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

(Final 03-15-2012)

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 hydrocarbons (PAHs). The exposure pathways considered in the conceptual site model are: **incidental 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 exposure from all four exposure pathways for each chemical. Standard U.S. EPA 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 default values used in California.

Risks posed by direct exposure to multiple chemicals with similar health effects are considered to be additive or cumulative. For example, the total risk posed by the presence of carcinogenic chemicals is the sum of the theoretical risk posed by each individual chemical. The same is true for chemicals that cause noncarcinogenic health effects. Use of these screening levels for single chemicals is limited to the extent that the screening levels remain protective of human health should other chemicals with similar health effects are present. Assuming all four chemicals are present at the same location and at concentrations at their respective screening levels, the estimated total risk is 4×10^{-6}. For reference, the USEPA National Contingency Plan (NCP) is commonly cited as the basis for acceptable risks in risk management decisions. According to the NCP, an acceptable site-specific lifetime incremental cancer risk falls with the range of 1 in a million (1×10^{-6}) to 100 in a million (1×10^{-4}). Cancer risks below or within the range of 10^{-6} to 10^{-4} are generally considered protective of human health by the USEPA. The estimated total risk for the four chemicals considered in this document (4×10^{-6}) falls within this range.

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[1] and three exposure scenarios (residential,

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[1] There are several definitions of what constitutes surface soil ("near" surface soil is typically the top 6 inches of soil) to quantify potential exposures in health risk assessments. Surface soil can be defined as soil to a depth of 2 feet below ground surface

commercial/industrial, and a utility trench worker) were considered. This document describes the technical background for the development of the soil screening levels.

2 INTRODUCTION

The equations used to develop the soil screening levels are identical to the equations used to derive the USEPA's Regional Screening Levels (RSLs; USEPA 2011). Exposure parameter values were assumed to equal the default 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 sufficiently protective because the assumptions used to calculate the values are based on conservative assumptions and exposures.

The volatilization factor used in the RSLs was replaced with volatilization factors 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 factors used to calculate concentrations in outdoor air consider mass balance. The volatilization algorithm used in the RSLs can overestimate the amount of contaminant volatilizing into outdoor air (Cal/EPA, 2005). In the ASTM volatilization algorithm[2], if the calculated volatilization rate depletes the source before the end of the exposure duration, 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.

For incidental ingestion of soil, dermal contact with soil, and inhalation of dust, the concentration in soil is assumed to be constant at the screening level for the entire exposure duration. This assumption is conservative for volatile chemicals or chemicals that are expected to biodegrade in soil, such as benzene and ethylbenzene.

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. 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, a residential receptor is assumed to come into contact with soil at concentrations

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or as indicated in the supporting documentation for the CHHSLs and ESLs, a depth of approximately 10 feet is generally used to delineate between shallow soil, where a potential exists for regular direct contact, and deep soil where only periodic exposure is considered likely.

[2] The ASTM VF differs from the approach used by USEPA in the development of the RSLs. The VF used to calculate the RSLs assumes infinite sources over a large source area for the dispersion term. The ASTM VF algorithm is considered more appropriate for leaking underground fuel tank (LUFT) sites. Further details on the differences are presented in the Draft California LUFT Guidance Manual, version 2.0, 2010).

equivalent to the screening level every day (350 days/year) for a total of 30 years. While most residential exposures would not occur at the default levels used to derive these screening levels, the defaults are designed to be protective for this hypothetical scenario.

Note that 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

Risk-based soil screening levels were developed for benzene, ethylbenzene, naphthalene and PAHs. These constituents are considered the primary risk-driving compounds at petroleum-impacted sites.

Total petroleum hydrocarbons (TPH) were not considered as a chemical 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 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 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.

Methyl tert-butyl ether (MTBE) was not considered as a chemical of concern for the following reasons:[3]

> *For benzene, the USEPA RSL in soil for residential land use is 1.1 mg/kg, which is approximately 1,650-times lower than its soil saturation concentration. For MTBE, the residential soil RSL is 43 mg/kg, which is about 200-times lower than its soil saturation concentration. Even though the MTBE content of gasoline may be 10- to 15-times that of benzene, potential risks from direct contact with soil will still be driven by benzene, which is about 60-times more toxic than MTBE. Currently, USEPA does not evaluate MTBE as a potential human carcinogen. The State of California has developed a cancer slope factor for MTBE based on a combination of data from two animal studies, one study by the inhalation route and the other study by the oral route. Numerous*

[3] Written communication with the Department of Toxic Substances Control, Human and Ecological Risk Office.

uncertainties have been identified in the animal studies, including severe mortality and lack of histopathological criteria. In addition, the mechanism of MTBE carcinogenicity is not known. Given the uncertainties associated with MTBE carcinogenicity, benzene will be the risk-driving chemical of concern associated with fuel-related hydrocarbons, especially considering that benzene is a known human carcinogen with a known mechanism of action.

The soil screening level for "PAH" is appropriate for comparison with the total concentration of the seven carcinogenic PAHs, as benzo(a)pyrene equivalents (BaPe)[4]. The carcinogenic PAHs typically analyzed during site investigations 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 PAHs 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 typically not found in petroleum mixtures.

2.3 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 where a particular exposure occurs is 25 by 25 meters (approximately 82 by 82 feet) or less. This does not mean that the site or the property has to be less than 25 by 25 meters. If the area of impacted soil where a particular exposure is larger, a site-specific risk analysis may be warranted.
- The receptor is located at the downgradient edge for inhalation exposure. 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 meters per second (m/s) on average. If the average wind speed is lower, a site-specific risk analysis may be warranted.
- The default input parameters for all exposure scenarios were obtained from DTSC defaults for California hazardous waste sites. If the exposure scenarios are different, a site-specific risk analysis may be warranted.

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[4] The Office of Environmental Health Hazard Assessment (OEHHA) of Cal/EPA has developed potency equivalency factors (PEFs) for carcinogenic PAHs based on their potential toxicity when compared to benzo(a)pyrene [B(a)P]. To estimate B(a)P toxicity equivalents (TEQs; referred to as BaPe), the concentration of each carcinogenic PAH detected in soil is multiplied by the appropriate PEF developed by OEHHA [benz[a]anthracene (0.1), benzo[a]pyrene (1.0), benzo[b]fluoranthene (0.1), benzo[k]fluoranthene (0.1), chrysene (0.01), dibenz(a,h)anthracene (0.34), and indeno(1,2,3-cd)pyrene (0.1). The sum of BaPe concentrations for a mixture of PAH results in a total BaPe for each sample; the total BaPe concentrations should be compared to the soil screening level for PAHs.

3 CONCEPTUAL SITE MODEL

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

3.1 Exposure Pathways

The soil screening levels consider four exposure pathways simultaneously:

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

Incidental 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 concentration must be estimated using volatilization and particulate emission factors.

3.2 Receptors Considered

Soil screening levels were calculated for three exposure scenarios. The exposure scenarios considered were:

- residential;
- commercial/industrial worker; and
- a worker in a utility trench or similar construction project (utility worker).

It is assumed that all four of the exposure pathways (discussed in section 3.1) are potentially complete for each scenario. However, the input parameter values are different for each receptor.

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 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 (Table 1). For noncarcinogenic health effects, the intake is not added over the exposure period. In this case, the child is the more sensitive receptor; therefore the noncarcinogenic screening levels are developed for a child receptor and are protective for the adult resident.

The commercial/industrial exposure scenario assumes that the receptor is an adult and works in an office or outdoors at a site. In this scenario, it is assumed that the receptor works for a total of 25 years at 250 days/year at the same location.

For the utility or construction worker, 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 and/or increased inhalation rates.

3.3 Depths to Which the Screening Levels Apply

Two sets of screening levels were developed for the residential and commercial/industrial scenarios 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 full depth of 0 to 10 feet is assumed to contribute to outdoor air concentrations for all scenarios.

For the residential and commercial/industrial exposure scenarios, it is assumed that residents and commercial workers could contact soil at depths between ground surface and 5 feet bgs. For the utility or construction worker, it is assumed that direct contact with soil could occur at depths between ground surface and 10 feet bgs.

4 DERIVATION OF SCREENING LEVELS

This section describes how the soil screening levels were calculated. Except the volatilization term, standard equations from the USEPA RSLs were used. A target risk level of 1×10^{-6} for carcinogens and a target hazard index of 1.0 for noncarcinogens were used.

4.1 Equations Used

4.1.1 Exposure Equations

The equations used to develop the soil screening levels are presented in Tables 1 through 3 for each receptor. The variable definitions are presented in Table 4. USEPA considers the carcinogenic PAHs to be “mutagens” and as such, has unique equations to calculate 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 an outdoor air concentration 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; and
- 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. The assumed receptor location at the edge of the downwind side of the source 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 in the model.

The ASTM VF is actually composed of two equations as presented 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 presented in Table 6. Unless there are site-specific conditions, reasonable estimates for the length and width of the source are 25 meters each (approximately 82 by 82 feet). The thickness of impacted soil is assumed to equal 3.05 meters (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/m^3)] (DTSC 2011). For the utility trench (construction) worker, a PEF value of 1×10^6 [(mg/kg)/(mg/m^3)] 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 presents the default values 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 and ethylbenzene will not be on the skin long enough (due to volatilization) to absorb through 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 noncarcinogenic inhalation reference doses are presented 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 noncarcinogenic 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 SOIL SCREENING LEVELS

Table 8 shows the soil screening levels calculated for each exposure scenario.

Table 8: Summary of Soil Screening Levels for different Exposure Scenarios and Receptors

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	8.2	12	14
Ethylbenzene	21	32	89	134	314
Naphthalene	9.7	9.7	45	45	219
PAH*	0.063**	NA	0.68	NA	4.5

Notes:

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

** DTSC (2009) reports average ambient PAH concentrations (as BaPe) in California ranging from 0.16 to 0.21 mg/kg, and upper tolerance limits (UTLs) ranging from 0.9 to 1.5 mg/kg. The screening level shown in this table is "risk-based" and is far below the average ambient concentrations for PAHs in California. It is suggested that DTSC citation (2009) be consulted for sites with PAH contamination.

NA = Not Applicable

Note, the screening levels for naphthalene are the same for the top 5 feet and for 5 to 10 feet bgs based on volatilization to outdoor air. This is because naphthalene is only carcinogenic from the inhalation exposure pathway and not from oral or dermal contact. The screening levels based on carcinogenic mode of action and inhalation were the most conservative (i.e., the carcinogenic screening levels were less than the noncarcinogenic screening levels).

6 APPLYING SOIL SCREENING LEVELS

The maximum concentrations of petroleum constituents in soil should be compared to those listed in Table 8 for the specified depth bgs and the receptor scenario. The concentration limits for 0 to 5 feet bgs are protective for ingestion of soil, dermal contact with soil, inhalation of volatile soil emissions, and inhalation of particulate emissions, and the 5 to 10 feet bgs concentration limits are protective for inhalation of volatile soil emissions in outdoor air. Both the 0 to 5 feet bgs concentration limits and the 5 to 10 feet bgs concentration limits for the appropriate site classification (residential or commercial/industrial) shall be satisfied. In addition, if exposure to construction workers or utility trench workers is reasonably anticipated, the concentration limits for the utility worker shall also be satisfied.

7 DISCUSSION

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.

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 and hospitals; OEHHA 2005).

8 REFERENCES

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USEPA. 2011. Integrated Risk Information System (on-line database of toxicity parameters). Accessed May 2011. http://www.epa.gov/IRIS/

TABLES

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

(page 1 of 3)

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

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

(page 2 of 3)

Noncarcinogenic (Hazard) – Residential

Incidental ingestion of soil

$$C_{res\text{-}sol\text{-}nc\text{-}ing} = \frac{THQ \times BW_c \times AT_{nc} \times ED_c \times 365\,d/yr}{EF_r \times ED_c \times \frac{1}{RfD_o} \times IRS_c \times \frac{1E-6\,kg}{mg}}$$

Inhalation of particulates and volatiles

$$C_{res\text{-}sol\text{-}nc\text{-}inh} = \frac{THQ \times AT_{nc} \times ED_c \times 365\,d/yr}{EF_r \times ED_c \times ET_r \times \frac{1\,day}{24\,hours} \times \frac{1}{RfC}\left(VF_r + \frac{1}{PEF_r}\right)}$$

Dermal contact with soil

$$C_{res\text{-}sol\text{-}nc\text{-}der} = \frac{THQ \times BW_c \times AT_{nc} \times ED_c \times 365\,d/yr}{EF_r \times ED_c \times \frac{1}{\left(RfD_o \times GIABS\right)} \times SAS_c \times AF_c \times ABS_d \times \frac{1E-6\,kg}{mg}}$$

Total

$$C_{res-sol-nc-tot} = \frac{1}{\frac{1}{SL_{res-sol-nc-ing}} + \frac{1}{SL_{res-sol-nc-inh}} + \frac{1}{SL_{res-sol-nc-der}}}$$

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

(page 3 of 3)

Carcinogenic – Mutagenic
Incidental ingestion of soil
$$SL_{res-sol-mu-ing} = \frac{TR \times AT_{Carc} \times 365 d/yr}{SF_o \times EF_r \times IFSM_{adj} \times 1E{-}6\, kg/mg}$$
where
$$IFSM_{adj} = \frac{ED_{0\text{-}2}(2 years) \times IRS_c \times 10}{BW_c} + \frac{ED_{2\text{-}6}(4 years) \times IRS_c \times 3}{BW_c} + \frac{ED_{6\text{-}16}(10 years) \times IRS_a \times 3}{BW_a} + \frac{ED_{16\text{-}30}(14 years) \times IRS_a \times 1}{BW_a}$$
Inhalation of particulates and volatiles
$$SL_{res-sol-mu-inh} = \frac{TR \times AT_{Carc} \times 365 d/yr}{IUR \times \left(\frac{1000\,\mu g}{mg}\right) \times EF_r \times \left(VF_{s\_r} + \frac{1}{PEF_r}\right) \times ET_r \times \left(\frac{1\ day}{24\ hours}\right) \times \left(\begin{matrix} ED_{0-2}(2 years) \times 10 + ED_{2-6}(4 years) \times 3 + \\ ED_{6-16}(10 years) \times 3 + ED_{16-30}(14 years) \times 1 \end{matrix}\right)}$$
Dermal Contact with soil
$$SL_{res-sol-mu-der} = \frac{TR \times AT_{Carc} \times 365 d/yr}{\frac{SF_o}{GIABS} \times EF_r \times DFSM_{adj} \times ABS_d \times 1E{-}6\, kg/mg}$$
where
$$DFSM_{adj} = \left[\begin{matrix} \frac{ED_{0\text{-}2}(2 years) \times SAS_c \times AF_c \times 10}{BW_c} + \frac{ED_{2\text{-}6}(4 years) \times SAS_c \times AF_c \times 3}{BW_c} + \\ \frac{ED_{6\text{-}16}(10 years) \times SAS_a \times AF_a \times 3}{BW_a} + \frac{ED_{16\text{-}30}(14 years) \times SAS_a \times AF_a \times 1}{BW_a} \end{matrix}\right]$$
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

$$SL_{c/i-sol-ca-ing} = \frac{TR \times AT_{Carc} \times 365d/yr \times BW_{c/i}}{SF_o \times EF_{c/i} \times ED_{c/i} \times IRS_{c/i} \times 1\text{E}-6\,kg/mg}$$

Inhalation of particulates and volatiles

$$SL_{c/i-sol-ca-inh} = \frac{TR \times AT_{Carc} \times 365d/yr}{IUR \times \left(\frac{1000\,\mu g}{mg}\right) \times EF_{c/i} \times \left(VF_{c/i} + \frac{1}{PEF_{c/i}}\right) \times ED_{c/i} \times ET_{c/i} \times \left(\frac{1\ day}{24\ hours}\right)}$$

Dermal Contact with soil

$$SL_{c/i-sol-ca-der} = \frac{TR \times AT_{Carc} \times 365d/yr \times BW_{c/i}}{\frac{SF_o}{GIABS} \times EF_{c/i} \times ED_{c/i} \times SAS_{c/i} \times AF_{c/i} \times ABS_d \times 1\text{E}-6\,kg/mg}$$

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

$$C_{c/i\text{-}sol\text{-}nc\text{-}ing} = \frac{THQ \times BW_{c/i} \times AT_{nc} \times ED_{c/i} \times 365d/yr}{EF_{c/i} \times ED_{c/i} \times \frac{1}{RfD_o} \times IRS_{c/i} \times \frac{1E-6kg}{mg}}$$

Inhalation of particulates and volatiles

$$C_{c/i\text{-}sol\text{-}nc\text{-}inh} = \frac{THQ \times AT_{nc} \times ED_{c/i} \times 365d/yr}{EF_{c/i} \times ED_{c/i} \times ET_{c/i} \times \frac{1day}{24hours} \times \frac{1}{RfC}\left(VF_{c/i} + \frac{1}{PEF_{c/i}}\right)}$$

Dermal contact with soil

$$C_{c/i\text{-}sol\text{-}nc\text{-}der} = \frac{THQ \times BW_{c/i} \times AT_{nc} \times \text{ED}_{c/i} \times 365\,\text{d/yr}}{EF_{c/i} \times \text{ED}_{c/i} \times \frac{1}{(\text{RfD}_o \times \text{GIABS})} \times \text{SAS}_{c/i} \times \text{AF}_{c/i} \times \text{ABS}_d \times \frac{1\text{E}-6\text{kg}}{\text{mg}}}$$

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

$$SL_{ut-sol-ca-ing} = \frac{TR \times AT_{Carc} \times 365d/yr \times BW_{ut}}{SF_o \times EF_{ut} \times ED_{ut} \times IRS_{ut} \times 1E-6\,kg/mg}$$

Inhalation of particulates and volatiles

$$SL_{ut-sol-ca-inh} = \frac{TR \times AT_{Carc} \times 365d/yr}{IUR \times \left(\frac{1000\,\mu g}{mg}\right) \times EF_{ut} \times \left(VF_{ut} + \frac{1}{PEF_{ut}}\right) \times ED_{ut} \times ET_{ut} \times \left(\frac{1\ day}{24\ hours}\right)}$$

Dermal Contact with soil

$$SL_{ut-sol-ca-der} = \frac{TR \times AT_{Carc} \times 365d/yr \times BW_{ut}}{\frac{SF_o}{GIABS} \times EF_{ut} \times ED_{ut} \times SAS_{ut} \times AF_{ut} \times ABS_d \times 1E-6\,kg/mg}$$

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

$$C_{ut\text{-}sol\text{-}nc\text{-}ing} = \frac{THQ \times BW_{ut} \times AT_{nc} \times ED_{ut} \times 365d/yr}{EF_{ut} \times ED_{ut} \times \frac{1}{RfD_o} \times IRS_{ut} \times \frac{1E-6kg}{mg}}$$

Inhalation of particulates and volatiles

$$C_{ut\text{-}sol\text{-}nc\text{-}inh} = \frac{THQ \times AT_{nc} \times ED_{ut} \times 365d/yr}{EF_{ut} \times ED_{ut} \times ET_{ut} \times \frac{1day}{24hours} \times \frac{1}{RfC}\left(VF_{ut} + \frac{1}{PEF_{ut}}\right)}$$

Dermal contact with soil

$$C_{ut\text{-}sol\text{-}nc\text{-}der} = \frac{THQ \times BW_{ut} \times AT_{nc} \times ED_{ut} \times 365d/yr}{EF_{ut} \times ED_{ut} \times \frac{1}{(RfD_o \times GIABS)} \times SAS_{ut} \times AF_{ut} \times ABS_d \times \frac{1E-6kg}{mg}}$$

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}	days	365 x 70	70 years by definition (USEPA 1989)
Averaging time for noncarcinogens	AT_{nc}	days	365 x ED	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/d	2900	DTSC HERO (2011)
Skin surface area exposed to soil, residential adult	SAS_a	cm^2/d	5700	DTSC HERO (2011)

Table 4: Default Exposure Parameters (concluded)

Parameter	Variable Name	Units	Value	Reference
Skin surface area exposed to soil, commercial/industrial	$SAS_{c/i}$	cm^2/d	5700	DTSC HERO (2011)
Skin surface area exposed to soil, utility worker	SAS_{ut}	cm^2/d	5700	DTSC HERO (2011)
Particulate emission factor, residential	PEF_r	m^3/kg	1.3×10^9	DTSC HERO (2011)
Particulate emission factor, commercial/industrial	$PEF_{c/i}$	m^3/kg	1.3×10^9	DTSC HERO (2011)
Particulate emission factor, utility worker	PEF_{ut}	m^3/kg	1.0×10^6	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	1×10^{-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 (2011). Department of Toxic Substances Control, Office of Human and Ecological Risk (HER0). 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:

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

Mass-balance considered:

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

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	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*	$(cm^3$ 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	Ethyl-benzene	Naphtha-lene	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)	$1/(\mu g/m^3)$	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	0.060	2	0.009	ND	OEHHA RELs
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.

OEHHA RELs. OEHHA Chronic Reference Exposure Levels (RELs). http://www.oehha.ca.gov/risk/chemicaldb/

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 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	8.2	12	14
Ethylbenzene	21	32	89	134	314
Naphthalene	9.7	9.7	45	45	219
PAH*	0.063**	NA	0.68	NA	4.5

* 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.

** DTSC (2009) reports average ambient PAH concentrations (as BaPe) in California ranging from 0.16 to 0.21 mg/kg, and upper tolerance limits (UTLs) ranging from 0.9 to 1.5 mg/kg. The screening level shown in this table is "risk-based" and therefore in this case is far below the average ambient concentrations for PAHs in California. It is suggested that DTSC (2009) be consulted for sites with PAH contamination.

NA = Not Applicable

FIGURES

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

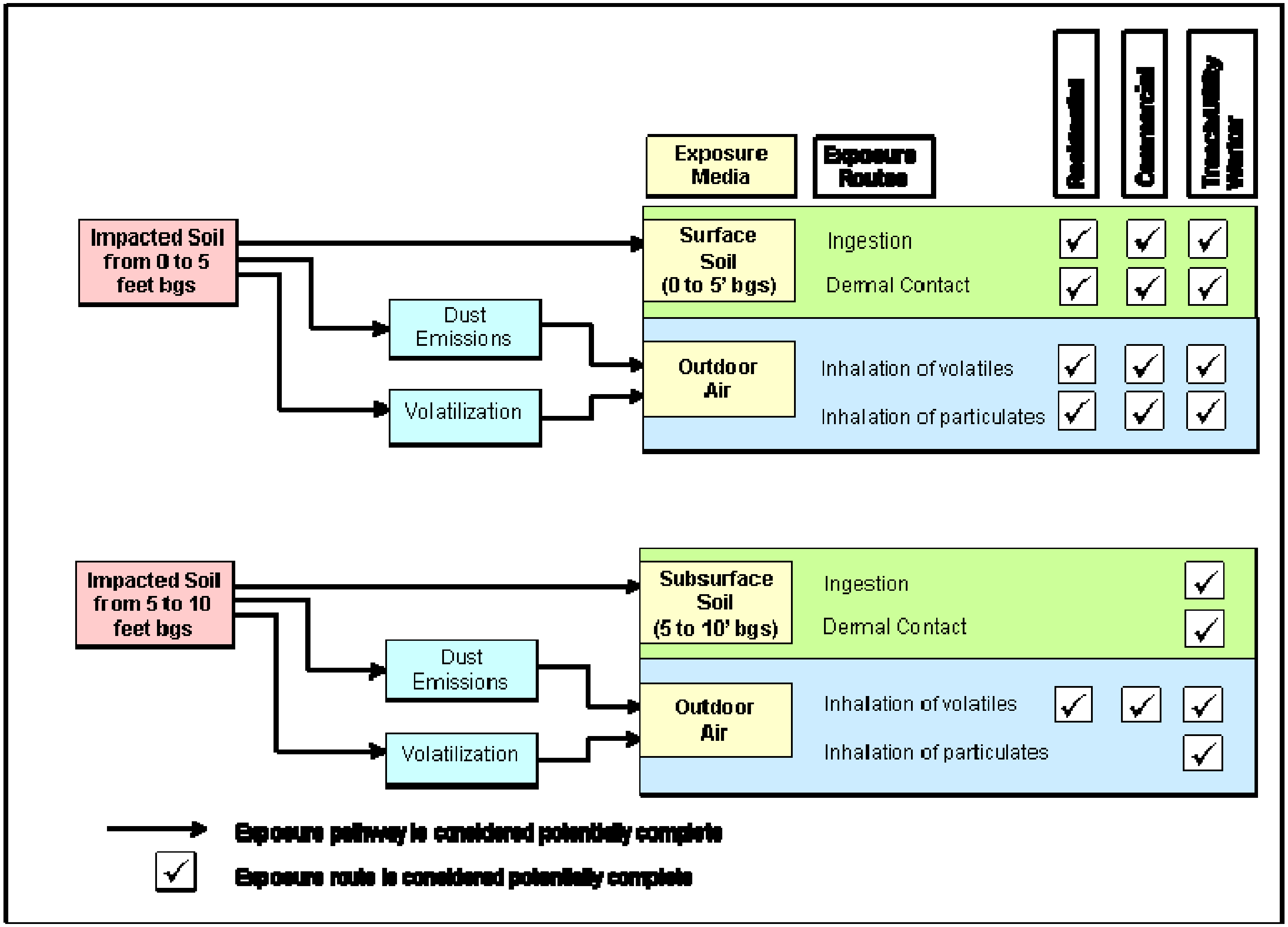

Figure 2. Schematic for the ASTM Volatilization Factor.