 m (1,000 cm) by 10 m was recommended. Accordingly, the Enclosed Space Floor Length (L_B) and Enclosed Space Floor Width (W_B) were assumed to be 1,000 cm each.

Area of Enclosed Space Below Grade (A_B) is in fact the foundation area. It is calculated from the Enclosed Space Floor Length (L_B), cm and Enclosed Space Floor Width (W_B).

Floor Wall Seam Crack Width (W) and Crack-to-Total Area Ratio (η) are related according to US EPA (2003e). US EPA assumed a square house and that the only crack is a continuous edge crack between the foundation slab and wall*, Floor Wall Seam Perimeter (X_{crack}),* ("perimeter crack"). There is little information available on crack width or crack ratio. The suggested defaults for crack ratio in regulatory guidance, literature and models also vary. The crack ratio used by Johnson and Ettinger (1991) for illustrative purposes ranged from 0.001 to 0.01. The US EPA (2003e) recommended default value of 4.00E-04 was selected to derive attenuation factors for the chemicals of interest.

The Johnson and Ettinger model assumes that the *Crack Depth Below Grade (Z_{crack})* goes through the whole foundation thickness. The same assumption was made in this modeling procedure.

Diffusion Path Length, L_d corresponds to the difference between Depth below grade to top of contamination, L_t and Depth below grade to bottom of enclosed space floor, L_F. *Convection Path Length (L_p)* corresponds to the foundation thickness.

Crack Radius (r_{crack}) and Area of Crack (A_{crack}) were spreadsheet-calculated following Johnson and Ettinger (1991).

The method used with the Johnson and Ettinger model to estimate the soil gas advection rate *Soil Gas Advection Rate (Q_{soil})* through the building is an analytical solution for two-dimensional soil gas flow to a small horizontal drain - "Perimeter Crack Model" (US EPA, 2003e). Use of this model can be problematic in that Q_{soil} values are sensitive to soil-vapor permeability and consequently a wide range in flows can be predicted. An alternate empirical approach is to select a Q_{soil} value on the basis of tracer tests (i.e., mass balance approach). A disadvantage with the tracer test approach is that only limited data are available and there do not appear to be any tracer studies for field sites with fine-grained soils. Accordingly, two options exist, namely to assign a default value of 5 L/min as recommended by US EPA (2003e) or to calculate it using the spreadsheet. The option recommended by US EPA was selected to calculate the attenuation factor α.

6.7. Residential vs. Industrial/Commercial Land Use

Two of the five groups of parameters (toxicity, exposure, chemical properties, soil properties, and building parameters), namely the building and exposure groups, were found to contribute to the difference in the screening numbers under industrial/commercial conditions. While the screening numbers developed need to be applicable to many industrial, commercial, and administrative buildings built under stringent construction requirements due to their size and/or work activities/practices to be performed there, the screening numbers must also be protective of typical small-building businesses, e.g., small stores, gas-stations, etc., as well. As a result, it was decided to apply the same building parameters, except for the exchange ratio (1.00 for Industrial/Commercial buildings) to calculate the soil gas to indoor air attenuation factor α, as the ones used under the residential scenario.

At the same time, it was deemed unnecessarily conservative to apply the residential exposure parameters to industrial/commercial settings. The US EPA (2001b) exposure parameters for workers were applied instead, namely a 70 year Averaging Time for Carcinogens, a 25 year Averaging Time for Non-Carcinogens, 25 years for Exposure Duration, and 250 days per year for Exposure Frequency.

Based on the information provided above, reasonably conservative values were selected for all parameters to derive the soil-gas screening numbers for the chemicals of interest.

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Version 3.0; 02/03

Reset to Defaults

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

YES: X

OR

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

YES:

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (μg/kg)	Chemical
71432		Benzene

MORE ↓

ENTER Average soil temperature, T_S (^oC)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) 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 A SCS soil type (used to estimate soil vapor permeability)		ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22	9	49	0	9	10	30	S	OR	

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
S	1.66	0.375	0.054	0.002	S	1.66	0.375	0.054	0.002	SIC	1.8	0.3	0.15	0.002

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
9	40	1000	1000	244	0.1	0.5	5

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 soil concentration.	

END

Figure B-3. Example of DATAENTER worksheet for benzene under residential land use (with engineered fill) scenario.

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)	Physical state at soil temperature, (S,L,G)
8.80E-02	9.80E-06	5.54E-03	25	7,342	353.24	562.16	5.89E+01	1.79E+03	2.9E-05	6.0E-02	L

END

Figure B-3. Example of CHEMPROPS worksheet for benzene under residential land use (with engineered fill) scenario.

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm³/cm³)	Stratum B soil air-filled porosity, θ_a^B (cm³/cm³)	Stratum C soil air-filled porosity, θ_a^C (cm³/cm³)	Stratum A effective total fluid saturation, S_{te} (cm³/cm³)	Stratum A soil intrinsic permeability, k_i (cm²)	Stratum A soil relative air permeability, k_{rg} (cm²)	Stratum A soil effective vapor permeability, k_v (cm²)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (μg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm³/s)
9.46E+08	40	0.321	0.321	0.150	0.003	1.01E-07	0.998	1.01E-07	4,000	1.00E+00	3.39E+04

Area of enclosed space below grade, A_B (cm²)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m³/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm²/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm²/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm²/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm²/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	9	7,998	4.83E-03	1.99E-01	1.79E-04	1.42E-02	1.42E-02	1.77E-03	2.26E-03	40	9

Soil-water partition coefficient, K_d (cm³/g)	Source vapor conc., C_{source} (μg/m³)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm³/s)	Crack effective diffusion coefficient, D^{crack} (cm²/s)	Area of crack, A_{crack} (cm²)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (μg/m³)	Finite source β term (unitless)	Finite source ψ term (sec)$^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.18E-01	9.15E+02	0.10	8.33E+01	1.42E-02	4.00E+02	1.74E+57	9.94E-04	9.09E-01	NA	NA	NA	NA

Finite source indoor attenuation coefficient, $\langle\alpha\rangle$ (unitless)	Mass limit bldg. conc., $C_{building}$ (μg/m³)	Finite source bldg. conc., $C_{building}$ (μg/m³)	Final finite source bldg. conc., $C_{building}$ (μg/m³)	Unit risk factor, URF (μg/m³)$^{-1}$	Reference conc., RfC (mg/m³)
NA	NA	NA	NA	2.9E-05	6.0E-02

END

Figure B-3. Example of INTERCALCS worksheet for benzene under residential land use (with engineered fill) scenario.

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Reset to Defaults

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

YES [X]

OR

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

YES [ ]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (μg/kg)	Chemical
71432		Benzene

MORE ↓

ENTER Average soil temperature, T_S (^oC)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) 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 A SCS soil type (used to estimate soil vapor permeability)		ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22	9	19	0	9	10		S	OR	

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
S	1.66	0.375	0.054	0.002	S	1.66	0.375	0.054	0.002					

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP (g/cm-s^2)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
9	40	1000	1000	244	0.1	1	5

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	25	250	1.0E-06	1
				Used to calculate risk-based soil concentration.	

END

Figure B-4. Example of DATAENTER worksheet for benzene under industrial/commercial land use (without engineered fill) scenario.

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-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)	Physical state at soil temperature, (S,L,G)
8.80E-02	9.80E-06	5.54E-03	25	7,342	353.24	562.16	5.89E+01	1.79E+03	2.9E-05	6.0E-02	L

END

Figure B-4. Example of CHEMPROPS worksheet for benzene under industrial/commercial land use (without engineered fill) scenario.

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)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R ($\mu g/kg$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
7.88E+08	10	0.321	0.321	ERROR	0.003	1.01E-07	0.998	1.01E-07	4,000	1.00E+00	6.78E+04

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. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} ($atm\text{-}m^3/mol$)	Henry's law constant at ave. soil 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)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	9	7,998	4.83E-03	1.99E-01	1.79E-04	1.42E-02	1.42E-02	0.00E+00	1.42E-02	10	9

Soil-water partition coefficient, K_d (cm^3/g)	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., $C_{building}$ ($\mu g/m^3$)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.18E-01	1.06E+03	0.10	8.33E+01	1.42E-02	4.00E+02	1.74E+57	1.16E-03	1.23E+00	NA	NA	NA	NA

Finite source indoor attenuation coefficient, $\langle\alpha\rangle$ (unitless)	Mass limit bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Final finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	NA	NA	NA	2.9E-05	6.0E-02

END

Figure B-4. Example of INTERCALCS worksheet for benzene under industrial/commercial land use (without engineered fill) scenario.

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Appendix C: Exposure Algorithms and Parameters Used to Calculate Screening Numbers Based on Exposure to Soil-Bound Chemicals

The following equations were copied from page 23 and 24 of the "Region 9 PRGs Table 2002 Update" Memo written by Stan Smucker to PRGs Table Users on October 1, 2002. This document can be found at http://www.epa.gov/region09/waste/sfund/prg/index.htm. $C_{res\text{-}risk}$ is the soil concentration that would be protective of residents from chemicals that cause cancer. $C_{res\text{-}haz}$ is the soil concentration that would be protective of chemicals that cause non-cancer adverse health effects. If either an oral or inhalation Cancer Slope Factor existed for chemical a $C_{res\text{-}risk}$ was computed. If either an oral or inhalation Risk Reference Dose existed for chemical a $C_{res\text{-}haz}$ was computed. The lower of the $C_{res\text{-}risk}$ or $C_{res\text{-}haz}$ was selected as the value for the direct contact value.

$$C_{res-risk} = \frac{TR \times AT_c}{EF_r \times \left[\left(\frac{IFS_{adj} \times CSF_o}{10^6\, mg/kg}\right) + \left(\frac{SFS_{adj} \times ABS \times CSF_o}{10^6\, mg/kg}\right) + \left(\frac{InF_{adj} \times CSF_i}{VF}\right)\right]} \quad \text{Eq. C-1}$$

$$C_{res-haz} = \frac{THQ \times BWc \times AT_n}{ED_c \times EF_r \times \left[\left(\frac{1}{RfD_o} \times \frac{IRSc}{10^6\, mg/kg}\right) + \left(\frac{1}{RfD_o} \times \frac{SA_c \times AF \times ABS}{10^6\, mg/kg}\right) + \left(\frac{1}{RfD_i} \times \frac{IRA_c}{VF}\right)\right]} \quad \text{Eq. C-2}$$

$$C_{ind-risk} = \frac{TR \times BW_a \times AT_c}{EF_r \times \left[\left(\frac{IRS_o \times CSF_o}{10^6\, mg/kg}\right) + \left(\frac{SA_o \times AF_o \times ABS \times CSF_o}{10^6\, mg/kg}\right) + \left(\frac{IRA_a \times CSF_i}{VF}\right)\right]} \quad \text{Eq. C-3}$$

$$C_{ind-haz} = \frac{THQ \times BW_a \times AT_n}{ED_o \times EF_o \times \left[\left(\frac{1}{RfD_o} \times \frac{IRS_o}{10^6\, mg/kg}\right) + \left(\frac{1}{RfD_o} \times \frac{SA_o \times AF_o \times ABS}{10^6\, mg/kg}\right) + \left(\frac{1}{RfD_i} \times \frac{IRA_a}{VF}\right)\right]} \quad \text{Eq. C-4}$$

In the above equations, IFS_{adj}, SFS_{adj} and InF_{adj} are functions for estimating total exposure dose from ingestion, dermal absorption and inhalation, respectively, of soil-bound chemical:

$$IFS_{adj} = \left(IRS_a \times \frac{(ED_r - ED_c)}{BW_a}\right) + \left(IRS_c \times \frac{ED_c}{BW_c}\right) \quad \text{Eq. C-5}$$

$$SFS_{adj} = \left(AF_a \times SA_a \times \frac{(ED_r - ED_c)}{BW_a} \right) + \left(AF_c \times SA_c \times \frac{ED_c}{BW_c} \right) \quad \textit{Eq. C-6}$$

$$InF_{adj} = \left(IRA_a \times \frac{(ED_r - ED_c)}{BW_a} \right) + \left(IRA_c \times \frac{ED_c}{BW_c} \right) \quad \textit{Eq. C-7}$$

The terms and factors in the above equations are defined in Table C-1. Values of exposure parameters used in screening number calculations are listed in Tables C-1 and C-2.

Table C-1. Values of Exposure Parameters Developed for U.S. EPA's "Superfund" Program.

Parameter	Abbreviation	Value	Units
Body weight (adult)	BW_a	70	kg
Body weight (child)	BW_{c-}	15	kg
Averaging time: carcinogens	AT_c	25550	days
Averaging time: noncarcinogens	AT_n	ED x 365	days
Exposed skin area for soil/dust (adult resident)	SA_{r-}	5700	cm^2 /day
Exposed skin area for soil/dust (adult worker)	SA_o	3300	cm^2 /day
Target Risk	TR	10^{-6}	unitless
Target Hazard Quotient	THQ	1.0	unitless
Oral Cancer Slope Factor	SF_o	See Table 3	unitless
Inhalation Slope Factor	SF_i	See Table 3	unitless
Oral Risk Reference Dose	RfD_o	See Table 3	unitless
Inhalation Risk Reference Dose	RfD_i	See Table 3	unitless
Volatilization Factor	VF	See Table C2	m^3 air/kg soil
Particulate Emission Factor	PEF	See Table C2	m^3 air/kg soil
Exposed skin area for soil/dust (child)	SA_c	2800	cm^2 /day
Skin absorption factor	ABS	See Table C-2	unitless

Parameter	Abbreviation	Value	Units
Adherence Factor (child)	AF_c	0.2	mg/cm^2
Adherence Factor (worker)	AF_o	0.2	mg/cm^2
Inhalation rate (adult)	IRA_a	20	m^3/day
Inhalation rate (child)	IRA_c	10	m^3/day
Soil ingestion (adult)	IRS_a	100	mg/day
Soil ingestion (child)	IRS_c	200	mg/day
Soil ingestion: occupational	IRS_o	100	mg/day
Exposure frequency: residential	EF_r	350	d/y
Exposure frequency: occupational	EF_o	250	d/y
Exposure duration: residential	ED_r	30	years
Exposure duration: childhood	ED_c	6	years
Exposure duration: occupational	ED_o	25	years

Table C-2. Chemical Specific Parameters for Exposure Equations

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	**Volatilization Factor[3]**
Miscellaneous Chemicals			
2,4-D	5%	1.316×10^9	
2,4-D	10%	1.316×10^9	
Pentachlorophenol	25%	1.316×10^9	
Perchlorate		1.316×10^9	
Lipophillic Chemicals			
Aldrin	5%	1.316×10^9	
Benzo(a)pyrene	13%	1.316×10^9	
Chlordane	4%	1.316×10^9	
DDD	5%	1.316×10^9	

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
DDE	5%	1.316×10^9	
DDT	5%	1.316×10^9	
Dieldrin	5%	1.316×10^9	
1,4-Dioxane	10%	1.316×10^9	
Dioxin (2,3,7,8-TCDD)	0.2%	1.316×10^9	
Endrin	5%	1.316×10^9	
Heptachlor	5%	1.316×10^9	
Lindane	5%	1.316×10^9	
Kepone	5%	1.316×10^9	
Methoxychlor	5%	1.316×10^9	
Mirex	5%	1.316×10^9	
PCBs	14%	1.316×10^9	
Toxaphene	5%	1.316×10^9	
Inorganic Chemicals			
Antimony and compounds	1%	1.316×10^9	
Antimony pentoxide	1%	1.316×10^9	
Antimony potassium tartrate	1%	1.316×10^9	
Antimony tetroxide	1%	1.316×10^9	
Antimony trioxide	1%	1.316×10^9	
Arsenic	4%	1.316×10^9	
Barium and compounds	1%	1.316×10^9	
Beryllium and compounds	1%	1.316×10^9	
Beryllium oxide	1%	1.316×10^9	
Beryllium sulfate	1%	1.316×10^9	
Cadmium and compounds	0.1%	1.316×10^9	
Chromium III	1%	1.316×10^9	
Chromium VI	1%	1.316×10^9	
Cobalt	1%	1.316×10^9	
Copper and compounds	1%	1.316×10^9	

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
Fluoride	1%	1.316×10^9	
Lead and lead compounds	1%	1.316×10^9	
Lead subacetate	1%	1.316×10^9	
Lead acetate	1%	1.316×10^9	
Mercury and compounds	10%	1.316×10^9	
Molybdenum	1%	1.316×10^9	
Nickel and compounds	0.02%	1.316×10^9	
Nickel subsulfide	0.02%	1.316×10^9	
Selenious acid	10%	1.316×10^9	
Selenium	1%	1.316×10^9	
Silver and compounds	1%	1.316×10^9	
Thallium and compounds	1%	1.316×10^9	
Vanadium and compounds	1%	1.316×10^9	
Zinc	1%	1.316×10^9	
Zinc phosphide	1%	1.316×10^9	
Volatile Chemicals			
Benzene	10%		2784
Carbon tetrachloride	10%		1965
Dichloroethane, 1,2-	10%		4924
Dichloroethylene, cis-1,2-	10%		2904
Dichloroethylene, trans 1,2-	10%		2106
Ethylbenzene	10%		4152
Methyl tert butyl ether	10%		8670
Naphthalene	10%		43256
Tetrachloroethylene	10%		3189
Tetraethyl lead	10%		5516
Toluene	10%		3553
Trichloroethane, 1,1,1-	10%		2390
Trichloroethylene	10%		2595

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
Vinyl chloride	10%		1037
Xylenes	10%		4368

Notes

1 Suggested values in Table 7 are from (DTSC, 1994) Table 2. page A-6

2 Value taken from Smucker (2002) applied to nonvolatile chemicals.

3 Values taken from Smucker (2002) applied to volatile chemicals

References

Department of Toxic Substances Control (DTSC). 1994. *Preliminary Endangerment Assessment Guidance Manual*, Department of Toxic Substances Control, California Environmental Protection Agency, Sacramento, CA.

Smucker S. 2002. “Region 9 PRGs Table 2002 Update”. Memo written by Stan Smucker to PRGs Table Users. October 1, 2002. http://www.epa.gov/region09/waste/sfund/prg/index.htm.

Appendix D: Pros and Cons for Including Exposure to Chemicals in Crops Grown in Contaminated Soil

The issue is whether or not the backyard gardening exposure pathway should be included in developing soil-screening numbers under SB32. This pathway involves estimating the amount of chemical transferred from the soil to the edible portion of produce and then estimating the amount of produce consumed by people. The issue of its absence from the Risk-Based Screening Levels (RBSLs) developed by San Francisco Bay Regional Water Quality Control Board was raised by one of the peer reviewers from the University of California. This appendix describes the arguments for and against the inclusion of the pathway in the screening numbers being developed by the Office of Environmental Health Hazard Assessment.

Pro

Several of the chemicals for which SB32 mandates Cal/EPA to develop Soil-screening Numbers have been found in vegetables and fruit that are grown in backyard gardens. The United States Department of Agriculture (USDA) periodically analyzes produce purchased at supermarkets around the country. In a report dated September 2000, several pesticides that have been banned for many years were found in a number of fruits and vegetables that are commonly found in backyard gardens. Clearly, vegetables purchased in supermarkets are not grown in backyard gardens and it is unclear how the chemical got into the vegetables. However, since chemicals like DDT have been banned for decades it is unlikely these crops were sprayed with these chemicals. These relatively nonvolatile pesticides are ubiquitous in agricultural soils because they do not readily degrade. Therefore, it is likely that the source of these pesticides is the soil to which they were applied years ago.

A number of studies had been conducted measuring the both the concentration of a given chemical in the soil in which crops were grown and the concentration in the crop. Travis and Arms (1988) found a correlation between the plant-soil partition coefficient and the K_{ow} (octanol/water coefficient). Therefore, there is documentation that plants grown in contaminated soil become contaminated themselves.

People consume much larger quantities of vegetables and fruits than the amount of soil that regulatory agencies assume to be ingested each day as part of the exposure assessment portion of a site health risk assessment. If these vegetables take up the chemical to any degree, people with gardens are almost certainly exposed to higher amounts of chemical than estimated by assessments lacking this pathway.

Con

SB32 is intended to assist property owners in determining whether California regulatory agencies will likely require cleanup of their property and gives the property owner a way to estimate possible costs of cleanup activities. Food pathways are rarely considered by regulatory agencies in conducting human health risk assessments. Therefore, including a gardening pathway would not reflect current risk assessment practices.

The mechanism(s) by which chemicals in soil are transferred into plants is not well understood. This makes it difficult to develop mathematical models to predict the movement of chemicals from soil to plants. There is enormous uncertainty in models that do exist. While there are studies measuring ratio of concentrations of chemicals in soil to that in produce grown in the soil, there is still a paucity of data on this for most chemicals.

The amount of backyard grown produce consumed by people varies greatly. Most Californians buy all their produce from markets, while some have small backyard gardens. A very few grow a substantial portion of their diet in their backyards. It is not clear how best to include the large divergent population into a representative component of screening value calculations.

Summary

Scientists suspect the food exposure pathway from backyard grown produce may be significant based on real and anecdotal evidence, but cannot accurately estimate its contribution to environmental exposure for most chemicals. In fact, the uncertainties in the food pathway exposure assessment are considerable. It is clear that a soil to plant pathway exists. However, it is not clear what are the most important mechanisms for transfer of soil contaminants to plants and how to best quantify that transfer. There is also insufficient information to determine which food plants are the most important to consider in any model and how to obtain and incorporate consumption patterns of that food for the model.

While dealing with uncertainties in quantifying exposure pathways for health risk assessment is not unusual, dealing with the scope of the uncertainties for the food pathway is especially difficult. For this reason, USEPA and California agencies regulating site cleanups, have chosen not to routinely include this pathway in site-specific risk assessments for most chemicals. Lead is the only exception. Therefore, the soil-screening number for lead will be based on the Department of Toxic Substances Lead Spread computational tool. The soil-screening numbers for brownfield sites are intended to give property owners a sense whether DTSC or one of the RWQCBs may require cleanup based on a site-specific risk assessment.

Appendix E: Comments and Responses on the draft report *Proposed Methodology for Calculating Advisory Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (OEHHA, 2004)

Table of Contents

Commenters

(CCLR)	California Center for Land Recycling- Stephanie Shakofsky
(CoO-GN,MG)	City of Oakland – Gopal Nair, Mark Gom
(CVRCB-AV)	Central Valley Regional Water Quality Control Board - Antonia Vorster
(AS)	Andrew Sheldon
(DTSC-SD)	Department of Toxic Substances Control-Stephen Dizio
(EnviroCoalition)-	California Communities Against Toxics-Jane Williams, California Environmental Rights Alliance- Joe Lyou, Del Amo Action Committee – Cynthia Babich, Desert Citizens Against Pollution – Roland Valentine, Greenaction - Bradley Angel
(GLI-JG,OA,BB)	Greenling Institute – Jo Gamboa, Orson Aguilar, Ben Benavidez
(LARQCB-DB)	Los Angeles Regional Water Quality Control Board - David Bacharowski
(LARQCB-YR)	Los Angeles Regional Water Quality Control Board - Yue Rong
(SOMA – NO)	Soma Corporation- Norm Ozaki
(SC -BM)	Sierra Club – Bill Magavern
(SFRWQCB – RB)	San Francisco Regional Water Quality Control Board - Roger Brewer
(SJIA-TS)	San Jose International Airport – Tom Stoflet
(SR-JF)	Soil Research - Jim Frampton
(T&R)	Treadwell & Rollo, Inc- Glenn Leong

Comments Related to the Main Body of the Document

***Comment 1 (SR-JF)*:** The main body of the text is replete with generalities and conclusions without supporting information. The reader is often referred to Appendix B to explain conclusions made in the main part of the document.

Response: The OEHHA document on recommended methodology was designed to make the main body of the document understandable to readers unfamiliar with detailed mathematical equations. Mathematical details were put in the appendices. This is one of the standard types of document organization that OEHHA will continue to use in its soil-screening level program.

Comment 2 (SR-JF)**:** The Proposed Methodology does not adequately explain in the main body of the document how the model was constructed and the rational for the physical and chemical parameters that were used to generate screening values.

Response: The OEHHA document on recommended methodology was designed to make the main body of the document understandable to readers unfamiliar with detailed mathematical equations. Mathematical details were put in the appendices. This is one of the standard types of document organization that OEHHA will continue to use in its soil-screening level program.

Comment 3 (SR-JF)**:** In the main body of the text, OEHHA should outline the main assumptions used in proposed methodology. For example, the proposed methodology assumes an "infinite source," the source is only soil and not ground water, and that soil contamination extends upward to the engineered fill.

Response: In the revised document, screening numbers for volatile chemicals are based on soil gas levels. It is not assumed that the contamination in soil gas comes directly from soil and not from contaminated groundwater. Details regarding the depth below a building where contaminated soil gas is initially located remains in Appendix B for reasons given in the response to Comment 2.

Comment 4 (SR-JF)**:** Appendix B needs to be better integrated with the main body of the text.

Response: In the main body of the text, OEHHA states, in general terms, how the Johnson and Ettinger model was used to calculate soil-gas-screening numbers. All technical details appear in Appendix B and not in the main body of the text. The reasons for choosing this document organization are stated in the response to Comment 3.

Comment 5 (SR-JF)**:** OEHHA scientists stated that they "Concurred with the opinions of the two [peer review] panel members who criticized the methodology used for predicting indoor air contamination from soil gas." OEHHA should point out in the Proposed Methodology what aspects of the methodology were criticized and why they concurred with the criticism.

Response: The criticism of the two UC peer reviewers was that the initial US EPA version of the Johnson and Ettinger model predicted a ratio of indoor air contamination to soil gas contamination that is unrealistically low. OEHHA believes that it might have been helpful to some readers of the proposed methodology document if more information had been provided. However, OEHHA has used a revised version of the Johnson and Ettinger model with default parameters changed in the direction recommended by the two UC peer reviewers.

Comment 6 (SFRWQCB – RB)**:** Page 5:

"Two of the UC panel member reports state reasons why the methodology can underpredict indoor air contaminant concentrations (McKone, 2003; Nazaroff, 2003), particularly when used to model vapor emissions from fine-grained, silty and clayey soils. The RWQCB subsequently revised their document to reflect these recommendations (July 2003 update to screening levels document)."

Response: OEHHA agrees with this comment.

Comment 7 (SFRWQCB – RB)**:** "This value is consistent with recommendations of the two UC peer review panel members. This value is also consistent with soil gas-to-indoor air attenuation factors incorporated into to the updated, July 2003 edition of the RWQCB document."

Response: OEHHA agrees with this comment.

Comment 8 (SR-JF)**:** Ratios for indoor air contaminant concentrations to soil gas concentrations (defined as alpha) are given in Table 2 and are said to be calculated using the "advanced model for vapor intrusion of volatile chemicals and tetraethyl lead." OEHHA did not explain how these ratios were derived or how they were to be used in this section of the report, yet the public is apparently supposed to accept these ratios at face value. OEHHA should clearly explain the origin of these numbers in this section of the "Proposed Methodology" and show how they will be used to establish soil-screening levels.

Response: The OEHHA document on recommended methodology was designed to make the main body of the document understandable to readers unfamiliar with detailed mathematical equations. Mathematical details were put in the appendices. This is one of the standard types of document organization that OEHHA will continue to use in its soil-screening level program.

Comment 9 (SR-JF)**:** OEHHA scientists stated that they used the 2002 version of the J&E model with soil parameters that describe a dry course grained soil of low organic carbon content and with parameters recommended by the US EPA. The primary equations and parameters used to calculate soil-screening numbers, along with the rationale, should be presented in this section. At a minimum, equations in Appendix B should be referenced by equation number. Therefore, OEHHA should also number the equations in Appendix B.

Response: In the main body of the text, OEHHA will expand the discussion of material in Appendix B and will make more precise references to material in Appendix B in future documents on soil-screening levels.

Comment 10 (SR-JF)**:** OEHHA needs to describe how they calculated the numbers given in Tables 6 and 9 in Section 5 of the Proposed Methodology. For example, what were indoor air contaminant concentrations upon which the derived soil gas levels were based? I presume that these are the same as the "Target Indoor Air Concentrations" discussed in Appendix B. These Target Indoor Air Concentrations should be tabulated and the equations and parameters should be described up front, or at least referred to by equation number in Appendix B.

Response: Target indoor air concentrations will be defined and explained in future documents on soil-gas-screening level calculations published by OEHHA.

Comment 11 (SR-JF)**:** OEHHA has back-calculated soil-screening numbers for various chemicals of concern. Screening levels for VOCs are given in Table 6 for residential land use and Table 9 for commercial/industrial land use. OEHHA needs to explain how these numbers were derived within the main body of the text, or at least refer to specific equations in Appendix B. In addition, OEHHA needs to explain how there methodology differs from the EPA model.

Response: The OEHHA document on recommended methodology was designed to make the main body of the document understandable to readers unfamiliar with detailed mathematical equations. Mathematical details were put in the appendices. This is one of the standard types of document organization that OEHHA will continue to use in its soil-screening level program.

Comment 12 (SFRWQCB – RB)**:** In Tables 6 and 9 (vapor intrusion concerns), I deleted the soil-screening levels for vapor intrusion, retained the screening levels for soil gas and added columns for OEHHA and RWQCB indoor air screening levels. This again makes the comparison to RWQCB ESLs for soil gas and indoor air much clearer and highlights the similarities. Note that OEHHA screening levels for indoor air need to be added.

Response: For purposes of simplicity and clarity, the tables at issue in this comment now contain only the screening numbers calculated by OEHHA. .

Comment 13 (SFRWQCB – RB)**:** Revise Table 5. Comparison of Soil Levels for Volatile Chemicals Based on Direct Exposure to Soil-Bound Chemicals (Inhalation, Ingestion and Dermal Absorption): Residential Land Use

Response: This table has been removed. ***Comment 14 (SFRWQCB – RB)*****:** Revise Table 6. Comparison of Indoor Air and Soil Gas Levels for Volatile Chemicals and Tetraethyl Lead Based on the Proposed Methodology Based for Vapor Intrusion to Indoor Air: Residential Land Use

Response: This table has been removed. ***Comment 15 (SFRWQCB – RB):*** Revise Table 8. Comparison of Soil Levels for Volatile Chemicals Based on Direct Exposure to Soil-Bound Chemicals (Inhalation, Ingestion and Dermal Absorption): Commercial/Industrial Land Use. Note that the OEHHA soil-screening levels for volatile chemicals at commercial/industrial sites appear to have been inadvertently replaced with screening levels for residential sites in your Table 8. These need to be added to the final tables.

Response: This table has been removed.

Comment 16 (SFRWQCB – RB): Revise Table 9. Comparison of Indoor Air and Soil Gas Levels for Volatile Chemicals and Tetraethyl Lead Based on the Proposed Methodology Based for Vapor Intrusion to Indoor Air: Commercial/Industrial Land Use

Response: This table has been removed.

Comment 17 (SFRWQCB – RB): Revise Table 4. Soil Levels for Nonvolatile Chemicals Based on Direct Exposure to Contaminated Soil: Residential Land Use (Inhalation, Ingestion and Dermal Absorption)

Response: This table has been removed.

Comment 18 (SFRWQCB – RB): Revise Table 7. Soil Levels for Nonvolatile Chemicals Based on Direct Exposure to Contaminated Soil: Commercial/Industrial Land Use (Inhalation, Ingestion and Dermal Absorption)

Response: This table has been removed.

Comment 20 (SR-JF): P. 5, 2nd paragraph and Table 2: Ratios for indoor air contaminant concentrations to soil gas concentrations (defined as alpha) are given in Table 2 and are said to be calculated using the "advanced model for vapor intrusion of volatile chemicals and tetraethyl lead." OEHHA did not explain how these ratios were derived or how they were to be used in this section of the report, yet the public is apparently supposed to accept these ratios at face value. OEHHA should clearly explain the origin of these numbers in this section of the "Proposed Methodology" and show how they will be used to establish soil-screening levels.

Response: The alpha is an intermediate calculation produced by the J&E model. The table of alpha values was included to compare one chemical to another. How the value of alpha is used to calculate a soil-gas-screening level from the target indoor air concentration is explained in the main text.

Comment 21 (SR-JF): P. 13, last paragraph: OEHHA should describe how they determined "soil gas concentrations that are equivalent to selected soil levels" as shown in Tables 6 and 9. OEHHA should show equations and input parameters and explain why input parameters were selected. I presume OEHHA used the equation shown in Section 3.4 in Appendix B.

Response: OEHHA screening numbers for volatile chemicals are now based on soil gas levels and not on concentrations per kg of soil. Therefore, the methodology for calculating soil gas levels from soil concentrations is not discussed.

Comments on Legislative Scope

Comment 22 (GLI-JG,OA,BB)*:* Consider other state's screening numbers in compliance with H&S Code § 57008(b)(2)(D).

Response: OEHHA reviewed screening levels from other states that are in the summary prepared by the California Center for Land Recycling and reviewed screening levels published by the State of Washington under the Model Toxics Control Act. Differences between these levels and those calculated by the methodology proposed by OEHHA are due to differences in toxicity criteria or to differences in the exposure algorithms used for screening level calculation.

***Comment 23 (CCLR)*:** OEHHA should give equal weight to all considerations, as mandated by SB32, and not develop assumptions based on the above text to the exclusion of other considerations. It is CCLR's opinion that OEHHA's interpretation of this text has lead them to use *unrealistically* conservative assumptions in their volatile modeling, which results in driving the screening level numbers for volatiles to below detection limits, effectively creating a zero screening level for this common contaminant.

Response: OEHHA does not agree with this comment because the assumptions and parameters used by OEHHA to estimate the ratio of contaminant soil gas concentration beneath a building to the concentration inside a building is consistent with current U.S. EPA recommendations. The parameters used by OEHHA are similar to, but not as conservative as those recommended in the peer review of Dr. William Nazaroff.

Comment 24 (GLI-JG,OA,BB)*:* Consider cleanup levels approved by DTSC and the RWQCBs and other local agencies in compliance with H&S Code § 57008(b)(2)(B)-(C).

Response: When information on cleanup levels at sites where DTSC has authority becomes available, OEHHA will compare recommended soil-screening levels with these cleanup levels. The report that will be used for this comparison is being prepared by departments or boards other than OEHHA within Cal/EPA.

Comment 25 (T&R): Consideration of Factors Required under Health and Safety Code Section 57008 Subsection (2)(C) - One of the factors required for consideration in the development of the screening levels is the following:

> *Cleanup levels that have been established for the contaminant at sites that have been, or are being, investigated or remediated under Chapter 6.8 (commencing with Section 25300) of Division 20, or cleaned up or abated under Division 7 (commencing with Section 13000) of the Water Code or under any other remediation program administered by a federal or local agency.*

In Section 2, the subject document indicates that "OEHHA staff did not formally consider Cleanup levels that have been established for the contaminant at sites". This is an important factor that must be given equal weight in the factors considered in the development of the soil-screening levels. At a minimum, OEHHA should consider cleanup levels established or to be established by DTSC as noted in the Fact Sheets available at the following Internet address: http://www.dtsc.ca.p,ov/SiteCleanup/Cleanup SitesIndex.html. Cleanup orders for the various Regional Water Quality Control Boards (RWQCBs) are also available via the Internet. Some of the orders include soil cleanup levels. OEHHA should be at least review cleanup level information that the public can access. OEHHA should compile cleanup levels from DTSC, the various RWQCBs, and other regulatory agencies. The cleanup levels approved by DTSC and the various RWQCBs likely include consideration of protection of human health and safety, but may also take into account technical constraints of remediation, as well as background concentrations of metals. These same considerations should be incorporated into the soil-screening levels.

Response: When information on cleanup levels at sites where DTSC has authority becomes available, OEHHA will compare recommended soil-screening levels with these cleanup levels.

The report that will be used for this comparison is being prepared by departments or boards other than OEHHA within Cal/EPA.

Comment 26 (T&R): Consideration of Factors Required under Health and Safety Code Section 57008 Subsection (2)(D) - One of the factors required for consideration in the development of the screening levels is the following:

Screening numbers that have been published by other agencies in the state, in other states, and by federal agencies.

Although the PRGs, ESLs, and Risk Based Concentrations (RBCs) from U.S. EPA Region 3 were considered, screening levels from other states must also be considered. Screening levels have been developed for the State of Washington under their Model Toxics Control Act Cleanup Regulations. The State of Washington has screening levels, as well as defined methods for developing site-specific values for a variety of situations. Their methodology (readily available on the Internet), should be considered for incorporation into the cleanup levels.

Response: OEHHA reviewed cleanup levels published by a number of other regulatory agencies including the State of Washington under the Model Toxics Control Act. Differences between these levels and those calculated by the methodology proposed by OEHHA are due to differences in toxicity criteria or to differences in the exposure algorithms used for screening level calculation. OEHHA has selected California toxicity criteria over others and has used exposure criteria used by other California regulatory agencies.

Comment 27 (LARQCB)-YRR: The OEHHA screening numbers are based on human exposure only, no consideration of impact of leaching contaminant to groundwater quality. I therefore suggest to have a default to Cal/EPA screening numbers developed by Region 2.

Response: OEHHA agrees that protection of groundwater is not addressed in the proposed methodology. It is not appropriate for OEHHA to agree or disagree with the proposed default to screening levels published by Region 2 .

Comment 28 (LARQCB-DB): The OEHHA screening numbers are based on human exposure only, no consideration of impact of leaching contaminant to groundwater quality. Screening numbers generated are to be used by property owners, developers, citizen groups etc., to estimate the degree of effort that may be necessary to remediate a contaminated property. If soil-screening numbers do not incorporate inputs to ground water, then the screening numbers can not reasonably determine the degree of effort necessary for site remediation, we all know that ground water remediation including assessment, monitoring, and clean up can be many orders of magnitude more costly than soil cleanup. We therefore feel that the screening numbers should not be used for sites where the contaminates have impacted the ground water and we suggest that OEHHA needs to have a default to Cal/EPA screening numbers developed by the San Francisco Regional Water Quality Control Board in order to fully address the ground water issues.

Response: OEHHA agrees that protection of groundwater is not addressed in the proposed methodology. It is not appropriate for OEHHA to agree or disagree with the proposed default to screening levels published by Region 2.

Comment 29 (CVRCB-AV): We support OEHHA's decision not to develop soil-screening levels to protect water resources. The wide variability in site conditions throughout California would require that a single set of water-protective screening levels be established at concentrations that reflect the reasonable worst-case, which would likely be overly conservative in many situations. Generation of less protective screening levels would be inadequate to provide water resource protection in some locations. These problems would significantly restrict the usefulness of such screening levels. Additionally, water quality standards for groundwater and surface water, established by the nine Regional Water Boards, vary from location to location, based on variation in beneficial uses of water resources. Because the Central Valley Region supplies water to most urban and agricultural areas of the state, standards for groundwater quality applicable to Central Valley groundwaters tend to be more stringent than those found elsewhere in the state. We have developed a method to generate screening levels for groundwater and surface water, based on applying promulgated narrative and numeric water quality standards. Attached is a summary of this method. Additional information and supporting documentation are available on our web site at http://www.swrcb.ca.gov/rwqcb5/available_documents/index.html#WaterQualityGoals

Response: OEHHA will consider this comment and other comments from staff of the State Water Resources Control Board and Regional Water Quality Control Boards in reporting on the feasibility of statewide screening levels for the protection of groundwater.

Comment 30 (SJIA-TS): The definition of a screening number is too vague and will provide little value if it has no regulatory approval for cleanup or to determine if excavated or exported soil from one site is acceptable for re-use at another site. There needs to be a much more uniform approach that will be acceptable by all regulatory agencies on the use of the screening levels; otherwise the regulated community is left to the mercy of uniformed and unqualified consultants and lawyers to assist the regulated community to sort out the appropriateness on inappropriateness of the levels should they pose unreasonable financial and legal burdens upon the property owner, particularly if they cause unjustified and costly delays in the development of a land use projects or property transfers.

Response: It is not appropriate for OEHHA to agree or disagree because this comment addresses an act of the State Legislature.

Comment 31 (SJIA-TS): OEHHA/RWQCB need to establish standards that are applied uniformly between all regulatory agencies. This was recommended in the UST task force I referenced above, and I have yet to see this implemented. Clearly, the agencies have large databases of site closures and cleanups that should be peer reviewed. From these databases, the appropriate standards that are protective of human and health and the environment, and that are technically defensible, should be made available on the web for any type of land use develop project and as a function of each type of environmental media for which the screening number intends to protect. Cleanup levels should not be left to the arbitrary decision making of certain regulatory personnel.

Response: OEHHA believes that consistency in site risk assessment is very important and will continue to promote consistency in developing final soil-screening numbers.

Comment 32 (SJIA-TS): All comments to this draft document and prior methodologies using the "Most stringent hazard criterion" on establishing these screening numbers should be also made available for public review on Cal/EPA's web site. Peer review must be allowed and incorporated by the regulated community, and not be limited to just UC scientists.

Response: Comments on the proposed methodology will be published and made available on a Cal/EPA website. As required by SB 32, the California Environmental Protection Agency will hold three public workshops for discussion and to receive comments on screening numbers developed by OEHHA. This process will enable any interested party to publicly state opinions on methodology and policy issues related to the screening numbers.

Comment 33 (SR-JF): The legislature is placing a severe burden on the California EPA by asking the Agency to calculate soil-screening numbers, even if they are only meant to be "advisory". Published numbers will take on a life of their own, regardless of their stated limitations. In effect, generic screening numbers will be scientifically meaningless.

Response: It is not appropriate for OEHHA to agree or disagree with this comment because it addresses the legislative definition and future use of screening levels.

Comment 34 (SR-JF): General Comments on what SB 32 stated that Cal/EPA (by default, OEHHA) should consider when determining screening numbers:

(A) "The toxicology of the contaminant": OEHHA should also point out whether OEHHA levels differ from EPA levels and why. Further, a contaminant's "potential for causing environmental damage to natural resources" was not considered in the report. Such a consideration would require an understanding of a chemical's persistence and mobility in the environment.

Response: We disagree with this comment. OEHHA is recommending that screening numbers be based on toxicity criteria recommended by DTSC. This OEHHA recommendation and DTSC choice of toxicity criteria are generally policy choices. What, if any, differences there may be between U.S. EPA and OEHHA toxicity criteria does not appear to be relevant to the recommendation made by OEHHA.

(B) Risk Assessment prepared by federal and state agencies, etc.: SB 32 did not request Cal/EPA to consider risk assessment methodologies under (B) (see Section 4 of the report). Rather, SB 32 requested Cal/EPA to consider risk assessments. OEHHA did not provide a survey of risk assessments. OEHHA should review specific risk assessment and show how they were considered in establishing soil-screening levels.

Response: OEHHA disagrees with this comment. U.S. EPA risk assessments on chemicals listed in the OEHHA document are available on the U.S. EPA website. OEHHA risk assessment documents on these same chemicals are available on the OEHHA website. These are the risk assessment documents reviewed for the screening number project.

(C) Cleanup levels under California cleanup programs: OEHHA deferred this consideration to another Cal/EPA document reporting on a pilot study as required by SB 32 (Section 57009 of the Health and safety Code). However, the requirements under Section 57009 only apply to the San Francisco Regional Water Quality Control Board (RWQCB Region II) screening levels. Therefore, OEHHA should include considerations of cleanup levels under other California programs.

Response: OEHHA disagrees. By agreement with Cal/EPA, the report on cleanup levels is not being prepared by OEHHA. But is being prepared by boards and departments within Cal/EPA

(D) Screening numbers published by other agencies: OEHHA stated they "reviewed" a compilation of screening levels published by the California Center for Land Recycling. Where is this review? Where are the screening numbers published by other agencies? What are the bases for these numbers?

Response: This "comment" is one question followed by a second question. The answer to the first question is that the compilation prepared by CCLR is proprietary information. The answer to the second question is that U.S. EPA Region 9 screening levels (PRGs) are included in the OEHHA report. U.S. EPA Region 3 screening levels are referenced and are available on the website.

(E) Results of external peer review of RWQCB Region II screening numbers: OEHHA stated that the major criticism of the review panel was of the methodology used to predict indoor air contamination from chemicals in soil gas. According to OEHHA, this methodology was based upon the "Johnson and Ettinger" model as implemented in by the US EPA in 2001. A revision of this model (US EPA, 2003) was "evaluated" by OEHHA "using parameters recommended in the user's guide." OEHHA stated that the calculated ratio of indoor air contaminant concentrations to soil gas concentrations was "consistent with recommendations by the two UC peer review panel members." Apart from the lack of supporting documentation for OEHHA's statements, Cal/EPA was only required by SB 32 to conduct a scientific peer review process in accordance with section 57004 of the Health and Safety Code. However, Section 57004 would also require that the methodology used by OEHHA be peer reviewed. There is no documentation of such a review. OEHHA should explain why, if they concurred with the opinions of the two panel members who criticized the Johnson and Ettinger methodology, they continued to support this model. It would prove valuable to readers of this "Proposed Methodology" if the comments by the peer reviewers were included in the appendices of this document.

Response: The main criticisms of the U. C. peer reviewers were that the flux of soil gas into residences was too low, that the air exchange rate was too low and that the resulting dilution of soil gas into indoor air was too high in the first version of the Johnson and Ettinger model released by U.S. EPA. In the current U.S. EPA version used by OEHHA, soil gas flux into a building and air exchange rate are greater than default values in the previous version, resulting in a lower dilution of soil gas in indoor air.

SB 32 did require a scientific peer review of the Risk Based Screening Levels. However, SB 32 does not require a scientific peer review of methodology recommended by OEHHA for calculating soil-screening numbers. As required by SB 32, the California Environmental Protection Agency will hold three public workshops for discussion and to receive comments on screening numbers developed by OEHHA. This process will enable any interested party to publicly state opinions on methodology and policy issues related to the screening numbers.

Comments on Risk Management

Comment 35 (SJIA-TS): Municipalities are probably the largest soil broker sources in California for new land use projects. However, conversation with several companion cities in the Bay area indicate that they have never heard of this document. It seems reasonable that the regulated community be better informed of this prior to finalization. Consequently, I am recommending a mass emailing notice of this document be sent to all Public Works and Environmental Services Departments of the major cities in the state of California, and that finalization of this document be postponed until we have had a chance to conduct an appropriate peer review of it. OEHHA needs to more fully understand how these levels, if not developed in partnership, can adversely affect commercial transactions.

Response: OEHHA has forwarded this comment to the California Environmental Protection Agency's Office of the Secretary to facilitate better communication. OEHHA encourages representatives of municipalities and counties to communicate any concerns that they may have with the proposed methodology far calculating soil-screening numbers. The published numbers will be available for further review and workshops.

Comment 36 (SJIA-TS): All carcinogenic, reference dose factors and PRGs should undergo a through peer review by a multi-disciplinary team from both private and the public sectors to assess their accuracy and validity, since the use of these and other exposure factors can overestimate the risk by orders of magnitude. I suggest OEHHA review several publications such as "Exaggerating Risk, Technological Reality, and Sticker Shock", prepared by the Hazardous Waste Cleanup Project. While these reports all 10 years old, and there may be more updated ones, they provide extremely useful insight from the regulated community.

Response: SB 32 does not give OEHHA resources or authority to carry out the activities recommended by this commenter.

Comment 37 (SC –BM): Complying with the statutory charge to use a risk assessment methodology consistent with the "most stringent" US EPA Superfund methodology, OEHHA used a risk level of 1 in a million. We would strongly oppose any relaxation of that risk level. In fact, we believe a risk level of 1 in 10 million would be justified, to provide a sufficient safety factor.

Response: OEHHA believes that the target lifetime cancer risk level of one in a million is the selection most consistent with the requirements of SB 32 because it is the "most stringent" applied by U.S. EPA and DTSC at sites in California and therefore the most appropriate basis for identifying sites where remediation efforts may be required.

Comment 38 (CCLR): CCLR recommends that OEHHA consider screening levels based on a risk factor of 10^{-4} or 10^{-5} in situations where a screening level based on a risk factor of 10^{-6} falls below either established background concentration or Acceptable Detection Limit (ADL).

Response: OEHHA believes that the target lifetime cancer risk level of one in a million is the selection most consistent with the requirements of SB 32 because it is the "most stringent" applied by U.S. EPA and DTSC at sites in California and therefore the most appropriate basis for identifying sites where remediation efforts may be required.

Comment 39 (CCLR): OEHHA should adjust their Hazard Quotient to create screening level numbers that are relevant and user-friendly.

Response: OEHHA is currently developing a spreadsheet to facilitate calculation of the hazard quotient.

Comment 40 (GLI-JG,OA,BB): Adopt a clear formula for adjusting screening levels for total exposure to contaminated soil when more than one contaminant is found at a site.

Response: OEHHA will develop a spreadsheet to facilitate calculation of the hazard quotient. The spreadsheet will contain the equation (formula) that is precisely stated in this document.

Comment 41 (LARQCB-DB): The 0EHHA screening numbers were derived assuming exposure to one chemical with a specific, potential health effect at a given site (Target Hazard Quotient = 1.0). For multiple chemicals, OEHHA recommends a hazard index approach to provide protection. In contrast, the Regional Board's ESLs were derived by applying a predetermined safety factor (e.g., Target Hazard Quotient = 0.2) to provide protection for exposure to more than one chemical. We consider 0EHHA's approach to be reasonable and in agreement with the hazard index approach recommended by the US EPA Superfund program and by the Department of Toxic Substances and Control (DTSC).

Response: The hazard index approach is recommended by U.S. EPA, DTSC and also at RWQCB sites when OEHHA reviews site risk assessments at the request of a RWQCB. OEHHA thanks the author for his comment and plans to keep this method in its report.

Comment 42 (T&R): Soil Screening Levels Lower Than Detection Limits - The subject document indicates that the screening values "are not intended for use by regulatory agencies that have authority to require remediation of contaminated soil" but the soil screening levels will likely be used by various nonCal-EPA agencies as cleanup levels. The U.S. EPA Preliminary

Remediation Goals (PRGs) and the San Francisco Bay Regional Water Quality Control Board Environmental Screening Levels (ESLs) also contain similar language warning that their levels are not intended for use as actual cleanup levels. The PRGs and ESLs have been used by many agencies as de facto cleanup levels in lieu of site-specific cleanup levels. It is likely that the subject document will be used in the same manner. As noted by members of the Office of Environmental Health Hazard Assessment (OEHHA) during the April 6, 2004 workshop in Sacramento, "we cannot control misuse of the soil screening levels". Knowing that the soil screening levels will likely be used as cleanup levels by some regulatory agencies, the inclusion of soil screening levels below analytical detection limits (primarily for volatile organic compounds) further compounds the misuse of the soil screening levels. At a minimum, OEHHA can control misuse of the levels by removing levels that cannot be measured. Removal of the soil screening levels for volatile organic compounds, as suggested previously, would effectively remove the soil screening levels lower than detection limits.

Response: For volatile chemicals in soil, OEHHA encourages using soil-gas-screening levels rather than bulk soil-screening levels. However, OEHHA does not have authority to require soil gas measurements. OEHHA noted this concern and has other technical concerns with the soil-screening numbers for volatile chemicals. OEHHA has decided to only provide soil-gas-screening numbers for the volatile chemicals.

Comments on the Absence of a Backyard Gardening Scenario

Comment 43 (SC –BM): The methodology should consider a backyard gardening scenario, as recommended by one of the peer reviewers. The draft does acknowledge that "several of the chemicals for which SB 32 mandates Cal/EPA to develop Soil Screening Levels have been found in vegetables and fruit that are grown in backyard gardens … there is documentation that plants grown in contaminated soil become contaminated themselves." OEHHA omitted the food pathway because it is rarely considered by regulatory agencies - a rationale that is not based on human health protection, but on regulatory practice. Also, OEHHA states that developing mathematical models for the food pathway would be difficult, and that most Californians do not grow a substantial portion of their diet in their backyards: These points are partially valid, but do not justify the near-total exclusion (lead being, the one exception) of a food pathway. Since we know some people do grow food in their backyards on infill sites, the draft report's refusal to incorporate a backyard gardening scenario at all is not justified.

Response: It is possible to establish soil-screening levels based on a backyard gardening scenario. As stated in Appendix D, they would be very uncertain. More importantly the purpose of these screening levels is to enable property owners to estimate cleanup costs. These costs are dependent on current practices at regulatory agencies. These agencies do not routinely use this pathway in their decisions. Therefore, they were not included in computing these screening levels.

Comment 44 (EnviroCoalition): On page D-2 you state," The mechanism(s) by which chemicals in soil are transferred into plums is not well understood. This makes it difficult to develop mathematical model to predict the movement of chemicals from soil to plants. This is enormous uncertainty in models that do exist." Yet you relied on the Johnson and Ettinger Model to propose screening numbers for soil vapor intrusion and you did not include the soil and vapors being transmitted into plants in the proposed screening numbers because of the lack of a validated model.

Response: The concerns in this comment are addressed in the response to Comment 43.

Comment 45 (EnviroCoalition): Our organizations represent environmental justice communities, and the communities we represent not only engage in backyard gardening, they also engage in other behaviors that you chose not to include in the scenarios: they often raise backyard livestock for consumption and eat eggs from fowl that forage in their backyards, they breastfeed their infants, and they spend a lot of their time gardening in their backyards.

Response: See above for the gardening scenario. The biotransfers from soil into meat, milk or eggs is extremely complex. Developing soil-screening level for these pathways will require an enormous level of financial commitment. The uncertainty associated with these values will dwarf even those of the backyard garden. Given limited resources, the size of the task and the limited number of individuals exposed it is unlikely that this will be a priority in the foreseeable future.

Comment 46 (EnviroCoalition): … we remain concerned that you did not include exposure scenarios that would be protective of environmental justice communities the backyard gardening scenario, nor did you appear to include exposures to pregnant women or breastfeeding infants, protecting the most vulnerable populations during the most vulnerable windows of development.

Response: The breast milk pathway was not included because like the gardening pathway it is not typically used by regulatory agencies when evaluating sites. Furthermore, for most chemicals it doesn't significantly increase estimates of risk because exposures are estimated for a thirty-year span only one year of which is assumed to involve breastfeeding. As the mandated child specific toxicity criteria become available over the next few years it will be important to revaluate this issue as criteria are being developed for several of the chemicals for which we have developed screening levels.

Comment 47 (SFRWQCB – RB): Appendix D: the risk-based screening level for lead presented in the tables (260 mg/kg) does not appear to include uptake in homegrown produce, as inferred in Appendix D.

Response: Both the residential and industrial have been updated. A homegrown produce pathway was assumed for the residential but not the industrial.

Comments on Nonvolatile Chemicals

Comment 48 (CCLR, T&R, CoO-GN, SJIA-TS, GLI-JG,OA, BB): OEHHA should compare their draft screening level numbers to established statewide background concentrations and adjust those screening levels that currently fall below background (such as Arsenic), following USEPA's methodology. Additionally, the user guide accompanying OEHHA's screening levels should instruct the user (as USEPA Region 9 does in their PRG guidance document) to consider background concentrations when choosing the screening levels as cleanup goals.

Response: OEHHA acknowledges that naturally occurring background soil concentrations are a major issue in determining a screening level for arsenic. The health-based screening number for arsenic is intended for arsenic contamination resulting from human activity. However, the majority of soils in California have naturally occurring arsenic at concentrations above the health-based screening number.

OEHHA thanks commenters for focusing attention on the issue of background concentrations, which is a major concern for the Department of Toxic Substances Control and the State Water Resources Control Board. These agencies are working toward recommendations on how background concentration information should be used in site risk assessment in California. These recommendations will be published in a separate document.

Comment 49 (SJIA-TS): The screening levels do not account for background levels. This is particularly important for some metals in the Bay area, and probably elsewhere. For example, naturally occurring arsenic and mercury are often found above the screening levels of 0.43 ppm and 18 ppm, respectively. The screening level methodology must have a provision that the screening level or background level, whichever level is higher is allowed, and let the regulated community demonstrate the background level.

Response: The concerns in this comment are addressed in the response to Comment 48.

Comment 50 (T&R): Lead Screening Values - The lead soil screening value for residential land use (260 mg/kg) is the same as that for commercial/industrial land use. This is likely a typographical error.

Response: The lead screening numbers for the residential scenario and the commercial/industrial scenario have been modified in response to this comment.

Comment 51 (CoO-GN): The proposed soil screening levels of lead (260 mg/kg) for industrial/commercial land use is the same as that of residential level. This value is significantly higher than the USEPA Region 9 PRG (750 mg/kg) as well as the ESL (750 mg/kg) established by the SWQCB. Since lead is widely present in urban soils all over the state, the proposed, level will be of great impact, especially in Brownfield projects. 1t would be useful to take a closer look at the assumptions, those resulted in the same screening levels for both residential and industrial/commercial land uses.

Response: The lead screening numbers for the residential scenario and the commercial/industrial scenario have been changed in response to this comment.

***Comment 52 (SFRWQCB – RB)*:** Appendix D: the risk-based screening level for lead presented in the tables (260 mg/kg) does not appear to include uptake in homegrown produce, as inferred in Appendix D.

Response: The screening levels for lead in both table 4 and 7 have been updated. Please see those values with the explanations in the footnotes. The homegrown produce is considered as a pathway for the residential scenario.

Comment 53 (SJIA-TS): Some screening levels are not sound science. For example the screening levels for DDT are not in proportion to actual risk. I know of no empirical data that would indicate that levels below 1.6 ppm of DDT in soil or 2.3 ppm of DDE in soil are protective of human health and the environment. If you have this data, I'd like to see it. If OEHHA is suggesting that soil containing DDT above these levels is unsafe, then OEHHA is placing a huge stigma on large land masses were DDT was legally applied. Neither these levels nor the RWQCB's ESLs for these parameters are technically defensible.

Response: The document describes exactly how the values for DDT and DDE were determined. The exposure assessment criteria are identical with all other chemicals and the toxicity criteria for these two chemical is what appears on the OEHHA website.

Comment 54 (T&R): Additionally, please explain how use of a hazard index approach (Section 6) can be applied to chemicals not considered carcinogens when also evaluating lead. Since the lead screening level was developed using the Lead Spread model, lead should probably considered separately from carcinogenic and noncarcinogenic chemicals.

Response: An example is now included in the main body of the text that describes how to use the soil-screening values and site concentrations to address this issue. Lead is considered a noncarcinogen unless the lead is known to exist as lead acetate in which case it should be treated as a carcinogen.

Comments Related to Volatile Chemicals

Comment 55 (CCLR, SJIA-TS): In light of the established sensitivity of the Johnson & Ettinger model to site-specific conditions, OEHHA should take a realistic approach to developing the assumptions to be applied to the model so that the resulting screening levels are a practical "estimate (of) the degree of effort that may be necessary to remediate a contaminated property"(HSC §57008(a)(3)).

Response: OEHHA selected the latest version of the US EPA recommended Johnson and Ettinger model-based spreadsheet to calculate the soil-gas screening levels. Parameter values are believed to be appropriate for screening values applicable throughout the entire state of California.

Comment 56 (CCLR): CCLR strongly urges OEHHA to adopt a finite source model with a reasonable, default thickness of contaminated soil (e.g., five meters).

Response: For volatile organic chemicals, tetraethyl lead and elemental mercury, OEHHA now recommends soil-gas screening levels only without total soil concentration screening levels. The soil-gas screening levels are calculated from the Target Indoor Air Concentration and the attenuation factor α. The Johnson and Ettinger model was used to compute the attenuation factor α. Those two parameters do not depend on the contamination thickness.

Comment 57 (T&R): Assumption of infinite depth of contamination in Johnson and Ettinger Model - The use of an infinite depth (i.e., an infinite source of contamination for volatilization) significantly affects the calculation of volatile organic compound screening levels. This is significantly different than the assumption used in the San Francisco Bay Regional Water Quality Control Board (215 centimeters). Please explain the difference and why the infinite depth assumption is reasonable.

Response: The concerns in this comment are addressed in the response to Comment 56.

Comment 58 (LARQCB-DB): The OEHHA's soil screening numbers for vapor intrusion also assumes an infinite thickness of contaminated soil is present beneath a building. In contrast, the Regional Board's ESLs assumes a finite thickness (two meters) of contaminated soil is present. With the goal of providing conservative estimates for protection of human health, we have no objection to the conservative assumption and consider OEHHA's approach to be both reasonable and valid.

Comment 59 (SR-JF): OEHHA states that the methodology that OEHHA used does not assume any limit on the depth of contamination. What does it mean? Does this mean that the depth to the contaminated soil or ground water was zero and the contamination was infinitely deep? Please explain.

Comment 60 (CVRCB-AV): The draft OEHHA document contains two types of screening levels for vapor intrusion into buildings, those based on bulk soil sampling and those based on soil gas. Our experience with sampling these media has led us to strongly favor soil gas over bulk soil in most situations. Bulk soil samples for volatile contaminants are prone to under-representing actual concentrations in the subsurface. It is very difficult to obtain and transport bulk soil samples without significant loss of the volatile contaminants to the atmosphere. Additional losses occur in laboratory handling of bulk soil samples. For these reasons, we normally require soil gas sampling and equilibrium partitioning calculations to more accurately assess the amounts of volatile contaminants in the subsurface. Soil gas screening levels would, therefore, be very useful.

Response: The concerns in those comments are addressed in the response to Comment 56.

Comment 61 (CoO-GN): Many of the screening levels proposed for VOCs are below their laboratory detection limits. This issue was brought up by many attendees during the April 6 meeting with OEHHA in Sacramento. In response to this issue, OEHHA suggested measuring soil gas-instead of the total soil concentration. We believe the collection of soil gas instead of a soil sample is more time consuming and expensive.

Response: As discussed in the response to Comment 56, OEHHA now does not recommend screening levels for VOCs based on bulk soil concentration. For VOCs, OEHHA bases soil-screening numbers on concentrations in soil gas. These soil-gas-screening numbers are above current levels of detection.

Comment 62 (LARQCB-YR): There is no standard protocol for soil gas analysis. EPA method TO-14 or TO-15 has inadequate QA/QC protocol. Therefore, we recommend to use LARQCB/ DTSC soil gas guideline (1/03) (http://www.swrcb.ca.gov/rwgcb4/html/DTSC/RWQCB_SoilGasGuidelines.html) to analyze soil gas samples.

Comment 63 (LARQCB-DB): inadequate QA/QC protocol. Therefore, we recommend using LARQCB/DTSC soil gas guideline (1/03) (http://www.swrcb.ca.gov/rwgcb4/htmVDTSC RWQCB Soil Gas Guidelines to analyze soil gas samples.

Response: OEHHA developed the recommendation to base screening levels for VOCs on soil gas levels in consultation with scientists in DTSC and RWQCBs, who have expertise in soil gas sampling. OEHHA supports recommendations and requirements from these agencies that have authority over decisions regarding remediation at many sites with contaminated soil or groundwater in California.

Comment 64 (LARQCB-YR, -DB): We need a unified approach to obtain soil gas concentration. Now, people use different method to obtain that, for example, using soil gas sample results, using soil matrix sample results to convert into soil gas concentration, using flux chamber method, or using mathematical modeling to predict, etc.

Response: The concerns in this comment are addressed in the response to Comment 63.

Comment 65 (LARQCB-YR, -DB): According to experienced professionals in indoor air intrusion field, soil gas concentrations in soil and in our indoor air usually vary from time to time in great latitude. So, we need to have a protocol to monitor soil gas concentration over time, just like we do with groundwater monitoring. A monitoring program for soil gas concentrations must go along with the screening numbers to be meaningful.

Response: The concerns in this comment are addressed in the response to Comment 63.

Comment 66 (LARQCB-YR, -DB): We recommend to use unit ug/L for soil gas measurement. For example, equation 3.4 (page B-7) is incorrect, which should have a factor of a thousand (1,000) due to the use of unit of ug/M3 in soil gas.

Response: In response to your comment, the soil gas concentrations were recalculated in µg/L to facilitate comparison to measured data. The soil gas equation was corrected accordingly by a factor of 1,000.

Comment 67 (LARQCB-YR, -DB): We recommend to number all of equations for readers' easy reference.

Response: Equations in the appendices are now numbered for reader’s easy reference.

Comment 68 (LARQCB-YR, -DB): Please double check the equation for Di(eff) (the 2nd equation in page B-4). Many references use theta's power of 7/3, instead of 3.33 (10/3) (e.g., Rong, Y. 1999. A study of vadose zone transport model VLEACH, Journal of soil contamination 8(2): pp. 217-229).

Response: The User's Guide For Evaluating Subsurface Vapor Intrusion Into Buildings (US EPA, 2003), and the latest version of the corresponding spreadsheet use power of 3.33 in the equation calculating D_i^{eff}. Also, the original journal article by Jury *et al.* ("Behavior Assessment Model for Trace Organics in Soil: I. Model Description", J. Environ. Qual., Vol. 12, no. 4, 1983) recommends the same power of 3.33.

Comment 69 (LARQCB-DB): Soil moisture content and changes thereof can have a significant impact on vapor migration, as evidenced here by the high model sensitivity. The magnitude and direction of impact (e.g., increase or decrease) on vapor migration due to differences in soil moisture content can arise from a variety of factors, including the intrinsic physical/chemical characteristics of the chemical of interest (e.g., water solubility). As noted on page B-9, a mixture of crushed rock or gravel and sand is expected to have lower porosity and vapor permeability, and higher moisture content than equal volume of sand. Since moisture content can affect vapor migration differently depending on differences in factors such as physical/chemical characteristics of the chemical of interest, we are not sure if the model assumption of the first soil layer below concrete to consist of sand only would in fact prove to be conservative.

Response: The US EPA spreadsheet does not list gravel as a soil type. However, a mixture of crushed rock or gravel and sand is expected to have lower porosity and vapor permeability than equal volume of sand. It was decided to replace the mixture of crushed rock or gravel and sand layer with a layer of sand with same thickness for the purpose of the modeling exercise. This is a reasonably conservative assumption not expected to lead to overprotective soil-screening values due in part to the minimum layer thickness selected.

Comment 70 (CVRCB-AV): We applaud the efforts of the Office of Environmental Health Hazard Assessment to develop methods for establishing soil screening levels for vapor intrusion into buildings and direct contact exposures. The Regional Water Boards often find ourselves in the situation of being the only regulatory agency providing oversight for assessment and cleanup of some contaminated sites. While our expertise is well suited to determine threats to groundwater and surface water resources from contaminants in soil, we do not have sufficient health risk assessment knowledge to be able to determine when levels of contaminants in soil warrant further health risk evaluation. We hope that the screening levels developed by OEHHA will provide us with such a tool.

Response: OEHHA developed soil-screening numbers following consultation with scientists in DTSC, SWRCB and RWQCBs. OEHHA joins the commenter in the hope that the screening numbers will be useful.

Comment 71 (CVRCB-AV): We oversee investigation of many sites, such as dry cleaners, where PCE and other volatile contaminants may pose health risks to nearby residents and workers. Soil gas screening levels for vapor intrusion into buildings will prove quite valuable in the investigation of these sites. We have three concerns with the development of these screening levels. First, will the levels developed by OEHHA adequately protect sensitive receptors, such as children and those with asthma or other types of respiratory sensitivity to chemicals? Second, the progress of site investigation often leads to actual air sampling within residences and other structures. To evaluate these data, the final OEHHA document should also include the indoor air criteria that form the basis of the soil gas screening levels. In addition to screening levels based on long-term cancer risk, short-term exposure levels based on more acute effects would also be very useful in our assessment work, to allow us to determine how rapidly abatement of potential health risks should be performed.

Response: OEHHA was given a mandate to develop health protective soil-screening levels. Those levels were developed using the chronic toxicity parameters published by the California EPA. When not available, the US EPA chronic toxicity parameters were used. The chronic toxicity parameters are derived considering safety factors to protect for sensitive receptors, such as children. The indoor air criteria for each chemical is the lower of the Cancer and Non-Cancer Target Indoor Concentration. It is called Target Indoor Air Concentration. It may be calculated as shown in the document section with the corresponding title. Development of short-term soil-screening levels is beyond the scope of this document.

While the methodology used to calculate target indoor air concentrations and soil gas screening numbers was selected to protect the most sensitive individuals from adverse health impacts, there is uncertainty in our scientific knowledge of the relationships between chemical exposure and diseases such as asthma. If information suggesting that a screening number is not health protective for certain individuals becomes available, OEHHA will recommend appropriate changes in the target indoor air concentration and soil gas screening number.

Comment 72 (CoO-GN): The proposed screening levels for VOCs take into account only the exposure from soil-bound contaminants, and not the contaminants present in the groundwater. In situation, where significant exposure to VOCs from contaminated groundwater is an issue, no guidance or methodology is available in the proposed document.

Response: The screening numbers for VOCs that are now based on soil gas levels do take into account VOCs from groundwater that is not used as a source of domestic water. VOCs from groundwater intrude into indoor air by first volatilizing into soil gas. Therefore, soil-gas-screening numbers for VOCs are protective of adverse health impacts from VOCs in groundwater, provided that the groundwater is not used for drinking or other purposes.

Comment 73 (SJIA-TS): Further, some levels cannot be detected by current laboratory analysis. For example, the soil gas level for benzene as I understand is 0.16 parts per billion (ppb). Common reporting limits for benzene in soil is 5 ppb; therefore this level is 31 times lower than the laboratory limit. This was the same problem with some of the Marshack levels particularly with regard to PNAs and other select constituents.

Response: The screening numbers for benzene in soil gas are not below limits of detection. For example, all laboratories certified to use US EPA method TO-15 must be able to detect benzene at the method of detection limit (MDL) of 0.29 ppb (0.29 moles of benzene per 10^9 moles gas) in air or soil gas. Conversion of this MDL to units µg/L gives 9.3 E-04 µg/L, which is below the residential and commercial/industrial screening numbers for benzene.

***Comment 74 (SC –BM)**:* Indoor air contamination by soil vapor intrusion is a significant pathway, as recognized by this report and by U.S. EPA, and the methodology should not be weakened in the final report.

Response: OEHHA applied the most recent version of the US EPA recommended Johnson and Ettinger model-based spreadsheet, reasonably conservative assumptions and California-representative values for the model parameters. Therefore, the methodology has not been weakened.

Comment 75 (EnviroCoalition): On page 13-20 you state, "Aside from the uncertainties in the structure: of the Johnson and Ettinger Model, widely discussed it the scientific literature (the model has not been completely validated), a number of uncertainties are inherent to its parameters."

Response: OEHHA used reasonably conservative parameter values and scenarios. As a result, the uncertainty inherent to the model and its parameters is believed to have produced health protective soil-gas screening levels.

Comment 76 (SOMA – NO): The State should identify the parameters that have the greatest impact on results of the J&E model and make recommendations about the use of site-specific values for those that control the outcome of the modeling. Based on a serious of sensitivity tests conducted on several but no all input parameters in the J&E model, SOMA noted that prominent controlling factors in the model are soil type, soil vapor permeability, and indoor air exchange rate. The values of these parameters can make a significant difference in the indoor air concentration estimated by the model.

Response: SOMA provided a valuable comment. However, the OEHHA mandate was limited to producing health protective soil-screening levels. This comment should be considered when developing a policy on the use and site-specific modification of those screening levels. The screening numbers calculated by OEHHA are intended for use in screening evaluations that generally do not use site-specific information.

Comment 77 (SOMA – NO): Indoor air exchange rate is generally governed by building requirements specified in the Uniform Building Code. As a result, there are only a few default values for this parameter based on the future use of the building (e.g.. residence, commercial building, garage, etc.). However, the soil type and soil vapor permeability at a site can be quite variable and may greatly influence the estimated indoor air concentration.

Response: The concerns in this comment are addressed in the response to Comment 76.

Comment 78 (James McCarty, P.E.): I was reviewing the draft Proposed Methodology for Calculating Advisory Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil. I was wondering how the indoor air values were reduced for 8-hour exposure. Since the exposure/duration parameters are in units of years, it is not clear to me at what point this was done. I see in the footnote on page 17 of Appendix B that "the derived 8 hours exposure Soil Screen level was used as Initial Soil Concentration". If the soil concentrations for a 10-6/HI 1 risk were calculated using the J&E model with the industrial/commercial exposure parameters, how are they adjusted for an 8-hour instead of a 24-hour exposure?

Response: As shown in section 3.1 of Appendix B, the calculation of Target Indoor Air Concentration (cancer and non-cancer) does not consider the number of hours working indoor. The proposed methodology follows US EPA, (2003) User's Guide For Evaluating Subsurface Vapor Intrusion Into Buildings, Office Of Emergency And Remedial Response, U.S. Environmental Protection Agency, Washington, D.C., June 19, 2003. The accompanying Johnson and Ettinger spreadsheet measures the exposure duration in days, not hours. Accordingly, OEHHA made the already widely accepted exposure assumptions, namely Exposure Frequency of 250 days per year for 25 years of exposure duration for commercial/industrial scenario versus 350 days per year for 30 years for residential scenario, respectively.

In addition, the Johnson and Ettinger spreadsheet does not provide a way to modify the Inhalation Rate. OEHHA indirectly considered the Inhalation Rate for Indoor Worker. OEHHA adopted the assumption of Inhalation Rate of 20 m^3/day for Indoor Worker following the US EPA (2001) Supplemental Guidance for Developing Soil-screening Levels for Superfund Sites, Solid Waste and Emergency Response, OSWER 9355.4-24, March 2001, Exhibit 1-2, Commercial/Industrial Scenario for Indoor Worker. This assumption was made to consider higher activity, respectively inhalation rate during typical 8-hr workday. Since this Inhalation Rate equals the Inhalation Rate for Residential Receptor based on 24-hour exposure duration ("resident day"), no adjustment of the values in the spreadsheet was deemed necessary. We agree that the statement in the Notes under the table showing *"...8 hours"* is confusing and will remove it."

Comment 79 (SR-JF): Appendix B-6: OEHHA should explain how the parameter for intrinsic permeability fits into the methodology, as it is not discussed elsewhere. In addition, the van Genuchten did not model air permeability. Rather, he developed an equation for predicting the hydraulic conductivity of water in unsaturated soils.

Response: OEHHA used the soil vapor permeability correspondent to sand for soil stratum A. The parameter soil vapor permeability is estimated by using measured data from field pneumatic tests. According to US EPA (2003) User's Guide… the parameter intrinsic permeability may be used to calculate the soil vapor permeability when measured data are not available. The commented text was included for completeness and compliance with the original US EPA document (the User's Guide). OEHHA agrees that it is not a part of the presented methodology and will remove this text from the final version of the report.

Comment 80 (SR-JF): Appendix B-8: OEHHA should explain why the depth to the source L_T, was only the depth of the engineered fill. This term is used in the J&E model to define the vertical distance from the top of a soil column to the contamination source.

Response: According to US EPA L_T is the source-building separation distance. L_t is the depth below grade to top of contamination. Under the OEHHA scenario the term L_T includes the thickness of the sand layer and the thickness of the engineered fill, the term L_t includes the foundation thickness, the thickness of the sand layer, and the thickness of the engineered fill. The top of contamination was assumed to start at the ground surface. However, the contaminated soil would be replaced by the foundation, sand layer, and engineered fill layer. As a result, the contamination starts immediately below the engineered fill.

Comment 81 (SR-JF): Appendix B does provide the equations and parameters used. In fact, it is largely copied from the US EPA User's Guide. (It would also help if equations in Appendix B were numbered.)

Response: OEHHA was authorized to develop soil-screening levels, including for the soil to indoor air pathway, and not to develop or modify any existing methodology, e.g., the Johnson and Ettinger model. OEHHA used the latest available methodology published by EPA for that pathway and provided references for each citation. However, OEHHA introduced significant modifications to complete the tasks of the project, namely scenario modifications, Cal/EPA toxicity values, the default values for a number of parameters were substituted by values believed to be representative for California, the equations presented in the User's Guide were re-written to back-calculate the attenuation factor α and to calculate the soil-gas screening levels, etc.

Comment 82 (SR-JF): For the assistance of the reader, OEHHA should provide an illustration of the conceptual model.

Response: Conceptual model has been added to the document.

Comment 83 (SR-JF): I do not believe that the J&E model was intended for calculating generic soil screening levels. Therefore, OEHHA needs to explain why the model being proposed for calculating generic soil screening levels in California when the US EPA has not done the same.

Response: In calculating screening numbers, OEHHA now uses the Johnson and Ettinger model only to calculate the ratio of contaminant in soil gas to contaminant in indoor air. The model was developed to calculate this attenuation factor.

Comment 84 (SR-JF): Finally, given the great uncertainty in estimating certain soil parameters, the lack of uncertainty analysis is a glaring omission.

Response: As briefly discussed in the document text, the Johnson and Ettinger model is not completely validated. However, this model was published and recommended by the US EPA for modeling the subsurface vapor migration into buildings indoor air. Discussion of the model structure uncertainties is beyond the scope of this document. However, OEHHA selected reasonably conservative values for the model parameters.

***Comment 85 (SR-JF)*:** Mercury is a volatile inorganic substance… Why was it not considered for vapor migration to indoor air?

Response: OEHHA agrees and has included a screening level for mercury vapor in soil gas.

Comment 86 (SOMA – NO): The State should identify the parameters that are field-related and encourage the collection of data for those parameters that are controlling factors in the J&E model. As stated above, soil type and soil vapor permeability are important controlling factors in the J&E model that may vary from one site to another. Data collection for these parameters would represent more realistic scenarios at each site and may influence the estimated indoor air concentration.

Response: OEHHA agrees that soil type and soil vapor permeability are important factors and adds that soil water content and organic carbon content are important factors in estimating contaminant flux using the Johnson and Ettinger model. These are clearly site-specific parameters. However, soil-screening numbers are not site specific. OEHHA encourages using soil gas levels as screening number for volatile contaminants in soil.

Comment 87 (SOMA – NO): The State should identify soil type and soil vapor permeability as important parameters in the J&E model. In addition, the method of identifying soil types should be identified. This is important because, in the absence of site-specific soil vapor permeability values, J&E assigns default soil vapor permeability values to each soil type, based on the Soil Conservation System (SCS) classification system. Soil vapor permeability and soil type are intricately linked.

Response: See response to comment 86.

Comment 88 (SOMA – NO): SOMA has compiled a table of default soil vapor permeability values in the J&E model that are assigned to the various SCS soil types (see Table 1). The table also includes a column of "Practical Range of Soil Vapor Permeabilities, by Soil Type", as presented in User's Guide for the model (U.S. EPA 2003, June 19). The table in the User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (page 51, U.S. EPA 2003, June 19) uses soil classifications that are not consistent with those used in the J&E model. We recommend that the State include SOMA's Table 1 in the guidance document as a reference; however, we recommend that the column entitled "Practical Range of Soil Vapor Permeabilities by Soil Type" be further clarified by using soil types consistent with the J&E model and that a literature search be performed to find permeability values that are better detailed to match the J&E soil type classifications.

Response: OEHHA agrees that soil type and soil vapor permeability are important factors and adds that soil water content and organic carbon content are important factors in estimating contaminant flux using the Johnson and Ettinger model. These are clearly site-specific parameters. However, soil-screening numbers are not site specific.

Comment 89 (GLI-JG, OA, BB): Adopt the San Francisco RWQCB indoor air ESLs for volatile chemicals?

Response: The Department of Toxic Substances control is developing recommendations for estimating contamination of indoor air due to soil gas intrusion. When these recommendations are published, OEHHA plans to meet with SWRCB, RWQCB and DTSC staff to calculate revised soil-gas-screening levels for volatile contaminants. For this reason, OEHHA does not plan to make an interim and very minor change in soil-gas-screening levels before the DTSC recommendations are published.

Other Comments

Comment 91 (EnviroCoalition): During our discussions a few years ago with Region 9 EPA on the PRGs, it was revealed that they were not really designed to be protective of children's health in most instances. In fact, this is the reason that the legislature decided not to use the PRGs as screening levels in Senator Escutia's original Brownfield's legislation. However, I note that for some chemicals, for some scenarios, that the screening numbers OEHHA has put forth are higher than Region 9 EPA's PRGs. For instance, for the residential land use scenario for soil, 12 out of 43 levels exceed the PRGs (Table 4). Can you explain to us why this would occur if these numbers were being protective of children's health in a residential scenario?

Response: Different dermal absorption factors were assumed in six of the chemicals and USEPA had different toxicity criteria for the other six. Child specific toxicity criteria were not considered by either OEHHA or USEPA because those criteria are not yet available.

Comment 92 (SC –BM): As the draft report recognizes, these screening numbers are only for human health protection and are not meant for protection of water quality or ecological health. In preparing the guidance document on how to use the screening numbers Cal/EPA should include full consideration of protecting the waters and ecology of California.

Response: This is very important and will be forwarded to the authors of the implementation document.

Comment 93 (DTSC - SD): Staff have noted to me that the soil screening numbers for the element lead reflect the use of our "leadspread" model and target the 95th percentile (not a 95% UCL) of exposed individuals. This is not consistent with the use we recommend for the model, for the child resident we specify the 99th percentile, in part because the 95th percentile excludes one out of every 20 children, and in many neighborhoods I can count over 20 kids. Using the 99th percentile for the child resident yields a soil screening level of approximately 150 ppm.

Recently, for the adult, the new USEPA adult lead model, targeting the pregnant woman, specifies a soil screening level of about 800 ppm.

Response: OEHHA finds the recommendation to protect 99 percent of the population to be reasonable. Soil screening levels for lead in Table 5 are now consistent with this recommendation. OEHHA scientists are unable to find adequate documentation on the calculation of a lead screening level of 800 mg/kg using the U.S. EPA adult lead model.

Therefore, this value is not adopted as the screening level for commercial/industrial scenarios at this time.

Appendix F. Bibliography of Risk Assessment Documents for Chemicals on the Initial List for Development of Soil-Screening Numbers.

Volatile Chemicals

Benzene

ATSDR (Agency for Toxic Substances and Disease Registry). 1997. Toxicological profile for Benzene. Update. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp3.html

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, Benzene, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

NTP (National Toxicology Program). 1986. Toxicology and Carcinogenesis Studies of Benzene (CAS No. 71-43-2) in F344/N Rats and B6C3F1 Mice (Gavage Studies). NTP, Research Triangle Park, NC.

OEHHA (2001) Public Health Goal for Benzene in Drinking Water, Office Of Environmental Health Hazard Assessment, California Environmental Protection Agency, June 2001, downloaded at http://www.oehha.ca.gov/water/phg/allphgs.html

Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes. 1996. Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236-246.

U.S. EPA. Toxicological Profile for Benzene, Integrated Risk Information System, Washington, DC, downloaded at http://www.epa.gov/iris/subst/0276.htm

U.S. EPA. (2002) Toxicological Review of Benzene (Noncancer Effects) (Cas No. 71-43-2) In Support of Summary Information on The Integrated Risk Information System (IRIS). U.S. Environmental Protection Agency, October 2002. Washington, DC, EPA/635/R-02/001f

U.S. EPA. (1999) Extrapolation of the benzene inhalation unit risk estimate to the oral route of exposure. National Center for Environmental Health, Office of Research and Development. Washington, DC. NCEA-W-0517.

U.S. EPA. (1998) Carcinogenic effects of benzene: an update. Prepared by the National Center for Environmental Health, Office of Research and Development. Washington, DC. EPA/600/P-97/001F.

Carbon Tetrachloride

ATSDR (Agency for Toxic Substances and Disease Registry). 2003. Toxicological profile for Carbon Tetrachloride. Draft for Public Comment. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp30.html

Bruckner, J.V., W.F. MacKenzie, S. Muralidhara, R. Luthra, G.M. Kyle and D. Acosta. 1986. Oral toxicity of carbon tetrachloride: Acute, subacute and subchronic studies in rats. Fund. Appl. Toxicol. 6(1): 16-34.

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, Carbon Tetrachloride, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

Della Porta, G., B. Terracini and P. Shubik. 1961. Induction with carbon tetrachloride of liver cell carcinomas in hamsters. J. Natl. Cancer Inst. 26(4): 855-863.

OEHHA (2000) Public Health Goal for Carbon Tetrachloride in Drinking Water, Office Of Environmental Health Hazard Assessment, California Environmental Protection Agency, September 2000, downloaded at http://www.oehha.ca.gov/water/phg/allphgs.html

U.S. EPA. Toxicological Profile for Carbon Tetrachloride, Integrated Risk Information System, Washington, DC, downloaded at http://www.epa.gov/iris/subst/0020.htm

U.S. EPA. 1984. Health Assessment Document for Carbon Tetrachloride. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. EPA 600/8/82-001F.

1,2-Dichloroethane

ATSDR (Agency for Toxic Substances and Disease Registry). 2001. Toxicological profile for 1,2-Dichloroethane. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp38.html

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, 1,2-Dichloroethane, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

NCI (National Cancer Institute). 1978. Bioassay of 1,2-Dichloroethane for Possible Carcinogenicity. NCI Carcinogenesis Technical Report Series No. 55. DHEW Publ. No. (NIH) 78-1361, Washington DC.

OEHHA (1999) Public Health Goal for 1,2-Dichloroethane in Drinking Water, Office Of Environmental Health Hazard Assessment, California Environmental Protection Agency, February 1999, downloaded at http://www.oehha.ca.gov/water/phg/allphgs.html

Reitz, R.H., T.R. Fox, J.C. Ramsey, J.K. Quast, P.W. Langvardt and P.G. Watanabe. 1982. Pharmacokinetics and micromolecular interactions of ethylene dichloride in rats after inhalation or gavage. Toxicol. Appl. Pharmacol. 62: 190-204.

Spencer, H.C., V.K. Adams, E.M. McCollister and D.D. Irish. 1951. Vapor toxicity of ethylene dichloride determined by experiments on laboratory animals. Ind. Hyg. Occup. Med. 4: 482-493.

U.S. EPA. Toxicological Profile for 1,2-Dichloroethane, Integrated Risk Information System, Washington, DC, downloaded at http://www.epa.gov/iris/subst/0149.htm

U.S. EPA. 1985. Health Assessment Document for 1,2-Dichloroethane. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Research Triangle Park, NC. EPA 600/8-84-006F.

cis-Dichloroethylene

ATSDR (Agency for Toxic Substances and Disease Registry). 1996. Toxicological profile for 1,2-Dichoroethene. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp87.html

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, *cis*-Dichloroethylene, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

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Galli, A., C. Bauer, G. Bronzetti, et al. 1982. Attivita genetica dell' 1,2-dichloroetilene. a) Studio in vitro. Boll. Soc. Ital. Biol. Sper. 58: 860-863. (Ital.)

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U.S. EPA. Toxicological Profile for *cis*-Dichloroethylene, Integrated Risk Information System, Washington, DC, downloaded at http://www.epa.gov/iris/subst/0418.htm

U.S. EPA. 1984. Health Effects Assessment for cis-1,2-Dichloroethylene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

trans-Dichloroethylene

ATSDR (Agency for Toxic Substances and Disease Registry). 1996. Toxicological profile for 1,2-Dichoroethene. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp87.html

Barnes, D.W., V.M. Sanders, K.L. White, Jr., G.M. Shopp and A.E. Munson. 1985. Toxicology of trans-1,2-dichloroethylene in the mouse. Drug Chem. Toxicol. 8: 373-392.

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, *trans*-Dichloroethylene, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

Freundt, J.J., G.P. Liebaldt and E. Lieberwirth. 1977. Toxicity studies on trans-1,2-dichloroethylene. Toxicology. 7: 141-153.

Hayes, J.R., L.W. Condie, J.L. Egle and J.F. Borzelleca. 1987. The acute and subacute toxicity in rats of trans-1,2-dichloroethylene in drinking water. J. Amer. College Toxicol. 6(4): 471-478.

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U.S. EPA. Toxicological Profile for *trans*-Dichloroethylene, Integrated Risk Information System, Washington, DC, downloaded at http://www.epa.gov/iris/subst/0314.htm

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ATSDR (Agency for Toxic Substances and Disease Registry). 1999. Toxicological profile for Ethylbenzene. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp110.html

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, Ethylbenzene, downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

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ATSDR (Agency for Toxic Substances and Disease Registry). 1999. Toxicological profile for Mercury. Public Health Service, U.S. Department of Health and Human Services, Atlanta, Ga, downloaded at http://www.atsdr.cdc.gov/toxprofiles/tp46.html

California EPA. Office of Environmental Health Hazard Assessment Toxicity Criteria Database, Mercury, inorganic downloaded at http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

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