Technical Justification for Soil Screening Levels for Direct Contact and Outdoor Air Exposure Pathways

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1 EXECUTIVE SUMMARY

Soil Screening Levels have been proposed to be used in conjunction with vapor intrusion criteria and groundwater criteria for identifying sites posing a low-threat to human health and the environment. That is, these Soil Screening Levels are just one of three sets of criteria that should be evaluated to determine if a site is low-threat.

The Soil Screening Levels discussed in this document have been proposed for benzene, naphthalene, and polyaromatic hydrocarbon (PAH) to define sites that are low-threat with respect to “direct contact” with soil. The exposure pathways considered in the site conceptual model are: ingestion of soil, dermal contact with soil and inhalation of dust and volatile emissions from soil. Note these exposure pathways are assumed to occur simultaneously, i.e. the screening levels are protective of the cumulative exposure from all four exposure pathways.

These screening levels were derived using standard USEPA and Cal/EPA risk assessment equations. The exposure parameter values, chemical toxicity values, and chemical fate and transport properties are based on standard values used in California.

Different screening levels have been developed for two soil horizons, one from 0 to 5 feet below ground surface (bgs), and one from 5 to 10 feet bgs. This document describes the technical background for the development of the direct contact screening levels. Three exposure scenarios (types of receptors and land use) were considered and the screening levels for each soil horizon were chosen to be the most conservative of the three scenarios.

The soil screening level for “PAH” is appropriate to be compared with site concentrations for the total concentration of the seven carcinogenic PAHs. The carcinogenic PAHs are: benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

The toxicity value used for the entire group of carcinogenic hydrocarbons is California’s Office of Environmental Health Hazard Assessment (OEHHA) cancer potency value for benzo(a)pyrene. This is a conservative assumption because the few PAHs that are more carcinogenic than benzo(a)pyrene are not commonly found in petroleum mixtures.

2 INTRODUCTION

The equations used to develop the Soil Screening Levels came from the California Environmental Protection Agency (Cal/EPA) OEHHA’s California Human Health Screening Levels (CHHSLs; OEHHA 2005). Exposure parameters values were assumed to equal the defaults values used in OEHHA’s California Human Health Screening Levels (CHHSLs; OEHHA 2005). The Soil Screening Levels presented in this document are conservative because the assumptions used to calculate the values are based on worst case exposure scenarios.

The CHHSLs for “direct contact with soil” pathways, do not include volatilization of chemicals from the soil to outdoor air. For the Soil Screening Levels presented in this document a volatilization factor was added to the CHHSL equations in order to be conservative and was obtained from the American Society of Testing Material’s (ASTM’s) Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM 1996). The ASTM volatilization factor used to calculate concentrations in outdoor air considers mass balance. The volatilization algorithm commonly used in USEPA screening level equations can greatly overestimate the amount of contaminant volatilizing into outdoor air for volatile chemicals (OEHHA, 2005). In the ASTM volatilization algorithm, if the calculated volatilization rate depletes the source before the end of the exposure duration, then the volatilization rate is adjusted so that the total source mass is assumed to volatilize by the end of the exposure duration. By using this mass-balance check, it is ensured that the total amount volatilized does not exceed the total amount of contaminant in soil (which can happen with the USEPA volatilization algorithm).

For dermal contact with soil, ingestion of soil, and inhalation of dust pathways, the exposure concentration in soil is assumed to be constant at the screening level for the entire exposure duration.

2.1 Screening Levels vs. Risk

These Soil Screening Levels represent concentrations that indicate that the site is a low-threat risk for human health; they cannot be used to estimate site-specific risks. Multiple conservative assumptions were made when developing these Soil Screening Levels. Actual site risk is expected to be lower than the risk targets used to develop the screening levels. For example, for residential sites, the receptor is assumed to come into contact with soil with concentrations at the screening level almost every day (350 days/year) for a total of 30 years. While most residential exposures would not be at the default levels used in this analysis, the defaults used here are designed to be protective for this hypothetical "reasonable worst case" scenario.

Site concentrations exceeding the screening levels do not indicate unacceptable human health risks with regards to these pathways; rather, an exceedance may indicate that a site-specific evaluation of human health risk is warranted.

3 CONCEPTUAL SITE MODEL

This section describes the exposure scenarios and receptors considered in the development of the Soil Screening Levels.

3.1 Exposure Pathways

The Screening Levels consider four exposure pathways simultaneously:

- ingestion of soil,
- dermal contact with soil,
- inhalation of volatile soil emissions, and
- inhalation of particulate emissions.

Ingestion of and dermal contact with soil are direct exposure pathways, i.e., the receptor is assumed to contact the soil directly and, therefore, the exposure point concentration is the actual concentration in soil. For the inhalation exposure pathways, the exposure medium is outdoor air; the outdoor air concentrations must be estimated using volatilization and particulate emission factors.

3.2 Receptors Considered

Soil Screening levels were calculated for three exposure scenarios, and then the most conservative screening level was chosen for the screening levels. The exposure scenarios considered were:

- residential,

- commercial/industrial, and
- workers in a utility trench or similar construction project.

It is assumed that all four of the exposure pathways (discussed in section 3.1) are potential exposure pathways for each of the three types of receptors. The input parameter values are different for each receptor, however.

For the residential exposure scenario, it is assumed that the receptor is a child for 6 years and then an adult for 24 years. When calculating carcinogenic risk, the total intake of a chemical over a lifetime is used; therefore, the carcinogenic residential screening levels are protective of the combined child plus adult scenario. For non-carcinogenic health effects, the intake is not added over the exposure period. In that case, the child is the more sensitive receptor, therefore the non-carcinogenic screening levels are developed for a child receptor and are protective for the adult resident as well.

The commercial/industrial exposure scenario assumes that the receptor is an adult and works in an office or outdoors at the site; however, the adult is not expected to be digging in the soil. In this scenario, it is assumed that the receptor works for a total of 25 years at 250 days/year at the same location. It is likely that the direct contact exposure assumptions are very conservative for this exposure scenario.

For the utility or construction worker, it is assumed that the worker may be working directly with the impacted soil. In this exposure scenario, the exposure duration is assumed to be much shorter than in the other two scenarios; however, the chemical intake per day may be higher due to increased incidental ingestion.

3.3 Depths to Which the Screening Levels Apply

Two sets of screening levels were developed, based on depth of impacted soil: one set applies to 0 to 5 feet below ground surface (bgs) and the other set applies to 5 to 10 feet bgs. The screening levels applying to soil at 0 to 5 feet bgs represent the lowest of the screening levels calculated for the resident, worker, and utility worker. Screening levels for soil from 5 to 10 feet bgs represent the lower value of either a utility trench/construction worker or the volatilization to outdoor air pathway for all of the receptors. That is, the full depth of 0 to 10 feet is assumed to contribute to outdoor air concentrations for all scenarios. Therefore, the screening levels for both soil horizons are protective of inhalation of volatile emissions.

When calculating the residential screening levels, it is assumed that residents may come into contact with the soil between the ground surface and a depth of 5 feet (“surface soil”). For impacted soil at depths from 5 to 10 feet (a “swimming pool” or “septic system installation” scenario), it is assumed that the potential risk posed to residents by direct contact would be small, because excavations by the homeowner to that depth would be rare (exposure frequency and duration are short), most of the petroleum-affected soil would likely be removed to create the swimming pool or septic system, and petroleum constituents in soil would volatilize and biodegrade very quickly if the affected soil was placed at the ground surface (i.e. the top few inches of soil).

For commercial/industrial receptors it is assumed that commercial workers could contact the soil at depths between ground surface and 5 feet. In the case of a utility trench or construction worker, it was assumed that direct contact (dermal and ingestion) with soils could occur at depths from 0 to 10 feet.

4 DERIVATION OF SCREENING LEVELS

This section describes how the Soil Screening Levels were calculated. Standard equations from the OEHHA CHHSLs were used for everything except the volatilization term which was discussed in Section 2. A target risk level of 1×10^{-6} risk for carcinogens and a target hazard index of 1.0 for non-carcinogens were assumed in all cases.

4.1 Equations Used

4.1.1 Exposure Equations

The equations used to develop the Soil Screening Levels are shown in Tables 1 through 3 and the variable definitions are shown in Table 4.

4.1.2 Volatilization Factor

As mentioned previously, the CHHSLs do not include a volatilization factor (VF), i.e. they do not consider volatile emissions to outdoor air. A VF was included in the Soil Screening Levels, however to be conservative. The volatilization factor used to predict outdoor air concentrations due to volatilization from the soil is based on the ASTM guidance (1996).

The assumptions in the ASTM volatilization factor algorithm (ASTM 1996) are:

- Dispersion in air is modeled from a ground-level source. It is assumed that the air in the outdoor air "box" is well-mixed.
- The receptor is located onsite, directly over the impacted soil, 24 hours/day for the entire exposure duration.
- A long-term average exposure–point concentration is estimated for the entire exposure duration.

The conceptual model for volatile emissions and inhalation of outdoor air is shown in Figure 1. Note the assumed receptor location at the edge of the downwind side of the source (for 24 hours/day for the entire exposure duration) is the most conservative location that could be used. The dispersion of contaminant in the air, or mixing, is limited to the height of the breathing zone; that is, vertical dispersion upwards as the air blows towards the receptor is not considered by the model. This is one exposure scenario where the actual exposure assumed in the risk calculations would be impossible to achieve and the algorithm used to estimate the risk from volatile emission is very conservative.

The ASTM VF is actually composed of two equations shown in Table 5: one equation assumes an infinite source, and the other one equation includes a mass balance check to limit the volatilization term so that the amount volatilized cannot exceed the total amount of mass in the soil initially. The VF is calculated using both equations and the lower of the two volatilization rates is used for the VF in the exposure equations. The default input values are shown in Table 6.

4.1.3 Particulate Emission Factor

A particulate emission factor (PEF) is used to estimate the outdoor air concentrations due to chemicals airborne on particulates (dust). The default value used for the PEF for the residential and commercial/industrial scenarios is the default value used in the CHHSLs = (1.3×10^9) [(mg/kg)/(mg/m^3)]. For the utility trench (construction) worker, a PEF value of 1×10^6 [(mg/kg)/(mg/m^3)] was used (DTSC 2005).

4.2 Exposure Parameter Values Used

The CHHSLs do not have a utility trench/construction worker receptor, so the default exposure parameters for this receptor were obtained from California Department of Toxic Substances Control (DTSC) Human and Ecological Risk Division (HERD) "Human Health Risk Assessment (HHRA) Note Number 1" (DTSC 2005). Table 4 shows the default values used for each parameter and provides the reference document where the value was obtained.

4.2.1 Ingestion of Soil

Receptors working or playing outdoors may ingest soil through incidental contact of the mouth with hands and clothing. For the residential and commercial exposure scenarios, one of the very conservative assumptions made is that the chemical concentrations remain constant over time in the soil. In reality, this would not be the case for especially for volatile chemicals in the top few feet of soil, where most of the direct contact would occur. Benzene is highly fugitive in surface soil, quickly depleting the upper soil depths.

4.2.2 Dermal Contact with Soil

Some soil contaminants may be absorbed across the skin into the bloodstream. Absorption will depend upon the amount of soil in contact with the skin, the concentration of chemicals in soil, the skin surface area exposed, and the potential for the chemical to be absorbed across the skin.

4.2.3 Inhalation of Volatile and Particulate Emissions in Outdoor Air

The inhalation exposure route includes the inhalation of both volatile and particulate emissions. The inhalation slope factors and non-carcinogenic inhalation reference doses are shown in Table 7.

5 RESULTS: SOIL SCREENING LEVELS

Table 8 (which is included here for convenience) shows the Soil Screening Levels.

Table 8: Soil Screening Levels

Depth (feet)	Benzene (mg/kg)	Naphthalene (mg/kg)	PAH (mg/kg)
0 to 5	2.3	13	0.038
5 to 10	100	1500	7.5

*Notes: Based on the seven carcinogenic PAHs as benzo(a)pyrene toxicity equivalent [BaPe]. The PAH screening level is only applicable where soil was affected by either waste oil and/or Bunker C fuel.

Table 9 shows the soil screening levels calculated for each exposure scenario. Note that the lowest screening level was chosen for the two different soil depths to obtain the screening levels in Table 9.

Table 9: Summary of Soil Screening Levels for Each Receptor

Chemical	**Residential** mg/kg	**Commercial/ Industrial** mg/kg	**Utility** mg/kg	**Subsurface Soil -- Volatilization only** (for 5 to 10' bgs) **Residential Scenario** mg/kg
Benzene	2.3	120	100	130
Naphthalene	13	45	1500	33,000
PAH	0.038	2.3	7.5	1×10^6

6 DISCUSSION OF RESULTS

This document has presented Soil Screening Levels to be used to identify sites that are low threat to human health risk for the direct contact pathways from impacted soil. These Soil Screening Levels are designed to be used in conjunction with the Vapor Intrusion Criteria and Groundwater Criteria to determine if the site is a low-threat from all exposure pathways.

Three exposure scenarios were originally considered: residential, commercial/industrial, and a utility trench/construction worker. The final Soil Screening Levels were chosen as the lowest values for each receptor. The equations used were based on the equations used by OEHHA in the development of the CHHSLs, with the exception of the volatilization rate. A volatilization rate term was added to the Soil Screening Level equations to be conservative.

OEHHA has indicated that the residential exposure scenario is protective for other sensitive uses of a site. This means that these screening levels are also appropriate for other sensitive uses of the property (e.g., day-care centers, hospitals, etc.) (Cal/EPA 2005).

7 REFERENCES

American Society for Testing and Materials (ASTM). 1996. Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites, ASTM E1739-95, Philadelphia, PA.

DTSC (Department of Toxic Substances Control). 2005. Human and Ecological Risk Division (HERD). Human Health Risk Assessment (HHRA) Note Number 1. Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Military Facilities.

OEHHA (Office of Environmental Health Hazard Assessment). 2005. Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil, Integrated Risk Assessment Branch, Office of Environmental Health Hazard Assessment. (Cal/EPA), January 2005 Revision. Available at: http://www.oehha.ca.gov/risk/Sb32soils05.html

OEHHA (2009). OEHHA Cancer Potency Values as of July 21, 2009.

SF RWQCB ESLs. Regional Water Quality Control Board (RWQCB) Region 2 – San Francisco. 2008. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Interim Final. May

USEPA. 1989. Risk Assessment Guide for Superfund (RAGS) Volume I Human Health Evaluation Manual (Part A) EPA/540/1-89/002, Office of Emergency and Remedial Response. December.

TABLES

Table 1: Equations Used to Develop Soil Screening Levels for the Direct Contact Pathways for a Residential Exposure Scenario

Carcinogenic – Residential

Age-Adjusted Ingestion Rate

$$\mathrm{IFS}_{adj} = \left[\frac{ED_c \times IRS_c}{BW_c} + \frac{ED_a \times IRS_a}{BW_a}\right]$$

Age-Adjusted Dermal Contact Rate

$$\mathrm{SFS}_{adj} = \left[\frac{ED_c \times SAS_c \times AF_c}{BW_c} + \frac{ED_a \times SAS_a \times AF_a}{BW_a}\right]$$

Age-Adjusted Inhalation Rate

$$\mathrm{InF}_{adj} = \left[\frac{ED_c \times InhR_c}{BW_c} + \frac{ED_a \times InhR_a \times AF_a}{BW_a}\right]$$

Total

$$C_{res-risk} = \frac{TR \times AT_{Carc} \times 365\,\mathrm{d/yr}}{\mathrm{EF_r} \times \left[\left[\frac{\mathrm{IFs}_{adj} \times SF_o}{1E6\,\mathrm{mg/kg}}\right] \times \left[\frac{\mathrm{SFS}_{adj} \times \mathrm{ABS} \times \mathrm{SF_o}}{1E6\,\mathrm{mg/kg}}\right] \times \left[\mathrm{InF}_{adj} \times \mathrm{SF_i} \times \left(\mathrm{VF_r} + \frac{1}{\mathrm{PEF_r}}\right)\right]\right]}$$

Non-Carcinogenic (Hazard) – Residential

$$C_{res\text{-}haz} = \frac{THQ \times BW_c \times 365\,\mathrm{d/yr}}{EF_r \times ED_c \times \left[\left(\frac{1}{\mathrm{RfD_o}} \times \frac{\mathrm{IRS_c}}{10^6\ mg/kg}\right) + \left(\frac{1}{\mathrm{RfDo}} \times \frac{\mathrm{SAS_c} \times \mathrm{AF_c} \times \mathrm{ABS_d}}{10^6\ mg/kg}\right) + \left(\frac{1}{\mathrm{RfD_i}} \times \mathrm{InhR_c}\left(\mathrm{VF_r} + \frac{1}{\mathrm{PEF_r}}\right)\right)\right]}$$

Table 2: Equations Used to Develop Soil Screening Levels for the Direct Contact Pathways for a Commercial/Industrial Exposure Scenario

Carcinogenic – Commercial/Industrial (c/i)

$$C_{c/i-risk} = \frac{TR \times BW_{c/i} \times AT_{Carc} \times 365\,d/yr}{EF_r \times \left[\left(\frac{IRS_{c/i} \times SF_o}{1E6\,mg/kg}\right) \times \left(\frac{SAS_{c/ij} \times AF_{c/i} \times ABS \times SF_o}{1E6\,mg/kg}\right) \times \left[InR_{c/i} \times SF_i \times \left(VF_r + \frac{1}{PEF_r}\right)\right]\right]}$$

Non-Carcinogenic – Commercial/Industrial

$$C_{res\text{-}haz} = \frac{THQ \times BW_{a/i} \times 365\,d/yr}{EF_{c/r} \times ED_{c/i} \times \left[\left(\frac{1}{RfD_o} \times \frac{IRS_{c/i}}{10^6\,mg/kg}\right) + \left(\frac{1}{RfDo} \times \frac{SAS_{c/i} \times AF_{/ic} \times ABS_d}{10^6\,mg/kg}\right) + \left(\frac{1}{RfD_i} \times InhR_{c/i}\left(VF_r + \frac{1}{PEF_r}\right)\right)\right]}$$

Table 3: Equations Used to Develop Soil Screening Levels for the Direct Contact Pathways for a Utility Trench Worker or Construction Exposure Scenario

Carcinogenic – Utility Trench Worker (ut)

$$C_{uti-risk} = \frac{TR \times BW_{ut} \times AT_{Carc} \times 365\,d/yr}{EF_{utr} \times \left[\left(\frac{IRS_{uti} \times SF_o}{1E6\,mg/kg}\right) \times \left(\frac{SAS_{utj} \times AF_{ut} \times ABS \times SF_o}{1E6\,mg/kg}\right) \times \left[InR_{ut} \times SF_i \times \left(VF_{ut} + \frac{1}{PEF_{utr}}\right)\right]\right]}$$

Non-Carcinogenic – Utility Trench Worker

$$C_{res\text{-}haz} = \frac{THQ \times BW_{ut} \times 365\,d/yr}{EF_{ut} \times ED_{uti} \times \left[\left(\frac{1}{RfD_o} \times \frac{IRS_{ut}}{10^6\,mg/kg}\right) + \left(\frac{1}{RfDo} \times \frac{SAS_{ut} \times AF_{ut} \times ABS_d}{10^6\,mg/kg}\right) + \left(\frac{1}{RfD_i} \times InhR_{ut}\left(VF_{ut} + \frac{1}{PEF_{ut}}\right)\right)\right]}$$

Table 4: Default Exposure Parameters

Parameter	Variable Name	Units	Value	Reference
Averaging time for carcinogens	AT_{carc}	years	70	70 years by definition (USEPA 1989)
Body weight, residential child	BW_c	kg	15	OEHHA (2005)
Body weight, residential adult	BW_a	kg	70	OEHHA (2005)
Body weight, commercial/industrial	$BW_{c/i}$	kg	70	OEHHA (2005)
Body weight, utility worker	BW_{ut}	kg	70	DTSC HERD (2005)
Exposure duration, residential child	ED_c	years	6	OEHHA (2005)
Exposure duration, residential adult	ED_a	years	24	OEHHA (2005)
Exposure duration, commercial/industrial	$ED_{c/i}$	years	25	OEHHA (2005)
Exposure duration, utility worker	ED_{ut}	years	1	DTSC HERD (2005) Assumption is 1 month at 20 d/month, therefore ED = 1
Exposure frequency, residential child	EF_c	d/year	350	OEHHA (2005)
Exposure frequency, residential adult	EF_a	d/year	350	OEHHA (2005)
Exposure frequency, commercial/industrial	$EF_{c/i}$	d/year	250	OEHHA (2005)
Exposure frequency, utility worker	EF_{ut}	d/year	20	DTSC HERD (2005), assumption is 1 month at 20 d/month
Soil ingestion rate, residential child	IRS_c	mg/d	200	OEHHA (2005)
Soil ingestion rate, residential adult	IRS_a	mg/d	100	OEHHA (2005)
Soil ingestion rate, commercial/industrial	$IRS_{c/i}$	mg/d	100	OEHHA (2005)
Soil ingestion rate, utility worker	IRS_{ut}	mg/d	330	DTSC HERD (2005)
Soil to skin adherence factor, residential child	AF_c	mg/cm^2	0.2	OEHHA (2005)
Soil to skin adherence factor, residential adult	AF_a	mg/cm^2	0.07	DTSC HERD (2005)
Soil to skin adherence factor, commercial/industrial	$AF_{c/i}$	mg/cm^2	0.2	OEHHA (2005)
Soil to skin adherence factor, utility worker	AF_{ut}	mg/cm^2	0.8	DTSC HERD (2005)
Skin surface area exposed to soil, residential child	SAS_c	cm^2	2800	OEHHA (2005)
Skin surface area exposed to soil, residential adult	SAS_a	cm^2	5700	DTSC HERD (2005)
Skin surface area exposed to soil, commercial/industrial	$SAS_{c/i}$	cm^2	5700	DTSC HERD (2005)
Skin surface area exposed to soil, utility worker	SAS_{ut}	cm^2	5700	DTSC HERD (2005)
Inhalation rate, residential child	$InhR_c$	m^3/day	10	OEHHA (2005)
Inhalation rate, residential adult	$InhR_a$	m^3/day	20	OEHHA (2005)

Parameter	Variable Name	Units	Value	Reference
Inhalation rate, commercial/industrial	$InhR_{c/i}$	m^3/day	14	OEHHA (2005)
Inhalation rate, utility worker	$InhR_{ut}$	m^3/day	20	DTSC HERD (2005)
Averaging time for vapor flux	*tau*	sec	See reference	ASTM (1996) - equals exposure duration in seconds
Particulate emission factor, residential and commercial/industrial	PEF_a	m^3/kg	1.3×10^9	OEHHA (2005)
Particulate emission factor, utility worker	PEF_{ut}	m^3/kg	1.0×10^6	DTSC HERD (2005)
Dermal absorption factor from soils	ABS_d	unitless	See Table 7	
Oral cancer slope factor	SF_o	unitless	See Table 7	
Inhalation cancer slope factor	SF_i	unitless	See Table 7	
Oral reference dose	RfD_o	unitless	See Table 7	
Inhalation reference dose	RfD_i	unitless	See Table 7	
Target hazard quotient	*THQ*	unitless	1	OEHHA (2005)
Target individual excess lifetime cancer risk	*TR*	unitless	1×10^{-6}	OEHHA (2005)

References:

ASTM (1996). American Society for Testing and Materials, Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites, ASTM E1739-95, Philadelphia, PA.

DTSC HERD (2005). Department of Toxic Substances Control, Human and Ecological Risk Division (HERD). Human Health Risk Assessment (HHRA) Note Number 1. Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Military Facilities.

OEHHA (2005). Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil, Integrated Risk Assessment Branch, Office of Environmental Health Hazard Assessment. (Cal/EPA).

USEPA. **1989**. Risk Assessment Guide for Superfund (RAGS) Volume I Human Health Evaluation Manual (Part A) EPA/540/1-89/002, Office of Emergency and Remedial Response. December 1989.

Table 5: Equations Used to Estimate Volatilization and Particulate Emission Factors

Volatilization and Particulate Emission Factors

Effective Diffusion Coefficient (D_{eff})

$$D_{eff} = D_{air}\left(\frac{\theta_a^{10/3}}{\theta_T^{2}}\right) + D_{water}\,\frac{1}{H}\left(\frac{\theta_W^{10/3}}{\theta_T^{2}}\right)$$

Volatilization Factor (VF)

Infinite source:

$$VF\left[\frac{(mg/m^3-air)}{(mg/kg-soil)}\right] = \frac{2\cdot W\cdot \rho_b}{U_{air}\cdot \delta_{air}}\sqrt{\frac{D_{eff}\cdot H}{\pi(\theta_w + FOC\cdot K_{oc}\cdot \rho_b + H\cdot \theta_a)tau}}\times 10^3\,\frac{cm^3kg}{m^3g}$$

Mass-balance considered:

$$VF\left[\frac{(mg/m^3-air)}{(mg/kg-soil)}\right] = \frac{W\cdot \rho_b\cdot d}{U_{air}\cdot \delta_{air}\cdot tau}\times 10^3\,\frac{cm^3kg}{m^3g}$$

Calculate VF using both equations, then use the lower of the two values.

VF_r : Use $tau = tau_c + tau_r$

$VF_{c/i}$: Use $tau = tau_{c/i}$

VF_{ut} : Use $tau = tau_{ut}$

Table 6: Default Volatilization and Soil-Specific Parameters

Parameter	Variable Name	Units	Value	Reference
Fraction organic carbon in soil	*FOC*	g OC/g soil	0.01	ASTM (1996)
Thickness of impacted soil	*D*	cm	305	ASTM (1996) (10 feet)
Wind speed in outdoor air mixing zone	U_{air}	cm/s	225	ASTM (1996)
Width of source area parallel to wind, or groundwater flow direction	*W*	cm	1500	ASTM (1996)
Outdoor air mixing zone height	δ_{air}	cm	200	ASTM (1996)
Volumetric air content in vadose-zone soils	Θ_A	$(cm^3)/(cm^3)$	0.26	ASTM (1996)
Total soil porosity	θ_T	$(cm^3)/(cm^3)$	0.38	ASTM (1996)
Volumetric water content in vadose-zone soils	Θ_W	$(cm^3)/(cm^3)$	0.12	ASTM (1996)
Soil bulk density	ρ_b	g/cm^3	1.7	ASTM (1996)
Averaging time for vapor flux, residential adult	tau_r	s	7.57E8	ASTM (1996) = ED_r in sec
Averaging time for vapor flux, residential child	tau_c	s	1.89E8	ASTM (1996) = ED_c in sec
Averaging time for vapor flux, commercial/industrial	$tau_{c/i}$	s	7.88E8	ASTM (1996) = $ED_{c/i}$ in sec
Averaging time for vapor flux, utility worker	tau_{ut}	s	3.15E7	ASTM (1996) = ED_{ut} in sec
Effective diffusion coefficient in soil	D_{eff}	cm^2/s	Chem. specific	calculated
Diffusion coefficient in air	D_{air}	cm^2/s	Chem. specific	See Table 7.
Diffusion coefficient in water	D_{water}	cm^2/s	Chem. specific	See Table 7.
Organic carbon-water sorption coefficient	K_{oc}	mL/g	Chem. specific	See Table 7.
Henry's Law coefficient	*H*	-	Chem. specific	See Table 7.

References:

ASTM. 1996. Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites, ASTM E1739-95, Philadelphia, PA.

Table 7: Chemical Parameter Values

Chemical Parameters[1]	Units	Benzene	Naphthalene	PAH[1]	Reference
Henry's Law constant	-	0.23	0.018	1.9E-5	SF RWQCB ESLs
Organic carbon partition coefficient	mL/g	58.9	1500	5.9E+6	SF RWQCB ESLs
Diffusion coefficient in air	cm^2/s	0.090	0.060	ND	SF RWQCB ESLs
Diffusion coefficient in water	cm^2/s	9.8E-6	8.4E-6	ND	SF RWQCB ESLs
Toxicity Parameters					
Oral slope factor (SF_o)	1/(mg/kg-d)	0.1	ND	12	OEHHA (2009)
Inhalation slope factor (SF_i)	1/(mg/kg-d)	0.1	0.12	3.9	OEHHA (2009)
Oral reference dose (RfD_o)	mg/kg-d	0.004	0.020	0.030	SF RWQCB ESLs
Inhalation reference dose (RfD_i)	mg/kg-d	0.0086	8.6E-4	0.030	SF RWQCB ESLs
Dermal absorption factor from soil	-	ND	0.13	0.13	SF RWQCB ESLs

ND = No Data

SF RWQCB ESLs. Regional Water Quality Control Board (RWQCB) Region 2 – San Francisco. 2008. Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Interim Final. May

OEHHA (2009). OEHHA Cancer Potency Values as of July 21, 2009.

[1] The chemical properties for benzo(a)pyrene were used as a surrogate in developing screening levels for the "PAH" group.

Table 8: Soil Screening Levels

Depth (feet)	Benzene (mg/kg)	Naphthalene (mg/kg)	PAH (mg/kg)
0 to 5	2.3	13	0.038
5 to 10	100	1500	7.5

*Notes: Based on the seven carcinogenic PAHs as benzo(a)pyrene toxicity equivalent [BaPe].
The PAH screening level is only applicable where soil is affected by either waste oil and/or Bunker C fuel.

Table 9: Summary of Soil Screening Levels for Each Receptor

Chemical	Residential mg/kg	Commercial/ Industrial mg/kg	Utility mg/kg	Subsurface Soil -- Volatilization only (for 5 to 10' bgs) Residential Scenario mg/kg
Benzene	2.3	120	100	130
Naphthalene	13	45	1500	33,000
PAH	0.038	2.3	7.5	1×10^6

FIGURES

Figure 1. Conceptual Site Model for the Soil Screening Levels.

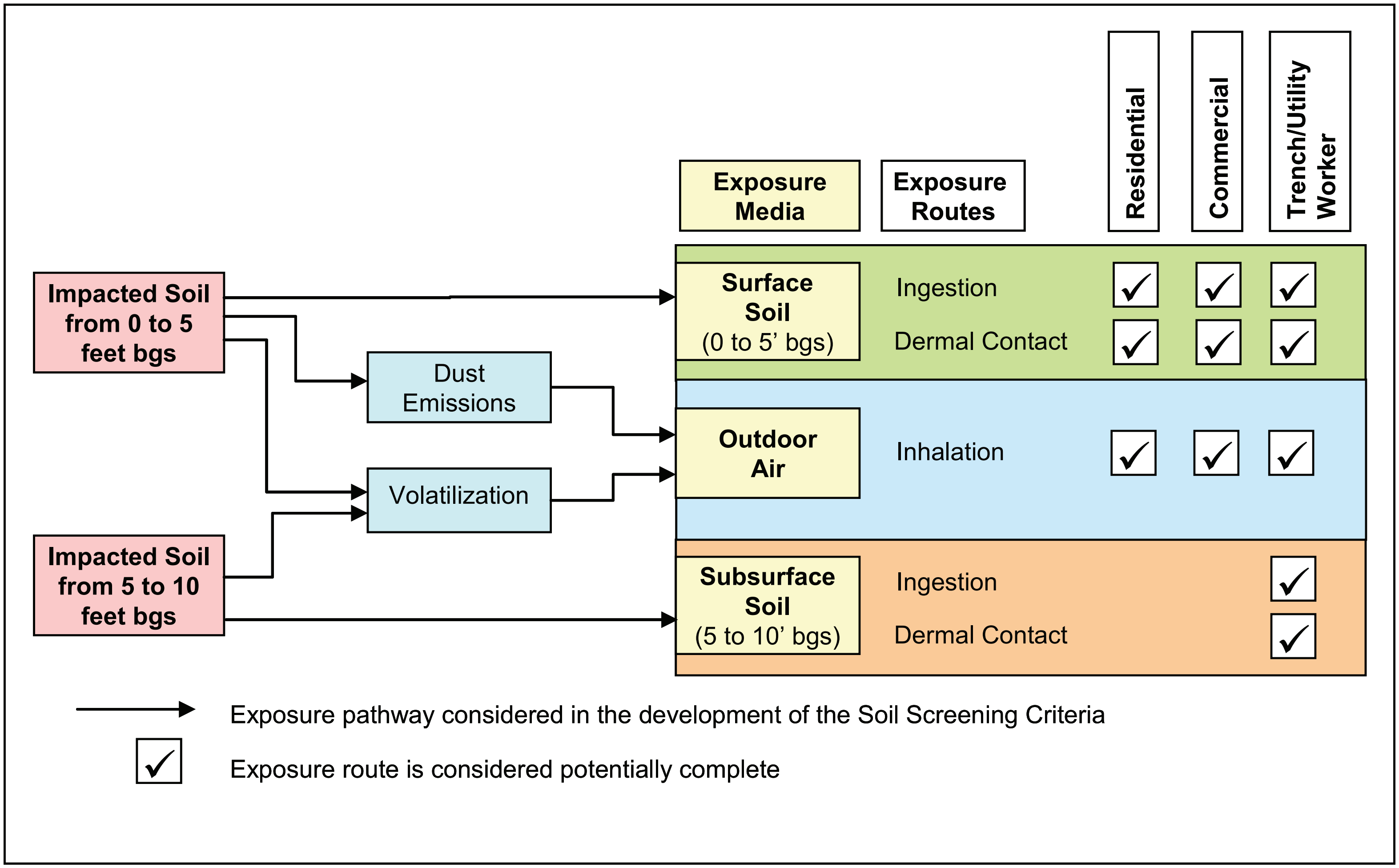

Figure 2. Schematic for the ASTM Volatilization Factor.