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

External Review Draft
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Integrated Risk Assessment Section
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Table of Contents

1. Introduction 1

2. Summary of OEHHA's Review of Published Screening Numbers 4

3. Comments in UC Peer Review Reports that are Related to Protection of Human Health 5

4. Methodology for Calculating Screening Numbers Based on Protection of Public Health and Safety 5

5. Cost-of-Cleanup Screening Numbers 13

6. Application of Screening Numbers to Sites Where More Than One Chemical Contaminant Has Been Identified 22

7. References 22

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) A-1

Appendix B: Application of the Johnson and Ettinger Model to Derive Risk-Based Soil to Indoor Air Component for the Soil Screening Level Approach B-1

Appendix C: Exposure Algorithms and Parameters Used to Calculate Screening Numbers Based on Exposure to Soil-Bound Chemicals C-1

Appendix D: Pros and Cons for Including Exposure to Chemicals in Crops Grown in Contaminated Soil D-1

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 (HSC §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 others are identified by the Department of Toxic Substances Control (DTSC) and the State Water Resources Control Board (SWRCB) 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."

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
1,1,1-Trichloroethane (1,1,1-TCA)[2]	Cadmium and/or cadmium compounds
Trichloroethylene (TCE)	Chromium (VI) compounds
Vinyl chloride[2]	Chromium and/or chromium (III) compounds
Xylene[2]	Cobalt and/or cobalt compounds
Nonvolatile Neutral Organic Compounds	Copper and/or copper compounds
Aldrin	Fluoride salts
Benzo(a)pyrene[2]	Lead and/or lead compounds
Chlordane	Mercury and/or mercury compounds
DDT, DDE, DDD	Molybdenum and/or molybdenum compounds
Dieldrin	Nickel and/or nickel compounds
1,4 Dioxane[2]	Perchlorate
Dioxin (2,3,7,8-TCDD)	Selenium and/or selenium compounds
Endrin	Silver and/or silver compounds
Heptachlor	Thallium and/or thallium compounds
Kepone	Vanadium and/or vanadium compounds
Lindane (hexachlorocyclohexane)	Zinc and/or zinc compounds
Methoxychlor	
Mirex	
Organic Lead Compounds	
Polychlorinated biphenyls (PCBs)	
Toxaphene	

[1] The criteria for classifying a chemical as volatile are Henry's law constant less than 10^{-5} atmos.-m-/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. Environmental Protection Agency (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.usepa.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."

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 prior to publication of final screening numbers.

OEHHA staff have reviewed screening numbers published by U.S. EPA including risk-based concentrations (RBCs) developed by Region 3 (U.S. EPA Region 3, 2000) and preliminary remediation goals (PRGs) developed by Region 9 (Smucker, 2002). OEHHA scientists have also reviewed a compilation of screening levels published by states other than California prepared by the California Center for Land Recycling (CCLR, 2003) and have reviewed 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.

3. Comments in UC Peer Review Reports that are Related to Protection of Human Health

The peer review, mandated by SB 32, HSC §57008(b)(1), of 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)" was completed in January 2003 by a panel of scientists selected by the University of California (UC). As required in HSC §57004, the panel reviewed the scientific basis used for RBSL calculation. Each panel member submitted a separate report. The major criticism in these reports of the above document, that is related to OEHHA's efforts to develop SB 32 screening numbers protective of human health, were concerns with the methodology used to predict indoor air contamination from chemicals in soil gas: Two of the UC panel member reports state reasons why the methodology can under predict indoor air contaminant concentrations (McKone, 2003; Nazaroff, 2003).

OEHHA scientists concur with the opinions of the two panel members who criticized the methodology used for predicting indoor air contamination from soil gas. This methodology was based on a computer model developed from the Johnson and Ettinger (1991) model by U.S. EPA and released in 2001. Since releasing the original model, U.S. EPA released a revision of the model in November 2002 and released and published a user's guide (U.S. EPA, 2003). OEHHA scientists have evaluated the November 2002 version of the U.S. EPA Johnson and Ettinger model using parameters recommended in the user's guide. When soil parameters describing a relatively dry and sandy soil are used, the ratio of indoor air contaminant concentration to soil gas concentration (termed α) predicted by the model is approximately equal to 0.001 for the listed volatile contaminants other than tetraethyl lead (Table 2). This value is consistent with recommendations of the two UC peer review panel members.

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

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 methodology developed and published by U.S. EPA to support its "Superfund" program. The RWQCBs allows the same methodology to be used in evaluating their sites. OEHHA scientists also 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, the use of U.S. EPA exposure assessment methodology and Cal/EPA toxicity criteria appears to be appropriate for calculating screening numbers to be used for the purpose described in SB 32.

Table 2. Ratio of Indoor Air Concentration to Soil Gas Concentration (α) Resulting from Soil Gas beneath a Building (Calculated Using the Advanced Model for Vapor Intrusion of Volatile Chemicals and Tetraethyl Lead)

Chemical	α
Benzene	9.00 E-04
Carbon Tetrachloride	8.05 E-04
1,2-Dichloroethane	1.07 E-03
cis-1,2-Dichloroethylene	7.75 E-04
trans-1,2-Dichloroethylene	7.42 E-04
Ethylbenzene	7.81 E-04
Methyl *tert*-Butyl Ether	1.08 E-03
Naphthalene	6.98 E-04
Tetrachloroethylene	7.51 E-04
Tetraethyl Lead[1]	1.52 E-04
Toluene	8.89 E-04
1,1,1-Trichloroethane	8.06 E-04
Trichloroethylene	8.17 E-04
Vinyl Chloride	1.05 E-03
m-Xylene	7.35 E-04
o-Xylene	8.92 E-04
p-Xylene	7.99 E-04
	Average value of α = 8.08 E-04
	Standard deviation = 2.00 E-04

[1] Tetraethyl lead does not meet the criteria 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.

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.

For purposes of calculating screening numbers based on contamination of indoor air by chemicals in soil gas, OEHHA scientists have 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). The parameters are listed in Appendix B. Parameters describing coarse-grained, dry soil of low organic carbon content were chosen because they correspond to a stringent application of this methodology and because they are appropriate for certain regions of California. 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, 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 using methodology described in Appendix B. For the volatile chemicals that are assessed as carcinogens by DTSC, screening numbers were also calculated based on cancer risk.

In estimating 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. To calculate screening numbers for a commercial/industrial land use scenario, Equations 4.3 and 4.4 from the document were used (Appendix C). For lead and lead compounds, a screening number was calculated using the software Leadspread (DTSC, 2003).

In calculating screening numbers based on exposure to soil-bound chemicals, the daily exposure was assumed to be the same for the residential and the commercial/industrial scenario. The assumed frequency was 250 days per year for commercial/industrial exposure and 350 days per year for residential exposure. The duration was assumed to be 25 years for commercial/industrial exposure and 30 years for residential exposure. For calculating screening numbers based on exposure to indoor air contaminated by chemicals in soil gas, the values for frequency of exposure (days/year) and duration of exposure (years) were identical to the values used for exposure to soil-bound chemicals. However, it was assumed that exposure to chemicals in indoor air occurred for eight hours per day in a commercial/industrial scenario and that it occurred for 24 hours per day for a residential scenario.

Carcinogenic potency factors and chronic reference levels published by OEHHA and U.S. EPA for chemicals in Table 1 are listed in Table 3. An OEHHA toxicity criterion was normally used in calculating a screening number. A U.S. EPA toxicity criterion was used only when an appropriate OEHHA criterion was not available.

Screening numbers based on cancer risk were calculated for all chemicals in Table 3 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

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 (Appendix C). 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 3. 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)			

Table 3 (Continued)

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] $mg/kg\text{-}d)^{-}$	$_i$[6] $mg/kg\text{-}d)^{-}$	REL[7] $(\mu g/m^3)$
Inorganic Chemicals					
Antimony and compounds			**RfD** 4.00E-04 (I)		
Arsenic	1.5 (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)

Table 3 (Continued)

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] $mg/kg\text{-}d)^{-}$	$_i$[6] $mg/kg\text{-}d)^{-}$	REL[7]($\mu g/m^3$)
Mercury and compounds			3.00E-04 (I)	RfD	
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)
Dichloroethane, 1,2-	0.047 (O)	0.072 (O)	3.00E-02 (I)	1.40E-03	
Dichloroethylene, cis 1,2-			1.00E-02 (I)	1.00E-02 (I)	
Dichloroethylene, trans 1,2-			2.00E-02 (I)	2.00E-02 (I)	
Ethylbenzene			1.00E-01 (I)	5.71E-01 (O)*	2.00E+03 (O)

Table 3 (Continued)

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)$^{-}$	$_i$[6] mg/kg-d)$^{-}$	REL[7](μg/m^3)
Methyl tert butyl ether	0.0018 (O)	0.00091 (O)	RfD	8.60E-01 (I)	
Naphthalene	TBD (O)	TBD (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 (I)	
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, U.S. (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

5. Soil Levels Calculated Using the Proposed Methodology

Soil levels were calculated for two land use scenarios. First, they were calculated for an "unrestricted" land use scenario as required in SB 32. Algorithms used in these calculations were U.S. EPA's algorithms for a residential scenario. For the calculation of screening numbers for "another" land use scenario required in SB 32, OEHHA selected a commercial/industrial scenario.

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 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 ventilation rate of 20 cubic meters of air per day (U.S. EPA, 2001).

For chemicals that are not volatile, soil levels are based on the appropriate toxicity criteria from Table 3 and on the estimates of exposure to soil-bound contamination by the oral, dermal and inhalation routes. The algorithms and exposure parameters used in these calculations are presented in Appendix C. For nonvolatile chemicals, soil levels calculated for residential land use are listed in Table 4, and soil levels calculated for commercial/industrial land use are listed in Table 7.

For volatile chemicals, soil levels were calculated using the algorithms for estimating exposure to soil-bound contamination by the oral, dermal and inhalation routes. A soil level was also calculated for exposure resulting from inhalation of indoor air contaminated by soil gas using the Johnson and Ettinger model (USEPA, 2003). Assumptions and parameters used in these calculations are listed in Appendix B. For each of these chemicals, the soil level based on contamination of indoor air by soil gas is lower than the number based on exposure to soil-bound chemical. Therefore, the number based on indoor air contamination by soil gas is the selected soil level in Table 6 for residential land use scenarios and in Table 9 for commercial/industrial land use scenarios.

` For purposes of comparison with screening numbers published by government agencies with regulatory authority in California, SWQCB Region 2 (San Francisco Bay) ESLs and U.S. EPA PRGs are also listed in Table 4 and Table 5 for residential land use scenarios and in Table 7 and Table 8 for commercial/industrial land use scenarios. ESLs and PRGs that are identical to recommended screening numbers appear in bold face type.

Quantitative analysis of soil gas is an alternative to analysis of soil samples. To allow the use of soil gas measurements, Table 6 lists soil gas concentrations that are equivalent to the selected soil levels for residential land use scenarios. Table 9 lists soil

gas concentrations that are equivalent to the selected soil levels for commercial/industrial land use scenarios.

For benzene, carbon tetrachloride, 1,2-dichloroethane, methyl tertiary butyl ether, tetrachloroethylene, trichloroethylene and vinyl chloride, the differences between soil gas levels calculated using the proposed methodology in this document and soil gas levels calculated by SWQCB Region 2 in Table 6 are solely due to differences between the α factors in this document (Table 2) and the constant α factor 0.001 used by SWQCB Region 2. For toluene, 1,1,1-trichloroethane and xylene, the differences in soil gas levels are largely due to differences in toxicity values used in the calculations.

Table 4. Soil Levels (mg/kg soil) for Nonvolatile Chemicals Based on Total Exposure to Contaminated Soil: Residential Land Use (Inhalation, Ingestion and Dermal Absorption)

Chemical	Soil Level Calculated Using the Proposed Methodology		Published Screening Level for Comparison			
			SWQCB Region 2 ESL[1]		U. S. EPA Region 9 PRG[2]	
	mg/kg soil	basis[3]	mg/kg soil	[4]	mg/kg soil	[4]
Organic Acidic Chemicals						
2,4-D	**6.9E+02**	(nc)			**6.9E+02**	
2,4,5-T	5.5E+02	(nc)			4.9E+02	(d)
Pentachlorophenol	**4.4E+00**	(ca)	**4.4E+00**		3.0E+00	(a)
Organic Neutral Chemicals						
Aldrin	3.3E-02	(ca)	2.9E-02	(d)	2.9E-02	(d)
Benzo(a)pyrene	**3.8E-02**	(ca)	**3.8E-02**		6.2E-02	(a)
Chlordane	4.3E-01	(ca)	4.4E-01	(d)	1.6E+00	(a)
DDD	2.3E+00	(ca)	2.4E+00	(d)	2.4E+00	(d)
DDE	1.6E+00	(ca)	1.7E+00	(d)	1.7E+00	(d)
DDT	1.6E+00	(ca)	1.7E+00	(d)	1.7E+00	(d)
Dieldrin	3.5E-02	(ca)	2.3E-03	(c)	3.0E-02	(d)
1,4 Dioxane	1.8E+01	(ca)	1.8E-03	(c)	4.4E+01	(a)
Dioxin (2,3,7,8-TCDD)	4.6E-06	(ca)	4.5E-06	(d)	3.9E-06	(a)
Endrin	2.1E+01	(nc)	6.5E-04	(c)	1.8E+01	(d)
Heptachlor	1.3E-01	(ca)	1.4E-02	(c)	1.1E-01	(a)
Lindane	5.0E-01	(ca)	4.9E-02	(c)	4.4E-01	(a)
Kepone	3.5E-02	(ca)			6.1E-02	(a)
Methoxychlor	3.4E+02	(nc)	1.9E+01	(c)	3.1E+02	(d)
Mirex	3.1E-02	(ca)			2.7E-01	(a)
PCBs	8.9E-02	(ca)	2.2E-01	(a)	2.2E-01	(a)
Toxaphene	4.6E-01	(ca)	4.2E-04	(c)	4.4E-01	(a)
Inorganic Chemicals						
Antimony and compounds	3.0E+01	(nc)	6.3E+00	(g)	3.1E+01	(d)
Arsenic	4.3E-01	(ca)	5.5E+00	(e)	3.9E-01	(a)
Barium and compounds	5.2E+03	(nc)	7.5E+02	(f)	5.4E+03	(d)
Beryllium and compounds	**1.5E+02**	(nc)	4.0E+00	(f)	**1.5E+02**	(d)
Beryllium oxide[6]	9.1E-02	(ca)				(d)

Chemical	Soil Level Calculated Using the Proposed Methodology		Published Screening Level for Comparison			
			SWQCB Region 2 ESL[1]		U. S. EPA Region 9 PRG[2]	
	mg/kg soil	basis[3]	mg/kg soil	[4]	mg/kg soil	[4]
Beryllium sulfate[6]	2.1E-04	(ca)				(d)
Cadmium and compounds	**1.7E+00**	(ca)	**1.7E+00**		3.7E+01	(a)
Chromium III	**1.0E+05**	(max)	7.5E+02	(f)	**1.0E+05**	
Chromium VI	1.7E+01	(ca)	1.8E+00	(h)	3.0E+01	(a)
Cobalt	6.6E+02	(nc)	4.0E+01	(f)	9.0E+02	(d)
Copper and compounds	3.0E+03	(nc)	2.3E+02	(f)	3.1E+03	(d)
Fluoride	4.6E+03	(nc)		(g)	3.7E+03	(d)
Lead and lead compounds	2.6E+02	(nc)*	2.0E+02	(f)	4.0E+02	(h)
Lead acetate[6]	2.3E+00	(ca)				
Mercury and compounds	1.8E+01	(nc)	2.5E+00	(g)	2.3E+01	(d)
Molybdenum	3.8E+02	(nc)	4.0E+01	(f)	3.9E+02	(d)
Nickel and compounds	**1.6E+03**	(nc)	1.5E+02	(f)	**1.6E+03**	
Nickel subsulfide[6]	3.8E-01	(ca)				
Perchlorate[5]	postponed		7.0E-03	(c)	3.9E+01	
Selenium	3.8E+02	(nc)	1.0E+01	(f)	3.9E+02	(d)
Silver and compounds	3.8E+02	(nc)	2.0E+01	(f)	3.9E+02	(d)
Thallium and compounds	5.0E+00	(nc)	1.0E+00	(g)	5.2E+00	(d)
Vanadium and compounds	5.3E+02	(nc)	1.1E+02	(g)	5.5E+02	(d)
Zinc	**2.3E+04**	(nc)	6.0E+02	(f)	**2.3E+04**	

[1] Environmental Screening Levels (ESLs) published by SWQCB Region 2 (2003), http://www.swrcb.ca.gov/rwqcb2/esl.htm

[2] Preliminary Remediation Goals (PRGs) published by U.S. EPA Region 9 (2003), http://www.epa.gov/region09/waste/sfund/prg/index.htm

[3] (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a RfD for chronic toxic effects other than cancer, (nc)* DTSC leadspread was used to compute the values for lead, (max) values greater than 10^5 were set at 10^5.

[4] Explanation for difference with the Soil Level Calculated Using the Proposed Methodology: (a) California toxicity criterion differs from the corresponding U.S. EPA criterion, (b) denotes that a new California toxicity criterion for the chemical is expected to be published during 2004, (c) denotes that the ESL is based on protection of groundwater which was not considered in the calculation of recommended screening numbers, (d) denotes that, in calculating the PRG, it was assumed that dermal absorption of the chemical is 0%, (e) denotes that the ESL was set at the estimated upper bound of soil concentration of naturally occurring arsenic in soil, (f) denotes that the ESL is based on potential adverse impacts on the environment, (g) denotes that the ESL was calculated by setting the hazard index equal to 0.2, whereas the recommended screening numbers were calculated using a hazard index of 1. (h) based on a trench worker.

[5] 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

[6] 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.

Table 5. Comparison of Soil Levels (mg/kg soil) for Volatile Chemicals Based on the Proposed Methodology for Estimating Contamination of Indoor Air by Chemicals in Soil Gas with Screening Numbers Based on Exposure to Soil-Bound Chemicals (Inhalation, Ingestion and Dermal Absorption): Residential Land Use

Chemical	**Soil Level Based on:**				**Published Screening Level for Comparison (explanation[1])**			
	Soil Gas Contamination of Indoor Air		**Exposure to Soil-Bound Chemical**		**SWQCB Region 2 ESL[2]**		**U. S. EPA Region 9 PRG[3]**	
Benzene	1.6 E-04	(ca)	1.8E-01	(ca)	*4.4E-02*	(d)	6.0E-01	(a)
Carbon tetrachloride	4.2 E-05	(ca)	8.5E-02	(ca)	*1.2E-02*	(c)	2.5E-01	(a)
1,2-Dichloroethane	7.4 E-04	(ca)	4.4E-01	(ca)	*4.5E-03*	(c)	2.8E-01	(a)
cis-1,2-Dichloroethylene	9.0 E-02	(nc)	4.3E+01	(nc)	*1.9E-01*	(c)	4.3E+01	
Trans-1,2-Dichloroethylene	9.6 E-02	(nc)	6.3E+01	(nc)	*6.7E-01*	(c)	6.9E+01	
Ethylbenzene	pp[4]		pp[4]		*3.3E+00*	(c)	8.9E+01	(a)
Methyl tert butyl ether	8.3 E-02	(ca)	5.4E+01	(ca)	*2.3E-02*	(c)	1.7E+01	(a)
Naphthalene	pp[5]	(b)	pp[5]	(b)	*4.2E+00*	(c)	5.6E+01	
Tetrachloroethylene	4.8 E-04	(ca)	5.4E-01	(ca)	*8.8E-02*	(d)	5.7E+00	(a)
Tetraethyl lead	3.6 E-07	(nc)	7.8E-03	(nc)			6.1E-03	
Toluene	8.8 E-01	(nc)	4.6E+02	(nc)	*2.9E+00*	(c)	5.2E+02	
1,1,1-Trichloroethane	2.2 E+00	(nc)	2.1E+03	(nc)	*7.8E+00*	(c)	1.2E+03	
Trichloroethylene	2.3 E-03	(ca)	2.3E+00	(ca)	*2.6E-01*	(d)	5.3E-02	(a)
Vinyl chloride	9.5 E-06	(ca)	2.5E-02	(ca)	*6.7E-03*	(d)	7.9E-02	(a)
Xylenes	3.4 E+00	(nc)	1.3E+03	(nc)	*1.5E+00*	(d)	2.7E+02	

[1] (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a RfD for chronic toxic effects other than cancer, (a) denotes that the recommended screening number is based on a California toxicity criterion that differs from the corresponding U.S. EPA criterion, (b) denotes that a new California toxicity criterion for the chemical is expected to be published during 2004, (c) denotes that the ESL is based on protection of groundwater which was not considered in the calculation of recommended screening numbers, (d) denotes that the ESL is based on soil gas contamination of indoor air

[2] Environmental Screening Levels (ESLs) published by SWQCB Region 2 (2003), http://www.epa.gov/region09/waste/sfund/prg/index.htm

[3] Preliminary Remediation Goals (PRGs) published by U.S. EPA Region 9 (2003), http://www.swrcb.ca.gov/rwqcb2/esl.htm

[4] Calculation of a screening number for the chemical has been postponed (pp) while it is in the process of listing as a substance known to the state to cause cancer under the authoritative body provision (CCR, Title 22, 12000).

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

Table 6. Selected Soil Levels Based on the Proposed Methodology for Volatile Chemicals and Tetraethyl Lead Based on Exposure to Indoor Air: Residential Land Use

Chemical	**Soil Levels Based on Soil Gas Intrusion**		**SF RWQCB ESL Based on Soil Gas Intrusion**	
	Concentration in Soil (mg/kg)	**Concentration in Soil Gas (μg/m^3)**	**Concentration in Soil (mg/kg)**	**Concentration in Soil Gas (μg/m^3)**
Benzene	1.6 E-04	9.3E+1	1.8 E-01	8.4 E+01
Carbon tetrachloride	4.2 E-05	7.2 E+01	1.2 E-02	5.8 E+01
1,2-Dichloroethane	7.4 E-04	1.1 E+02	2.5 E-02	1.2 E+02
cis-1,2-Dichloroethylene	9.0 E-02	4.7 E+04	1.6 E+00	7.3 E+03
Trans-1,2-Dichloroethylene	9.6 E-02	9.8 E+04	3.1 E+00	1.5 E+04
Ethylbenzene	pp[1]	pp[1]	4.7 E+00	2.2 E+03
Methyl tert butyl ether	8.3 E-02	8.7 E+03	2.0 E+00	9.4 E+03
Naphthalene	pp[2]	pp[2]	4.5 E+00	6.3 E+02
Tetrachloroethylene	4.8 E-04	5.5 E+02	8.8 E-02	4.1 E+02
Tetraethyl lead	3.6 E-07	2.4 E+00	NA	NA
Toluene	8.8 E-01	3.5 E+05	1.8 E+02	8.3 E+04
1,1,1-Trichloroethane	2.2 E+00	2.8 E+06	9.8 E+01	4.6 E+04
Trichloroethylene	2.3 E-03	1.5 E+03	2.6 E-01	1.2 E+03
Vinyl chloride	9.5 E-06	3.0 E+01	6.7 E-03	3.1 E+01
Xylenes	3.4 E+00	8.2 E+05	4.5 E+01	2.1 E+04

[1] Calculation of a screening number for the chemical has been postponed (pp) while it is in the process of listing as a substance known to the state to cause cancer under the authoritative body provision (CCR, Title 22, 12000).
[2] Calculation of a screening number for the chemical has been postponed (pp) until the toxicity criterion currently being developed by OEHHA is published as a final document
NA Not Available

The large differences in Table 6 between soil levels in column 2 and soil levels in column 4 are due to differences in the assumed extent of contamination below the soil surface. In calculating soil levels, SWQCB Region 2 assumed that contamination extended to a depth of 300 cm, whereas the proposed methodology in this document does not assume any limit on the depth of contamination.

Table 7. Soil Levels (mg/kg soil) for Nonvolatile Chemicals Based on Total Exposure to Contaminated Soil: Commercial/Industrial Land Use (Inhalation, Ingestion and Dermal Absorption)

Chemical	Soil Level Calculated Using the Proposed Methodology		Published Screening Level for Comparison (explanation[1])			
			SWQCB Region 2 ESL[2]		U. S. EPA Region 9 PRG[3]	
	mg/kg soil	basis[3]	mg/kg soil	[4]	mg/kg soil	[4]
Organic Acidic Chemicals						
2,4-D	**7.7E+03**	(nc)			**7.7E+03**	
2,4,5-T	6.1E+03	(nc)			4.9E+03	(d)
Pentachlorophenol	1.3E+01	(ca)	5.0E+00	(f)	9.0E+00	(a)
Organic Neutral Chemicals						
Aldrin	1.3E-01	(ca)	1.0E-01		1.0E-01	(d)
Benzo(a)pyrene	**1.3E-01**	(ca)	**1.3E-01**		2.1E-01	(a)
Chlordane	**1.7E+00**	(ca)	**1.7E+00**		6.5E+00	(a)
DDD	9.0E+00	(ca)	1.0E+01		1.0E+01	(d)
DDE	6.3E+00	(ca)	4.0E+00	(f)	7.0E+00	(d)
DDT	6.3E+00	(ca)	4.0E+00	(f)	7.0E+00	(d)
Dieldrin	1.3E-01	(ca)	2.3E-03	(c)	1.1E-01	(d)
1,4 Dioxane	6.4E+01	(ca)	1.8E-03	(c)	1.6E+02	
Dioxin (2,3,7,8-TCDD)	1.9E-05	(ca)	1.8E-05		1.6E-05	(a)
Endrin	2.3E+02	(nc)	6.5E-04	(c)	1.8E+02	(d)
Heptachlor	5.2E-01	(ca)	1.4E-02	(c)	3.8E-01	(a)
Lindane	2.0E+00	(ca)	4.9E-02	(c)	1.7E+00	(a)
Kepone	1.3E-01	(ca)			2.2E-01	(a)
Methoxychlor	3.8E+03	(nc)	1.9E+01	(c)	3.1E+03	(d)
Mirex	1.2E-01	(ca)			9.6E-01	(a)
PCBs	3.0E-01	(ca)	7.4E-01		7.4E-01	(a)
Toxaphene	1.8E+00	(ca)	4.2E-04	(c)	1.6E+00	(a)
Inorganic Chemicals						
Antimony and compounds	3.8E+02	(nc)	4.0E+01	(g)	4.1E+02	(d)
Arsenic	1.5E+00	(ca)	5.5E+00	(e)	1.6E+00	(a)
Barium and compounds	6.3E+04	(nc)	1.5E+03	(f)	6.7E+04	(d)
Beryllium and compounds	1.7E+03	(nc)	8.0E+00	(f)	1.9E+03	(d)
Beryllium oxide[6]	4.1E-01	(ca)				
Beryllium sulfate[6]	9.5E-04	(ca)				
Cadmium and compounds	7.5E+00	(ca)	7.4E+00		4.5E+02	(a)
Chromium III	**1.0E+05**	(max)	7.5E+02	(f)	**1.0E+05**	

Chemical	**Soil Level Calculated Using the Proposed Methodology**		**Published Screening Level for Comparison (explanation[1])**			
			SWQCB Region 2 ESL[2]		**U. S. EPA Region 9 PRG[3]**	
	mg/kg soil	**basis[3]**	**mg/kg soil**	**[4]**	**mg/kg soil**	**[4]**
Chromium VI	3.7E+01	(ca)	1.8E+00	(h)	6.4E+01	(a)
Cobalt	3.2E+03	(nc)	8.0E+01	(f)	1.9E+03	(d)
Copper and compounds	3.8E+04	(nc)	2.3E+02	(f)	4.1E+04	(d)
Fluoride	5.7E+04	(nc)		(g)	3.7E+04	(d)
Lead and lead compounds	2.6E+02	(nc)*	7.5E+02	(h)	7.5E+02	(h)
Lead acetate[6]	1.0E+01	(ca)				
Mercury and compounds	1.8E+02	(nc)	1.0E+01	(g)	3.1E+02	(d)
Molybdenum	4.8E+03	(nc)	4.0E+01	(f)	5.1E+03	(d)
Nickel and compounds	1.6E+04	(nc)	1.5E+02	(f)	2.0E+04	(d)
Nickel subsulfide[6]	**1.1E+04**	**(ca)**			**1.1E+04**	
Perchlorate[5]	postponed	(b)	7.0E-03	(c)	3.9E+01	
Selenium	4.8E+03	(nc)	1.0E+01	(f)	5.1E+03	(d)
Silver and compounds	4.8E+03	(nc)	4.0E+01	(f)	5.1E+03	(d)
Thallium and compounds	6.3E+01	(nc)	1.3E+01	(g)	6.7E+01	(d)
Vanadium and compounds	6.7E+03	(nc)	2.0E+02	(g)	7.2E+03	(d)
Zinc	**1.0E+05**	(max)	6.0E+02	(f)	**1.0E+05**	

[1] Environmental Screening Levels (ESLs) published by SWQCB Region 2 (2003), http://www.swrcb.ca.gov/rwqcb2/esl.htm

[2] Preliminary Remediation Goals (PRGs) published by U.S. EPA Region 9 (2003), http://www.epa.gov/region09/waste/sfund/prg/index.htm

[3] (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a RfD for chronic toxic effects other than cancer, (nc)* DTSC leadspread was used to compute the values for lead, (max) values greater than 10^5 were set at 10^5.

[4] Explanation for difference with the Soil Level Calculated Using the Proposed Methodology: (a) California toxicity criterion differs from the corresponding U.S. EPA criterion, (b) denotes that a new California toxicity criterion for the chemical is expected to be published during 2004, (c) denotes that the ESL is based on protection of groundwater which was not considered in the calculation of recommended screening numbers, (d) denotes that, in calculating the PRG, it was assumed that dermal absorption of the chemical is 0%, (e) denotes that the ESL was set at the estimated upper bound of soil concentration of naturally occurring arsenic in soil, (f) denotes that the ESL is based on potential adverse impacts on the environment, (g) denotes that the ESL was calculated by setting the hazard index equal to 0.2, whereas the recommended screening numbers were calculated using a hazard index of 1. (h) based on a trench worker.

[5] 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

[6] 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.

Table 8. Soil Levels (mg/kg soil) for Volatile Chemicals Based on the Proposed Methodology for Estimating Contamination of Contamination of Indoor Air by Chemicals in Soil Gas with Screening Numbers Based on Exposure to Soil-Bound Chemicals (Inhalation, Ingestion and Dermal Absorption): Commercial/Industrial Land Use

Chemical	Screening Number Based on:				Published Screening Level for Comparison (explanation[1])			
	Soil Gas Contamination of Indoor Air		Exposure to Soil-Bound Chemical		SWQCB Region 2 ESL[2]		U. S. EPA Region 9 PRG[3]	
Benzene	2.6 E-04	(ca)	1.8E-01	(ca)	*4.4E-02*	(d)	6.0E-01	(a)
Carbon tetrachloride	7.1 E-05	(ca)	8.5E-02	(ca)	*1.2E-02*	(c)	2.5E-01	(a)
1,2-Dichloroethane	1.2 E-03	(ca)	4.4E-01	(ca)	*4.5E-03*	(c)	2.8E-01	(a)
cis-1,2-Dichloroethylene	1.3 E-01	(nc)	4.3E+01	(nc)	*1.9E-01*	(c)	4.3E+01	
trans-1,2-Dichloroethylene	1.3 E-01	(nc)	6.3E+01	(nc)	*6.7E-01*	(c)	6.9E+01	
Ethylbenzene	pp[4]		pp[4]		*3.3E+00*	(c)	8.9E+01	(a)
Methyl tert butyl ether	1.4 E-01	(ca)	5.4E+01	(ca)	*2.3E-02*	(c)	1.7E+01	(a)
Naphthalene	pp[5]	(b)	Pp[5]	(b)	*4.2E+00*	(c)	5.6E+01	
Tetrachloroethylene	8.1 E-04	(ca)	5.4E-01	(ca)	*8.8E-02*	(d)	5.7E+00	(a)
Tetraethyl lead	5.0 E-07	(nc)	7.8E-03	(nc)			6.1E-03	
Toluene	1.2 E+00	(nc)	4.6E+02	(nc)	*2.9E+00*	(c)	5.2E+02	
1,1,1-Trichloroethane	3.0 E+00	(nc)	2.1E+03	(nc)	*7.8E+00*	(c)	1.2E+03	
Trichloroethylene	3.8 E-03	(ca)	2.3E+00	(ca)	*2.6E-01*	(d)	5.3E-02	(a)
Vinyl chloride	1.6 E-05	(ca)	2.5E-02	(ca)	*6.7E-03*	(d)	7.9E-02	(a)
Xylenes	4.8 E+00	(nc)	1.3E+03	(nc)	*1.5E+00*	(d)	2.7E+02	

[1] (ca) denotes that the screening number is based on a carcinogenic potency factor, (nc) denotes that the screening number is based on a RfD for chronic toxic effects other than cancer, (a) denotes that the recommended screening number is based on a California toxicity criterion that differs from the corresponding U.S. EPA criterion, (b) denotes that a new California toxicity criterion for the chemical is expected to be published during 2004, (c) denotes that the ESL is based on protection of groundwater which was not considered in the calculation of recommended screening numbers, (d) denotes that the ESL is based on soil gas contamination of indoor air

[2] Environmental Screening Levels (ESLs) published by SWQCB Region 2 (2003), http://www.swrcb.ca.gov/rwqcb2/esl.htm

[3] Preliminary Remediation Goals (PRGs) published by U.S. EPA Region 9 (2003), http://www.epa.gov/region09/waste/sfund/prg/index.htm

[4] Calculation of a screening number for the chemical has been postponed (pp) while it is in the process of listing as a substance known to the state to cause cancer under the authoritative body provision (CCR, Title 22, 12000).

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

Table 9. Selected Soil Levels Based on the Proposed Methodology for Volatile Chemicals and Tetraethyl Lead Based on Exposure to Indoor Air: Commercial/Industrial Land Use

Chemical	Soil Level Based on Soil Gas Intrusion		SF RWQCB ESL Based on Soil Gas Intrusion	
	Concentration in Soil (mg/kg)	Concentration in Soil Gas (μg/m^3)	Concentration in Soil (mg/kg)	Concentration in Soil Gas (μg/m^3)
Benzene	2.6 E-04	1.6 E+02	5.0 E-01	2.8 E+02
Carbon tetrachloride	7.1 E-05	1.2 E+02	3.5 E-02	1.9 E+02
1,2-Dichloroethane	1.2 E-03	1.8 E+02	6.9 E-02	3.9 E+02
Cis-1,2-Dichloroethylene	1.3 E-01	6.6 E+04	3.6 E+00	2.0 E+04
trans-1,2-Dichloroethylene	1.3 E-01	1.4 E+05	7.3 E+00	4.1 E+04
Ethylbenzene	pp[1]	pp[1]	1.3 E+01	7.4 E+03
Methyl tert butyl ether	1.4 E-01	1.5 E+04	5.6 E+00	3.1 E+04
Naphthalene	Pp[2]	Pp[2]	1.2 E+01	1.8 E+03
Tetrachloroethylene	8.1 E-04	9.2 E+02	2.5 E-01	1.4 E+03
Tetraethyl lead	5.0 E-07	3.4 E+00	NA	NA
Toluene	1.2 E+00	4.9 E+05	4.2 E+02	2.3 E+05
1,1,1-Trichloroethane	3.0 E+00	4.0 E+06	2.3 E+02	1.3 E+05
Trichloroethylene	3.8 E-03	2.5 E+03	7.3 E-01	4.1 E+03
Vinyl chloride	1.6 E-05	5.0 E+01	1.9 E-02	1.0 E+02
Xylenes	4.8 E+00	1.1 E+06	1.0 E+02	5.8 E+04

[1] Calculation of a screening number for the chemical has been postponed (pp) while it is in the process of listing as a substance known to the state to cause cancer under the authoritative body provision (CCR, Title 22, 12000).
[2] Calculation of a screening number for the chemical has been postponed (pp) until the toxicity criterion currently being developed by OEHHA is published as a final document
NA Not Available

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

For sites with multiple contaminants, the hazard index for carcinogenic chemicals and the hazard index for non-carcinogenic chemicals should be calculated separately. For carcinogenic chemical species $S_1, S_2, \ldots, S_n$ with soil concentrations $C_1, C_2, \ldots, C_n$ and screening numbers $SN_1, SN_2, \ldots, SN_n$, the carcinogenic hazard index is

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

For carcinogenic chemical species $S_1, S_2, \ldots, S_n$ with soil concentrations $C_1, C_2, \ldots, C_n$ and screening numbers $SN_1, SN_2, \ldots, SN_n$, the carcinogenic hazard index is also calculated using the above expression. For sites with multiple contaminants, the carcinogenic chemicals hazard index and the non-carcinogenic chemicals hazard index 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.

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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: Application of the Johnson and Ettinger Model to Derive Risk-Based Soil to Indoor Air Component for the Soil Screening Level Approach

1. Introduction

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 is a one-dimensional analytical solution to diffusive and convective transport of vapors formulated as an attenuation factor that relates the vapor concentration in the indoor space to the vapor concentration at the source. To facilitate the use of the Johnson-Ettinger Model (JEM), US EPA, in 1997, prepared spreadsheet versions of the model. The spreadsheets can be used to calculate the incremental risk from inhalation of vapors migrating to indoor air, and in reverse mode to back-calculate risk-based media-specific concentrations for contaminants of interest. In other words, the spreadsheets can back-calculate an "acceptable" soil or groundwater concentration given a user-defined risk level (i.e., target risk level or target hazard quotient). These calculated acceptable concentrations are generic by nature and can be expected to predict only whether or not a risk-based exposure soil and/or groundwater level will be exceeded at the site. Therefore, they can be used as a first-tier screening tool to identify sites needing further assessment. Since 1997, the JEM has been widely used in many states and has undergone many updates and modifications. US EPA (2003e) has recently published new versions of the Johnson and Ettinger Model (JEM) – based spreadsheets, namely screening and advanced level versions for soil, soil-gas, and groundwater, and versions used to model Non-Aqueous Phase Liquids, as well.

This document presents the development of risk-based soil and soil gas screening levels for the soil to indoor air pathway. The resulting values will be used as a component in the derivation of generic screening numbers for a number of chemicals of interest to the State of California.

2. Limitations of the Derived Screening Values

The JEM was developed for use as a screening level model and, consequently, is based on a number of simplifying assumptions regarding contaminant distribution and occurrence, subsurface characteristics, transport mechanisms, and building construction. As a result, the model cannot be used if the site of interest poses conditions that contradict those assumptions. Accordingly, in such cases, the generic screening number should not be used. Instead, site-specific data should be collected and the advanced versions of the JEM used to develop site-specific soil and soil gas numbers. When site-specific soil gas numbers are calculated, soil gas sampling should be performed and a comparison between the measured and calculated concentrations made. Indoor air sampling may also be performed in some situations, i.e., after the building is constructed, but not yet in use (to avoid any contribution of internal sources of similar chemical vapors migrating from paints, plastics, glues, household cleaning products, etc.). The indoor air sampling results may be compared to the calculated Target (health-protective) Indoor Air Concentration. Accordingly, the first step to be taken when evaluating a site is to decide on the applicability of the generic screening number(s) to that site.

A list of limitations for the use of the JEM for the developed generic screening levels 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 JEM 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 JEM.

- 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 JEM alone and requires coupling with additional models.

3. Model Steps Calculating the Screening Number Soil-Indoor Air Component

The derivation of the soil to indoor air component may be described in four consecutive steps.

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

3.1 Calculation of Target Indoor Air Concentration

The Target Indoor Air Concentration ($C_{building}$) will be the lower of the one based on cancer and the one based on the most sensitive non-cancer effect. Exposure assumptions and chemical-specific toxicity values are used to calculate both target concentrations.

Cancer Target Indoor Air Concentration

$$C_{ia-c} = \frac{TR \times AT_c \times 365\ days/yr}{URF \times EF \times ED}$$

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

Non-Cancer Target Indoor Air Concentration

$$C_{ia-nc} = \frac{THQ \times AT_{nc} \times 365\ days/year}{EF \times ED \times 1/RfC}$$

C_{ia-nc} Non-Cancer Target Indoor Air Concentration, μg/m^3
THQ Target Hazard Quotient, unitless
AT_{nc} Averaging Time for Non-Carcinogens, yr
RfC Reference Concentration, μg/m^3, chemical-specific
EF Exposure Frequency, days/yr
ED Exposure Duration, yr

3.2 Calculation of Soil to Indoor Air Attenuation Factor α

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

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

α Steady-state attenuation factor, unitless
D_T^{eff} Total overall effective diffusion coefficient, cm^2/s
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.
$Q_{building}$ Building ventilation rate, cm^3/s
L_T Source-building separation, cm
Q_{soil} Volumetric flow rate of soil gas into the enclosed space, cm^3/s

L_{crack} Enclosed space foundation or slab thickness, cm
A_{crack} Area of total cracks, cm^2
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).

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

$$D_T^{eff} = \frac{L_T}{\sum_{i=0}^{n} L_i / D_i^{eff}}$$

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
L_T Distance between the source of contamination and the bottom of the enclosed space floor, cm.

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

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

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

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:

$$H'_{TS} = \frac{exp\left[-\frac{\Delta H_{v,TS}}{R_c}\left(\frac{1}{T_S} - \frac{1}{T_R}\right)\right]}{RT_S}$$

H'_{TS} Henry's law constant at the system temperature, dimensionless
$\Delta H_{v,TS}$ Enthalpy of vaporization at the system temperature, cal/mol
T_S System temperature, °K

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

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

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

$\Delta H_{v,TS}$ Enthalpy of vaporization at the system temperature, cal/mol
$\Delta H_{v,b}$ Enthalpy of vaporization at the normal boiling point, cal/mol
T_s System temperature, ^oK
T_C Critical temperature, ^oK
T_B Normal boiling point, ^oK
n Constant, unitless.

US EPA (2003e) provides a table showing the value of n as a function of the ratio T_B/T_C. A conversion tool is also downloadable.

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

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

$$Q_{building} = (L_B\ W_B\ H_B\ ER) / 3{,}600\ s/h$$

$Q_{building}$ Building ventilation rate, cm^3/s
L_B Length of building, cm
W_B Width of building, cm
H_B Height of building, cm
ER Air exchange rate, (1/h).

The volumetric flow rate of soil gas entering the building (Q_{soil}) is calculated by the analytical solution of Nazaroff (1988) such that:

$$Q_{soil} = \frac{2\pi\ \Delta P\ k_v\ X_{crack}}{\mu\ ln(2Z_{crack} / r_{crack})}$$

Q_{soil} Volumetric flow rate of soil gas entering the building, cm^3/s
π 3.14159
ΔP Pressure differential between the soil surface and the enclosed space, $g/cm\text{-}s^2$
k_v Soil vapor permeability, cm^2
X_{crack} Floor-wall seam perimeter, cm
μ Viscosity of air, g/cm-s
Z_{crack} Crack depth below grade, cm
r_{crack} Equivalent crack radius, cm

$$r_{crack} = \eta\left(A_B / X_{crack}\right)$$

r_{crack} Equivalent crack radius, cm
η A_{crack}/A_B, $(0 \leq \eta \geq 1)$
A_B Area of the enclosed space below grade, cm^2
X_{crack} Floor-wall seam perimeter, cm

Soil vapor permeability is typically measured from field pneumatic tests. If field data are lacking, however, an estimate of the value of k_v can be made with limited data.

Soil intrinsic permeability (k_i) is a property of the medium alone that varies with the size and shape of connected soil pore openings. It can be estimated from the soil saturated hydraulic conductivity:

$$k_i = \frac{K_s\ \mu_w}{\rho_w\ g}$$

k_i Soil intrinsic permeability, cm^2
K_s Soil saturated hydraulic conductivity, cm/s
μ_w Dynamic viscosity of water, g/cm-s (= 0.01307 at 10°C)
ρ_w Density of water, g/cm^3 (= 0.999)
g Acceleration due to gravity, cm/s^2 (= 980.665)

Schaap and Leij (1997) computed the Soil Conservation Service (SCS) class average values of the saturated hydraulic conductivity (K_s) for each of the 12 SCS soil textural classifications. With these values, a general estimate of the value of k_i can be made by soil type.

The relative air permeability of soil (k_{rg}) is the effective air permeability divided by the intrinsic permeability and therefore takes into account the effects of the degree of water saturation on air permeability. Parker et al. (1987) extended the relative air permeability model of van Genuchten (1980) to allow estimation of the relative permeabilities of air and water in a two-or three-phase system:

$$k_{rg} = \left(1 - S_{te}\right)^{1/2}\left(1 - S_{te}^{1/M}\right)^{2M}$$

k_{rg} Relative air permeability, unitless ($0 \leq k_{rg} \leq 1$)
S_{te} Effective total fluid saturation, unitless
M van Genuchten shape parameter, unitless.

Given a two-phase system (i.e., air and water), the effective total fluid saturation (S_{te}) is calculated as:

$$S_{te} = \frac{(\theta_w - \theta_r)}{(n - \theta_r)}$$

S_{te} Effective total fluid saturation, unitless
θ_w Soil water-filled porosity, cm^3/cm^3
θ_r Residual soil water content, cm^3/cm^3
n Soil total porosity, cm^3/cm^3

3.3 Calculation of the Soil Gas Level

With a calculated value of α, the steady-state vapor-phase concentration of the contaminant at the source depth (C_{source}) is calculated as:

$$C_{source} = C_{building} / \alpha$$

α Steady-State Attenuation Factor, unitless
C_{source} Soil Gas Level at the Source, $\mu g/m^3$
$C_{building}$ Target Indoor Air Concentration, $\mu g/m^3$

It is of general understanding that calculating soil concentrations from soil gas concentrations is a process involving additional uncertainty. That's why, US EPA (2003e) recommends collecting soil gas data from the site of interest to be compared to the calculated health protective soil gas level(s) shown above. If the site soil gas data exceed the calculated soil gas level, more advanced modeling to derive site-specific target soil gas level and/or indoor air sampling may be performed. If the collected soil gas data are equal or lower than the health protective soil gas level the pathway soil to indoor air may be excluded from further examination.

3.4 Estimation of Soil Screening Level

Considering the limited site data typically available in preliminary site assessments, and the application of the JEM as a first-tier screening tool to identify sites needing further assessment, the following partitioning equation based on Johnson et al. (1990) can be used to estimate the Soil to Indoor Air RBSL component corresponding to the Target Soil Gas Level calculated on step 3:

$$C_{soil} = \frac{C_{source}(\theta_w + K_d \rho_b + H'_{TS}\, \theta_a)}{H'_{TS}\, \rho_b}$$

C_{soil} Soil Screening Level for the chemical of interest, µg/kg soil
C_{source} Health Protective Soil Gas Level below slab, µg/m^3
H'_{TS} Henry's law constant at the system (soil) temperature, dimensionless
ρ_b Soil dry bulk density, g/cm^3
θ_w Soil water-filled porosity, cm^3/cm^3
K_d Soil-water partition coefficient, cm^3/g $(= K_{oc} \ x \ f_{oc})$
θ_a Soil air-filled porosity, cm^3/cm^3
K_{oc} Soil organic carbon partition coefficient, cm^3/g
f_{oc} Soil organic carbon weight fraction

4. Model Scenario

The generic soil screening levels are intended to provide a simple screening tool to facilitate the decision-making process while a soil-contaminated site is being evaluated. To serve this purpose a generic criterion must be conservative and reasonable enough to cover a variety of existing site conditions, within the state. When exceeded those screening numbers would trigger more complex site-specific modeling and/or sampling. However, if not exceeded, screening numbers may preclude further efforts in evaluating the soil-contaminated site of interest.

Considering the type of construction widely used in California and the need for reasonable conservativeness, a **one-story single-family slab on grade residential dwelling scenario** was assumed. In order to consider soils with maximum soil vapor permeability, it was assumed that the **soil underlying the building consists of sand and the contamination begins at surface**. According to the common residential construction requirements in California, the top one and a half inches (4 cm) layer of soil is removed and a minimum of four inches (10 cm) thick crushed rock or gravel, and sand mixture is installed in the excavation for the future building. A minimum of three and a half inches (9 cm) thick concrete layer is laid on the top. In locations where the underlying soil is predominantly of expansive type (e.g., sand), an additional minimum of twelve inches (30 cm) layer of engineered fill is first laid down before the four inches of crushed material is installed. This engineered fill material could be any soil type able to stabilize the building, i.e., soil with texture finer than sand. The JEM spreadsheet conservatively assumes that the foundation top starts at the ground surface level (the Convection path length, L_p is equal to the Crack depth below grade, Z_{crack} and to the Depth below grade to bottom of enclosed space floor, L_F). This way the exposed foundation area is maximized. The same assumption was made in this document. Based on the construction methods common in California, it was assumed that a **3.5-inches (9 cm) thick concrete foundation layer is starts at the ground surface and is underlain by a 4-inches (10 cm) of crushed rock or gravel and sand, and 12-inches (30 cm) of finer texture material**. **The top of contamination was assumed to be located immediately below the installed engineered fill material**. According to this, the thickness of the building floor (Depth Below Grade to Bottom of Enclosed Space Floor), $\mathbf{L_F}$ resulted in 9 cm, and the depth from the top of building floor to the contamination top (Depth Below Grade to Top of Contamination), $\mathbf{L_t}$ resulted in 49 cm. Accordingly, the Source- building separation, $\mathbf{L_T}$ resulted in 40 cm. **One contamination layer of infinite depth** was assumed to exist immediately below the engineered fill (0 was entered for the Depth Below Grade to Bottom of Contamination, $\mathbf{L_b}$).

5. Model Input Parameters

The derivation of soil to indoor air screening levels includes a number of different inputs, namely chemical properties, toxicity values, exposure assumptions, soil properties, building parameters. These input parameters were developed considering toxicity studies, soil-physics science, available studies of building characteristics, and expert opinion. The uncertainty of the key model parameters and the sensitivity of the JEM to those key model parameters are described in US EPA (2003e). Of the soil input parameters, the soil moisture parameters are of critical importance for the attenuation factor value. 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, depth to base of foundation, and foundation slab thickness are characterized by low uncertainty and sensitivity.

5.1 Soil Parameters

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 due to the area and volume of the crushed rock (gravel) entities. US EPA (2003e) does not provide any data about gravel parameters relevant to vapor migration and the JEM spreadsheet does not provide gravel-sand layer modeling capabilities. Accordingly, and to consider the need for erring on the side of public health protection, **the first soil layer below concrete was assumed to consist of sand only** and all the relevant parameters, namely soil dry bulk density, soil total porosity, soil water-filled porosity, soil air-filled porosity, and soil organic carbon fraction, were assigned values for sand. All **reasonably health protective US EPA-suggested default parameter values** were assigned to the second finer engineered fill material layer. According to US EPA (2003e), these input parameters are considered default parameters for a first-tier assessment, which should in most cases provide a reasonably (but not overly) conservative estimate of the vapor intrusion attenuation factor for a site. Values for a number of parameters are presented in Table B-1. Additional soil parameters and their values are discussed in the text below.

Table B-1. Input Parameters and Values Assigned to the Sand and Engineered Fill Layers

Parameters	Sand Layer	Engineered Fill Layer
Layer Thickness, cm	10	30
Vadose Zone Soil Dry Bulk Density (ρ_b^A), g/cm^3	1.66*	1.5***
Vadose Zone Soil Total Porosity (n^v), unitless	0.375*	0.43***
Vadose Zone Soil Air-Filled Porosity (θ_a^v), cm^3/cm^3	0.321*	0.13***
Vadose Zone Soil Water-Filled Porosity (θ_w^v), cm^3/cm^3	0.054*	0.3***
Vadose Zone Soil Organic Carbon Fraction (f_{oc}^v), unitless	0.002**	0.002***
Soil Saturated Hydraulic Conductivity (K_S), cm/h	26.78	0.76****

Notes

* Based on US EPA (2003e).

** Sand is characterized by Low Organic Carbon Fraction.

*** Based on US EPA (2003e) and US EPA (1996).

**** Silt Loam. Based on default value for Soil Water-Filled Porosity of 0.30 cm^3/cm^3 recommended by US EPA, and range of water-filled porosity of 0.065-0.3 cm^3/cm^3 for Silt Loam. However, the JEM is not sensitive to the Soil

Saturated Hydraulic Conductivity, and changing the soil type for the engineered fill layer does not changed the derived attenuation factors, soil screening levels, and soil gas screening levels. Therefore, the soil type selected for the second layer is arbitrary and does not impact the final results.

The **highest California average annual soil temperature of 22^0 C (72^0 F)** provided in US EPA (2003e) was used to maximize the vapor migration.

The soil vapor permeability, $\mathbf{k_v}$ of the first layer is used to calculate Q_{soil}. US EPA (2003e) provides a default value of 10^{-8} cm^2 for k_v. Considering the fact that k_v is one of the most sensitive model parameters associated with convective transport of vapors within the zone of influence of the building, it was preferred to use the spreadsheet to estimate it. However, tracer tests may be used in site-specific applications.

The soil organic carbon fraction, $\mathbf{f_{oc}}$ for sand is expected to be at the lowest limit of the range (0.001 - 0.006). A value of 0.002, as recommended by the US EPA (2003e) was assumed to provide a reasonably conservative measure for the selected scenario.

5.2 Building Parameters

A list of reasonably health protective model input parameters for building-related parameters is provided in Table B-2 below. The rationale for each parameter value selection is provided in the following text.

Table B-2. Building Input Parameters and Values

Input Parameter	Value
Soil-Building Pressure Differential (ΔP), g/cm-s^2	40
Indoor Air Exchange Rate (ER), hr^{-1}	0.25
Enclosed Space Height (H_B), cm	244
Enclosed Space Floor Length (L_B), cm	1,000
Enclosed Space Floor Width (W_B), cm	1,000
Floor Wall Seam Crack Width (W), cm	0.1
Floor Wall Seam Perimeter, X_{crack}(cm)	4,000
Area of Enclosed Space Below Grade, A_B(cm^2)	1,000,000
Crack-To-Total Area Ratio, η (unitless)	Spreadsheet-calculated
Crack Depth Below Grade, Z_{crack}(cm)	9
Diffusion Path Length, L_d(cm)	40
Convection Path Length, L_p(cm)	9
Crack Radius, r_{crack}(cm)	Spreadsheet-calculated
Area of Crack, A_{crack}(cm^2)	Spreadsheet-calculated
Exponent of Equivalent Foundation Peclet Number, exp(Pe^f) (unitless)	Spreadsheet-calculated
Soil Gas Advection Rate (Q_{soil}), L/m	Spreadsheet-calculated

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 may 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.

Indoor Air Exchange Rate (ER) Air exchange rates vary 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 0.25 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.

Enclosed Space Height (H_B) The JEM 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. 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) Those two parameters are used to estimate the Building Area and Subsurface Foundation Area. US EPA considered a Michigan guidance document indicating that the 111.5 m^2 area approximately corresponds to the 10th 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 (1,000 cm) was recommended. The California Department of Toxic Substances Control (DTSC, 1994) stated the same values to apply for the State of California. 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) This parameter 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), Floor Wall Seam Perimeter (X_{crack}), and Crack-to-Total Area Ratio (η) According to US EPA (2003e), the crack width and crack ratio are related. Assuming a square house and that the only crack is a continuous edge crack between the foundation slab and wall ("perimeter crack"), the crack ratio and crack width are related as follows:

$$\textit{Crack Ratio} = \frac{4\left(\textit{Crack With} / \sqrt{\textit{Subsurface Foundation Area}}\right)}{\textit{Subsurface Foundation Area}}$$

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 values fall within observed ranges. Those values were applied to derive attenuation factors for the chemicals of interest.

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

Diffusion Path Length, L_d and Convection Path Length, L_p 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. L_p corresponds to the foundation thickness.

Crack Radius, r_{crack} This parameter was calculated following Johnson and Ettinger (1991), as shown in Section 3.2 above.

Area of Crack, A_{crack} It was calculated as a product of η and A_B.

Exponent of Equivalent Foundation Peclet Number, exp(Pe^f) This parameter characterizes the transport through the building foundation. It is represented by the following dimensionless group:

$$\left(\frac{Q_{crack} L_{crack}}{D_{crack} A_{crack}}\right)$$

More details can be found in US EPA (2003e).

Soil Gas Advection Rate (Q_{soil}) The method used with the JEM to estimate the 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 second option was selected in order to maximize the use of California-specific scenario and parameter values.

5.3 Toxicity Values

All calculations were based on Cancer Risk Level of $1x10^{-6}$ and Non-Cancer Hazard Quotient of 1, widely used in the development of screening levels by many regulatory agencies, including US EPA and California EPA.

Cal/EPA database (OEHHA, 2004) was the generally 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 CalEPA database. The following two sources were planned to be 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, it was 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 toxicity values used are presented in Table B-3.

Table B-3. 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**	7.8 E-06	NA
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
Methyl *tert*-Butyl Ether	**2.6 E-07**	**8.0 E+03**	NA	3.0 E+00
Naphthalene	NA	**9.0 E+00**	NA	3.0 E-03
Tetrachloroethylene	**5.9 E-06**	NA	3.0 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	4.0 E-02
Vinyl Chloride	**7.8 E-05**	NA	8.8 E-06	**1.0 E-01**
m-Xylene	NA	**7.0 E+02**	NA	7.0 E+00
o-Xylene	NA	**7.0 E+02**	NA	7.0 E+00
p-Xylene	NA	**7.0 E+02**	NA	7.0 E+00

Notes
* Selected toxicity values shown in bold.
** Extrapolated from RfD.
NA Not Available.
URF Unit Risk Factor

5.4 Chemical-Specific Parameters

The source of **chemical data** used in the calculation is primarily EPA's Superfund Chemical Data Matrix (SCDM) database (US EPA, 2003d). For other 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-4.

Table B-4. Physical – Chemical Parameters

Chemical	K_{oc} (cm^3/g)	D_a (cm^2/s)	D_w (cm^2/s)	S (mg/L)	H' (unitless)	H (atm-m^3/mol)	T_R (^oC)	T_B (^oK)	T_C (^oK)	$\Delta H_{v,b}$ (cal/mol)	S,L,G
Benzene	5.89E+01	8.80E-02	9.80E-06	1.79E+03	2.27E-01	5.54E-03	25	353.24	562.16	7,342	L
Carbon Tetrachloride	1.74E+02	7.80E-02	8.80E-06	7.93E+02	1.24E+00	3.03E-02	25	349.90	556.60	7,127	L
1,2-Dichloroethane	1.74E+01	1.04E-01	9.90E-06	8.52E+03	4.00E-02	9.77E-04	25	356.65	561.00	7,643	L
Cis-1,2-Dichloroethylene	3.55E+01	7.36E-02	1.13E-05	3.50E+03	1.67E-01	4.07E-03	25	333.65	544	7,192	L
trans-1,2-Dichloroethylene	5.25E+01	7.07E-02	1.19E-05	6.30E+03	3.84E-01	9.36E-03	25	320.85	516.5	6,717	L
Ethylbenzene	3.63E+02	7.50E-02	7.80E-06	1.69E+02	3.22E-01	7.86E-03	25	409.34	617.20	8,501	L
Methyl *tert*-Butyl Ether	7.26E+00	1.02E-01	1.05E-05	5.10E+04	2.56E-02	6.23E-04	25	328.3	497.1	6,678	L
Naphthalene	2.00E+03	5.90E-02	7.50E-06	3.10E+01	1.98E-02	4.82E-04	25	491.14	748.40	10,373	S
Tetrachloroethylene	1.55E+02	7.20E-02	8.20E-06	2.00E+02	7.53E-01	1.84E-02	25	394.40	620.20	8,288	L
Tetraethyl Lead*	7.58E+02	1.32E-02	6.4E-06	2.9E-01	3.38E+01	8.26E-01	25	475.15	712.72	9,757	L
Toluene	1.82E+02	8.70E-02	8.60E-06	5.26E+02	2.72E-01	6.62E-03	25	383.78	591.79	7,930	L
1,1,1-Trichloroethane	1.10E+02	7.80E-02	8.80E-06	1.33E+03	7.03E-01	1.72E-02	25	347.24	545.00	7,136	L
Trichloroethylene	1.66E+02	7.90E-02	9.10E-06	1.47E+03	4.21E-01	1.03E-02	25	360.36	544.20	7,505	L
Vinyl Chloride	1.86E+01	1.06E-01	1.23E-05	8.80E+03	1.10E+00	2.69E-02	25	259.25	432.00	5,250	G
o-Xylene	3.63E+02	8.70E-02	1.00E-05	1.78E+02	2.12E-01	5.18E-03	25	417.60	630.30	8,661	L
p-Xylene	3.89E+02	7.69E-02	8.44E-06	1.85E+02	3.13E-01	7.64E-03	25	411.52	616.20	8,525	L
m-Xylene	4.07E+02	7.00E-02	7.80E-06	1.61E+02	3.00E-01	7.32E-03	25	412.27	617.05	8,523	L

Notes

K_{oc} Organic carbon partition coefficient
D_a Diffusivity in air
D_w Diffusivity in water
S Pure component water solubility
H' Henry's law constant
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
S,L,G Physical State at soil temperature (Soil, Liquid, Gas)
* T_C and $\Delta H_{v,b}$ for tetraethyl lead were estimated. Please refer to the text below.

5.5 Exposure Parameters

All exposure parameters were selected following US EPA (2001b). The exposure parameter values for residential and industrial/commercial scenarios differ and are shown in Table B-5. The same values were selected for all other parameters for both scenarios.

Table B-5. Exposure Parameters Used Under Residential and Industrial/Commercial Scenarios

Parameter	Scenario	
	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

6. Spreadsheets Application

The advanced level spreadsheet versions for soil published by the US EPA in 2003 include a soil screening level spreadsheet (SL-ADV Version 3.0; 02/03) and a soil gas screening level spreadsheet (SG-ADV Version 2.0; 02/03). The soil screening level spreadsheet can be used to calculate the risk-based soil concentration (backward mode) or to calculate the incremental risk from actual soil concentration (forward mode). The soil gas screening level spreadsheet can be used with measured (estimated) soil gas data to calculate the incremental risk from vapor intrusion to indoor air.

The spreadsheets were repeatedly run for each scenario and chemical of interest. The procedure is described below, but to understand what was done the reader must have some understanding of how these spreadsheets operate.

1. The soil screening level spreadsheet was used in backward mode to calculate the attenuation factor α (INTERCALCS worksheet) and the corresponding soil screening concentration appearing in the Final Indoor Exposure Soil Concentration cell (RESULTS worksheet).

2. Considering the fact that the values of C_{source} and $C_{building}$ on the INTERCALCS worksheet are based on unity of the initial soil concentration (1 μg contaminant/kg soil) and do not represent actual values, the Soil-Gas Screening Level was calculated in forward model mode (calculation of incremental risk from actual soil concentration). Accordingly, the calculated Final Indoor Exposure Soil Concentration calculated in Step 1 was used as input into the Initial Soil Concentration, C_R cell (DATAENTER worksheet) to calculate the corresponding screening soil gas concentration appearing in the Source vapor conc., C_{source} cell.

3. A number of checks were performed including using the Target Indoor Air Concentration, appearing in the Infinite source bldg. conc., $C_{building}$ cell with the

attenuation factor. In addition, the soil gas screening level spreadsheet was used with the calculated screening soil gas concentration as input into the Soil gas conc., C_g cell (DATAENTER worksheet) to verify the Incremental risk from vapor intrusion to indoor air (to correspond to 1.0 x10^{-6} or 1.0) as shown on the RESULTS worksheet.

7. Results

Modeling results for Attenuation Factors, Soil Screening Levels, and Soil Gas Screening Levels for all chemicals of interest are shown in Tables B-6 and B-7 below.

7.1 Screening Levels under the Residential Scenario

Table B-6. Attenuation Factors, Soil Screening Levels, and Soil Gas Screening Levels under the Residential Scenario

Chemicals	α, unitless	Soil Screening Level, μg/kg	Soil Gas Screening Level*, μg/m^3
Benzene	9.00 E-04	1.57 E-01	9.34 E+01
Carbon Tetrachloride	8.05 E-04	4.22 E-02	7.20 E+01
1,2-Dichloroethane	1.07 E-03	7.40 E-01	1.09 E+02
cis-1,2-Dichloroethylene	7.75 E-04	9.06 E+01	4.71 E+04
trans-1,2-Dichloroethylene	7.42 E-04	9.61 E+01	9.84 E+04
Ethylbenzene	7.81 E-04	9.28 E+03	2.67 E+06
Methyl *tert*-Butyl Ether	1.08 E-03	8.26 E+01 (7.37 E+04)	8.69 E+03 (7.75 E+06)
Naphthalene	6.98 E-04	3.54 E+03	1.35 E+04
Tetrachloroethylene	7.51 E-04	4.82 E-01	5.49 E+02
Tetraethyl Lead	1.52 E-04	3.57 E-04	2.40 E+00
Toluene	8.89 E-04	8.78 E+02	3.52 E+05
1,1,1-Trichloroethane	8.06 E-04	2.17 E+03	2.84 E+06
Trichloroethylene	8.17 E-04	2.29 E+00	1.49 E+03
Vinyl Chloride	1.05 E-03	9.49 E-03	2.98 E+01
m-Xylene	7.35 E-04	4.05 E+03	9.93 E+05
o-Xylene	8.92 E-04	4.30 E+03	8.19 E+05**
p-Xylene	7.99 E-04	3.45 E+03**	9.14 E+05

Notes

α Attenuation Factor

* Considering the fact that the values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values, the Soil-Gas Screening Level was calculated in forward model mode (calculation of incremental risk from actual soil concentration). The derived Soil Screening Level was used as Initial Soil Concentration.

** Representative Screening Levels for xylenes. The representative value for xylenes is based on the calculated lowest health-protective one amongst the three isomers. Accordingly, soil screening level for *p*-xylene appeared to be the representative one (Highest Henry's law constant. Please refer to the equation shown in section 3.4 above). The soil gas screening level for ***o***-xylene appeared to be the representative one due to the highest attenuation factor α.

( ) Based on non-cancer effect, RfC of 3.0 E+00 mg/m^3

7.2 Screening Levels under the Industrial/Commercial Scenario

Two of the five groups of parameters (soil, building, toxicity, chemical-specific, and exposure), namely the building and exposure, were found to contribute to the difference in the screening levels under industrial/commercial conditions. While the screening levels 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 levels must 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 for the vapor intrusion model as the ones used under the residential scenario.

At the same time, it was deemed unnecessary 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 years Averaging Time for Non-Carcinogens, 25 years for Exposure Duration, and 250 days per year for Exposure Frequency.

Table B-7. Attenuation Factors, Soil Screening Levels, and Soil Gas Screening Levels under the Industrial/Commercial Scenario

Chemicals	α, unitless	Soil screening level, μg/kg	Soil gas screening level*, μg/m^3
Benzene	9.00 E-04	2.63 E-01	1.56 E+02
Carbon Tetrachloride	8.05 E-04	7.09 E-02	1.21 E+02
1,2-Dichloroethane	1.07 E-03	1.24 E+00	1.82 E+02
cis-1,2-Dichloroethylene	7.75 E-04	1.27 E+02	6.60 E+04
trans-1,2-Dichloroethylene	7.42 E-04	1.34 E+02	1.37 E+05
Ethylbenzene	7.81 E-04	1.30 E+04	3.74 E+06
Methyl *tert*-Butyl Ether	1.08 E-03	1.39 E+02 (1.03 E+05)	1.46 E+04 (1.08 E+07)
Naphthalene	6.98 E-04	4.95 E+03	1.88 E+04
Tetrachloroethylene	7.51 E-04	8.10 E-01	9.23 E+02
Tetraethyl Lead	1.52 E-04	5.00 E-04	3.37 E+00
Toluene	8.89 E-04	1.23 E+03	4.93 E+05
1,1,1-Trichloroethane	8.06 E-04	3.04 E+03	3.98 E+06
Trichloroethylene	8.17 E-04	3.84 E+00	2.50 E+03
Vinyl Chloride	1.05 E-03	1.59 E-02	4.99 E+01
m-Xylene	7.35 E-04	5.67 E+03	1.39 E+06
o-Xylene	8.92 E-04	6.02 E+03	1.15 E+06***
p-Xylene	7.99 E-04	4.83 E+03***	1.28 E+06

Notes

α Attenuation Factor.

* Considering the fact that the values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values, the Soil-Gas Screening Level was calculated in forward model mode (calculation of incremental risk from actual soil concentration). The derived 8 hours exposure Soil Screening Level was used as Initial Soil Concentration.

** Representative Screening Levels for xylenes. The representative value for xylenes is based on the calculated lowest health-protective one amongst the three isomers. Accordingly, soil screening level for *p*-xylene appeared to be the representative one (Highest Henry's law constant. Please refer to the equation

shown in section 3.4 above). The soil gas screening level for ***o***-xylene appeared to be the representative one due to the highest attenuation factor α.
( ) Based on non-cancer effect, RfC of 3.0 E+00 mg/m^3

8. Development of Attenuation factor α, SoilGas Screening Level, and Soil Screening Level for Tetraethyl Lead

Tetraethyl Lead is the only chemical from the list of chemical of interest not included into the JEM spreadsheet (US EPA, 2003e). While chemical-physical parameters for the rest of chemicals under consideration were readily available in the VLOOK 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, SoilGas Screening Level, and Soil Screening Level were calculated by applying the tetraethyl lead's values for a number of physical-chemical and toxicity parameters into the Johnson and Ettinger Model spreadsheets 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-8. Chemical-Physical and Toxicity Parameters for Tetraethyl Lead (CAS No. 78-00-2)

Parameter	Value	Source
Organic Carbon Partition Coefficient, K_{oc}, (cm^3/g)	758	US EPA (2003a)
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 ^{o}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, (^{o}C)	25	US EPA (2001a)
Normal Boiling Point, t_b , (^{o}C)	≈ 202	US EPA (2003a)
Normal Boiling Point, T_B, (^{o}K)	475.15*	US EPA (2003a)
Critical Temperature, T_C, (^{o}K)	712.72**	US EPA (2001a)
Antoine coefficient, B, (^{o}C)	1,566.7**	US EPA (2001a)
Antoine coefficient, C, (^{o}C)	195	US EPA (2001a)
Gas constant, R_C, (cal/mol-^{o}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}, (^{o}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, (μg/m^3)$^{-1}$	NA	US EPA (2003b)
Reference Concentration, RfC, (μg/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 ^{o}K from ^{o}C.

** Calculated as shown in the text below.
*** Extrapolated from the 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**, for example, can be approximated from the normal boiling point by:

$$T_C \approx 3T_B / 2$$

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

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

where:

$\Delta H_{v,b}$ Enthalpy of vaporization at the normal boiling point, cal/mol
B Antoine coefficient, ^oC
R_C Gas constant (= 1.9872 cal/mol- ^oK)
T_B Normal boiling point, ^oK
$(Z_g\text{-}Z_l)$ Compressibility factor difference, unitless (= 0.95 at T_B)
t_b Normal boiling point, ^oC
C Antoine coefficient, ^oC.

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 the table shown below. Antoine coefficient C resulted in 195 ^oC.

Antoine Coefficient C for Organic Compounds

Boiling Point (^oC)	C (^oC)	Boiling Point (^oC)	C (^oC)
<-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:
t_b Normal boiling point, ^oC

The value of the Antoine *B* coefficient can be estimated with a value of the *C* coefficient, the normal boiling point, and one pair of vapor pressure/temperature data:

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

where:

B Antoine coefficient, ^oC
t_b Normal boiling point, ^oC
C Antoine coefficient, ^oC
t_{Pv} Known temperature at vapor pressure Pv, ^oC
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 ^oC or 25 ^oC. 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%.

When all collected and calculated tetraethyl lead parameter values were added to the LOOKUP table in the US EPA soil screen spreadsheet SL-ADV-040903.xls, the following results were obtained:

Residential Scenario

Attenuation factor α = 1.52 E-04
Soil to Indoor Air Risk-Based Soil Screening Level = 3.57 E-04 μg/kg
Soil-Gas Screening Concentration = 2.40 E+00 μg/m^3

Industrial/Commercial Scenario

Attenuation factor α = 1.52 E-04
Soil to Indoor Air Risk-Based Soil Screening Level = 5.00 E-04 μg/kg
Soil-Gas Screening Concentration = 3.37 E+00 μg/m^3

9. Discussion of Uncertainties in the Derived Screening Levels

Aside from uncertainties in the structure of the Johnson and Ettinger Model, widely discussed in the scientific literature (the model has not been completely validated), a number of uncertainties are inherent to its parameters. Reasonably conservative values were selected for all parameters to derive the soil and soilgas

screening levels. The rationale for their selection and the corresponding justification are provided in the text above.

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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. $C_{res\text{-}haz}$ was 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.

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

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

$$C_{ind-risk} = \frac{TR \times BW_a \times AT_c}{EF_r\,[(\frac{IRS_o \times CSF_o}{10^6\, mg/kg}) + (\frac{SA_o \times AF_o \times ABS \times CSF_o}{10^6\, mg/kg}) + (\frac{IRA_a \times CSF_i}{VF})}$$

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

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:

$$IFS_{adj} = IRS_a \times \frac{(ED_r - ED_c)}{BW_a} + IRS_c \times \frac{ED_c}{BW_c}$$

$$SFS_{adj} = AF_a \times SA_a \times \frac{(ED_r - ED_c)}{BW_a} + AF_c \times SA_c \times \frac{ED_c}{BW_c}$$

$$InF_{adj} = IRA_a \times \frac{(ED_r - ED_c)}{BW_a} + IRA_c \times \frac{ED_c}{BW_c}$$

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

Parameter	Abbreviation	Value	Units
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
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			

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
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	
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	

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
Chromium VI	1%	1.316×10^9	
Cobalt	1%	1.316×10^9	
Copper and compounds	1%	1.316×10^9	
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

Chemical	Skin Absorption Factor[1]	Soil to Outdoor Air Partition Coefficient	
		Particulate Emission Factor[2]	Volatilization Factor[3]
Tetraethyl lead	10%		5516
Toluene	10%		3553
Trichloroethane, 1,1,1-	10%		2390
Trichloroethylene	10%		2595
Vinyl chloride	10%		1037
Xylenes	10%		4368

[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

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

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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 screen levels 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 issue paper describes the arguments for and against the inclusion of the pathway in the RBSLs 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 Levels have been found in vegetables and fruit that are grown in backyard gardens. 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 concentration of a given chemical in the soil in which crops were grown and the concentration in the vegetation. Travis and Arms (1988) found a correlation between the plant-soil partition coefficient and the K_{OW}. 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 doses 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 grow in that 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 divergence into a representative component of screen values.

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 and the food pathway is included. There more information on lead in food than with other chemicals and regulatory acceptance of a methodology for estimating uptake into plants. Therefore, the RBSL for lead will be based on the Department of Toxic Substances LeadSpread computational tool. The RBSLs 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.