APPENDIX B
DEVELOPMENT OF RISK-BASED TARGET LEVELS

Page

The procedure used to calculate Tier 1 risk-based target levels (RBTLs) and Tier 2 site-specific target levels (SSTLs) is presented in this appendix. This procedure requires quantitative values of:

- Target risk levels,
- Chemical-specific toxicological factors,
- Physical and chemical properties of the chemicals of concern (COCs),
- Receptor-specific exposure factors,
- Fate and transport parameters, and
- Mathematical models.

Each of these factors is discussed below. Additionally, this Appendix discusses the (i) target levels for lead (Section B.8), and (ii) estimation of risk and target levels when LNAPL is present on the groundwater surface (Section B.9).

For Tier 1 risk assessments, the RBTLs have been calculated by MDNR for each of the COCs (refer to Section 5.3.3), the receptors (refer to Section 6.1.2), and the commonly encountered routes of exposure (refer to Section 6.1.3) using conservative assumptions applicable to most Missouri sites. The resultant Tier 1 RBTLs are presented in Tables 7-1(a) through (f).

For Tier 2 and Tier 3 risk assessments, the risk evaluator will calculate the SSTLs using technically justifiable site-specific data and, for Tier 3, pathway-specific models. For Tier 2 risk assessments, the models used for developing the Tier 1 RBTLs must be used. A Tier 3 risk assessment may include different models, if approved by MDNR.

B.1 TARGET RISK LEVELS

A risk-based decision making process requires the specification of a target risk level for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, MDNR will use an **individual excess lifetime cancer risk (IELCR) of 1 x 10^{-5}** as the target risk for both current and future receptors. For non-carcinogenic effects, the acceptable level is a hazard quotient of one (1) for current and future receptors. Due to the limited number of COCs, additivity of risk is not considered.

For evaluating the ingestion of groundwater and protection of groundwater resource pathways, Maximum Contaminant Levels (MCLs) or, where MCLs are not available, health advisories were used as the target concentrations at the point of exposure. For chemicals that do not have such levels, the target concentration at the point of exposure (POE) was estimated assuming ingestion of groundwater under residential conditions.

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Allowable concentrations in surface water for COCs are presented in Table 6-1.

B.2 QUANTITATIVE TOXICITY FACTORS

Toxicity values for the COCs are presented in Table B-1. MDNR may update the data in Table B-1 as new information becomes available.

Typically, these toxicity values will also be used for Tier 3 risk assessments, although alternate values may be used at Tier 3 with adequate justification and the approval of MDNR. Current toxicity values may be obtained by consulting the following sources in the order listed:

- State recommended values,
- Integrated Risk Information System (IRIS),
- Direct communication with appropriate US EPA personnel, and
- Review of literature produced by qualified professionals to develop toxicity factors. Consult the appropriate Regional US EPA Office and MDNR for specific recommendations.

Note that the use of different values in a Tier 3 risk assessment will require a work-plan approved by MDNR.

B.3 PHYSICAL AND CHEMICAL PROPERTIES OF THE COCs

Physical and chemical properties of the COCs are listed in Table B-2. These values must be used for all MRBCA evaluations unless there are justifiable reasons to modify these values and MDNR concurs. The use of different values would be allowed only under a Tier 3 risk assessment.

B.4 EXPOSURE FACTORS

A list of the exposure factors and their values that were used to develop Tier 1 RBTL values is presented in Table B-3. The exposure factors are typically estimated based on literature rather than site-specific measurements. The values listed in Table B-3 are conservative values that are exceeded by about 5% of the population, i.e. they are the upper 95th percentile values. For a Tier 3 risk assessment, site-specific exposure factor values may be used with thorough justification and MDNR approval.

A source of exposure factor information is U.S. EPA's **Exposure Factors Handbook Volume 1 – General Factors (*August 1997*).** Other sources of exposure factor data may be used for Tier 3 risk assessment with approval of MDNR**.**

B.5 FATE AND TRANSPORT PARAMETERS

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For a Tier 1 risk assessment, MDNR has selected typical and conservative default values that are listed in Table B-4.

For a Tier 2 risk assessment, a combination of site-specific and default fate and transport values may be used. However, the value of each parameter used, whether site-specific or default, must be justified based on site-specific conditions. Where site- specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used.

For a Tier 3 risk assessment, the specific fate and transport parameters required to calculate the target levels will depend on the model used.

B.6 MATHEMATICAL MODELS

The input parameters mentioned above are used in two types of models, or equations, to calculate the risk-based target levels. These are the (i) uptake equations and (ii) fate and transport models. For Tier 1 and Tier 2 risk assessments, MDNR has selected the models and equations included in this appendix. These models have been programmed in the MRBCA Computational Software and were used to develop the Tier 1 target levels presented in Section 7.0.

For Tier 2 risk assessments, MDNR requires the use of the same equations and models. With the prior approval of MDNR through the submittal of a Tier 3 work plan, a different set of models may be used for Tier 3 risk assessments.

B.7 RISK-BASED TARGET LEVELS

The input parameters and models mentioned above are used to estimate risk-based target levels for each chemical and each route-of-exposure. For certain chemicals, the target levels developed for groundwater may exceed the solubility of a chemical. In such cases, the software indicates the actual calculated value with an asterisk that indicates that the calculated values exceed solubility. Similarly, for certain chemicals and pathways, soil target levels may exceed levels at which the soil is saturated by the chemical. In this case, the software presents the actual value with an asterisk that indicates that the calculated value exceeds the soil saturation value.

For both the above cases, the results can be interpreted to mean that the chemical and the pathway do not need any further evaluation and that the site-specific concentrations are protective of the pathway. Further, if concentrations above the solubility level in groundwater and above the soil saturation level are measured in a sample, the implication is that the sample had some free product in it.

B.8 TARGET LEVELS FOR LEAD

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable from the standpoints of both exposure and toxicity. Certain behaviors, such as crawling and playing on the floor or ground, result in increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overly toxic can result in impaired mental development.

U.S. EPA has developed a model (Integrated Exposure Uptake Biokinetic [IEUBK] Model) to predict the risk of elevated blood lead (PbB) in children under the age of seven that are exposed to environmental lead from various sources. The model predicts the probability that a child exposed to lead concentrations in a specified media will have a PbB level greater than 10 micrograms per deciliter (ug/dL), the level associated with adverse health effects (EPA, 1999).

Because of the greater vulnerability of children to exposure and toxicity, the primary concern in a residential setting is risk to children. In the non-residential scenario, children are not directly exposed, but fetuses carried by female workers can be exposed. The EPA has developed an adult lead methodology (ALM) to assess risk in this scenario (EPA, 1996b). The methodology is limited in terms of exposure media (soil/dust). Specifically, the methodology estimates the PbB concentrations in fetuses carried by women exposed to lead contaminated soils. Research is ongoing to develop a model capable of simulating multimedia exposures over the entire human lifetime. Until this model is developed, MDNR will require the use of IEUBK for residential and ALM for non-residential scenarios.

At petroleum impacted sites it is not necessary to use the IEUBK or ALM to assess lead risk and determine cleanup goals. Based on the above discussion, MDNR will use the following Tier 1 levels for lead (MDNR, 2001):

Residential land use soil (direct contact with soil)	260 mg/kg
Non-residential land use soil (direct contact with soil)	660 mg/kg

The groundwater target level where domestic use of groundwater is a complete pathway is 0.015 mg/l.

The above soil concentrations do not account for leaching to groundwater. At sites where this pathway is complete or potentially complete, MDNR may require a site-specific analysis.

B.9 TARGET LEVEL CALCULATION FOR LNAPL

As discussed in Sections 3.3 and 6.8, the MRBCA process allows for the calculation of risk and target levels when LNAPL is present. Under this condition, the primary routes of exposure are (i) indoor inhalation for a residential or a non-residential receptor, and, if the domestic use of groundwater pathway is complete or potentially complete, (ii) the protection of a current or potential future point of exposure (POE) groundwater well. For these pathways, the key step is the calculation of the vapor concentration and the dissolved concentration emanating from the LNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in Section B.1 to B.7 above.

Soil Vapor Concentration: The soil vapor concentration in equilibrium with LNAPL is the effective soil vapor concentration. This concentration depends on (i) the chemical-specific saturated soil vapor concentration, and (ii) the mole fraction of the chemical in the LNAPL for which the soil vapor concentration is being calculated. If the mole fraction of a COC is not known, default mole fractions, calculated using the weight fraction of a specific COC in the LNAPL (refer to Table 5-2), may be used. Alternatively, the evaluator may sample the LNAPL for laboratory analysis to determine site-specific values for the weight and mole fractions. The specific equations used to calculate the effective soil vapor or effective dissolved concentrations are presented in Section B.10.

In the forward model of risk assessment, the effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration in the POD and POE wells. In the backward mode of risk assessment, the Tier 1 RBTLs and Tier 2 and 3 SSTLs must be compared with the effective concentrations. The models and equations to be used are presented in Section B.10.

B.10 MODELS/EQUATIONS FOR ESTIMATING DTLs, TIER 1 AND TIER 2 TARGET LEVELS WITHIN THE MRBCA PROCESS

INDOOR INHALATION OF VAPORS
(CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)

Carcinogenic effects

$$RBTL_{ai} = \frac{TR \times BW \times AT_c \times 365}{IR_{ai} \times ET_{in} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ET_{in} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

$RBTL_{ai}$	=	Risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
IR_{ai}	=	Indoor inhalation rate [m^3/hr]
ET_{in}	=	Indoor Exposure time [hr/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

OUTDOOR INHALATION OF VAPORS
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{ao} = \frac{TR \times BW \times AT_c \times 365}{IR_{ao} \times ET_{out} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ao} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ET_{out} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

$RBTL_{ao}$	=	Risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

INGESTION AND INHALATION OF GROUNDWATER FROM POTABLE USE (CHILD AND ADULT RESIDENT)
(ONLY FOR CHEMICALS WITHOUT MO WATER QUALITY STANDARDS)

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times \left[\left(SF_o \times IR_w\right) + \left(SF_i \times ET \times K \times IR_a\right)\right]}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w\right) + \left(\frac{1}{RfD_i} \times K \times ET \times IR_a\right)\right]}$$

Source: RAGS, Vol. I, Part B, 1991, p. 21

where:

$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
IR_w	=	Water ingestion rate [L/day]
IR_a	=	Indoor inhalation rate [m^3/hr]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
K	=	Volatilization factor [L/m^3]
ET	=	Exposure time [hr/day]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
SF_i	=	Chemical-specific inhalation cancer slope or potency factor $[(mg/kg\text{-}day)^{-1}]$
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

DERMAL CONTACT WITH CHEMICALS IN WATER (CHILD AND ADULT RESIDENT)

Carcinogenic effects

$$RBTL_{dw} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_o \times SA \times PC \times ET \times EF \times ED}$$

Non-carcinogenic effects

$$RBTL_{dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_o}{SA \times PC \times ET \times EF \times ED}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-37

where:

$RBTL_{dw}$	=	Risk-based target level for dermal contact with groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]
SA	=	Skin surface area available for contact [cm^2]
PC	=	Chemical-specific dermal permeability constant [cm/hr]
ET	=	Exposure time [hour/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]

Note: Dermal slope factor and dermal reference dose are generally not available, instead as an approximation oral slope factor and oral reference dose are used to estimate risk from dermal exposure.

DERMAL CONTACT WITH CHEMICALS IN SURFICIAL SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)	
Carcinogenic effects $$RBTL_{dcss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_o \times 10^{-6} \times SA \times M \times RAF_d}$$ Non-carcinogenic effects $$RBTL_{dcss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF \times ED \times 10^{-6} \times SA \times M \times RAF_d}$$	where: $RBTL_{dcss}$ = Risk-based target level for dermal contact of chemicals in surficial soil [mg/kg] TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-] THQ = Target hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] SA = Skin surface area [cm^2/day] M = Soil to skin adherence factor [mg/cm^2] RAF_d = Chemical-specific dermal relative absorption factor [-] SF_o = Oral cancer slope factor [$(mg/kg\text{-}day)^{-1}$] RfD_o = Chemical-specific oral reference dose [mg/kg-day] *365* = Converts AT_c, AT_{nc} in years to days [day/year] *Note: Dermal slope factor and dermal reference dose are generally not available, instead as an approximation oral slope factor and oral reference dose are used to estimate risk from dermal exposure.*

INGESTION OF CHEMICALS IN SURFICIAL SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{ingss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_o \times 10^{-6} \times IR_{soil} \times RAF_o}$$

Non-carcinogenic effects

$$RBTL_{ingss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF \times ED \times 10^{-6} \times IR_{soil} \times RAF_o}$$

where:

$RBTL_{ingss}$	=	Risk-based target level for ingestion of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{soil}	=	Soil ingestion rate [mg/day]
RAF_o	=	Oral relative absorption factor [-]
SF_o	=	Oral cancer slope factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SURFICIAL SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{inhss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_i \times IR_{ao} \times ET_{out} \times (VF_{SS} + VF_p)}$$

Non-carcinogenic effects

$$RBTL_{inhss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{EF \times ED \times ET_{out} \times IR_{ao} \times (VF_{ss} + VF_p)}$$

where:

$RBTL_{inhss}$	=	Risk-based target level of inhalation of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
SF_i	=	Inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-day]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

Note: The depth to surficial soil for a construction worker is up to the typical construction depth.

INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT AND INGESTION OF CHEMICALS IN SURFICIAL SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{ss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times \left[\left(SF_o \times 10^{-6} \times \left(IR_{soil} \times RAF_o + SA \times M \times RAF_d\right)\right) + \left(SF_i \times IR_{ao} \times ET_{out} \times \left(VF_{ss} + VF_p\right)\right)\right]}$$

Non-carcinogenic effects

$$RBTL_{ss} = \frac{THQ \times BW \times AT_{nc} \times 365}{EF \times ED \times \left[\frac{10^{-6} \times \left(IR_{soil} \times RAF_o + SA \times M \times RAF_d\right)}{RfD_o} + \frac{ET_{out} \times IR_{ao} \times \left(VF_{ss} + VF_p\right)}{RfD_i}\right]}$$

Where:

$RBTL_{ss}$	=	Risk-based target level of surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{soil}	=	Soil ingestion rate [mg/day]
RAF_o	=	Oral relative absorption factor [-]
SA	=	Skin surface area [cm^2/day]
M	=	Soil to skin adherence factor [mg/cm^2]
RAF_d	=	Dermal relative adsorption factor [-]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
SF_o	=	Oral cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
SF_i	=	Inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
RfD_o	=	The chemical-specific oral reference dose [mg/kg-day]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-day]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ai-aa} \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ai-aa}}$$

where

$$IR_{ai-aa} = \frac{IR_{ai-c} \times ED_c \times EF_c \times ET_{i-c}}{BW_c} + \frac{IR_{ai-a} \times ED_a \times EF_a \times ET_{i-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B, 1991

Where:

$RBTL_{ai\text{-}adj}$	=	Age-adjusted risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
$IR_{ai\text{-}aa}$	=	Age-adjusted indoor inhalation rate [m^3/ kg]
$IR_{ai\text{-}c}$	=	Resident Child indoor inhalation rate [m^3/hr]
$IR_{ai\text{-}a}$	=	Resident Adult indoor inhalation rate [m^3/hr]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
$ET_{i\text{-}c}$	=	Indoor exposure time for a child [hour/day]
$ET_{i\text{-}a}$	=	Indoor exposure time for an adult [hour/day]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [mg/kg-day]$^{-1}$
365	=	Conversion factor [day/year]

OUTDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ao\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ao\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao\text{-}aa}}$$

where

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B 1991

Where:

$RBTL_{ao\text{-}adj}$	=	Age-adjusted risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
365	=	Conversion factor [day/year]
$IR_{ao\text{-}aa}$	=	Age-adjusted outdoor inhalation rate [m^3/kg]
$IR_{ao\text{-}c}$	=	Resident Child outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}a}$	=	Resident Adult outdoor inhalation rate [m^3/hr]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o\text{-}a}$	=	Outdoor exposure time for an adult [hour/day]

DIRECT INGESTION AND INHALATION OF GROUNDWATER FROM POTABLE USE (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{TR \times AT_c \times 365}{\left[\left(SF_o \times IR_{w\text{-}aa}\right) + \left(SF_i \times K \times IR_{a\text{-}aa}\right)\right]}$$

Non-carcinogenic effects

–

$$RBTL_{w\text{-}adj} = \frac{THQ \times AT_{nc} \times 365}{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa}\right) + \left(\frac{1}{RfD_i} \times K \times IR_{a-aa}\right)\right]}$$

where:

$$IR_{w\text{-}aa} = \frac{ED_c \times EF_c \times IR_{w-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{w-a}}{BW_a}$$

$$IR_{a\text{-}aa} = \frac{ED_c \times EF_c \times ET_c \times IR_{a-c}}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times IR_{a-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B, 1991, p. 21

Where:

$RBTL_{w-adj}$	=	Age-adjusted risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
IR_{w-aa}	=	Age-adjusted groundwater ingestion rate [L/kg]
IR_{w-c}	=	Resident Child groundwater ingestion rate [L/day]
IR_{a-c}	=	Resident Child inhalation rate [m^3/hr]
IR_{w-a}	=	Resident Adult groundwater ingestion rate [L/day]
IR_{a-a}	=	Resident Adult inhalation rate [m^3/hr]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ET_c	=	Resident Child exposure time [hr/day]
ET_a	=	Resident Adult exposure time [hr/day]
ED_a	=	Resident Adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]

DIRECT CONTACT WITH CHEMICALS IN GROUNDWATER (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{TR \times AT_c \times 365 \times 1000}{SF_o \times PC \times DC_{w-aa}}$$

Non-carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times 1000 \times RfD_o}{PC \times DC_{w-aa}}$$

where

$$DC_{w\text{-}aa} = \frac{ED_c \times EF_c \times ET_c \times SA_c}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times SA_a}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989, p. 6-35

Where:

$RBTL_{dcw-adj}$	=	Age-adjusted risk-based target level for dermal contact with chemicals in groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
PC	=	Chemical-specific dermal permeability constant [cm/hr]
DC_{w-aa}	=	Age-adjusted dermal contact rate with groundwater [hr-cm^2/kg]
SA_c	=	Resident child skin surface area available for contact [cm^2]
SA_a	=	Resident adult skin surface area available for contact [cm^2]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
ET_c	=	Exposure time for a child [hr/day]
ET_a	=	Exposure time for an adult [hr/day]

DERMAL CONTACT WITH SURFICIAL SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{dcss\text{-}adj} = \frac{TR \times AT_c \times 365}{SF_o \times SA_{aa} \times RAF_d \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{dcss\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{SA_{aa} \times RAF_d \times 10^{-6}}$$

where

$$SA_{aa} = \frac{ED_c \times EF_c \times M_c \times SA_c}{BW_c} + \frac{ED_a \times EF_a \times M_a \times SA_a}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

Where:

$RBTL_{dcss\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
RAF_d	=	Dermal relative absorption factor [-]
M_c	=	Resident Child soil to skin adherence factor [mg/cm^2]
M_a	=	Resident Adult soil to skin adherence factor [mg/cm^2]
RfD_o	=	Chemical-specific oral reference dose [(mg/kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
SA_{aa}	=	Age-adjusted skin surface area [mg/ kg]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
SA_c	=	Resident Child skin surface area [cm^2/day]
SA_a	=	Resident Adult skin surface area [cm^2/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

DIRECT INGESTION OF SURFICIAL SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ingss-adj} = \frac{TR \times AT_c \times 365}{SF_O \times IR_{s-aa} \times RAF_O \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{ingss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_O}{IR_{s-aa} \times RAF_O \times 10^{-6}}$$

where

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

Where:

$RBTL_{ingss-adj}$	=	Risk-based target level for ingestion of soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RAF_o	=	Oral relative absorption factor [-]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
$IR_{s\text{-}aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s\text{-}c}$	=	Resident child soil ingestion rate [mg/day]
$IR_{s\text{-}a}$	=	Resident adult soil ingestion rate [mg/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

OUTDOOR INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL
(AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{ss-adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i \times (VF_{ss} + VF_p)}$$

Non-carcinogenic effects

$$RBTL_{ss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao-aa} \times (VF_{ss} + VF_p)}$$

where

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B, 1991

Where:

$RBTL_{ss\text{-}adj}$	=	Age-adjusted risk-based target level in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil[kg-soil/m^3-air]
VF_p	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]
$IR_{ao\text{-}aa}$	=	Age-adjusted outdoor inhalation rate [m^3/kg]
$IR_{ao\text{-}c}$	=	Resident Child outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}a}$	=	Resident Adult outdoor inhalation rate [m^3/hr]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o\text{-}a}$	=	Outdoor exposure time for an adult [hour/day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
365	=	Conversion factor [day/year]

INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF. CHEMICALS IN SURFICIAL SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

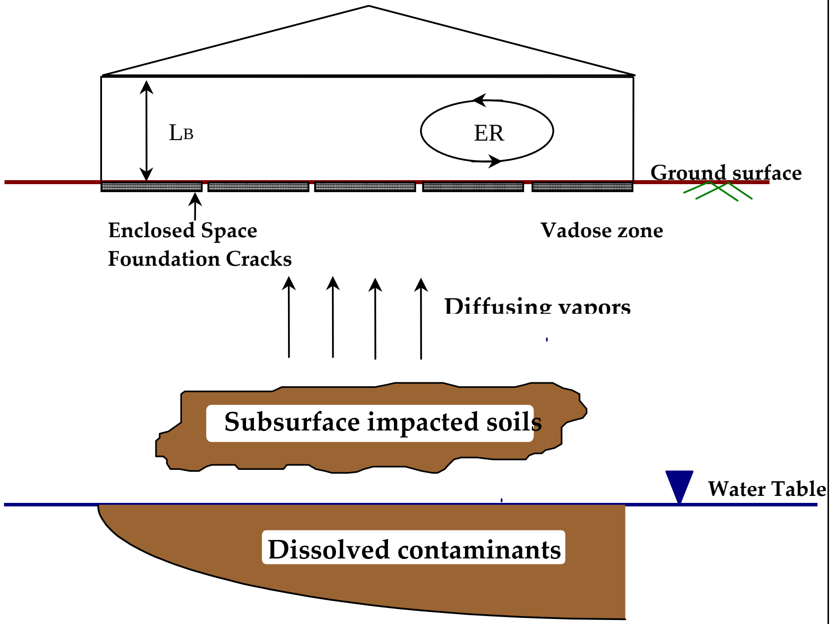
$$RBTL_{ss-combined} = \frac{TR \times AT_c \times 365}{SF_o \times 10^{-6} \times \left(IR_{s-aa} \times RAF_o + SA_{aa} \times RAF_d\right) + SF_i \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times \left(IR_{s-aa} \times RAF_o + SA_{aa} \times RAF_d\right) + \frac{1}{RfD_i} \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Note: All parameters are defined under the individual pathway equations.

SUBSURFACE SOIL VAPOR CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION



$$RBTL_{svi} = \frac{RBTL_{ai}}{VF_{sv}}$$

where:

$RBTL_{svi}$	=	Risk-based target level for indoor inhalation of vapors from subsurface [mg/m^3-air]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air [mg/m^3-air]
VF_{sv}	=	Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-]

Source: ASTM E1739-95

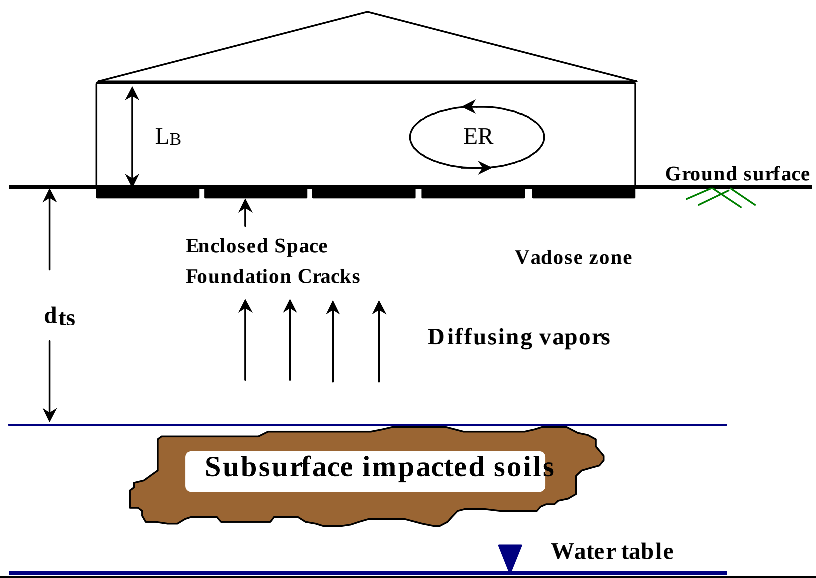
SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{VF_{sesp}}$$

where:

$RBTL_{si}$	=	Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg-soil]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air [mg/m^3-air]
VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]

Source: ASTM E1739-95



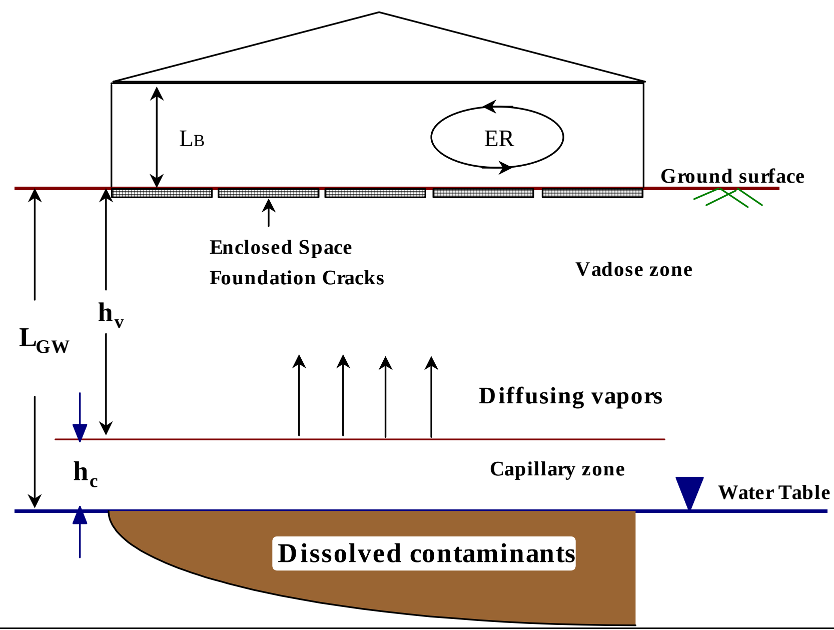
GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{VF_{wesp}}$$

where:

$RBTL_{wi}$	=	Risk-based target level for indoor inhalation of vapors from groundwater [mg/l-H_2O]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air (mg/m^3-air)
VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/l-H_2O)]

Source: ASTM E1739-95



VOLATILIZATION FACTORS
(SURFICIAL SOIL TO OUTDOOR AIR)

$$VF_{ss} = \left[Q/C \times \frac{\left(3.14 \times D_A \times \tau\right)^{1/2}}{\left(2 \times \rho_s \times D_A\right)} \times 10^{-4} \right]^{-1}$$

where:

$$D_A = \frac{\left(\theta_{as}^{10/3} \times D^a \times H + \theta_{ws}^{10/3} \times D^w\right) / \theta_T^2}{\rho_s \times K_{sv} + \theta_{ws} + \theta_{as} \times H}$$

or

$$VF_{ss} = \frac{W_a \times \rho_s \times d_s}{U_m \times \delta_a \times \tau} \times 10^3$$

Use smaller of the two VF_{ss}.

Source: Soil Screening Guidance, 1996

where:

- VF_{ss} = Volatilization factor from surficial soil to outdoor (ambient) air [kg-soil/m^3-air]
- Q/C = Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
- D_A = Apparent diffusivity [cm^2/s]
- τ = Averaging time for vapor flux [s]
- ρ_s = Vadose zone dry soil bulk density of surficial soil [g-soil/cm^3-soil]
- K_{sv} = Chemical-specific solid-water sorption coefficient [cm^3-H_2O/g-soil]
- D^a = Chemical-specific diffusion coefficient in air [cm^2/s]
- D^w = Chemical-specific diffusion coefficient in water [cm^2/s]
- θ_T = Total soil porosity in the surficial soils [cm^3/cm^3-soil]
- θ_{as} = Volumetric air content in the surficial soils [cm^3-air/cm^3-soil]
- θ_{ws} = Volumetric water content in the surficial soils [cm^3-H_2O/cm^3-soil]
- H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
- 10^{-4} = Conversion factor [m^2/cm^2]
- W_a = Dimension of soil source area parallel to wind direction [cm]
- d_s = Depth to base of surficial soil zone [cm]
- U_m = Mean annual wind speed [m/s]
- δ_a = Breathing zone height [cm]
- 10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

Note: Surficial soil properties are assumed same as the vadose zone properties.

VOLATILIZATION FACTORS
(PARTICULAR EMISSIONS FROM SURFICIAL SOIL)

$$VF_p = \left[Q/C \times \frac{3600}{0.036 \times (1 - V) \times \left(U_m / U_t \right)^3 \times F(x)} \right]^{-1}$$

where:

VF_p	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]
Q/C	=	Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
V	=	Fraction of vegetative cover [-]
U_m	=	Mean annual wind speed [m/s]
U_t	=	Equivalent threshold value of wind speed at 7 m [m/s]
$F(x)$	=	Function dependent on U_m/U_t derived using Cowherd *et al.* 1985 [-]
0.036	=	Empirical constant [g/m^2-hr]

Source: Soil Screening Guidance, 1996

VOLATILIZATION FACTORS (SUBSURFACE SOIL VAPOR TO INDOOR AIR)	
$$VF_{sv} = \frac{\left[\dfrac{D_s^{eff} / d_{sv}}{ER \times L_B}\right]}{1 + \left[\dfrac{D_s^{eff} / d_{sv}}{ER \times L_B}\right] + \left[\dfrac{D_s^{eff} / d_{sv}}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta}\right]}$$ Source: ASTM E1739-95	where: VF_{sv} = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil] θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil d_{sv} = Depth to subsurface soil vapor samples taken [cm] L_B = Enclosed space volume/infiltration area ratio [cm] L_{crack} = Enclosed space foundation or wall thickness [cm] ER = Enclosed space air exchange rate [1/s] D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s] η = Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]

VOLATILIZATION FACTORS
(SUBSURFACE SOIL TO INDOOR AIR)

$$VF_{sesp} = \frac{\dfrac{H \times \rho_s}{[\theta_{ws} + (K_{sv} \times \rho_s) + (H \times \theta_{as})]} \times \left[\dfrac{D_s^{eff} / d_{ts}}{ER \times L_B}\right]}{1 + \left[\dfrac{D_s^{eff} / d_{ts}}{ER \times L_B}\right] + \left[\dfrac{D_s^{eff} / d_{ts}}{(D_{crack}^{eff} / L_{crack}) \times \eta}\right]} \times 10^3$$

Source: ASTM E1739-95

where:

VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [m^3-air/(mg/kg-soil)]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]
ρ_s	=	Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$
	=	Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
θ_{as}	=	Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil
d_{ts}	=	Depth to subsurface soil sources [cm]
L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

VOLATILIZATION FACTORS
(GROUNDWATER TO INDOOR AIR)

$$VF_{wesp} = \frac{H \times \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right]}{1 + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right] + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{\left(D_{crack}^{eff} / L_{crack} \right) \times \eta} \right]} \times 10^3$$

Source: ASTM E1739-95

where:

VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-H_2O)]
H	=	Vadose zone chemical specific Henry's Law constant [(L-H_2O)/(L-air)]
L_{GW}	=	Depth to groundwater [cm]
L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
D_{ws}^{eff}	=	Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [L/m^3]

EFFECTIVE DIFFUSION COEFFICIENTS

D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

$$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in capillary fringe soils [cm^3-H2O/cm^3-soil]
θ_T	=	Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]

D_{ws}^{eff} : effective diffusion coefficient between groundwater and surface soil [cm^2/s]

$$D_{ws}^{eff} = (h_c + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$

where:

h_c	=	Thickness of capillary fringe [cm]
h_v	=	Thickness of vadose zone [cm]
D_{cap}^{eff}	=	Effective diffusion coefficient through capillary fringe [cm^2/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
L_{GW}	=	Depth to groundwater ($h_c + h_v$) [cm]

D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s]

$$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acap}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{wcap}	=	Volumetric water content in capillary fringe soils [cm^3-H2O/cm^3-soil]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]

D_{crack}^{eff} : effective diffusion coeff. through foundation cracks [cm^2/s]

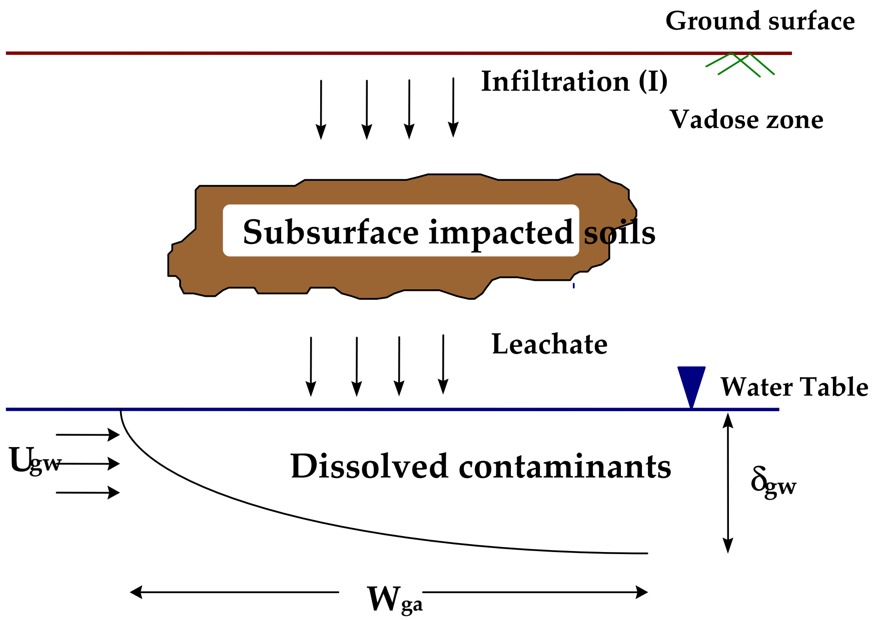
$$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acrack}	=	Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume]
θ_{wcrack}	=	Volumetric water content in foundation/wall cracks [cm^3-H_2O/cm^3-total volume]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]

Source: ASTM E1739-95

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER



$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

where:

$RBTL_{SL}$	=	Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]
$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
LF_{SW}	=	Leaching Factor (from subsurface soil to groundwater) [(mg/L-H2O)/(mg/kg-soil)]

Source: ASTM E1739-95

LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

$$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_{sv}\,\rho_s + H \times \theta_{as}] \times \left(1 + \frac{U_{gw} \times \delta_{gw}}{I \times W_{ga}}\right)}$$

where:

LF_{SW} = Leaching factor from subsurface soil to groundwater [(mg/L-H_2O)/(mg/kg-soil)]
ρ_s = Vadose zone dry soil bulk density [g-soil/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_{sv} = $f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
H = Chemical-specific Henry's Law constant [L-H_2O/L-air]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw} = Ki = Groundwater Darcy Velocity [cm/yr]
K = Hydraulic conductivity of the saturated zone [cm/year]
i = Hydraulic gradient in the saturated zone [-]
δ_{gw} = Groundwater mixing zone thickness [cm]
I = Infiltration rate of water through vadose zone [cm/year]
W_{ga} = Groundwater dimension parallel to groundwater flow direction [cm]

This equation consists of two parts (i) the Summer’s model and (ii) equilibrium conversion of the leachate concentration to a soil concentration on a dry weight basis.

Source: ASTM E1739-95

SOIL CONCENTRATION AT WHICH DISSOLVED PORE WATER AND VAPOR PHASES BECOME SATURATED

Single Component

$$C_s^{SAT} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv}\rho_s]$$

Multiple Components

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv}\rho_s]$$

where:

C_s^{SAT}	=	Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
S	=	Pure component solubility in water [mg/L-H_2O]
S_{ei}	=	Effective solubility of component *i* in water = $x_i \times S$ [mg/L-H_2O]
x_i	=	Mole fraction of component *i* = $(w_i \times MW_{avg})/MW_i$ [-]
w_i	=	Weight fraction of component *i* [-]
MW_{avg}	=	Average molecular weight of mixture [g/mole]
MW_i	=	Molecular weight of component *i* [g/mole]
ρ_s	=	Vadose zone dry soil bulk density [g-soil/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
f_{ocv}	=	Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM E1739-95

SOIL VAPOR CONCENTRATION AT WHICH VAPOR PHASE BECOMES SATURATED

Single Component

$$C_v^{SAT} = \frac{P^s \times MW}{R \times T} \times 10^6$$

Multiple Components

$$C_v^{SAT} = \frac{x_i \times P_i^s \times MW_i}{R \times T} \times 10^6$$

where:

- C_v^{SAT} = Soil vapor concentration at which vapor phase become saturated [mg/m^3-air]
- P^s = Saturate vapor pressure [atm]
- P_i^s = Effective vapor pressure of component *i* in water = $x_i \times P^s$ [atm]
- R = Ideal gas constant [0.08206 atm•L/mol•K]
- T = Temperature [K]
- S_{ei} = Effective solubility of component *i* in water = $x_i \times S$ [mg/L-H_2O]
- x_i = Mole fraction of component $i = (w_i \times MW_{avg})/MW_i$ [-]
- w_i = Weight fraction of component *i* [-]
- MW_{avg} = Average molecular weight of mixture [g/mole]
- MW_i = Molecular weight of component *i* [g/mole]
- ρ_s = Vadose zone dry soil bulk density [g-soil/cm^3-soil]
- 10^6 = Conversion factor [(g/L)/(mg/m^3)]

Source: ASTM E1739-95

DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\,\alpha_x}\left[1-\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-vt)\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]}{2\sqrt{\alpha_x\times v\times t}}\right]\times$$

$$\left[erf\left[\frac{(y+Y/2)}{2\sqrt{\alpha_y\,x}}\right] - erf\left[\frac{(y-Y/2)}{2\sqrt{\alpha_y\,x}}\right]\right]\times\left[erf\left[\frac{(z+Z)}{2\sqrt{\alpha_z\,x}}\right] - erf\left[\frac{(z-Z)}{2\sqrt{\alpha_z\,x}}\right]\right]$$

where:

C	=	Dissolved-phase concentration [mg/L]
C_o	=	Dissolved-phase concentration at the source (at x=y=z=0) [mg/L]
v	=	Retarded seepage velocity [m/sec]
λ	=	Overall first order bio-decay rate [1/day]
α_x	=	Longitudinal dispersivity [m]
α_y	=	Lateral dispersivity [m]
α_z	=	Vertical dispersivity [m]
x, y, z	=	Spatial coordinates [m]
t	=	Time [day]
x	=	Distance along the centerline measured from the downgradient edge of the groundwater source [m]
Y	=	GW source dimension perpendicular to GW flow direction [m]
Z	=	GW source (mixing zone) thickness [m]
DA F	=	$C_o/C(x)$

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\,\alpha_x}\left[1-\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right]\times erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right]\times erf\left[\frac{Z}{2\sqrt{\alpha_z\,x}}\right]$$

At the centerline, for steady-state the concentration without decay can be obtained by setting y = 0, z = 0, x << vt, and $\lambda = 0$ as:

$$\frac{C(x)}{C_o} = erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right]\times erf\left[\frac{Z}{2\sqrt{\alpha_z\,x}}\right]$$

Note: Compare to ASTM E1739-95, p. 31, where $Y = S_w$ $Z = S_d$, $v = u$, and $C_o = C_{source}$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

Allowable soil concentration at the source [mg/kg] $= \textit{Target groundwater concentration at the POE} \times \dfrac{DAF_{POE}}{LF_{SW}}$

Allowable groundwater concentration at the POC [mg/L] $= \textit{Target groundwater concentration at the POE} \times \dfrac{DAF_{POE}}{DAF_{POD}}$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
LF_{SW}	=	Dry soil leaching factor [(mg/L-H_2O)/(mg/kg-soil)]

Concentration at POE is expressed in mg/L-H_2O

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

First order decay rate [1/day] $= \dfrac{0.693}{Half\ \ Life}$; $\quad v = \dfrac{Ki}{\theta_{TS} R_s}$

Retardation factor for organics in the saturated zone (R_s) $= 1 + \left(\dfrac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right)$, $\quad K_{ss} = f_{ocs} \times K_{oc}$ (for organics only)

where:

v	=	Regarded seepage velocity [cm/year]
K	=	Hydraulic conductivity in saturated zone [cm/year]
i	=	Hydraulic gradient in saturated zone [-]
ρ_{ss}	=	Saturated zone dry soil bulk density [g-soil/cm^3-soil]
K_{ss}	=	Chemical-specific soil-water sorption coefficient in the saturated zone [cm^3-H_2O/g-soil]
K_{oc}	=	Chemical-specific normalized partition coefficient [cm^3/g-C]
θ_{TS}	=	Total porosity in the saturated zone [cm^3/g-C]
f_{ocs}	=	Fractional organic carbon content in the saturated zone [g-C/g-soil]

STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

$$C_{gw} = \frac{C_{sw}\left(Q_{gw} + Q_{sw}\right)}{Q_{gw}} - C_{su}\left(\frac{Q_{sw}}{Q_{gw}}\right)$$

where:

Q_{gw}	=	Impacted groundwater discharge into the stream [ft^3/day]
C_{gw}	=	Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
Q_{sw}	=	Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft^3/day]
C_{sw}	=	Allowable concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
C_{su}	=	The COCs' concentration upstream of the groundwater plume discharge [mg/L]

STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POC

$$\text{Allowable soil concentration at the source [mg/kg]} = \textit{Target concentration}\ \text{[mg/L]}\ \textit{at the POE} \times \frac{DAF_{POE}}{LF_{SW}}$$

$$\text{Allowable groundwater concentration at the POC [mg/L]} = \textit{Target concentration}\ \text{[mg/L]}\ \textit{at the}\ \text{POE} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and the source estimated using Domenico's equation
LF_{SW}	=	Dry soil leaching factor [(mg/L-H_2O)/(mg/kg-soil)]

For calculation of DAF_{POE} and DAF_{POD}, please refer to Domenico's model.

Table B-1
Toxicological Properties of Chemicals of Concern

Chemicals of Concern	Slope Factor Oral (SF_o) [kg-day/mg]	Slope Factor Inh. (SF_i) [kg-day/mg]	Reference Dose Oral (R_fD_o) (mg/kg-day)	Reference Dose Inh. (R_fD_i) (mg/kg-day)	Oral RA Factor (RAF_o)	Dermal RA Factor (RAFd)	Dermal Perm. Constant(PC) (cm/hr)
Benzene	2.90E-02	2.91E-02	3.00E-03	1.71E-03	1	0.3	0.021
Toluene	NA	NA	2.00E-01	1.14E-01	1	0.03	0.045
Ethylbenzene	NA	NA	1.00E-01	2.86E-01	0.92	0.3	0.074
Xylenes (mixed)	NA	NA	2.00E+00	2.00E-01	0.92	0.3	NA
Ethylene Dibromide (EDB)	8.50E+01	7.70E-01	5.70E-05	5.70E-05	1	0.1	NA
Ethylene Dichloride (EDC)	9.10E-02	9.10E-02	3.00E-02	1.40E-03	1	0.1	NA
Methyl-tert-butyl-ether(MTBE)	3.30E-03	3.50E-04	8.60E-01	8.57E-01	1	0.3	NA
Acenaphthene	NA	NA	6.00E-02	6.00E-02	1	0.3	NA
Anthracene	NA	NA	3.00E-01	3.00E-01	1	0.3	NA
Benzo(a)anthracene	7.30E-01	3.10E-01	NA	NA	1	0.13	0.81
Benzo(a)pyrene	7.30E+00	6.09E+00	NA	NA	0.85	0.13	1.2
Benzo(b)fluoranthene	7.30E-01	3.10E-01	NA	NA	1	0.13	1.2
Benzo(k)fluoranthene	7.30E-02	3.10E-02	NA	NA	1	0.13	NA
Chrysene	7.30E-03	3.10E-03	NA	NA	1	0.13	0.81
Dibenzo(a,h)anthracene	7.30E+00	3.10E+00	NA	NA	1	0.13	NA
Fluoranthene	NA	NA	4.00E-02	4.00E-02	0.5	0.1	0.36
Fluorene	NA	NA	4.00E-02	4.00E-02	1	0.3	NA
Naphthalene	NA	NA	2.00E-02	8.60E-04	1	0.3	0.069
Pyrene	NA	NA	3.00E-02	3.00E-02	1	0.1	NA
TPH-GRO	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TPH-DRO	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TPH-ORO	N/A	N/A	N/A	N/A	N/A	N/A	N/A
>C6 - C8 (Aliphatics)	NA	NA	5.00E+00	1.51E+00	1	0.1	NA
>C8 - C10 (Aliphatics)	NA	NA	1.00E-01	8.57E-02	1	0.1	NA
>C10 - C12 (Aliphatics)	NA	NA	1.00E-01	8.57E-02	1	0.1	NA
>C12 - C16 (Aliphatics)	NA	NA	1.00E-01	8.57E-01	1	0.1	NA
>C16 - C21 (Aliphatics)	NA	NA	2.00E+00	NA	1	0.1	NA
>C21 - C35 (Aliphatics)	NA	NA	2.00E+00	NA	1	0.1	NA
>C8 - C10 (Aromatics)	NA	NA	4.00E-02	5.71E-02	1	0.13	NA
>C10 - C12 (Aromatics)	NA	NA	4.00E-02	5.71E-02	1	0.13	NA
>C12 - C16 (Aromatics)	NA	NA	4.00E-02	5.71E-02	1	0.12	NA
>C16 - C21 (Aromatics)	NA	NA	3.00E-02	NA	1	0.13	NA
>C21 - C35 (Aromatics)	NA	NA	3.00E-02	NA	1	0.13	NA
Tertiary-amyl-methyl-ether (TAME)	NA	NA	4.00E-02	NA	1	0.13	NA
Tertiary-butyl- alcohol (TBA)	NA	NA	9.00E-02	8.50E-02	1	0.13	NA
Ethyl-tert-butyl-ether (ETBE)	NA	NA	1.00E-03	8.50E-02	1	0.13	NA
Diisopropyl ether (DIPE)	NA	NA	1.00E-01	2.85E-04	1	0.13	NA
Ethanol	NA	NA	3.30E-01	5.42E-01	1	0.13	NA
Methanol	NA	NA	5.00E-01	7.40E-02	1	0.1	NA
Arsenic	1.50E+00	1.50E+01	3.00E-04	NA	0.95	0.001	NA
Barium	NA	NA	7.00E-02	1.40E-04	1	0.01	NA
Cadmium	NA	6.30E+00	5.00E-04	NA	1	0.01	NA
Chromium III	NA	NA	1.50E+00	2.86E-05	1	0.1	NA
Chromium VI	NA	2.90E+02	3.00E-03	2.20E-06	0.025	0.01	NA
Selenium	NA	NA	5.00E-03	NA	0.8	0.1	NA

Notes:
N/A: Not Applicable
NA: Not Available

Table B-2
Physical and Chemical Properties of Chemicals of Concern

Chemicals of Concern	Molecular Weight (MW) (g/mol)	Water Solubility (S) (mg/L)	Henry's Law Constant (H)	Org. Carbon Adsorption Coeff. (K_{oc}) (cm^3/g)	Soil-Water Sorption Coeff. Vadose Zone (K_{sv}) (cm^3/g)	Soil-Water Sorption Coeff. Saturated zone (K_{ss}) (cm^3/g)	Molecular Diffusion Coefficient in air (Da) (cm^2/s)	in water (Dw) (cm^2/s)	Saturated Vapor Pressure (P^s) (mm Hg)
Benzene	78.11	1.75E+03	2.28E-01	5.89E+01	3.53E-01	3.53E-01	8.80E-02	9.80E-06	9.50E+01
Toluene	92	5.26E+02	2.72E-01	1.82E+02	1.09E+00	1.09E+00	8.70E-02	8.60E-06	2.82E+01
Ethylbenzene	106.17	1.69E+02	3.23E-01	3.63E+02	2.18E+00	2.18E+00	7.50E-02	7.80E-06	9.60E+00
Xylenes (mixed)	106.16	1.61E+02	3.01E-01	4.07E+02	2.44E+00	2.44E+00	7.00E-02	7.80E-06	8.06E+00
Ethylene Dibromide (EDB)	188	4.32E+03	2.93E-02	5.37E+01	3.22E-01	3.22E-01	2.17E-02	1.90E-05	1.10E+01
Ethylene Dichloride (EDC)	99	8.50E+03	4.00E-02	3.80E+01	2.28E-01	2.28E-01	1.00E-01	6.50E-04	8.13E+01
Methyl-tert-butyl-ether(MTBE)	88.15	5.10E+04	2.41E-02	1.12E+01	6.72E-02	6.72E-02	8.00E-02	1.00E-05	2.49E+02
Acenaphthene	154.21	4.24E+00	6.36E-03	7.08E+03	4.25E+01	4.25E+01	4.21E-02	7.69E-06	3.75E-03
Anthracene	178.24	4.34E-02	2.95E-02	2.95E+04	1.77E+02	1.77E+02	3.24E-02	7.74E-06	2.55E-05
Benzo(a)anthracene	228.3	9.40E-03	1.37E-04	3.98E+05	2.39E+03	2.39E+03	5.10E-02	9.00E-06	1.50E-07
Benzo(a)pyrene	252.32	1.62E-03	4.63E-05	1.02E+06	6.12E+03	6.12E+03	4.30E-02	9.00E-06	4.89E-09
Benzo(b)fluoranthene	252.32	1.50E-03	4.55E-03	1.23E+06	7.38E+03	7.38E+03	2.26E-02	5.56E-06	8.06E-08
Benzo(k)fluoranthene	252.32	8.00E-04	3.40E-05	1.23E+06	7.38E+03	7.38E+03	2.26E-02	5.56E-06	9.59E-11
Chrysene	228.3	1.60E-03	3.88E-03	3.98E+05	2.39E+03	2.39E+03	2.48E-02	6.21E-06	2.80E-09
Dibenzo(a,h)anthracene	278.4	2.49E-03	6.03E-07	3.80E+06	2.28E+04	2.28E+04	2.02E-02	5.18E-06	3.79E-13
Fluoranthene	202.26	2.06E-01	6.60E-04	1.07E+05	6.42E+02	6.42E+02	3.02E-02	6.35E-06	8.13E-06
Fluorene	166.22	1.98E+00	2.61E-03	1.38E+04	8.28E+01	8.28E+01	3.63E-02	7.88E-06	3.24E-03
Naphthalene	128.18	3.10E+01	1.98E-02	2.00E+03	1.20E+01	1.20E+01	5.90E-02	7.50E-06	8.89E-02
Pyrene	202.26	1.35E-01	4.51E-04	1.05E+05	6.30E+02	6.30E+02	2.72E-02	7.24E-06	4.25E-06
TPH-GRO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TPH-DRO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TPH-ORO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
>C6 - C8 (Aliphatics)	100	5.40E+00	5.10E+01	3.98E+03	2.39E+01	2.39E+01	1.00E-01	1.00E-05	4.79E+01
>C8 - C10 (Aliphatics)	130	4.30E-01	8.20E+01	3.16E+04	1.90E+02	1.90E+02	1.00E-01	1.00E-05	4.79E+00
>C10 - C12 (Aliphatics)	160	3.40E-02	1.20E+02	2.51E+05	1.51E+03	1.51E+03	1.00E-01	1.00E-05	4.79E-01
>C12 - C16 (Aliphatics)	200	7.60E-04	5.20E+02	5.01E+06	3.01E+04	3.01E+04	1.00E-01	1.00E-05	3.65E-02
>C16 - C21 (Aliphatics)	270	1.30E-06	4.90E+03	6.31E+08	3.79E+06	3.79E+06	1.00E-01	1.00E-05	8.40E-04
>C21 - C35 (Aliphatics)	270	1.30E-06	4.90E+03	6.31E+08	3.79E+06	3.79E+06	1.00E-01	1.00E-05	8.40E-04
>C8 - C10 (Aromatics)	120	6.50E+01	4.80E-01	1.58E+03	9.48E+00	9.48E+00	1.00E-01	1.00E-05	4.79E+00
>C10 - C12 (Aromatics)	130	2.50E+01	1.40E-01	2.51E+03	1.51E+01	1.51E+01	1.00E-01	1.00E-05	4.79E-01
>C12 - C16 (Aromatics)	150	5.80E+00	5.30E-02	5.01E+03	3.01E+01	3.01E+01	1.00E-01	1.00E-05	3.65E-02
>C16 - C21 (Aromatics)	190	6.50E-01	1.30E-02	1.58E+04	9.50E+01	9.50E+01	1.00E-01	1.00E-05	8.40E-04
>C21 - C35 (Aromatics)	240	6.60E-03	6.70E-04	1.26E+05	7.55E+02	7.55E+02	1.00E-01	1.00E-05	3.34E-07
Tertiary-amyl-methyl-ether (TAME)	102	4.29E+03	1.30E-01	4.17E+01	2.50E-01	2.50E-01	6.99E-02	7.37E-06	9.97E+01
Tertiary-butyl- alcohol (TBA)	74.1	2.35E+05	3.00E-03	4.22E+00	2.53E-02	2.53E-02	8.52E-02	9.11E-06	3.14E+01
Ethyl-tert-butyl-ether (ETBE)	102	5.03E+03	9.99E-02	3.72E+01	2.23E-01	2.23E-01	6.95E-02	7.34E-06	9.00E+01
Diisopropyl ether (DIPE)	102	2.67E+03	1.63E-01	6.46E+01	3.87E-01	3.87E-01	6.81E-02	7.15E-06	3.80E+01
Ethanol	46.1	2.96E+05	2.77E-04	1.19E+00	7.16E-03	7.16E-03	1.15E-01	1.22E-05	3.26E+01
Methanol	32.04	1.00E+06	1.87E-04	9.00E+00	5.40E-02	5.40E-02	1.50E-01	1.64E-05	1.22E+02
Arsenic	74.9	NA	NA	N/A	2.51E+01	2.51E+01	N/A	N/A	NA
Barium	137	NA	NA	N/A	1.10E+01	1.10E+01	N/A	N/A	NA
Cadmium	112.4	NA	NA	N/A	1.51E+01	1.51E+01	N/A	N/A	NA
Chromium III	52	NA	NA	N/A	1.20E+03	1.20E+03	N/A	N/A	NA
Chromium VI	52	NA	NA	N/A	1.90E+01	1.90E+01	N/A	N/A	NA
Selenium	78.96	NA	NA	N/A	2.20E+00	2.20E+00	N/A	N/A	NA

Notes:
N/A: Not Applicable
NA: Not Available

Table B-3 *(Page 1 of 2)*
Exposure Factors

Parameter	Symbol	Unit	Default
Averaging Time for Carcinogen	AT_c	year	70
Averaging Time for Non-Carcinogen	AT_{nc}	year	=ED
Body Weight:			
Resident Child	BW	kg	15
Resident Adult	BW	kg	70
Non-Residential Worker	BW	kg	70
Construction Worker	BW	kg	70
Exposure Duration:			
Resident Child	ED	year	6
Resident Adult	ED	year	24
Non-Residential Worker	ED	year	25
Construction Worker	ED	year	1
Exposure Time for Dermal Contact with Groundwater			
Resident Child	ETd	hours/day	1
Resident Adult	ETd	hours/day	1
Non-Residential Worker	ETd	hours/day	1
Construction Worker	ETd	hours/day	1
Exposure Frequency:			
Resident Child	EF	day/year	350
Resident Adult	EF	day/year	350
Non-Residential Worker	EF	day/year	250
Construction Worker	EF	day/year	90
Soil Ingestion Rate:			
Resident Child	IR_{soil}	mg/day	200
Resident Adult	IR_{soil}	mg/day	100
Non-Residential Worker	IR_{soil}	mg/day	100
Construction Worker	IR_{soil}	mg/day	100
Groundwater Ingestion Rate:			
Resident Child	IR_w	L/day	1
Resident Adult	IR_w	L/day	2
Non-Residential Worker	IR_w	L/day	2
Indoor Inhalation Rate (hourly):			
Resident Child	IR_{ai}	m^3/hr	0.416
Resident Adult	IR_{ai}	m^3/hr	0.833
Non-Residential Worker	IR_{ai}	m^3/hr	0.833

Table B-3 *(Page 2 of 2)*
Exposure Factors

Parameter	Symbol	Unit	Default
Exposure Time for Indoor Inhalation:			
Resident Child	ET_{in}	hr/day	18
Resident Adult	ET_{in}	hr/day	18
Non-Residential Worker	ET_{in}	hr/day	18
Construction Worker	ET_{in}	hr/day	10
Indoor Inhalation Rate (daily):			
Resident Child	IRa	m^3/day	7.5
Resident Adult	IRa	m^3/day	15.0
Non-Residential Worker	IRa	m^3/day	15.0
Outdoor Inhalation Rate (hourly):			
Resident Child	IR_{ao}	m^3/hr	0.416
Resident Adult	IR_{ao}	m^3/hr	0.833
Non-Residential Worker	IR_{ao}	m^3/hr	0.833
Construction Worker	IR_{ao}	m^3/hr	0.833
Exposure Time for Outdoor Inhalation:			
Resident Child	ET_{out}	hr/day	6
Resident Adult	ET_{out}	hr/day	6
Non-Residential Worker	ET_{out}	hr/day	6
Construction Worker	ET_{out}	hr/day	12
Outdoor Inhalation Rate (daily):			
Resident Child	IRa	m^3/day	2.5
Resident Adult	IRa	m^3/day	5.0
Non-Residential Worker	IRa	m^3/day	5.0
Construction Worker	IRa	m^3/day	10.0
Skin Surface Area:			
Resident Child	SA	cm^2/day	4236
Resident Adult	SA	cm^2/day	4714
Non-Residential Worker	SA	cm^2/day	4714
Construction Worker	SA	cm^2/day	4714
Soil to Skin Adherence Factor:			
Resident Child	M	mg/cm^2	1
Resident Adult	M	mg/cm^2	1
Non-Residential Worker	M	mg/cm^3	1
Construction Worker	M	mg/cm^2	1
Target Risk Level	TR	--	1.00E-05
Target Hazard Quotient	THQ	--	1

Note:

Defalut values are used to calculate DTLs and Tier 1 RBTLs.

Table B-4 *(Page 1 of 2)*

Fate and Transport Parameters

Parameter	Symbol	Unit	Default
SOIL PARAMETERS:			
Soil Source Dimension Parallel to Wind Direction	W_a	cm	1500
Depth to Subsurface Soil Sources	d_{ts}	cm	91.44
Depth of Surficial Soil Zone	d_s	cm	91.44
Depth to Soil Vapor Measurement	d_{sv}	cm	91.44
VADOSE ZONE:			
Total Soil Porosity	q_T	cm^3/cm^3-soil	0.434
Volumetric Water Content	q_{ws}	cm^3/cm^3	0.15
Volumetric Air Content	q_{as}	cm^3/cm^3	0.284
Thickness	h_v	cm	295
Dry Soil Bulk Density	r_s	g/cm^3	1.5
Fractional Organic Carbon Content	f_{ocv}	g-C/g-soil	0.006
SOIL IN CRACKS:			
Total Soil Porosity (set equal to q_T)	q_{Tcrack}	cm^3/cm^3-soil	0.434
Volumetric Water Content	q_{wcrack}	cm^3/cm^3	0.15
Volumetric Air Content	q_{acrack}	cm^3/cm^3	0.284
CAPILLARY FRINGE:			
Total Soil Porosity (set equal to q_T)	q_{Tcap}	cm^3/cm^3-soil	0.434
Volumetric Water Content	q_{wcap}	cm^3/cm^3	0.3906
Volumetric Air Content	q_{acap}	cm^3/cm^3	0.0434
Thickness	h_c	cm	5
GROUNDWATER PARAMETERS:			
Depth to Groundwater	L_{gw}	cm	300
GW Source Dimension Perpendicular to GW Flow Direction	Y	cm	1500
GW Source Dimension Parallel to GW Flow Direction	W_{ga}	cm	1500
Total Porosity in the Saturated Zone	q_{TS}	cm^3/cm^3	N/A
Dry Soil Bulk Density (Saturated Zone)	r_{ss}	g/cm^3	N/A
Fractional Organic Carbon Content in the Saturated Zone	f_{ocs}	g-C/g-soil	N/A
Groundwater Mixing Zone Thickness	d_{gw}	cm	200
Hydraulic Conductivity in the Saturated Zone	K	cm/year	625000
Hydraulic Gradient in the Saturated Zone	i	cm/cm	0.004
Groundwater Darcy Velocity	U_{gw}	cm/year	2500.00
Infiltration Rate of water through vadose zone	I	cm/year	14
AMBIENT AIR PARAMETERS:			
Breathing Zone Height	d_a	cm	200
Inverse of Mean Concentration at Center of Square Source	Q/C	$(g/m^2\text{-}s)/(kg/m^3)$	81.64
Fraction of Vegetative Cover	V	m^2/m^2	0.5
Mean Annual Wind Speed	U_m	m/s	4.69
Equivalent Threshold Value of Windspeed	U_t	m/s	11.32
Windspeed Distribution Function from Cowherd et. al, 1985	F(x)	unitless	0.194

Table B-4 *(Page 2 of 2)*

Fate and Transport Parameters

Parameter	Symbol	Unit	Default
ENCLOSED SPACE PARAMETERS:			
Enclosed Space Air Exchange Rate:			
Residential Structure	ER	1/24 hrs	12.096
Non-Residential Structure	ER	1/24 hrs	19.872
Enclosed Space Volume/Infiltration Area Ratio:			
Residential Structure	L_B	cm	200
Non-Residential Structure	L_B	cm	300
Enclosed Space Foundation or Wall Thickness:			
Residential Structure	L_{crack}	cm	15
Non-Residential Structure	L_{crack}	cm	15
Area Fraction of Cracks in Foundation/Walls:			
Residential Structure	h	cm^2/cm^2	0.01
Non-Residential Structure	h	cm^2/cm^2	0.01
PARTICULATE EMISSION RATE			
Residential and Non-Residential	P_e	g/cm^2sec	6.90E-14
Construction Worker	P_e	g/cm^2sec	6.90E-09
AVERAGING TIME FOR VAPOR FLUX:			
Resident Child	t	sec	1.89E+08
Age-Adjusted Individual	t	sec	9.46E+08
Resident Adult	t	sec	7.57E+08
Non-Residential Worker	t	sec	7.88E+08
Construction Worker	t	sec	3.15E+07

Notes:

Defalut values are used to calculate DTLs, Tier 1 RBTLs, and Tier 2 SSTLs.

N/A: Not Applicable