

Attachment 7

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

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. 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 developed for benzene, ethylbenzene, naphthalene, and polyaromatic hydrocarbon (PAH) to define sites that are low-threat with respect to “direct contact” with soil and inhalation of soil emissions. 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.

Standard USEPA risk assessment equations were used to derive the screening levels. The exposure parameter values, chemical toxicity values, and chemical fate and transport properties are based on standard values used in California.

Two sets of screening levels were 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 soil screening levels. Three exposure scenarios (residential, commercial/industrial and utility trench scenario) 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 (OEHHA 2010). This is a conservative assumption because the few PAHs that are more carcinogenic than benzo(a)pyrene are not found in petroleum mixtures.

2 INTRODUCTION

The equations used to develop the Soil Screening Levels came from the USEPA Regional Screening Levels (RSLs; USEPA 2011). Exposure parameters values were assumed to equal the defaults values used in

California Department of Toxic Substances (DTSC) Office of Human and Ecological Risk (HERO) "Human Health Risk Assessment (HHRA) Note Number 1" (DTSC 2011). The Soil Screening Levels presented in this document are conservative because the assumptions used to calculate the values are based on conservative assumptions and exposure scenarios.

The volatilization factor used in the RSLs was replaced with a volatilization factor obtained from the American Society of Testing Material's (ASTM's) Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM 1995). 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 overestimate the amount of contaminant volatilizing into outdoor air for volatile chemicals (Cal/EPA, 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 simple mass-balance check, it is ensured that the total amount volatilized does not exceed the total amount of contaminant in soil.

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. This assumption is very conservative for volatile chemicals or chemicals expected to biodegrade in soil such as benzene, ethylbenzene and naphthalene.

2.1 Screening Levels vs. Risk

The Soil Screening Levels represent concentrations, below which, indicate 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 that exceed 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.

2.2 Chemicals Considered

The Soil Screening Levels were developed for benzene, ethylbenzene, naphthalene and PAHs. Total petroleum hydrocarbons (TPH) were not considered separately as chemicals of concern. The stakeholders chose not to include TPH in policy for the following reasons:

- TPH consists of a mixture of more than 2000 chemicals.

- Once in the soil, the TPH starts weathering immediately changing its composition through time and from one site to the next.
- Bulk TPH measurements, such as those obtained by analytical method 8015M, are not suitable for risk assessment because they do not provide information about the composition of the TPH with respect to chemical toxicity and fate and transport properties.
- None of the regulatory agencies in California that are responsible for requiring risk assessment have an approved analytical method for evaluating TPH for purposes of risk assessment (such as a fractionation method). In fact, most analytical labs in California are not familiar with TPH fractionation.
- Benzene, ethylbenzene and naphthalene more accurately capture the risk that TPH poses for human health concerns.

2.2 Requirements for Using Screening Levels

There is only one “model” used in calculation of the Screening Levels. This model assumes the following:

- The area of impacted soil is 25 m by 25 m (approximately 82 by 82 feet) or less. If the area of impacted soil is larger than this, then a site-specific analysis of direct contact risk may be warranted.
- The receptor is always located at the downgradient edge for purposes of inhalation calculations. For residential exposures, it is assumed that the receptor is located on site for 24 hours/day for the entire exposure duration. For industrial and utility workers, it is assumed that the worker is located onsite for 8 hours/day.
- The wind speed is assumed to equal 2.25 m/s on average. If the average wind speed is much lower, then a site-specific analysis of direct contact risk may be warranted.
- The default input parameters for all of the exposure scenarios were obtained from DTSC defaults for California hazardous waste sites. If the exposure scenario at the site varies from these assumptions (that is, it is more conservative), then a site-specific risk analysis may be warranted.

3 CONCEPTUAL SITE MODEL

This section describes the exposure scenarios and receptors considered in the development of the Soil Screening Levels. Screening levels were developed for two different soil horizons. A schematic of the conceptual site model for these two soil horizons is shown in Figure 1.

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. Note, for benzo(a)pyrene (PAHs), the mutagenic exposure equations are used for calculating the screening level. In this case, the early life exposures (i.e., 0 to 2 years, 2 to 6 years and 6 to 16 years) are weighted more than they are in the non-mutagenic equations (see Table 1). 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 (i.e., coming into contact with soil below 5 feet below ground surface). 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 (1 year); however, the chemical intake per day is assumed to 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 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 inhalation of 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 and particulate emissions.

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 USEPA RSLs were used for everything except the volatilization term. 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, for each of the three receptors, and the variable definitions are shown in Table 4. Note, the USEPA considers the carcinogenic PAHs to be “mutagens” and as such has unique equations to calculate the screening levels. The mutagenic equations are for “early life exposures” and therefore only apply to the residential scenario.

4.1.2 Volatilization Factor

The volatilization factor (VF) used to predict outdoor air concentrations due to volatilization from the soil is based on the ASTM guidance (1995). The assumptions in the ASTM volatilization factor algorithm (ASTM 1995) 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 2. Note the assumed receptor location at the edge of the downwind side of the source (for 24 hours/day for the entire exposure duration for a resident) 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, upward vertical dispersion (i.e., dilution), as the air blows towards the receptor, is not considered by the model. This is one exposure scenario where the situation assumed in the risk calculations would be

impossible to achieve in a real exposure scenario because the algorithm used to estimate the risk from the volatile emissions is very conservative.

The ASTM VF is actually composed of two equations as 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. It is assumed that the length and width of the source are 25 m each (approximately 82 feet by 82 feet). The thickness of impacted soil is assumed to equal 3.05 m (10 feet).

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 1.3×10^9 [(mg/kg)/(mg/m³)] (DTSC 2011). For the utility trench (construction) worker, a PEF value of 1×10^6 [(mg/kg)/(mg/m³)] was used (DTSC 2011).

4.2 Exposure Parameter Values Used

All of the default exposure parameters for the receptors were obtained from DTSC's "Human Health Risk Assessment (HHRA) Note Number 1" (DTSC 2011). Table 4 shows the default values used for each parameter and provides the reference document where each parameter 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, especially for volatile chemicals in the top few feet of soil, where most of the direct contact would occur. Benzene, ethylbenzene and naphthalene are 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. Note, USEPA assumes that benzene, ethylbenzene, and naphthalene will not be on the skin long enough (due to volatilization) to absorb through the skin, therefore dermal uptake for these chemicals is not calculated.

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.

4.3 Chemical Parameter and Toxicity Values Used

The default chemical parameter values came from the RWQCB 2 Environmental Screening Levels (2007). The toxicity values for non-carcinogenic toxicity came from USEPA's On-line Risk Information System (IRIS, 2011). The carcinogenic toxicity values for benzene, ethylbenzene, and naphthalene came from OEHHA's list of cancer potency factors (OEHHA 2009). The carcinogenic oral slope factor for benzo(a)pyrene came from OEHHA's Public Health Goals for Chemicals in Drinking Water for Benzo(a)pyrene (OEHHA 2010).

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)	Ethylbenzene (mg/kg)	Naphthalene (mg/kg)	PAH* (mg/kg)
0 to 5	1.9	21	9.7	0.063
5 to 10	2.8	32	9.7	4.6

*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.

Note, the screening levels for naphthalene are the same for the top 5 feet as the 5 to 10 foot depth. This is because naphthalene has carcinogenic toxicity for the inhalation pathway and not for the oral (and dermal pathways). The carcinogenic mode of action was the driver (i.e., the carcinogenic screening levels were less than the non-carcinogenic screening levels) and the inhalation pathway was the limiting pathway for both soil horizons.

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 8.

Table 9: Summary of Soil Screening Levels for Each Receptor

Chemical	Residential		Commercial/ Industrial		Utility Worker
	0 to 5 feet bgs mg/kg	Volatilization to outdoor air (5 to 10 feet bgs) mg/kg	0 to 5 feet bgs mg/kg	Volatilization to outdoor air (5 to 10 feet bgs) mg/kg	0 to 10 feet bgs mg/kg
Benzene	1.9	2.8	28	810	180
Ethylbenzene	21	32	250	9,400	1,800
Naphthalene	9.7	9.7	3,100	3,100	2,200
PAH	0.063	190	0.68	160,000	4.6

As can be seen by comparing tables 8 and 9, the volatilization to outdoor air for the residential scenario was the limiting pathway for all of the chemicals except PAH. For PAH, the utility worker screening level (4.6 mg/kg) was the limiting screening level for the 5 to 10 feet below ground surface.

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 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 USEPA in the development of the RSLs, with the exception of the volatilization rate. A volatilization rate term from ASTM was substituted for the RSL volatilization term so that mass balance could be considered in the volatilization term (only).

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.) (OEHHA 2005).

7 REFERENCES

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TABLES

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

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Carcinogenic – Residential
<p>Incidental ingestion of soil,</p> $SL_{\text{res-sol-ca-ing}} = \frac{TR \times AT_{\text{Carc}} \times 365 \text{ d/yr}}{SF_o \times EF_r \times IFS_{\text{adj}} \times 1\text{E}-6 \text{ kg/mg}}$ <p>where</p> $IFS_{\text{adj}} = \left[\frac{ED_c \times IRS_c}{BW_c} + \frac{ED_a \times IRS_a}{BW_a} \right]$ <p>Inhalation of particulates and volatiles,</p> $SL_{\text{res-sol-ca-inh}} = \frac{TR \times AT_{\text{Carc}} \times 365 \text{ d/yr}}{IUR \times \left(\frac{1000 \text{ ug}}{\text{mg}} \right) \times EF_r \times \left(VF_r + \frac{1}{PEF_r} \right) \times (ED_c + ED_a) \times ET_r \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right)}$ <p>Dermal Contact with soil,</p> $SL_{\text{res-sol-ca-der}} = \frac{TR \times AT_{\text{Carc}} \times 365 \text{ d/yr}}{\frac{SF_o}{GIABS} \times EF_r \times DFS_{\text{adj}} \times ABS_d \times 1\text{E}-6 \text{ kg/mg}}$ <p>where</p> $DFS_{\text{adj}} = \left[\frac{ED_c \times SAS_c \times AF_c}{BW_c} + \frac{ED_a \times SAS_a \times AF_a}{BW_a} \right]$ <p>Total</p> $C_{\text{res-sol-ca-tot}} = \frac{1}{\frac{1}{SL_{\text{res-sol-ca-ing}}} + \frac{1}{SL_{\text{res-sol-ca-inh}}} + \frac{1}{SL_{\text{res-sol-ca-der}}}}$

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

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Noncarcinogenic (Hazard) – Residential
<p>Incidental ingestion of soil</p> $C_{res-sol-nc-ing} = \frac{THQ \times BW_c \times ED_c \times 365 \text{ d/yr}}{EF_r \times ED_c \times \frac{1}{RfD_o} \times IRS_c \times \frac{1E-6 \text{ kg}}{\text{mg}}}$
<p>Inhalation of particulates and volatiles,</p> $C_{res-sol-nc-inh} = \frac{THQ \times ED_c \times 365 \text{ d/yr}}{EF_r \times ED_c \times ET_r \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1}{RfC} \left(VF_r + \frac{1}{PEF_r} \right)}$
<p>Dermal contact with soil,</p> $C_{res-sol-nc-der} = \frac{THQ \times BW_c \times ED_c \times 365 \text{ d/yr}}{EF_r \times ED_c \times \left(\frac{1}{RfD_o \times GIABS} \right) \times SAS_c \times AF_c \times ABS_d \times \frac{1E-6 \text{ kg}}{\text{mg}}}$
<p>Total</p> $C_{res-sol-nc-tot} = \frac{1}{\frac{1}{SL_{res-sol-nc-ing}} + \frac{1}{SL_{res-sol-nc-inh}} + \frac{1}{SL_{res-sol-nc-der}}}$

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

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Carcinogenic – Mutagenic	
Incidental ingestion of soil,	
$SL_{res-sol-mu-ing} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{SF_o \times EF_r \times IFSM_{adj} \times 1E-6 \text{ kg/mg}}$	
where	
$IFSM_{adj} = \frac{ED_{0-2} \text{ (years)} \times IRS_c \times 10}{BW_c} + \frac{ED_{2-6} \text{ (years)} \times IRS_c \times 3}{BW_c} + \frac{ED_{6-16} \text{ (years)} \times IRS_a \times 3}{BW_a} + \frac{ED_{16-30} \text{ (years)} \times IRS_a \times 1}{BW_a}$	
Inhalation of particulates and volatiles,	
$SL_{res-sol-mu-inh} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{IUR \times \left(\frac{1000 \text{ ug}}{\text{mg}} \right) \times EF_r \times \left(VF_{s-r} + \frac{1}{PEF_r} \right) \times ET_r \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \left(ED_{0-2} \text{ (years)} \times 10 + ED_{2-6} \text{ (years)} \times 3 + ED_{6-16} \text{ (years)} \times 3 + ED_{16-30} \text{ (years)} \times 1 \right)}$	
Dermal Contact with soil,	
$SL_{res-sol-mu-der} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{\frac{SF_o}{GIABS} \times EF_r \times DFSM_{adj} \times ABS_d \times 1E-6 \text{ kg/mg}}$	
where	
$DFSM_{adj} = \left[\frac{ED_{0-2} \text{ (years)} \times SAS_c \times AF_c \times 10}{BW_c} + \frac{ED_{2-6} \text{ (years)} \times SAS_c \times AF_c \times 3}{BW_c} + \frac{ED_{6-16} \text{ (years)} \times SAS_a \times AF_a \times 3}{BW_a} + \frac{ED_{16-30} \text{ (years)} \times SAS_a \times AF_a \times 1}{BW_a} \right]$	
Total	
$C_{res-sol-mu-tot} = \frac{1}{\frac{1}{SL_{res-sol-mu-ing}} + \frac{1}{SL_{res-sol-mu-inh}} + \frac{1}{SL_{res-sol-mu-der}}}$	

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)	
Incidental ingestion of soil,	
$SL_{c/i-sol-ca-ing} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{SF_o \times EF_{c/i} \times ED_{c/i} \times IRS_{c/i} \times 1E-6 \text{ kg/mg}}$	
Inhalation of particulates and volatiles,	
$SL_{c/i-sol-ca-inh} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{IUR \times \left(\frac{1000 \text{ ug}}{\text{mg}} \right) \times EF_{c/i} \times \left(VF_{c/i} + \frac{1}{PEF_{c/i}} \right) \times ED_{c/i} \times ET_{c/i} \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right)}$	
Dermal Contact with soil,	
$SL_{c/i-sol-ca-der} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{\frac{SF_o}{GIABS} \times EF_{c/i} \times ED_{c/i} \times SAS_{c/i} \times AF_{c/i} \times ABS_d \times 1E-6 \text{ kg/mg}}$	
Total	
$C_{c/i-sol-ca-tot} = \frac{1}{\frac{1}{SL_{c/i-sol-ca-ing}} + \frac{1}{SL_{c/i-sol-ca-inh}} + \frac{1}{SL_{c/i-sol-ca-der}}}$	
Noncarcinogenic – Commercial/Industrial	
Incidental ingestion of soil	
$C_{c/i-sol-nc-ing} = \frac{THQ \times BW_{c/i} \times ED_{c/i} \times 365 \text{ d/yr}}{EF_{c/i} \times ED_{c/i} \times \frac{1}{RfD_o} \times IRS_{c/i} \times \frac{1E-6 \text{ kg}}{\text{mg}}}$	
Inhalation of particulates and volatiles,	
$C_{c/i-sol-nc-inh} = \frac{THQ \times ED_{c/i} \times 365 \text{ d/yr}}{EF_{c/i} \times ED_{c/i} \times ET_{c/i} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1}{RfC} \left(VF_{c/i} + \frac{1}{PEF_{c/i}} \right)}$	
Dermal contact with soil,	
$C_{c/i-sol-nc-der} = \frac{THQ \times BW_{c/i} \times ED_{c/i} \times 365 \text{ d/yr}}{EF_{c/i} \times ED_{c/i} \times \frac{1}{RfD_o \times GIABS} \times SAS_{c/i} \times AF_{c/i} \times ABS_d \times \frac{1E-6 \text{ kg}}{\text{mg}}}$	
Total	
$C_{c/i-sol-nc-tot} = \frac{1}{\frac{1}{SL_{c/i-sol-nc-ing}} + \frac{1}{SL_{c/i-sol-nc-inh}} + \frac{1}{SL_{c/i-sol-nc-der}}}$	

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)	
Incidental ingestion of soil,	
$SL_{ut-sol-ca-ing} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{SF_o \times EF_{ut} \times ED_{ut} \times IRS_{ut} \times 1E-6 \text{ kg/mg}}$	
Inhalation of particulates and volatiles,	
$SL_{ut-sol-ca-inh} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{IUR \times \left(\frac{1000 \text{ ug}}{\text{mg}}\right) \times EF_{ut} \times \left(VF_{ut} + \frac{1}{PEF_{ut}}\right) \times ED_{ut} \times ET_{ut} \times \left(\frac{1 \text{ day}}{24 \text{ hours}}\right)}$	
Dermal Contact with soil,	
$SL_{ut-sol-ca-der} = \frac{TR \times AT_{Carc} \times 365 \text{ d/yr}}{\frac{SF_o}{GIABS} \times EF_{ut} \times ED_{ut} \times SAS_{ut} \times AF_{ut} \times ABS_d \times 1E-6 \text{ kg/mg}}$	
Total	
$C_{ut-sol-ca-tot} = \frac{1}{\frac{1}{SL_{ut-sol-ca-ing}} + \frac{1}{SL_{ut-sol-ca-inh}} + \frac{1}{SL_{ut-sol-ca-der}}}$	
Noncarcinogenic – Utility Trench Worker	
Incidental ingestion of soil	
$C_{ut-sol-nc-ing} = \frac{THQ \times BW_{ut} \times ED_{ut} \times 365 \text{ d/yr}}{EF_{ut} \times ED_{ut} \times \frac{1}{RfD_o} \times IRS_{ut} \times \frac{1E-6 \text{ kg}}{\text{mg}}}$	
Inhalation of particulates and volatiles,	
$C_{ut-sol-nc-inh} = \frac{THQ \times ED_{ut} \times 365 \text{ d/yr}}{EF_{ut} \times ED_{ut} \times ET_{ut} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1}{RfC} \left(VF_{ut} + \frac{1}{PEF_{ut}}\right)}$	
Dermal contact with soil,	
$C_{ut-sol-nc-der} = \frac{THQ \times BW_{ut} \times ED_{ut} \times 365 \text{ d/yr}}{EF_{ut} \times ED_{ut} \times \left(\frac{1}{RfD_o} \times GIABS\right) \times SAS_{ut} \times AF_{ut} \times ABS_d \times \frac{1E-6 \text{ kg}}{\text{mg}}}$	
Total	
$C_{ut-sol-nc-tot} = \frac{1}{\frac{1}{SL_{ut-sol-nc-ing}} + \frac{1}{SL_{ut-sol-nc-inh}} + \frac{1}{SL_{ut-sol-nc-der}}}$	

Table 4: Default Exposure Parameters (continued)

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	DTSC HERO (2011)
Body weight, residential adult	BW_a	kg	70	DTSC HERO (2011)
Body weight, commercial/industrial	$BW_{c/i}$	kg	70	DTSC HERO (2011)
Body weight, utility worker	BW_{ut}	kg	70	DTSC HERO (2011)
Exposure duration, residential child	ED_c	years	6	DTSC HERO (2011)
Exposure duration, residential adult	ED_a	years	24	DTSC HERO (2011)
Exposure duration, commercial/industrial	$ED_{c/i}$	years	25	DTSC HERO (2011)
Exposure duration, utility worker	ED_{ut}	years	1	DTSC HERO (2011)
Exposure frequency, residential	EF_r	d/year	350	DTSC HERO (2011)
Exposure frequency, commercial/industrial	$EF_{c/i}$	d/year	250	DTSC HERO (2011)
Exposure frequency, utility worker	EF_{ut}	d/year	250	DTSC HERO (2011)
Exposure time for outdoor air, residential	ET_r	hours/day	24	DTSC HERO (2011)
Exposure time for outdoor air, commercial/industrial	$ET_{c/i}$	hours/day	8	DTSC HERO (2011)
Exposure time for outdoor air, utility worker	ET_{ut}	hours/day	8	DTSC HERO (2011)
Soil ingestion rate, residential child	IRS_c	mg/d	200	DTSC HERO (2011)
Soil ingestion rate, residential adult	IRS_a	mg/d	100	DTSC HERO (2011)
Soil ingestion rate, commercial/industrial	$IRS_{c/i}$	mg/d	100	DTSC HERO (2011)
Soil ingestion rate, utility worker	IRS_{ut}	mg/d	330	DTSC HERO (2011)
Soil to skin adherence factor, residential child	AF_c	mg/cm ²	0.2	DTSC HERO (2011)
Soil to skin adherence factor, residential adult	AF_a	mg/cm ²	0.07	DTSC HERO (2011)
Soil to skin adherence factor, commercial/industrial	$AF_{c/i}$	mg/cm ²	0.2	DTSC HERO (2011)
Soil to skin adherence factor, utility worker	AF_{ut}	mg/cm ²	0.8	DTSC HERO (2011)
Skin surface area exposed to soil, residential child	SAS_c	cm ²	2900	DTSC HERO (2011)
Skin surface area exposed to soil, residential adult	SAS_a	cm ²	5700	DTSC HERO (2011)
Skin surface area exposed to soil, commercial/industrial	$SAS_{c/i}$	cm ²	5700	DTSC HERO (2011)
Skin surface area exposed to soil, utility worker	SAS_{ut}	cm ²	5700	DTSC HERO (2011)

Table 4: Default Exposure Parameters (concluded)

Parameter	Variable Name	Units	Value	Reference
Particulate emission factor, residential	PEF_r	m ³ /kg	1.3 x 10 ⁹	DTSC HERO (2011)
Particulate emission factor, commercial/industrial	$PEF_{c/i}$	m ³ /kg	1.3 x 10 ⁹	DTSC HERO (2011)
Particulate emission factor, utility worker	PEF_{ut}	m ³ /kg	1.0 x 10 ⁶	DTSC HERO (2011)
Dermal absorption factor from soils	ABS_d	unitless	See Table 7	
Gastrointestinal absorption factor	$GIABS$	unitless	See Table 7	
Oral cancer slope factor	SF_o	1/(mg/kg-d)	See Table 7	
Inhalation Unit Risk	IUR	1/(ug/m ³)	See Table 7	
Oral reference dose	RfD_o	mg/kg-d	See Table 7	
Inhalation reference dose	RfC	mg/m ³	See Table 7	
Target hazard quotient	THQ	unitless	1	OEHHA (2005)
Target individual excess lifetime cancer risk	TR	unitless	1 x 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 HERO (2010). Department of Toxic Substances Control, Office of Human and Ecological Risk (HERO). Human Health Risk Assessment (HHRA) Note Number 1. Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Hazardous Waste Sites and Permitted Facilities. May 20, 2011

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:

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

Mass-balance considered:

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

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	2500	ASTM (1996)
Outdoor air mixing zone height	δ_{air}	cm	200	ASTM (1996)
Volumetric air content in vadose-zone soils	θ_A	(cm ³ air)/(cm ³ soil)	0.26	ASTM (1996)
Total soil porosity	θ_T	(cm ³ voids)/(cm ³ soil)	0.38	ASTM (1996)
Volumetric water content in vadose-zone soils	θ_W	(cm ³ water)/(cm ³ soil)	0.12	ASTM (1996)
Soil bulk density	ρ_b	g/cm ³	1.7	ASTM (1996)
Averaging time for vapor flux, residential adult	τ_{r}	s	7.57E8	ASTM (1996) = ED _r in sec
Averaging time for vapor flux, residential child	τ_{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	τ_{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	(cm ³ water)/(cm ³ air)	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	Units	Benzene	Ethylbenzene	Naphthalene	PAH ¹	Reference
Henry's Law constant	-	0.23	0.32	0.02	2.0E-5	SF RWQCB ESLs
Organic carbon partition coefficient	ml/g	58.9	360	1200	5.5E+6	SF RWQCB ESLs
Diffusion coefficient in air	cm ² /s	0.088	0.075	0.059	ND	SF RWQCB ESLs
Diffusion coefficient in water	cm ² /s	9.8E-6	7.8E-6	7.5E-6	ND	SF RWQCB ESLs
Toxicity Parameters						
Oral slope factor (SF _o)	1/(mg/kg-d)	0.1	0.011	ND	1.7	OEHHA (2009, 2010 – BaP PHG)
Inhalation unit risk (IUR)	1/(ug/m ³)	2.9E-5	2.5E-6	3.4E-5	1.1E-3	OEHHA (2009)
Oral reference dose (RfD _o)	mg/kg-d	0.004	0.1	0.020	ND	USEPA IRIS
Reference concentration (RfC)	mg/m ³	30	1000	3	ND	USEPA IRIS
Dermal absorption factor from soil	-	ND	ND	0.13	0.13	SF RWQCB ESLs
Gastrointestinal absorption factor	-	1	1	1	1	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.

USEPA IRIS. USEPA Integrated Risk Information System on-line database.

¹ The chemical properties for benzo(a)pyrene were used as a surrogate for the "PAH" group.

Table 8: Soil Screening Levels

Depth (feet)	Benzene (mg/kg)	Ethylbenzene (mg/kg)	Naphthalene (mg/kg)	PAH* (mg/kg)
0 to 5	1.9	21	9.7	0.063
5 to 10	2.8	32	9.7	4.6

*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		Commercial/ Industrial		Utility Worker
	0 to 5 feet bgs	Volatilization to outdoor air (5 to 10 feet bgs)	0 to 5 feet bgs	Volatilization to outdoor air (5 to 10 feet bgs)	0 to 10 feet bgs
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Benzene	1.9	2.8	28	810	180
Ethylbenzene	21	32	250	9,400	1,800
Naphthalene	9.7	9.7	3,100	3,100	2,200
PAH	0.063	190	0.68	160,000	4.6

FIGURES

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

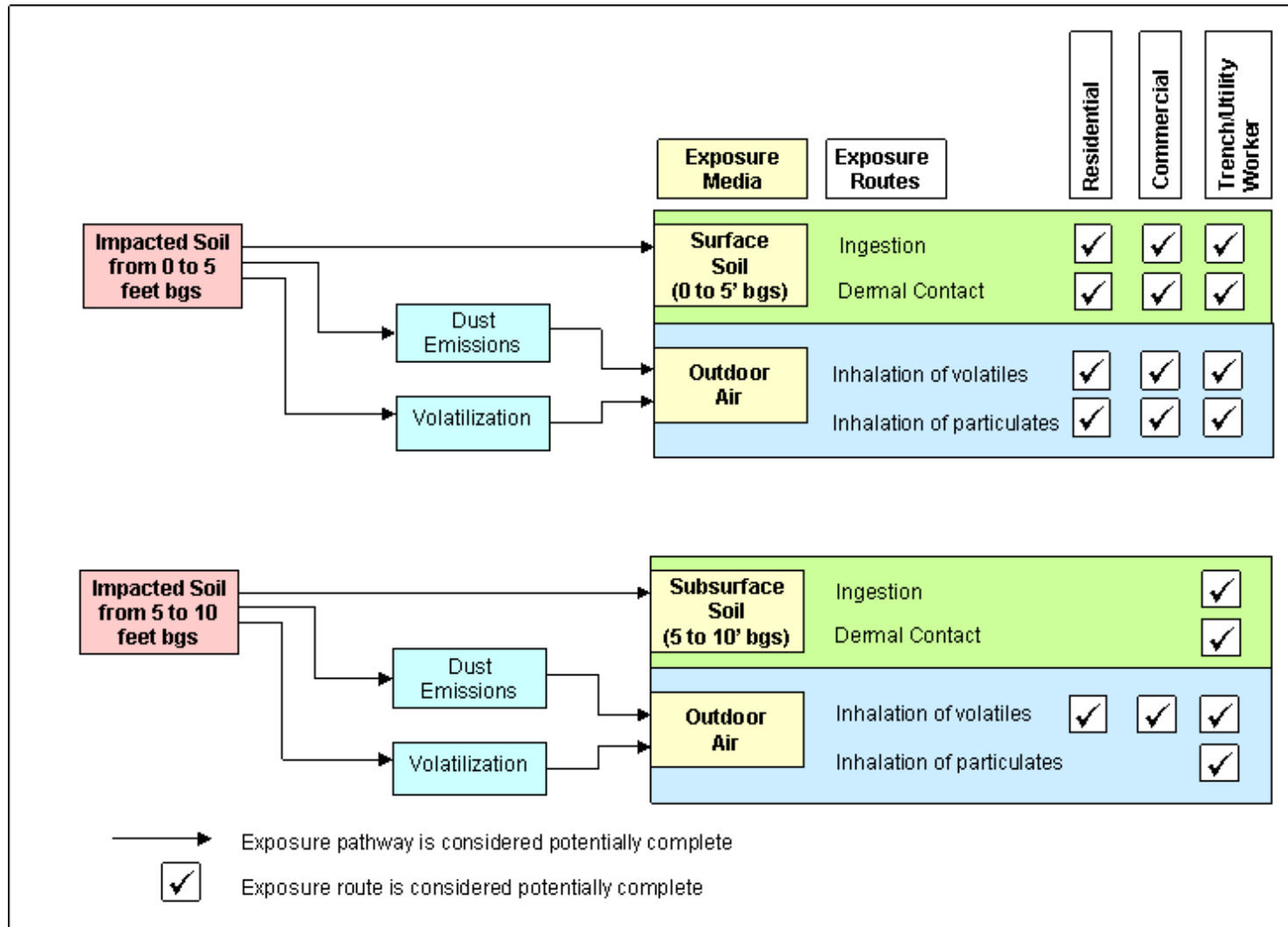


Figure 2. Schematic for the ASTM Volatilization Factor.

