

**OAKLAND RISK-BASED CORRECTIVE ACTION:
TECHNICAL BACKGROUND DOCUMENT**

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FOREWORD

Oakland Risk-Based Corrective Action: Technical Background Document establishes the technical basis for the Oakland risk-based corrective action (RBCA) approach.

The Oakland RBCA approach is the result of extensive work by the Urban Land Redevelopment (ULR) Program Technical Advisory Committee, consisting of representatives from the Alameda County Department of Environmental Health, the Department of Toxic Substances Control, the San Francisco Bay Regional Water Quality Control Board, the United States Environmental Protection Agency (U.S. EPA), Spence Environmental Engineering, volunteer environmental consultants, and the City of Oakland. The environmental consulting firms that volunteered their time and assisted with peer review included: Cambria Environmental Technology; Chaney, Walton & McCall; Environ; Geomatrix Consultants; ICF Kaiser; Levine-Fricke-Recon; SECOR International; SOMA Environmental Engineering; Subsurface Consultants; Weiss Associates; and Woodward-Clyde. The ULR Program was developed through a grant from the U.S. EPA, Region 9, Office of Underground Storage Tanks.

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1.0 INTRODUCTION

The City of Oakland risk-based corrective action (RBCA) approach is based on the guidelines prescribed in *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (ASTM 1995). ASTM (1995) integrates risk and exposure assessment practices with site assessment activities and remedial measures to ensure that the selected corrective action is protective of human health and the environment. The U.S. EPA has endorsed the ASTM (1995) approach and several state regulatory agencies across the nation have adopted it. The approach is being applied at a wide variety of sites, not just those with petroleum releases.

ASTM (1995) prescribes a three-tiered decision-making process for evaluating sites with potential environmental issues. In Tier 1, sites are characterized through information collected from historical records, a visual inspection, and minimal site investigation. Contaminant sources, impacted human and environmental receptors, and potential contaminant transport pathways are identified. Site concentrations are compared with Tier 1 risk-based screening levels (RBSLs) for all applicable exposure pathways. Site concentrations above Tier 1 RBSLs must be addressed through corrective actions or further analysis under Tiers 2 or 3.

In Tier 2, additional site characterization constituting a minimal incremental effort is undertaken to establish site-specific target levels (SSTLs). Tier 2 SSTLs are generally less stringent than Tier 1 RBSLs, but are still based on conservative assumptions. Site concentrations are compared with Tier 2 SSTLs for all applicable exposure pathways. Site concentrations above Tier 2 SSTLs must be addressed through corrective actions or further analysis under Tier 3.

Tier 3 represents a substantial incremental effort relative to Tiers 1 and 2. The analysis is more complex and may include highly-detailed site assessment, probabilistic evaluations, and sophisticated chemical fate and transport models. Tier 3 SSTLs are established and, if the selected target levels are exceeded and corrective action is necessary, a corrective action plan must be developed and implemented (ASTM 1995).

The Oakland RBCA approach forms the centerpiece of the City of Oakland Urban Land Redevelopment Program, which provides the following:

- ▶ Oakland-specific Tier 1 RBSLs
- ▶ Oakland-specific Tier 2 SSTLs based on Oakland's geology
- ▶ Guidance for conducting a cost-efficient Tier 3 analysis (City of Oakland 2000)

Section 2 explains the methodology behind the Oakland RBCA approach. Section 3 describes the input parameters used in the Oakland RBCA equations.

Appendix A presents the equations used to calculate the Oakland RBCA levels. Appendix B provides the justification for all the input parameter values selected. Appendix C contains a sensitivity analysis describing the relationship of each input parameter to the calculated RBCA levels. Appendix D presents spreadsheet validation results for the Oakland RBCA look-up tables that are found in *Oakland Urban Land Redevelopment Program: Guidance Document* (City of Oakland 2000).

2.0 METHODOLOGY

The Oakland RBCA approach is based on the methodology recommended by ASTM (1995) and is supported by other standard risk assessment literature (U.S. EPA 1989a, 1996).

The Oakland RBCA look-up tables contain Tier 1 RBSLs and Tier 2 SSTLs for commonly-found chemicals of concern. The Tier 1 RBSLs and Tier 2 SSTLs are presented for both a residential and a commercial/industrial land use scenario for each of eight exposure pathways. The Tier 1 RBSLs may be applied at all sites in Oakland; the Tier 2 SSTLs may only be applied at sites where one or more of the three predominant Oakland soil types (Merritt Sands, sandy silts and/or clayey silts) prevails. Different SSTLs are presented for each of these soil types. In order to qualify for either the Tier 1 or Tier 2 Oakland RBCA levels, a site must first pass a set of eligibility criteria developed to ensure that site conditions do not violate any of the basic assumptions incorporated in the Oakland RBCA approach (City of Oakland 2000).

The Oakland RBCA look-up tables are created using an Excel spreadsheet. The Oakland RBCA spreadsheet may be downloaded off of the internet at no cost at www.oaklandpw.com.

Section 2.1 discusses how human health risks are typically calculated. This lays the groundwork for “back-calculating” RBCA levels. **Section 2.2** presents the methodology used to compute the Oakland RBCA levels in each of the media considered.

2.1 Calculating Human Health Risk

Risk Assessment Guidance for Superfund (U.S. EPA 1989a) details the processes used to estimate human health risk from various contaminated media. The human health risk assessment calculation is sometimes called the “forward calculation”. The inputs required for this forward calculation are: chemical concentration, chemical toxicity, and exposure levels (e.g., two liters of water ingested per day). A risk assessment is conducted for an individual site and the calculated risk level is compared with a selected, “acceptable” risk level. If the acceptable risk is exceeded, the site may require corrective action.

Risk assessments analyze chemicals in two ways: as “carcinogens” and as “hazards” (or “non-carcinogens”). Carcinogens are chemicals that have been shown to cause cancer or are suspected to cause cancer. For carcinogens, the calculation of risk assumes that there is no “safe dose” (i.e., an exposure of any magnitude has some effect over a lifetime). The risk from these chemicals is presented as an “individual excess lifetime cancer risk” (IELCR) and represents the likelihood of developing “excess” cancer (i.e., additional cancer beyond the populations average) due to the estimated exposure to the chemical. The IELCR is expressed as a probability. The toxicity values for carcinogens are known as slope factors. The higher the slope factor is, the more risk a chemical poses at a given dose.

Hazards are chemicals that neither have been shown to cause cancer nor are suspected to cause cancer, but that may cause other health problems, such as liver toxicity, neurotoxicity, or respiratory malfunction. For hazards, the calculation of risk assumes that there is a safe dose (or “reference dose”) below which no adverse health effects occur. Exposure is not considered cumulative as in the carcinogenic risk calculation.

The measure used to determine the potential for non-carcinogenic adverse health effects is called a hazard quotient. A hazard quotient is the ratio of the estimated exposure level to the reference dose. A hazard quotient below one indicates that no adverse health effects are expected.

Hazard quotients are not probabilities. Chemicals with low reference doses are more toxic than ones with higher reference doses.

Some chemicals are both a carcinogen and a hazard. These chemicals have both a slope factor and a reference dose.

2.2 Calculating Risk-Based Corrective Action Levels

The Oakland RBCA approach calculates RBSLs and SSTLs by manipulating the human health risk assessment equations to solve for an acceptable concentration. Instead of calculating the risk (either IELCR or hazard quotient), a target risk level is plugged into the equations along with the exposure parameter values and chemical properties data. This method of calculating RBCA levels is sometimes called the “back-calculation”.

The methodology used to calculate the Oakland Tier 1 and Tier 2 RBCA levels is identical to that recommended by ASTM (1995), with the following exceptions:

- ▶ For carcinogenic health effects, residential exposure assumes a combined child/adult receptor (six years as a child and 24 years as an adult). This approach is more conservative (i.e., generates lower acceptable concentrations) than assuming the entire exposure is as an adult, as does ASTM (1995).
- ▶ For non-carcinogenic health effects, the residential receptor is always assumed to be a child. This approach is more conservative than assuming that the residential receptor is always an adult, as does ASTM (1995).
- ▶ A “water used for recreation” medium is included, with the RBCA equations based on the same principles that guided the development of the ASTM (1995) equations for exposure pathways in the other media. This medium is not addressed by ASTM (1995).
- ▶ ASTM (1995) default values are replaced with Oakland-specific values when appropriate.

The following subsections describe the exposure pathways considered for calculating RBCA levels in each of five media: surficial soil, subsurface soil, groundwater, air, and water used for recreation.

2.2.1 Surficial Soil

Surficial soil is defined as the top one meter of soil. Different RBCA levels are calculated for this shallow soil than for the rest of the unsaturated soil layer because it is assumed that direct receptor contact with surficial soil is possible. The potential exposure scenarios considered for chemicals in surficial soil are:

- ▶ ingestion of soil
- ▶ dermal contact with soil
- ▶ inhalation of vapors in outdoor air
- ▶ inhalation of particulates in outdoor air

The RBCA levels for surficial soil assume that all four of the potential exposure scenarios occur simultaneously; that is, the four doses are added together to obtain an overall dose from surficial soil, from which the RBCA level is then calculated.

Ingestion and dermal contact are direct pathways: the receptor is contacting the contaminant in the source area (i.e., in the surficial soil).

Inhalation of vapors and inhalation of particulates are indirect pathways: the receptor is contacting the contaminant outside of the source area (i.e., not in the surficial soil). For the inhalation scenarios, two volatilization factors are employed to account for the chemical moving from soil to outdoor air: in one case as a vapor; in the other as a particulate. A concentration in soil is then calculated below which air quality in the breathing zone is not impacted at a level that poses unacceptable risk.

2.2.2 *Subsurface Soil*

Subsurface soil is defined as vadose zone soil that is deeper than one meter below ground surface. Three different RBCA levels are calculated for subsurface soil, one for each of the following exposure scenarios:

- ▶ inhalation of vapors in indoor air
- ▶ inhalation of vapors in outdoor air
- ▶ ingestion of groundwater

These are indirect pathways. Volatilization and leaching factors from subsurface soil are employed to calculate the RBCA levels.

2.2.3 *Groundwater*

Three different RBCA levels are calculated for groundwater, one for each of the following exposure scenarios:

- ▶ ingestion of groundwater
- ▶ inhalation of vapors in indoor air
- ▶ inhalation of vapors in outdoor air

Ingestion of groundwater is a direct pathway. The inhalation of vapors scenarios are indirect pathways. Volatilization factors from groundwater are employed to calculate RBCA levels for each.

2.2.4 *Air*

Two different RBCA levels are calculated for air, one for each of the following exposure scenarios:

- ▶ inhalation of indoor air
- ▶ inhalation of outdoor air

These are direct pathways. (Note: RBCA levels for air are not presented in the Oakland RBCA tables. They are, however, used as inputs to back-calculate soil and groundwater concentrations protective of inhalation of indoor and outdoor air.)

2.2.5 Water Used for Recreation

The Oakland RBCA tables also contain RBSLs and SSTLs for water used for recreation. These RBCA levels apply to scenarios such as exposure to water in nearby creeks and exposure to groundwater or surface water used to fill swimming pools. This recreational-use scenario is not addressed by ASTM (1995).

The RBCA levels calculated for water used for recreation assume that the following two potential exposure scenarios occur simultaneously:

- ▶ ingestion of the water
- ▶ dermal contact with the water

These are direct pathways. They are based on a hypothetical swimming scenario in which the exposed individual's entire body is submerged.

3.0 INPUT PARAMETERS

The input parameters that comprise the Oakland RBCA equations fall into five categories:

- (1) soil-specific transport parameters
- (2) non-soil-specific transport parameters
- (3) receptor-specific parameters
- (4) target risk levels
- (5) chemical-specific parameters

The following subsections describe the individual input parameters that pertain to each of these categories. (For a detailed justification and analysis of the values selected for all input parameters, please refer to Appendix B.)

3.1 Soil-Specific Transport Parameters

The soil-specific transport parameter values selected for Oakland RBCA Tier 1 reflect conservative assumptions about the geology that may be found at any site in Oakland. The soil-specific transport parameter values selected for Oakland RBCA Tier 2 reflect the characteristics of the three predominant soil types found in Oakland. These soil types are: Merritt sands, sandy silts and clayey silts.

Merritt sands are mostly located in the flatlands area to the west of Lake Merritt. They are a fine-grained, silty sand with lenses of sandy clay and clay (Radbruch 1957). Merritt sands have a low moisture content and high permeability.

Sandy silts are found throughout Oakland. They are made up of unconsolidated, moderately-sorted sand, silt, and clay sediments, with both fine-grained and coarse-grained materials. Sandy silts have a medium moisture content and moderate permeability.

Clayey silts are primarily found along the Bay and estuary, and in land fills from those areas. They may contain organic materials, peaty layers and small lenses of sand. Clayey silts have a high moisture content and low permeability.

Table 1 provides a description of the soil-specific transport parameters.

Table 1. Description of Oakland RBCA Soil-Specific Transport Parameters

Input Parameter	Description
<i>Capillary fringe thickness</i>	Height of the zone just above the water table, where water is drawn upward by capillary attraction.
<i>Capillary fringe air content</i>	Fraction of the capillary fringe that is air: expressed as volume of air divided by total volume of soil.
<i>Capillary fringe water content</i>	Fraction of the capillary fringe that is water: expressed as volume of water divided by total volume of soil.
<i>Fraction organic carbon in soil (F_{oc}^*)^a</i>	Measure of the effect of organic carbon, clay and electromagnetic molecular forces on sorption of chemicals to soil.
<i>Groundwater Darcy velocity</i>	Measure of amount of groundwater flowing through the saturated zone (hydraulic conductivity X hydraulic gradient).
<i>Groundwater mixing zone thickness</i>	Depth to which contaminants entering groundwater from the unsaturated zone mix with the flow of groundwater.
<i>Infiltration rate through the vadose zone</i>	Amount of water (and, hence, contaminant) that travels through the vadose zone and reaches groundwater.
<i>Soil bulk density</i>	Weight of the soil per volume ([real density]—[total porosity][real density]).
<i>Soil to skin adherence factor</i>	Amount of soil that will stick to skin upon contact.
<i>Total soil porosity</i>	Pore spaces divided by total volume of soil.
<i>Vadose zone air content</i>	Fraction of the unsaturated zone that is air: expressed as volume of air divided by total volume of soil.
<i>Vadose zone water content</i>	Fraction of the unsaturated zone that is water: expressed as volume of water divided by total volume of soil.
<i>Vadose zone thickness</i>	Distance from the soil surface to the water table, excluding the capillary fringe.

^aIn the Oakland RBCA approach, this input parameter was modified to take into consideration that factors other than organic carbon also cause chemicals to sorb to soil (Spence and Gomez 1999).

3.2 Non-Soil-Specific Transport Parameters

The Oakland RBCA equations employ several transport parameters that do not vary by soil type. Table 2 provides a description of these.

Table 2. Description of Oakland RBCA Non-Soil-Specific Transport Parameters

Input Parameter	Description
<i>Areal fraction of cracks in building foundation</i>	Fraction of foundation or basement walls comprised of cracks (including expansion or drainage joint). It is the area of the cracks over the total area of the foundation walls.
<i>Foundation air content</i>	Fraction of air in cracks in the foundation or basement walls.
<i>Foundation water content</i>	Fraction of water in cracks in the foundation or basement walls.
<i>Foundation thickness</i>	Thickness of the building foundation (if any).
<i>Lower depth of surficial soil zone</i>	Maximum depth of soil with which an individual may come in direct contact.
<i>Depth to subsurface soil sources</i>	Distance from the foundation to the contamination in subsurface soil.
<i>Depth to groundwater</i>	Depth to the water table from the ground surface, including the capillary fringe.
<i>Width of source area parallel to wind or groundwater flow direction</i>	Distance from one side of the soil source to the other in the predominant direction of groundwater flow. The width of the source is used to estimate the size of the mixing zones in groundwater and outdoor air.
<i>Outdoor air mixing zone height</i>	Height of the imaginary “breathing box” used to estimate the size of the mixing zone in the air.
<i>Particulate emission rate</i>	Rate at which dust particles ≤ 10 μm in diameter become airborne and enter the breathing zone.
<i>Wind speed above ground surface in outdoor air mixing zone</i>	Average annual wind speed at the site in question.

3.3 Receptor-Specific Parameters

Receptor-specific parameters are those input parameters whose values vary by receptor (child, adult or worker) and land use scenario (residential or commercial/industrial). Table 3 provides a description of the receptor-specific parameters.

Table 3. Description of Oakland RBCA Receptor-Specific Parameters

Input Parameter	Description
<i>Averaging time for carcinogenic effects</i>	Number of years over which exposure to a carcinogen is statistically normalized.
<i>Averaging time for non-carcinogenic effects</i>	Same as the exposure duration (see below).
<i>Averaging time for vapor flux</i>	Length of time over which a chemical is assumed to volatilize from surficial soil.
<i>Body weight</i>	Average body weight of the receptor (child or adult).
<i>Building air volume/floor area</i>	The height of the ceiling.
<i>Exposure duration</i>	Number of years over which a person may be exposed to a chemical of concern.
<i>Exposure frequency</i>	Days per year a person may be exposed to a chemical.
<i>Exposure frequency to water used for recreation</i>	Days per year that a person might come in recreational contact with contaminated water.
<i>Exposure time to indoor air</i>	Hours per day a person is inside an impacted building.
<i>Exposure time to outdoor air</i>	Hours per day a person is outside at an impacted site.
<i>Exposure time to water used for recreation</i>	Average amount of time spent in contact with water used for recreation during each exposure.
<i>Groundwater ingestion rate</i>	Amount of groundwater that is extracted from a domestic well and ingested each day.
<i>Indoor air exchange rate</i>	Amount of indoor air replaced by outdoor air each day.
<i>Indoor inhalation rate</i>	Average volume of indoor air breathed per hour.
<i>Ingestion rate of water used for recreation</i>	Amount of water used for recreation that is inadvertently ingested (e.g., while swimming).
<i>Outdoor inhalation rate</i>	Average volume of outdoor air breathed per hour.
<i>Skin surface area exposed to soil</i>	Surface area of skin that may come in contact with surficial soil and absorb it soil through the skin.
<i>Skin surface area exposed to water used for recreation</i>	Surface area of skin that may come in contact with water used for recreation.
<i>Soil ingestion rate</i>	Amount of soil ingested per day. For adults, this may be from yard work; for children, from eating dirt.

3.4 Target Risk Levels

The Oakland RBCA equations employ two types of target risk levels: an individual excess lifetime cancer risk (IELCR) for carcinogenic health effects and a hazard quotient for non-carcinogenic health effects. If a chemical has both a slope factor and a reference dose, both target risk levels are used and two RBCA levels are generated for each exposure pathway.

For carcinogenic health effects, the target risk level represents a subjective risk level that is considered “acceptable”. For example, an IELCR of 1×10^{-6} means that, for each individual exposed to a given chemical of concern at the levels assumed in the model, there is a one-in-one-million chance of excess cancer over a lifetime. For non-carcinogenic health effects, if the

estimated dose is less than the reference dose, it is assumed that no adverse health effects occur. The hazard quotient is not based on a lifetime of exposure, as is the case with carcinogens; rather, it is based on a shorter term, chronic exposure.

Table 4 provides a description of the target risk levels.

Table 4. Description of Oakland RBCA Target Risk Levels

Input Parameter	Description
<i>Individual Excess Lifetime Cancer Risk (IELCR)</i>	Likelihood of a single person experiencing excess cancer from exposure to a chemical over a lifetime.
<i>Hazard Quotient</i>	Ratio of the estimated dose to the reference dose.

3.5 Chemical-Specific Parameters

The Oakland RBCA equations employ chemical-specific parameters to account for differences in the type and level of risk chemicals can pose. Table 5 provides a description of these.

Table 5. Description of Oakland RBCA Chemical-Specific Parameters

Input parameter	Description
<i>Slope factor (oral, inhalation and dermal)</i>	Estimate of the probability of a carcinogenic response per unit intake of a chemical over a lifetime.
<i>Reference dose (oral, inhalation and dermal)</i>	Toxicity value for evaluating non-carcinogenic health effects resulting from exposure to a chemical.
<i>Absorption adjustment factors</i>	Used to calculate the absorption of chemicals into the body, from dermal contact, oral intake or inhalation.
<i>Skin permeability coefficient</i>	Used to calculate movement of the chemical in water across the skin and into the bloodstream.
<i>Maximum Contaminant Level (MCL)</i>	The maximum concentration of a chemical that is allowed in drinking water by the State of California.
<i>Solubility</i>	Amount of the chemical that can dissolve in a fixed amount of water.
<i>Henry's Law constant</i>	Equilibrium ratio of the partial pressure of a chemical in air to the concentration in water.
<i>Organic carbon partition coefficient (K_{oc})</i>	Describes the affinity of the chemical for adsorbing to organic carbon in the soil.
<i>Partition coefficient for inorganics (K_s)</i>	Used only for metals to calculate their partitioning onto soil.
<i>Diffusion coefficient in air</i>	Measure of the amount of diffusion of a vapor-phase chemical in air.
<i>Diffusion coefficient in water</i>	Measure of the amount of diffusion of a chemical that is dissolved in water.

This appendix presents the equations used to calculate the Oakland Tier 1 RBSLs and Tier 2 SSTLs for each of the five media considered: surficial soil, subsurface soil, groundwater, air, and water used for recreation.

Please note the following:

- ▶ Different equations are used to calculate RBCA levels for carcinogenic and non-carcinogenic health effects.
- ▶ For carcinogenic health effects under the residential land use scenario, the equations assume an additive child/adult receptor; that is, the receptor is assumed to be a young child for six years of the 30-year exposure duration and an adult for the remaining 24 years. For non-carcinogenic health effects under the residential land use scenario, the equations assume that the receptor is always a child.
- ▶ For both carcinogenic and non-carcinogenic health effects under the commercial/industrial land use scenario, the equations assume that the receptor is always an adult.
- ▶ For the subsurface soil medium, if the calculated RBCA level exceeds the saturated soil concentration (C_{sat}), the target risk cannot be exceeded for any concentration and “SAT” is entered in the appropriate Tier 1 or Tier 2 table.
- ▶ For the groundwater and water used for recreation media, if the calculated RBCA level exceeds the solubility of the chemical in water, the target risk cannot be exceeded for any concentration and “>SOL” is entered in the appropriate Tier 1 or Tier 2 look-up table.
- ▶ If the RBCA level exceeds the California MCL for ingestion of groundwater, then (1) the MCL is entered in the Tier 1 and Tier 2 look-up tables in the exposure pathway “groundwater: ingestion”; and (2) the MCL is used as an input in the equation to calculate the RBCA level for the exposure pathway “subsurface soil: ingestion of groundwater impacted by leachate”.
- ▶ RBCA levels for air are not presented in the Oakland RBCA Tier 1 and Tier 2 look-up tables. They are used only as inputs to back-calculate soil and groundwater concentrations protective of inhalation of indoor and outdoor air.

Section A.1 defines the input parameter symbols used in the Oakland RBCA equations. **Section A.2** presents the equations used to calculate the Oakland RBCA levels for carcinogenic health effects. **Section A.3** presents the equations used to calculate the Oakland RBCA levels for non-carcinogenic health effects. **Section A.4** presents the equations for the volatilization factors, leaching factors, effective diffusion coefficients and saturated soil concentrations that are used in the Oakland RBCA calculations.

A.1 INPUT PARAMETER SYMBOLS

Table A-1 defines the input parameter symbols used in the Oakland RBCA equations.

Table A-1. Oakland RBCA Input Parameter Symbols

Parameter	Definition	Unit
AT_{carc}	averaging time for carcinogens	years
AT_{haz}	averaging time for non-carcinogens	years
$BW_{c,a,i}$	body weight (child, adult, worker)	kg
C_{sat}	saturated soil concentration	mg/kg
d	lower depth of surficial soil zone	cm
D^{air}	diffusion coefficient in air	cm ² /s
D^{water}	diffusion coefficient in water	cm ² /s
$ED_{c,a,i}$	exposure duration (child, adult, worker)	years
$EF_{c,a,i}$	exposure frequency (child, adult, worker)	d/year
$EF(sw)_{c,a}$	exposure frequency to water used for recreation (child, adult)	d/yr
ER	indoor air exchange rate	s ⁻¹
$ET(ind)_{c,a,i}$	exposure time to indoor air (child, adult, worker)	hr/d
$ET(out)_{c,a,i}$	exposure time to outdoor air (child, adult, worker)	hr/d
$ET(sw)_{c,a}$	exposure time to water used for recreation (child, adult)	hr/d
f_{oc}	fraction organic carbon in soil	g OC/g soil
H	Henry's Law constant	(cm ³ H ₂ O)/ (cm ³ air)
h_{cap}	capillary fringe thickness	cm
h_v	vadose zone thickness	cm
I	infiltration rate through the vadose zone	cm/yr
$ING(gw)$	groundwater ingestion rate	l/d
$ING(soil)_{c,a,i}$	soil ingestion rate (child, adult, worker)	mg/d
$ING(sw)_{c,a}$	ingestion rate of water used for recreation (child, adult)	l/hr
$INH(ind\ air)_{c,a,i}$	indoor inhalation rate (child, adult, worker)	m ³ /d
$INH(out\ air)_{c,a,i}$	outdoor inhalation rate (child, adult, worker)	m ³ /d
k_{oc}	organic carbon partition coefficient	(cm ³ H ₂ O)/ (g OC)
k_s	partition coefficient for inorganics	(cm ³ H ₂ O)/ (g soil)
LF	leaching factor	(mg/l)/ (mg/kg)
M	soil to skin adherence factor	mg/cm ²
MCL	maximum contaminant level	mg/l
L_B	building air volume/floor area	cm
L_{crack}	foundation thickness	cm
L_{gw}	depth to groundwater	cm
L_s	depth to subsurface soil sources	cm
P_e	particulate emission rate	g/cm ² /s
PC	skin permeability coefficient in water	cm/hr
RAF_d	dermal relative absorption factor	mg/mg
RAF_o	oral relative absorption factor	mg/mg

Table A-1—Continued.

RfD_{inh}	inhalation chronic reference dose	mg/kg/d
RfD_o	oral chronic reference dose	mg/kg/d
S	pure chemical solubility in water	mg/L
SF_{inh}	inhalation slope factor	1/(mg/kg/d)
SF_o	oral slope factor	1/(mg/kg/d)
$SSA(soil)_{c,a,i}$	skin surface area exposed to soil (child, adult, worker)	cm ²
$SSA(total)_{c,a}$	skin surface area exposed to water for recreation (child, adult)	cm ²
THQ	hazard quotient	unitless
TR	individual excess lifetime cancer risk	unitless
U_{air}	wind speed above ground surface in outdoor air mixing zone	cm/s
U_{gw}	groundwater Darcy velocity	cm/yr
VF_p	volatilization factor: surficial soils to outdoor air (particulates)	(mg/m ³)/ (mg/kg)
VF_{ss}	volatilization factor: surficial soils to outdoor air (vapors)	(mg/m ³)/ (mg/kg)
VF_{samb}	volatilization factor: subsurface soils to outdoor air	(mg/m ³)/ (mg/kg)
VF_{sesp}	volatilization factor: subsurface soils to indoor air	(mg/m ³)/ (mg/kg)
VF_{wesp}	volatilization factor: groundwater to indoor air	(mg/m ³)/ (mg/l)
VF_{wamb}	volatilization factor: groundwater to outdoor air	(mg/m ³)/ (mg/l)
W	width of source area parallel to wind or groundwater flow direction	cm
δ_{air}	outdoor air mixing zone height	cm
δ_{gw}	groundwater mixing zone thickness	cm
η	areal fraction of cracks in building foundation	(cm ² cracks)/ (cm ² area)
θ_{acap}	capillary fringe air content	(cm ³ air)/ (cm ³ soil)
θ_{acrack}	foundation cracks air content	(cm ³ air)/ (cm ³ soil)
θ_{as}	vadose zone air content	(cm ³ air)/ (cm ³ soil)
θ_T	total soil porosity	(cm ³ voids)/ (cm ³ soil)
θ_{wcap}	capillary fringe water content	(cm ³ water)/ (cm ³ soil)
θ_{wcrack}	foundation cracks water content	(cm ³ water)/ (cm ³ soil)
θ_{ws}	vadose zone water content	(cm ³ H ₂ O)/ (cm ³ soil)
ρ_s	soil bulk density	g/cm ³
τ	averaging time for vapor flux	s

A.2 RBCA EQUATIONS FOR CARCINOGENIC HEALTH EFFECTS

Equations A-1 through A-11 are the equations used to calculate the Oakland RBCA levels for carcinogenic health effects.

Equation A-1. RBCA Level for Surficial Soil—
Ingestion Of Soil, Dermal Contact With Soil, Inhalation Of Vapors and Particulates in Outdoor
Air
[mg/kg]

(A-1.1) Residential

$$RBSL_{\text{surf soil}} = \frac{TR}{\left[\frac{EF_c \times ED_c}{BW_c \times AT_{\text{carc}} \times 365 \frac{d}{yr}} \left[\left(SF_o \times 10^{-6} \frac{kg}{mg} \times (ING(\text{soil})_c \times RAF_o + SSA(\text{soil})_c \times M \times RAF_d) \right) + \left(SF_{\text{inh}} \times INH(\text{out air})_c \times \left(\frac{ET(\text{out})_c}{24} \right) \times (VF_{ss} + VF_p) \right) \right] \right] + \left[\frac{EF_a \times ED_a}{BW_a \times AT_{\text{carc}} \times 365 \frac{d}{yr}} \left[\left(SF_o \times 10^{-6} \frac{kg}{mg} \times (ING(\text{soil})_a \times RAF_o + SSA(\text{soil})_a \times M \times RAF_d) \right) + \left(SF_{\text{inh}} \times INH(\text{out air})_a \times \left(\frac{ET(\text{out})_a}{24} \right) \times (VF_{ss} + VF_p) \right) \right] \right] \right]}$$

(A-1.2) Commercial/Industrial

$$RBSL_{\text{surf soil}} = \frac{TR \times BW_i \times AT_{\text{carc}} \times 365 \frac{d}{yr}}{EF_i \times ED_i \left[\left(SF_o \times 10^{-6} \frac{kg}{mg} \times (ING(\text{soil})_i \times RAF_o + SSA(\text{soil})_i \times M \times RAF_d) \right) + \left(SF_{\text{inh}} \times INH(\text{out air})_i \times \left(\frac{ET(\text{out})_i}{24} \right) \times (VF_{ss} + VF_p) \right) \right]}$$

Equation A-2. RBCA Level for Subsurface Soil—
Inhalation of Indoor Air Vapors
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{\text{sub soil}} = \frac{RBSL_{\text{ind air}}}{VF_{\text{seep}}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-3. RBCA Level for Subsurface Soil—
Inhalation of Outdoor Air Vapors
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{sub\ soil} = \frac{RBSL_{out\ air}}{VF_{samb}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-4. RBCA Level for Subsurface Soil—
Ingestion of Groundwater Impacted by Leachate
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{sub\ soil} = \frac{RBSL_{gw}}{LF_{sw}}$$

Equation A-5. RBCA Level for Groundwater—
Ingestion of Groundwater*
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = MCL$$

*if no MCL exists, refer to equation A-6

Equation A-6. RBCA Level for Groundwater—
Ingestion of Groundwater*
[mg/l]

(A-6.1) Residential

$$RBSL_{GW} = \left[\frac{TR}{\frac{ED_c \times EF_c \times ING(gw)_c \times SF_o}{BW_c \times AT_{carc}} + \frac{ED_a \times EF_a \times ING(gw)_a \times SF_o}{BW_a \times AT_{carc}}} \right] \times 365 \frac{d}{yr}$$

(A-6.2) Commercial/Industrial

$$RBSL_{gw} = \frac{TR \times BW_i \times AT_{carc}}{SF_o \times ING(gw)_i \times EF_i \times ED_i} \times 365 \frac{d}{yr}$$

*only employed if no MCL exists for the chemical

Equation A-7. RBCA Level for Groundwater—
Inhalation of Indoor Air Vapors
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = \frac{RBSL_{ind\ air}}{VF_{wesp}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-8. RBCA Level for Groundwater—
Inhalation of Outdoor Air Vapors
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = \frac{RBSL_{out\ air}}{VF_{wamb}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-9. RBCA Level for Air—
Inhalation of Indoor Air Vapors
[mg/m³]

(A-9.1) Residential

RBSL_{ind air} =

$$\frac{\text{TR}}{\left[\frac{\text{ED}_c \times \text{EF}_c \times \text{INH}(\text{ind air})_c \times \left(\frac{\text{ET}(\text{ind})_c}{24} \right) \times \text{SF}_{\text{inh}}}{\text{BW}_c \times \text{AT}_{\text{carc}}} + \frac{\text{ED}_a \times \text{EF}_a \times \text{INH}(\text{ind air})_a \times \left(\frac{\text{ET}(\text{ind})_a}{24} \right) \times \text{SF}_{\text{inh}}}{\text{BW}_a \times \text{AT}_{\text{carc}}} \right]} \times 365 \frac{\text{d}}{\text{yr}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}$$

(A-9.2) Commercial/Industrial

$$\text{RBSL}_{\text{ind air}} = \frac{\text{TR} \times \text{AT}_{\text{carc}} \times \text{BW}_i}{\text{SF}_i \times \text{EF}_i \times \text{ED}_i \times \text{INH}(\text{ind air})_i \times \left(\frac{\text{ET}(\text{ind})_i}{24} \right)} \times 365 \frac{\text{d}}{\text{yr}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}$$

Equation A-10. RBCA Level for Air—
Inhalation of Outdoor Air Vapors
[mg/m³]

(A-10.1) Residential

RBSL_{out air} =

$$\frac{\text{TR}}{\left[\frac{\text{ED}_c \times \text{EF}_c \times \text{INH}(\text{out air})_c \times \left(\frac{\text{ET}(\text{out})_c}{24} \right) \times \text{SF}_{\text{inh}}}{\text{BW}_c \times \text{AT}_{\text{carc}}} + \frac{\text{ED}_a \times \text{EF}_a \times \text{INH}(\text{out air})_a \times \left(\frac{\text{ET}(\text{out})_a}{24} \right) \times \text{SF}_{\text{inh}}}{\text{BW}_a \times \text{AT}_{\text{carc}}} \right]} \times 365 \frac{\text{d}}{\text{yr}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}$$

(A-10.2) Commercial/Industrial

$$\text{RBSL}_{\text{out air}} = \frac{\text{TR} \times \text{AT}_{\text{carc}} \times \text{BW}_i}{\text{SF}_i \times \text{EF}_i \times \text{ED}_i \times \text{INH}(\text{out air})_i \times \left(\frac{\text{ET}(\text{out})_i}{24} \right)} \times 365 \frac{\text{d}}{\text{yr}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}$$

Equation A-11. RBCA Level for Water Used for Recreation—
Ingestion and Dermal Contact
[mg/l]

*Residential**

$$RBSL_{sw} = \frac{TR}{\left[\frac{EF(sw)_c \times ED_c \times SF_o}{BW_c \times AT_{carc} \times 365 \frac{d}{yr}} \left(ING(sw)_c + SSA(total)_c \times \frac{PC}{10^3 \text{ cm}^3/l} \right) + \frac{EF(sw)_a \times ED_a \times SF_o}{BW_a \times AT_{carc} \times 365 \frac{d}{yr}} \left(ING(sw)_a + SSA(total)_a \times \frac{PC}{10^3 \text{ cm}^3/l} \right) \right]}$$

*Commercial/industrial scenario not considered for this medium

A.3 RBCA EQUATIONS FOR NON-CARCINOGENIC HEALTH EFFECTS

Equations A-12 through A-22 are the equations used to calculate the Oakland RBCA levels for non-carcinogenic health effects.

Equation A-12. RBCA Level for Surficial Soil—
Ingestion of Soil, Dermal Contact with Soil, Inhalation of Vapors and Particulates in Outdoor Air
[mg/kg]

(A-12.1) Residential

$$RBSL_{surf \text{ soil}} = \frac{THQ \times BW_c \times AT_{haz} \times 365 \frac{d}{yr}}{EF_c \times ED_c \left[\frac{\left(10^{-6} \frac{kg}{mg} \times (ING(soil)_c \times RAF_o + SSA(soil)_c \times M \times RAF_d) \right)}{RfD_o} + \frac{\left(INH(out \ air)_c \times \left(\frac{ET(out)_c}{24} \right) \times (VF_{ss} + VF_p) \right)}{RfD_{inh}} \right]}$$

(A-12.2) Commercial/Industrial

$$RBSL_{surf \text{ soil}} = \frac{THQ \times BW_i \times AT_{haz} \times 365 \frac{d}{yr}}{EF_i \times ED_i \left[\frac{\left(10^{-6} \frac{kg}{mg} \times (ING(soil)_i \times RAF_o + SSA(soil)_i \times M \times RAF_d) \right)}{RfD_o} + \frac{\left(INH(out \ air)_i \times \left(\frac{ET(out)_i}{24} \right) \times (VF_{ss} + VF_p) \right)}{RfD_{inh}} \right]}$$

Equation A-13. RBCA Level for Subsurface Soil—
Inhalation of Indoor Air Vapors
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{sub\ soil} = \frac{RBSL_{ind\ air}}{VF_{seps}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-14. RBCA Level for Subsurface Soil—
Inhalation of Outdoor Air Vapors
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{sub\ soil} = \frac{RBSL_{out\ air}}{VF_{samb}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-15. RBCA Level for Subsurface Soil—
Ingestion of Groundwater Impacted by Leachate
[mg/kg]

Residential and Commercial/Industrial

$$RBSL_{sub\ soil} = \frac{RBSL_{gw}}{LF_{sw}}$$

Equation A-16. RBCA Level for Groundwater—
Ingestion of Groundwater*
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = MCL$$

*if no MCL exists, refer to equation A-17

Equation A-17. RBCA Level for Groundwater—
Ingestion of Groundwater*
[mg/l]

(A-17.1) Residential

$$RBSL_{gw} = \frac{THQ \times AT_{haz} \times BW_c \times RfD_o}{EF_c \times ED_c \times ING(gw)_c} \times 365 \frac{d}{yr}$$

(A-17.2) Commercial/Industrial

$$RBSL_{gw} = \frac{THQ \times AT_{haz} \times BW_i \times RfD_o}{EF_i \times ED_i \times ING(gw)_i} \times 365 \frac{d}{yr}$$

*only employed if no MCL exists for the chemical

Equation A-18. RBCA Level for Groundwater—
Inhalation of Indoor Air Vapors
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = \frac{RBSL_{ind\ air}}{VF_{wesp}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-19. RBCA Level for Groundwater—
Inhalation of Outdoor Air Vapors
[mg/l]

Residential and Commercial/Industrial

$$RBSL_{gw} = \frac{RBSL_{out\ air}}{VF_{wamb}} \times 10^{-3} \frac{mg}{\mu g}$$

Equation A-20. RBCA Level for Air—
Inhalation of Indoor Air Vapors
[mg/m³]

(A-20.1) Residential

$$RBSL_{ind\ air} = \frac{THQ \times AT_{haz} \times BW_c \times RfD_{inh}}{EF_c \times ED_c \times INH(ind\ air)_c \times \left(\frac{ET(ind)_c}{24}\right)} \times 365 \frac{d}{yr} \times 10^3 \frac{\mu g}{mg}$$

(A-20.2) Commercial/Industrial

$$RBSL_{ind\ air} = \frac{THQ \times AT_{haz} \times BW_i \times RfD_{inh}}{EF_i \times ED_i \times INH(ind\ air)_i \times \left(\frac{ET(ind)_i}{24}\right)} \times 365 \frac{d}{yr} \times 10^3 \frac{\mu g}{mg}$$

Equation A-21. RBCA Level for Air—
Inhalation of Outdoor Air Vapors
[mg/m³]

(A-21.1) Residential

$$RBSL_{out\ air} = \frac{THQ \times AT_{haz} \times BW_c \times RfD_{inh}}{EF_c \times ED_c \times INH(out\ air)_c \times \left(\frac{ET(out)_c}{24}\right)} \times 365 \frac{d}{yr} \times 10^3 \frac{\mu g}{mg}$$

(A-21.2) Commercial/Industrial

$$RBSL_{\text{out air}} = \frac{THQ \times AT_{\text{haz}} \times BW_i \times RfD_{\text{inh}}}{EF_i \times ED_i \times INH(\text{out air})_i \times \left(\frac{ET(\text{out})_i}{24} \right)} \times 365 \frac{\text{d}}{\text{yr}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}$$

Equation A-22. RBCA Level for Water Used for Recreation—
Ingestion and Dermal Contact
[mg/l]

Residential*

$$RBSL_{\text{sw}} = \frac{THQ \times RfD_o \times BW_c \times AT_{\text{haz}} \times 365 \frac{\text{d}}{\text{yr}}}{EF(\text{sw})_c \times ED_c \times ET(\text{sw})_c \times \left(ING(\text{sw})_c + SSA(\text{total})_c \times PC \times 10^{-3} \frac{\text{l}}{\text{cm}^3} \right)}$$

*Commercial/industrial scenario not considered for this medium

A.4 EQUATIONS FOR VOLATILIZATION FACTORS, LEACHING FACTORS, EFFECTIVE DIFFUSION COEFFICIENTS AND SATURATED SOIL CONCENTRATIONS

Equations A-23 through A-34 are the equations used to calculate the volatilization factors, leaching factors, effective diffusion coefficients and saturated soil concentrations that are employed in the Oakland RBCA equations.

Equation A-23. Volatilization factor from surficial soils to outdoor air (vapors)
[(mg/m³ air)/(mg/kg soil)]

$$VF_{\text{ss}} = \frac{2W\rho_s}{U_{\text{air}}\delta_{\text{air}}} \sqrt{\frac{D_s^{\text{eff}} H}{\pi(\theta_{\text{ws}} + k_s\rho_s + H\theta_{\text{as}})\tau}} \times 10^3 \frac{\text{cm}^3 \text{kg}}{\text{m}^3 \text{g}}$$

or:

$$VF_{\text{ss}} = \frac{W\rho_s d}{U_{\text{air}}\delta_{\text{air}}\tau} \times 10^3 \frac{\text{cm}^3 \text{kg}}{\text{m}^3 \text{g}}; \quad \text{whichever is less}$$

Equation A-24. Volatilization factor from surficial soils to outdoor air (particulates)
 [(mg/m³air)/(mg/kg soil)]

$$VF_p = \frac{P_e W}{U_{air} \delta_{air}} \times 10^3 \frac{cm^3 kg}{m^3 g}$$

Equation A-25. Volatilization factor from subsurface soils to outdoor air
 [(mg/m³air)/(mg/kg soil)]

$$VF_{samb} = \frac{H\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{as}] \left(1 + \frac{U_{air} \delta_{air} L_s}{D_s^{eff} W} \right)} \times 10^3 \frac{cm^3 kg}{m^3 g}$$

Equation A-26. Volatilization factor from subsurface soils to indoor air
 [(mg/m³air)/(mg/kg soil)]

$$VF_{seps} = \frac{\frac{H\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{as}]} \left[\frac{D_s^{eff} / L_s}{ER \cdot L_B} \right]}{1 + \left[\frac{D_s^{eff} / L_s}{ER \cdot L_B} \right] + \left[\frac{D_s^{eff} / L_s}{(D_{crack}^{eff} / L_{crack}) \eta} \right]} \times 10^3 \frac{cm^3 kg}{m^3 g}$$

Equation A-27. Volatilization factor from groundwater to indoor air
 [(mg/m³ air)/(mg/l H₂O)]

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

Equation A-28. Volatilization factor from groundwater to outdoor air
 [(mg/m³ air)/(mg/l H₂O)]

$$VF_{wamb} = \frac{H}{1 + \left[\frac{U_{air} \delta_{air} L_{gw}}{WD_{ws}^{eff}} \right]} \times 10^3 \frac{l}{m^3}$$

Equation A-29. Leaching factor from subsurface soil to groundwater
 [(mg/l H₂O)/(mg/kg soil)]

$$LF_{sw} = \frac{\rho_s}{[\theta_{ws} + k_s \rho_s + H\theta_{as}]} \left(1 + \frac{U_{gw} \delta_{gw}}{IW} \right) \times \frac{cm^3 kg}{l g}$$

Equation A-30. Effective diffusion coefficient in soil based on vapor-phase concentration
 [cm²/s]

$$D_s^{eff} = D^{air} \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{water} \left(\frac{1}{H} \right) \frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

Equation A-31. Effective diffusion coefficient through foundation cracks
[cm²/s]

$$D_{crack}^{eff} = D^{air} \frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^{water} \left(\frac{1}{H} \right) \frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

Equation A-32. Effective diffusion coefficient through capillary fringe
[cm²/s]

$$D_{cap}^{eff} = D^{air} \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^{water} \left(\frac{1}{H} \right) \frac{\theta_{wcap}^{3.33}}{\theta_T^2}$$

Equation A-33. Effective diffusion coefficient between groundwater and soil surface
(depth-weighted average)
[cm²/s]

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

Equation A-34. Soil concentration at which dissolved pore-water and vapor phases become saturated
[(mg/kg soil)]

$$C_{sat} = \frac{S}{\rho_s} [\theta_{ws} + k_s \rho_s + H\theta_{as}] \times \frac{1 \text{ g}}{\text{cm}^3 \text{ kg}}$$

APPENDIX B
JUSTIFICATION FOR INPUT PARAMETER VALUES

This appendix presents a detailed justification for the input parameter values selected for the Oakland Tier 1 and Tier 2 RBCA calculations. The organization mirrors section 3.0 of the body. The various input parameters are discussed in the following order:

- (1) **soil-specific transport parameters**
- (2) **non-soil-specific transport parameters**
- (3) **receptor-specific parameters**
- (4) **target risk levels**
- (5) **chemical-specific parameters**

Comparisons to the ASTM (1995) default values, used to calculate the example look-up tables contained therein, are made throughout this appendix. Please note that, although these values are helpful for comparison purposes, ASTM (1995) intended them to be only reasonable examples from a range of potential values and explicitly states that they “should not be viewed... as proposed remediation ‘standards’”.

The following list indexes the input parameters discussed in this appendix alphabetically by the section in which they may be found:

Index of Input Parameters

<i>absorption adjustment factors</i>	B.5.3
<i>areal fraction of cracks in building foundation/walls</i>	B.2.1
<i>averaging time for carcinogenic effects</i>	B.3.1
<i>averaging time for non-carcinogenic effects</i>	B.3.2
<i>averaging time for vapor flux</i>	B.3.3
<i>body weight</i>	B.3.4
<i>building air volume/floor area</i>	B.3.5
<i>capillary fringe air content</i>	B.1.1
<i>capillary fringe thickness</i>	B.1.1
<i>capillary fringe water content</i>	B.1.1
<i>depth to groundwater</i>	B.2.4
<i>depth to subsurface soil sources</i>	B.2.4
<i>diffusion coefficient in air</i>	B.5.10
<i>diffusion coefficient in water</i>	B.5.10
<i>exposure duration</i>	B.3.6
<i>exposure frequency (for all media except water used for recreation)</i>	B.3.7
<i>exposure frequency to water used for recreation</i>	B.3.8
<i>exposure time to indoor air</i>	B.3.9
<i>exposure time to outdoor air</i>	B.3.10
<i>exposure time to water used for recreation</i>	B.3.11
<i>foundation cracks air content</i>	B.2.2
<i>foundation cracks water content</i>	B.2.2

Index of Input Parameters—Continued

<i>foundation thickness</i>	B.2.3
<i>fraction organic carbon in soil</i>	B.1.2
<i>groundwater Darcy velocity</i>	B.1.3
<i>groundwater ingestion rate</i>	B.3.12
<i>groundwater mixing zone thickness</i>	B.1.4
<i>hazard quotient</i>	B.4.2
<i>Henry’s Law constant</i>	B.5.7
<i>individual excess lifetime cancer risk</i>	B.4.2
<i>indoor air exchange rate</i>	B.3.13
<i>indoor inhalation rate</i>	B.3.14
<i>infiltration rate through the vadose zone</i>	B.1.5
<i>ingestion rate of water used for recreation</i>	B.3.15
<i>lower depth of surficial soil zone</i>	B.2.4
<i>maximum contaminant level</i>	B.5.5
<i>organic carbon partition coefficient</i>	B.5.8
<i>outdoor air mixing zone height</i>	B.2.5
<i>outdoor inhalation rate</i>	B.3.16
<i>particulate emission rate</i>	B.2.6
<i>partition coefficient for inorganics</i>	B.5.9
<i>reference doses</i>	B.5.2
<i>skin permeability coefficient</i>	B.5.4
<i>skin surface area exposed to soil</i>	B.3.17
<i>skin surface area exposed to water used for recreation</i>	B.3.18
<i>slope factors</i>	B.5.1
<i>soil bulk density</i>	B.1.6
<i>soil ingestion rate</i>	B.3.19
<i>soil to skin adherence factor</i>	B.1.7
<i>solubility</i>	B.5.6
<i>total soil porosity</i>	B.1.8
<i>vadose zone air content</i>	B.1.8
<i>vadose zone thickness</i>	B.1.9
<i>vadose zone water content</i>	B.1.8
<i>width of source area parallel to wind or groundwater flow direction</i>	B.2.4
<i>wind speed above ground surface in outdoor air mixing zone</i>	B.2.7

B.1 SOIL-SPECIFIC TRANSPORT PARAMETERS

This section discusses the transport parameters whose input values vary by soil type. Table B-1 presents the Oakland RBCA values and indicates which of these diverge from the ASTM (1995) defaults.

Table B-1. Oakland RBCA Soil-Specific Transport Parameter Values

Oakland RBCA Input Parameter	Tier 1	Tier 2		
	All Soils	Merritt Sands	Sandy Silt	Clayey Silt
Capillary fringe air content (cm ³ /cm ³)	0.038	0.025*	0.02*	0.01*
Capillary fringe water content (cm ³ /cm ³)	0.342	0.33*	0.38*	0.49*
Capillary fringe thickness (cm)	5	10.1*	60.1*	152*
F _{oc} in soil (g/g)	0.01	0.01	0.015*	0.02*
Groundwater Darcy velocity (cm/yr)	6*	600*	60*	6*
Groundwater mixing zone thickness (cm)	1,524*	305*	762*	1,524*
Infiltration rate of water through the vadose zone (cm/yr)	3.0*	9.0*	6.0*	3.0*
Soil bulk density (g/cm ³)	1.7	1.72*	1.59*	1.33*
Soil to skin adherence factor (mg/cm ²)	0.5	0.2*	0.5*	1.0*
Total soil porosity (cm ³ /cm ³)	0.38	0.35*	0.4*	0.5*
Vadose zone air content (cm ³ /cm ³)	0.26	0.2*	0.15*	0.1*
Vadose zone water content (cm ³ /cm ³)	0.12	0.15*	0.25*	0.4*
Vadose zone thickness (cm)	295.0	289.9*	239.9*	148*

*Oakland-specific value

The following subsections discuss in detail the selection of, and justification for, each of the soil-specific transport parameter values.

B.1.1 Capillary Fringe Parameters: Air Content, Water Content and Thickness

The capillary fringe is defined as the region above the water table that is completely saturated (Freeze and Cherry 1979; Knox et al. 1993). Table B-2 compares the Oakland Tier 1 and Tier 2 values for *capillary fringe air content*, *capillary fringe water content* and *capillary fringe thickness* with the ASTM (1995) defaults.

Table B-2. Comparison of Oakland RBCA Capillary Fringe Thickness, Water Content and Air Content Values with ASTM (1995) Defaults

Input Parameter	Oakland RBCA				ASTM
	Tier 1	Tier 2			Default
	All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
Capillary fringe air content (cm ³ /cm ³)	0.038 ^a	0.025 ^b	0.020 ^b	0.010 ^b	0.038
Capillary fringe water content (cm ³ /cm ³)	0.342 ^a	0.330 ^b	0.380 ^b	0.475 ^b	0.342
Capillary fringe thickness (cm)	5 ^a	10.1 ^b	60.1 ^b	152 ^b	5

Source:

^aASTM (1995)

^bselected by Technical Advisory Committee (1996b)

The Oakland Tier 1 values agree with the ASTM (1995) defaults.

The Oakland Tier 2 values deviate from the ASTM (1995) defaults. These values represent an average of values recommended by environmental experts with Oakland field experience (Technical Advisory Committee 1996b). The finer the soil particles, the less air and more water is assumed to be present in the capillary fringe. The capillary fringe is also assumed to be thicker in finer-grained soils. These assumptions are supported by standard literature on the subject. Table B-3 compares the capillary rise values reported by Guymon (1994) with the Oakland Tier 2 values for *capillary fringe thickness*.

Table B-3. Comparison of Standard Capillary Rise Values with Oakland Tier 2 *Capillary Fringe Thickness* Values

Unconsolidated Material	Guymon (1994)		Oakland Tier 2
	Grain size (mm)	Capillary Rise* (cm)	Capillary Rise (cm)
Medium sand	0.50 - 0.20	24.6	
Fine sand	0.20 - 0.10	42.8	10.1 ^a
Silt (sample #1)	0.10 - 0.05	105.5	60.1 ^b ; 152.0 ^c
Silt (sample #2)	0.05 - 0.02	200.0 ^d	

*capillary rise measured after 72 days; all samples were approximately 41% porous

^ainput parameter value for Merritt sands

^binput parameter value for sandy silts

^cinput parameter value for clayey silts

^dstill rising after 72 days

The Oakland RBCA values are conservative because they assume that there is some air trapped in the capillary fringe, which makes it more permeable to chemicals volatilizing from the groundwater.

B.1.2 Fraction Organic Carbon in Soil

Fraction organic carbon in soil is included as an input parameter in the both the ASTM (1995) and Oakland RBCA models because it has a major impact on the ability of chemicals to sorb to soil. The Oakland RBCA value for this input parameter takes into account the fact that mineral surfaces, such as clay, and electromagnetic molecular forces also cause chemicals to sorb, even if no organic carbon is present (Lyman et al. 1992; Knox et al. 1993). Table B-4 compares the Oakland Tier 1 and Tier 2 values for *fraction organic carbon in soil* with the ASTM (1995) default.

Table B-4. Comparison of Oakland RBCA *Fraction Organic Carbon in Soil* Values with ASTM (1995) Default (g/g)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
0.010 ^a	0.010 ^a	0.015 ^a	0.020 ^a	0.010

Source:

^aSpence and Gomez (1999)

The Oakland Tier 1 value agrees with the ASTM (1995) default.

The Oakland Tier 2 values deviate from the ASTM (1995) default for the sandy silts and clayey silts soil types. These deviations reflect the results of the Oakland soils characterization study (Spence and Gomez 1999). The soils characterization study was performed to more accurately predict sorption of organic chemicals to soil by taking into account factors other than organic carbon.

Sorption of chemicals to organic carbon is the only process considered in the ASTM (1995) equations to account for retardation. The equations assume that the mathematical product of fraction organic carbon (F_{oc}) and the organic carbon partition coefficient (K_{oc}) equals the distribution coefficient (K_s). Although F_{oc} is known to be an important contributor to sorption, it is only a partial predictor of the total sorption that occurs. To address this shortcoming, the soils characterization study measured the partitioning (or sorption) of dissolved-phase benzene onto the three Oakland soil types. Once the actual partitioning was measured for benzene, a soil-specific parameter (“ F_{oc}^* ”) was calculated for each of the three soil types. The F_{oc}^* value is used to predict the variability in the level of sorption, from one soil type to another, for all organic chemicals. The Oakland RBCA approach still accounts for chemicals sorbing differently from one another by employing chemical-specific K_{oc} values in the equations.

B.1.3 Groundwater Darcy Velocity

Groundwater Darcy velocity, a measure of water flux, is the mathematical product of hydraulic conductivity and hydraulic gradient. Since Darcy velocity is difficult to measure independently, values for hydraulic conductivity and hydraulic gradient were selected and the Darcy velocity was then calculated. Table B-5 compares the Oakland Tier 1 and Tier 2 values for groundwater Darcy velocity with the ASTM (1995) default.

Table B-5. Comparison of Oakland RBCA Groundwater Darcy Velocity Values with ASTM (1995) Default (cm/yr)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
6 ^{a,c}	600 ^b	60 ^b	6 ^b	2500

Source:

^aselected by Technical Advisory Committee (1998)

^bselected by Technical Advisory Committee (1996b)

^c*Infiltration rate through the vadose zone, groundwater Darcy velocity and groundwater mixing zone thickness* all affect the “ingestion of groundwater impacted by leachate” pathway only and the values for these input parameters were selected as a group. The Tier 1 values selected mirror those for clayey silts, which is the soil type with the most conservative combination of values for these input parameters.

Both the Oakland Tier 1 and Tier 2 values deviate from the ASTM default.

The hydraulic gradient used to calculate Darcy velocity (0.002 cm/cm) is on the low end of Oakland gradients and therefore conservative (Woodward-Clyde 1992). The values selected for hydraulic conductivity are supported by standard text values. Table B-6 compares hydraulic conductivity values reported by Freeze and Cherry (1979) with the Oakland RBCA values.

Table B-6. Comparison of Standard Hydraulic Conductivity Values with Oakland RBCA Values

Freeze and Cherry (1979, Table 2.2)			Oakland RBCA
Soil Type	Hydraulic Conductivity (cm/s)	Hydraulic Conductivity (cm/yr, extrapolated)	Hydraulic Conductivity [†] (cm/yr)
Silty sand	1E-5 to 9E-2	30 to 3E+6	3E+5 ^a
Silt, loess	1E-7 to 2E-3	3 to 6E+4	3E+4 ^b
Glacial till	1E-10 to 1E-4	3E+3 to 3.2E+3	3E+3 ^c

[†]values rounded to one significant figure

^ainput parameter value for Merritt sands

^binput parameter value for sandy silts

^cinput parameter value for clayey silts

The Oakland RBCA values for groundwater Darcy velocity are all significantly more conservative than the ASTM (1995) default, because a lower Darcy velocity results in less dilution of chemicals leaching to groundwater.

B.1.4 Groundwater Mixing Zone Thickness

The thickness of the mixing zone in groundwater is used to calculate the chemical concentration in groundwater at the down-gradient edge of the soil source. Table B-7 compares the Oakland Tier 1 and Tier 2 values for *groundwater mixing zone thickness* with the ASTM (1995) default.

Table B-7. Comparison of Oakland RBCA *Groundwater Mixing Zone Thickness* Values with ASTM (1995) Default (cm)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
1,524 ^{a,b}	305 ^a	762 ^a	1,524 ^a	200

Source:

^aselected by Technical Advisory Committee (1998)

^b*Infiltration rate through the vadose zone, groundwater Darcy velocity and groundwater mixing zone thickness* all affect the “ingestion of groundwater impacted by leachate” pathway only and the values for these input parameters were selected as a group. The Tier 1 values selected mirror those for clayey silts, which is the soil type with the most conservative combination of values for these input parameters.

Both the Oakland Tier 1 and Tier 2 values deviate from the ASTM default.

The input value for *groundwater mixing zone thickness* is used to estimate the concentration of a chemical in groundwater extracted from a well. Varying hydraulic conductivity in the three different soil types is assumed to influence the well screen length required to extract the same amount of groundwater. The lower the hydraulic conductivity is, the longer the well screen length that is required.

The Oakland RBCA approach is conservative. All water pulled from the well is assumed to be fully mixed over the depth of the mixing zone. In reality, when a well is pumped, it also draws water from below the well screen, where the chemical concentration is likely lower.

B.1.5 Infiltration Rate of Water through the Vadose Zone

The infiltration rate is the amount of water that travels through the vadose zone and reaches groundwater. Table B-8 compares the Oakland Tier 1 and Tier 2 values for *infiltration rate of water through the vadose zone* with the ASTM (1995) default.

Table B-8. Comparison of Oakland RBCA *Infiltration Rate* Values with ASTM (1995) Default (cm/yr)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
3.0 ^{a,d}	9.0 ^b	6.0 ^c	3.0 ^a	30

Source:

^aTechnical Advisory Committee (1998); equal to 5 percent of average Oakland rainfall
^bTechnical Advisory Committee (1998); equal to 15 percent of average Oakland rainfall
^cTechnical Advisory Committee (1998); equal to 10 percent of average Oakland rainfall
^d*Infiltration rate through the vadose zone, groundwater Darcy velocity and groundwater mixing zone thickness* all affect the “ingestion of groundwater impacted by leachate” pathway only and the values for these input parameters were selected as a group. The Tier 1 values selected mirror those for clayey silts, which is the soil type with the most conservative combination of values for these input parameters.

Both the Oakland Tier 1 and Tier 2 values deviate from the ASTM (1995) default.

The Oakland RBCA values assume that infiltration rate is influenced by soil grain size and permeability. Standard literature indicates that the Oakland RBCA values are conservative. Table B-9 compares the range of recharge rate values reported by Walton (1988) for areas geologically similar to Oakland with the Oakland RBCA infiltration rate values.

Table B-9. Comparison of Standard Recharge Rates with Oakland RBCA *Infiltration Rate* Values (in/yr)

Walton (1988) (Originally based on Heath 1982)		Oakland RBCA
Region	Recharge Rate	Infiltration Rate
Western Mountain Ranges	0.100 - 2	3.6 ^a ; 2.4 ^b ; 1.2 ^c
Alluvial Basins	0.001 - 1	

^ainput parameter value for Merritt sands

^binput parameter value for sandy silts

^cinput parameter value for clayey silts

B.1.6 Soil Bulk Density

Soil bulk density accounts for pore spaces and therefore differs from rock density. The following equation is used to calculate soil bulk density:

$$\text{soil bulk density} = (1 - \text{total porosity}) (2.65 \text{ g/cm}^3)$$

Table B-10 compares the Oakland Tier 1 and Tier 2 values for *soil bulk density* with the ASTM (1995) default.

Table B-10. Comparison of Oakland RBCA *Soil Bulk Density* Values with ASTM (1995) Default (g soil/cm³ soil)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
1.7 ^a	1.72 ^b	1.59 ^b	1.33 ^b	1.7

Source:

^aASTM (1995)

^bbased on total soil porosity values selected by Technical Advisory Committee (1996b)

The Oakland Tier 1 value agrees with the ASTM (1995) default.

The Oakland Tier 2 values deviate from the ASTM (1995) default. These values were calculated using the total soil porosity values selected by the Technical Advisory Committee (1996b) and discussed in section B.1.8.

B.1.7 Soil to Skin Adherence Factor

The soil to skin adherence factor determines the amount of soil that will stick to an individual's skin upon contact. Table B-11 compares the Oakland Tier 1 and Tier 2 values for *soil to skin adherence factor* with the ASTM (1995) default.

Table B-11. Comparison of Oakland RBCA *Soil to Skin Adherence Factor* Values with ASTM (1995) Default (mg soil/cm² soil)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
0.5 ^a	0.2 ^b	0.5 ^b	1.0 ^b	0.5

Source:

^aASTM (1995)

^bU.S. EPA (1992)

The Oakland Tier 1 value agrees with the ASTM (1995) default.

The Oakland Tier 2 values deviate from the ASTM (1995) default, except for sandy silts. These values are conservative and are based on studies reported by U.S. EPA (1992) that showed soil adherence to skin to be a function of grain size. Based on these studies, U.S. EPA (1992) concluded that "0.2 [mg/cm²] may be the best value to represent an average overall exposed skin and 1 [mg/cm²] may be a reasonable upper value."

B.1.8 Vadose Zone Air Content, Vadose Zone Water Content and Total Soil Porosity

Vadose zone air content, vadose zone water content and total soil porosity are interrelated and are discussed here as a group. Total soil porosity is the sum of air content and water content. Total soil porosity is used in the RBCA calculations because it is not the effective soil porosity but the total soil porosity that is operative in diffusion processes. Table B-12 compares the Oakland Tier 1 and Tier 2 values for *total soil porosity*, *vadose zone water content* and *vadose zone air content* with the ASTM (1995) defaults.

Table B-12. Comparison of Oakland RBCA *Total Soil Porosity*, *Vadose Zone Water Content* and *Vadose Zone Air Content* Values with ASTM (1995) Defaults (cm³/cm³)

Input Parameter	Oakland RBCA				ASTM
	Tier 1	Tier 2			Default
	All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
Total soil porosity	0.38 ^b	0.35 ^a	0.40 ^a	0.5 ^a	0.38
Vadose zone water content	0.12 ^b	0.15 ^a	0.25 ^a	0.4 ^a	0.12
Vadose zone air content	0.26 ^b	0.20 ^a	0.15 ^a	0.1 ^a	0.26

Source:

^aselected by Technical Advisory Committee (1996b)

^bASTM (1995)

The Oakland Tier 1 values agree with the ASTM (1995) defaults.

The Oakland Tier 2 values deviate from the ASTM (1995) defaults. These values represent an average of values recommended by environmental experts with Oakland field experience (Technical Advisory Committee 1996b). The Tier 2 input parameter values selected for each soil type reflect the following considerations:

- (1) The total soil porosity value should be reflective of the vadose zone in between the source and the building or the source and the ground surface. If there are any lower permeability (i.e., higher water content) lenses, they will be the limiting layer for diffusion and the air content and water content values should account for their presence.
- (2) Total soil porosity in sand is diminished if the sand is “dirty” or not well-sorted because the larger pore spaces fill up with small particles.
- (3) Total soil porosity in clays increases as the clay particle sizes decrease, resulting in a greater percent volumetric water content, and an absolute volumetric air content that is the same as or lower than that found in clays with larger particle sizes.
- (4) Soils may be wetter in the winter and drier in the summer; therefore, the input parameter values should reflect an annual average.
- (5) *Total soil porosity* is not the critical parameter, per se; rather, the model is driven by the values selected for *vadose zone air content* and *vadose zone water content*.

The Oakland Tier 2 *total soil porosity* values are supported by standard groundwater and soils texts. Table B-13 compares the ranges of total soil porosity values reported by Freeze and Cherry (1979) with the Oakland Tier 2 values.

Table B-13. Comparison of Standard Total Porosity Value Ranges for Various Soil Types with Oakland Tier 2 Values
(cm³_{voids}/cm³_{soil})

Freeze and Cherry (1979)		Oakland Tier 2
Unconsolidated Deposits	Total Soil Porosity (Range)	Total Soil Porosity
Sand	0.25 - 0.50	0.35 ^a
Silt	0.35 - 0.50	0.40 ^b
Clay	0.40 - 0.70	0.50 ^c

^a:input parameter value for Merritt sands

^b:input parameter value for sandy silts

^c:input parameter value for clayey silts

Texts do not typically report standard values for air content and water content in the vadose zone. Heath (1989) defines specific yield as the amount of water in storage in the vadose zone that drains under the influence of gravity, and specific retention as the amount of water that is retained in the pore spaces under the influence of gravity. Specific yield may be considered a conservative air content value and specific retention a conservative water content value. Table B-14 compares the Heath (1989) values for specific yield and retention with the Oakland Tier 2 values for *vadose zone air content* and *vadose zone water content*, respectively.

Table B-14. Comparison of Standard Specific Retention and Specific Yield Values with Oakland Tier 2 *Vadose Zone Air Content* and *Vadose Zone Water Content* Values
(cm³/cm³)

Material	Heath (1989)		Oakland Tier 2	
	Specific Yield	Specific Retention	Air Content	Water Content
Sand	0.22	0.03	0.20 ^a	0.15 ^a
Soil	0.40	0.15	0.15 ^b	0.25 ^b
Clay	0.02	0.48	0.10 ^c	0.40 ^c

^a:input parameter value for Merritt sands

^b:input parameter value for sandy silts

^c:input parameter value for clayey silts

The Oakland RBCA Tier 2 values for *vadose zone air content* and *vadose zone water content* take into consideration that clays hold more water and sands less. The Oakland RBCA values are conservative because the vadose zone air content is assumed to be on the high end of potential values, which renders the vadose zone more permeable to chemicals volatilizing from the soil and groundwater.

B.1.9 Vadose Zone Thickness

The thickness of the vadose zone is determined by the depth to groundwater and the thickness of the capillary fringe. Table B-15 compares the Oakland Tier 1 and Tier 2 values for *vadose zone thickness* with the ASTM (1995) default.

Table B-15. Comparison of Oakland RBCA *Vadose Zone Thickness* Values with ASTM (1995) Default (cm)

Oakland RBCA				ASTM
Tier 1	Tier 2			Default
All Soils	Merritt Sands	Sandy Silts	Clayey Silts	All Soils
295.0 ^a	289.9 ^b	239.9 ^b	148.0 ^b	295.0

Source:

^aASTM (1995)

^bcalculated from values for *capillary fringe thickness* and *depth to groundwater* selected by Technical Advisory Committee (1996b)

For a discussion of how the values for *capillary fringe thickness* and *depth to groundwater* were selected, and a comparison with standard literature values, refer to sections B.1.1 and B.2.5, respectively.

B.2 NON-SOIL-SPECIFIC TRANSPORT PARAMETERS

This section discusses the transport parameters whose input values do not vary by soil type. Table B-16 presents the Oakland RBCA values and indicates which of these diverge from the ASTM (1995) defaults.

Table B-16. Oakland RBCA Non-soil-specific Transport Parameter Values

Input Parameter	Value
Areal fraction of cracks in building foundation (cm ² /cm ²)	0.001*
Foundation cracks air content (cm ³ /cm ³)	0.26
Foundation cracks water content (cm ³ /cm ³)	0.12
Foundation thickness (cm)	15
Lower depth of surficial soil zone (cm)	100
Depth of subsurface soil sources (cm)	100
Depth to groundwater (cm)	300
Width of source area parallel to wind or groundwater flow direction (cm)	1500
Outdoor air mixing zone height (cm)	200
Particulate emission rate (g/cm ² /s)	1.38E-11*
Wind speed above ground surface in outdoor air mixing zone (cm/s)	322*

*Oakland-specific value

The following subsections discuss in detail the selection of, and justification for, each of the non-soil-specific transport parameter values.

B.2.1 Areal Fraction of Cracks in Building Foundation

Cracks in the foundation or basement walls can allow greater concentrations of a volatilized chemical to infiltrate a building. The Oakland RBCA value for *areal fraction of cracks in building foundation* deviates from the ASTM (1995) default (see Table B-17).

Table B-17. Comparison of Oakland RBCA *Areal Fraction of Cracks in Building Foundation* Value with ASTM (1995) Default (cm²/cm²)

Oakland RBCA	ASTM Default
0.001 ^{a,b}	0.01

Source:

^aTechnical Advisory Committee (1997)

^bAmerican Society of Heating, Refrigerating, and Air Conditioning Engineering (1981)

The Oakland RBCA value was selected by the Technical Advisory Committee (1997) and is considered a typical assumption for buildings with slab floors. The value is supported by California data, collected by Carlos et al. and presented by the American Society of Heating, Refrigerating, and Air Conditioning Engineering (ASHRAE 1981).

B.2.2 Foundation Cracks Air Content and Water Content

Foundation cracks air content and *foundation cracks water content* are interrelated and discussed here together. The more air present in foundation or basement wall cracks, the more easily a volatilized chemical can infiltrate a building. The Oakland RBCA values for *foundation cracks air content* and *foundation cracks water content* agree with the ASTM (1995) default (see Table B-18).

Table B-18. Comparison of Oakland RBCA *Foundation Cracks Air Content* and *Foundation Cracks Water Content* Values with ASTM (1995) Defaults (cm)

Input Parameter	Oakland RBCA	ASTM Default
Foundation cracks air content	0.26 ^a	0.26
Foundation cracks water content	0.12 ^a	0.12

Source:

^aASTM (1995)

If one assumes that foundation cracks typically become filled with dirt over time, the Oakland RBCA values reflect conservative assumptions about the air content in that dirt.

B.2.3 Foundation Thickness

The thickness of a building foundation can effect the indoor air concentration of a chemical volatilizing from the soil or groundwater. The Oakland RBCA value for *foundation thickness* agrees with the ASTM (1995) default (see Table B-19).

Table B-19. Comparison of Oakland RBCA *Foundation Thickness* Value with ASTM (1995) Default (cm)

Oakland RBCA	ASTM Default
15 ^a	15

Source:

^aCalifornia Building Code (1998)

The input parameter value for foundation thickness reflects the minimum construction standard for building foundations. The California Building Code (1998) requires a foundation thickness of six inches, or approximately 15 cm, for one-story buildings. The Oakland RBCA value is conservative under many scenarios because the California Building Code (1998) requires an eight-inch foundation for two-story buildings and a ten-inch foundation for buildings of three stories or more.

B.2.4 Source Geometry Parameters

Source geometry parameters serve to define the lateral and vertical extent of contamination. The Oakland RBCA values for *lower depth of surficial soil zone*, *depth to subsurface soil sources*, *depth to groundwater*, and *width of source area parallel to wind or groundwater flow direction* agree with the ASTM (1995) defaults (see Table B-20).

Table B-20. Comparison of Oakland RBCA Source Geometry Parameter Values and ASTM (1995) Defaults (cm)

Input Parameter	Oakland RBCA	ASTM Default
Lower depth of surficial soil zone	100 ^a	100
Depth to subsurface soil sources	100 ^a	100
Depth to groundwater	300 ^a	300
Width of source area parallel to wind or groundwater flow direction	1500 ^a	1500

Source:

^aASTM (1995); Technical Advisory Committee (1996b)

The value for *lower depth of surficial soil zone* simply delineates the vertical extent of the surficial soil medium for the purpose of defining the exposure pathway of concern.

The depth and width of the source area will obviously vary from site to site. The Oakland RBCA approach is conservative because it assumes a moderate to large source area close to the ground surface.

Note that groundwater in Oakland is typically encountered at anywhere from 10 to 30 feet (Gomez 1999). The selected value of ten feet is therefore conservative. If actual site depth to groundwater is less than ten feet and inhalation of chemicals volatilizing from groundwater is the primary exposure pathway of concern, then the site in question is not eligible for application of the Oakland RBCA levels (City of Oakland 2000).

B.2.5 Outdoor Air Mixing Zone Height

The height of the outdoor air mixing zone defines the area from which a person draws air to breathe. The Oakland RBCA value for *outdoor air mixing zone height* agrees with the ASTM (1995) default (see Table B-21).

Table B-21. Comparison of Oakland RBCA *Outdoor Air Mixing Zone Height* Value with ASTM (1995) Default (cm)

Oakland RBCA	ASTM Default
200 ^a	200

Source:
^aASTM (1995)

The Oakland RBCA value reflects the breathing area of an average person.

B.2.6 Particulate Emission Rate

The particulate emission rate is used to calculate a high-end estimate of the amount of breathable dust particles (<10 microns) originating from exposed soil that are present in outdoor air. Dust particles are assumed to come from the top few centimeters of the soil surface. The Oakland RBCA value for *particulate emission rate* deviates from the ASTM (1995) default (see Table B-22).

Table B-22. Comparison of Oakland RBCA *Particulate Emission Rate* Value with ASTM (1995) Default (g/cm²/s)

Oakland RBCA	ASTM Default
1.38E-11 ^a	6.9E-14

^abased on Soil Screening Guidance (U.S. EPA 1995)

The particulate emission rate for the Oakland RBCA approach is based on *Soil Screening Guidance* (U.S. EPA 1995). Both the Oakland RBCA and ASTM (1995) particulate emission rates are derived from the Cowherd unlimited erosion potential model (U.S. EPA 1985);

however, different input values are used to calculate the rate. U.S. EPA (1995) inputs are very conservative and produce a higher particulate emission rate than the ASTM (1995) default.

B.2.7 Wind Speed above Ground Surface in Outdoor Air Mixing Zone

Wind speed can effect the concentration of a chemical of concern in the outdoor air through dispersion. The Oakland RBCA value for *wind speed above ground surface in outdoor air mixing zone* deviates from the ASTM (1995) default (see Table B-23).

Table B-23. Comparison of Oakland RBCA *Wind Speed* Value with ASTM (1995) Default (cm/s)

Oakland RBCA	ASTM Default
322 ^a	225

Source:

^aextrapolated from wind rose data provided by the Bay Area Air Quality Management District (BAAQMD 1996)

Average annual wind speeds for different areas of Oakland were extrapolated from wind rose data, and the lowest of these wind speeds was selected as the Oakland RBCA input parameter value (see Table B-24).

Table B-24. Location-specific Wind Speeds in Oakland (cm/s)

West Oakland (Sewage Treatment Plant)	East Oakland (Oakland International Airport)	Oakland-Berkeley Hills (Vollmer Peak)
322 ^{a,d}	418 ^b	640 ^c

^ameasured from 4/1/92 through 3/31/93

^bmeasured from 1/1/60 through 12/31/64

^cmeasured from 1/1/90 through 12/4/90

^dselected as the average annual wind speed for Oakland

The lower the wind speed is, the lower are the RBCA levels for the outdoor air exposure pathways. The selected wind speed value of 322 cm/s is conservative because it is the lowest of the average annual wind speeds measured in Oakland.

B.3 RECEPTOR-SPECIFIC PARAMETERS

This section discusses the input parameters whose values vary by receptor and land use scenario. The three potential receptors in the Oakland RBCA approach are: child residential, adult residential and adult commercial/industrial (i.e., worker). As described in section 2.2 of the body, the Oakland RBCA residential land use exposure scenario assumes a combined child/adult receptor for carcinogenic health effects and a child receptor for non-carcinogenic effects.

Table B-25 presents the Oakland RBCA values for the receptor-specific parameters and indicates which of these diverge from the ASTM (1995) defaults.

Table B-25. Oakland RBCA Receptor-Specific Input Parameter Values and Sources

Input Parameter	Residential		Commercial/ Industrial
	Child	Adult	Worker
Averaging time for carcinogenic effects (yr)	70*	70	70
Averaging time for non-carcinogenic effects (yr)	6*	24*	25
Averaging time for vapor flux (s)	9.46E+08 ^a	9.46E+08 ^a	7.88E+08
Body weight (kg)	15*	70	70
Building air volume/floor area (cm ³ /cm ²)	229*	229*	305*
Exposure duration (yr)	6*	24	25
Exposure frequency (d/yr)	350*	350	250
Exposure frequency to water used for recreation (d/yr)	120*	120*	NA
Exposure time to indoor air (hr/d)	24*	24*	9*
Exposure time to outdoor air (hr/d)	16*	16*	9*
Exposure time to water used for recreation (hr/d)	2*	1*	NA
Groundwater ingestion rate (liters/d)	1*	2	1
Indoor air exchange rate (s ⁻¹)	5.60E-04*	5.60E-04*	1.40E-03*
Indoor inhalation rate (m ³ /d)	10*	15	20
Ingestion rate while playing in water used for recreation (liters/hr)	0.05*	0.05*	NA
Outdoor inhalation rate (m ³ /d)	10*	20*	20
Skin surface area exposed to soil (cm ²)	2000*	5000*	5000*
Skin surface area exposed to water used for recreation (cm ²)	8000*	20,000*	NA
Soil ingestion rate (mg/d)	200*	100	50

*Oakland-specific value

Note: NA indicates that the input parameter is not applicable to the commercial/industrial land use scenario

The following subsections discuss in detail the selection of, and justification for, each of the receptor-specific parameter values.

B.3.1 Averaging Time for Carcinogenic Effects

The averaging time for carcinogenic effects is the length of time used to statistically normalize the intake of a carcinogen. Table B-26 compares the Oakland RBCA values for *averaging time for carcinogenic effects* with the ASTM (1995) defaults.

Table B-26. Comparison of Oakland RBCA Values for *Averaging Time for Carcinogenic Effects* with ASTM (1995) Defaults

(yrs)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 70 ^a ; Adult: 70 ^a	70
Commercial/Industrial	70 ^a	70

Source:

^aU.S. EPA (1996)

The Oakland RBCA value for *averaging time for carcinogenic effects* agrees with the ASTM (1995) default for both the residential and commercial/industrial land use scenarios. This value is based on an average life expectancy of approximately 70 years. This is standard throughout risk assessment literature and U.S. EPA toxicity data are based on it.

The Oakland RBCA approach assumes that the chemical concentration remains constant over the entire exposure duration (30 years for residential; 25 years for commercial/industrial). For volatile and soluble chemicals, this is a very conservative assumption since the concentration will actually decrease over time.

B.3.2 Averaging Time for Non-carcinogenic Effects

The averaging time for non-carcinogenic effects is set equal to the exposure duration because non-carcinogenic effects are not considered cumulative; instead, a daily intake level is determined. Table B-27 compares the Oakland RBCA values for *averaging time for non-carcinogenic effects* with the ASTM (1995) defaults.

Table B-27. Comparison of Oakland RBCA Residential Scenario Values for *Averaging Time for Non-carcinogenic Effects* with ASTM (1995) Defaults
(yrs)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 6 ^a ; Adult: 24 ^a	30
Commercial/Industrial	25 ^a	25

Source:

^aU.S. EPA (1996)

The Oakland RBCA value for *averaging time for non-carcinogenic effects* agrees with the ASTM (1995) default for both the residential and commercial/industrial land use scenarios. Note, however, that this input parameter cancels out of the equation along with *exposure duration* since non-carcinogenic effects are calculated based on a daily intake and not cumulative exposure. Therefore, what is relevant is the conservative assumption that the receptor is always a young child.

B.3.3 Averaging Time for Vapor Flux

Averaging time for vapor flux is the length of time over which a chemical is assumed to volatilize from surficial soil. Table B-28 compares the Oakland RBCA values for *averaging time for vapor flux* with the ASTM (1995) defaults.

Table B-28. Comparison of Oakland RBCA Values for *Averaging Time for Vapor Flux* with ASTM (1995) Defaults
(s)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	9.46E+08 ^a	9.46E+08
Commercial/Industrial	7.88E+08 ^a	7.88E+08

Source:

^aASTM (1995)

The Oakland RBCA value for *averaging time for vapor flux* agrees with the ASTM (1995) default for both the residential and commercial/industrial land use scenarios.

The Oakland RBCA values are set equal to the input value for *exposure duration*, in seconds. For a discussion of how the values for exposure duration were selected and a comparison with research data, refer to [section 3.6](#).

B.3.4 Body Weight

Body weight is assumed to influence the effect of a given concentration of a chemical on an exposed individual. Table B-29 compares the Oakland RBCA values for *body weight* with the ASTM (1995) defaults.

Table B-29. Comparison of Oakland RBCA Values for *Body Weight* with ASTM (1995) Defaults
(yrs)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 15 ^a ; Adult: 70 ^a	70
Commercial/Industrial	70 ^a	70

Source:

^aU.S. EPA (1996)

The Oakland RBCA value for *body weight* deviates from the ASTM (1995) default for the residential land use scenario because the potential for a child receptor is taken into account in the Oakland RBCA calculations. The Oakland RBCA value for children is 15 kg, based on U.S. EPA (1996) data. For children between the ages of 0 and 6, this value falls slightly below the mean (U.S. EPA 1989a). The Oakland RBCA value is therefore moderately conservative.

The Oakland RBCA value for *body weight* agrees with the ASTM (1995) default for the commercial/industrial land use scenario. The Oakland RBCA value for adults for both the

residential and commercial/industrial land use scenarios is 70 kg. This value is based on both ASTM (1995) and U.S. EPA (1996) data and approximates a mean value for individuals between the ages of 6 and 75 years (U.S. EPA 1989b).

B.3.5 Building Air Volume/Floor Area

The building air volume divided by the floor area is the height of the ceiling. Larger rooms allow for a greater reduction in the concentration of a volatilized chemical in the air. Table B-30 compares the Oakland RBCA values for *building air volume/floor area* with the ASTM (1995) defaults.

Table B-30. Comparison of Oakland RBCA Values for *Building Air Volume/Floor Area* with ASTM (1995) Defaults (cm³/cm²)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 229 ^a ; Adult: 229 ^a	200
Commercial/Industrial	305 ^b	300

Source:

^aCalifornia Building Code (1998)

^bbased on U.S. EPA (1997) delineation of “typical” ceiling heights

The Oakland RBCA values for *building air volume/floor area* deviate from the ASTM (1995) defaults for both the residential and commercial/industrial land use scenarios.

The Oakland RBCA value for the residential land use scenario is based on the minimum California Building Code (1998) requirement of seven feet, six inches for residential structures. The Oakland RBCA value for the commercial/industrial land use scenario assumes an average ceiling height of 10 feet. This value reflects the average of the values defined by U.S. EPA (1997) as “typical” for residential (eight feet) and commercial (12 feet), and was selected to account for commercial enterprises operating on the ground floor of older, mixed-use structures.

B.3.6 Exposure Duration

The exposure duration is the number of years over which an individual is assumed to be exposed to a chemical of concern. Table B-31 compares the Oakland RBCA values for *exposure duration* with the ASTM (1995) defaults.

Table B-31. Comparison of Oakland RBCA Values for *Exposure Duration* with ASTM (1995) Default (yrs)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 6 ^a ; Adult: 24 ^a	30
Commercial/Industrial	25 ^a	25

Source:

^aU.S. EPA (1996)

The Oakland RBCA values for *exposure duration* agree with the ASTM (1995) default for both the residential and commercial/industrial land use scenarios. (Under the residential land use scenario, the child and adult *exposure duration* values are added together.) Research data indicate that both values are conservative. Table B-32 compares the Oakland RBCA values for residential land use exposure duration with U.S. EPA data on homeowners living continually in the same house.

Table B-32. Comparison of Oakland RBCA Values for Residential Land Use Scenario *Exposure Duration* with U.S. EPA Data on Homeowners Living Continually in the Same House (yrs)

Oakland RBCA	U.S. EPA 1989b (50th percentile)	U.S. EPA 1989b (90th percentile)
30	9	30

The Oakland RBCA value for the residential land use scenario is 30 years: 24 as an adult and 6 as a child. The U.S. EPA (1989b) values are based on an analysis of 1983 Bureau of Census data. They indicate that the Oakland RBCA values are very conservative. Still, other population mobility studies indicate that the U.S. EPA (1989b) findings probably underestimate the conservatism of the Oakland RBCA value for three reasons. First, Oakland is an urban area and the U.S. EPA (1989b) analysis includes rural areas where population mobility tends to be lower. Second, many Oakland residents are not homeowners and studies have shown that the average residence time of an apartment dweller ranges from 18 to 24 months (U.S. EPA 1989b). Third, individuals living in the Western United States tend to be more mobile than those living in other areas of the country. Israeli and Nelson (1992) take these factors into account in their analysis (see Table B-33).

Table B-33. Comparison of Oakland RBCA Value for Residential Land Use Scenario Exposure Duration with Israeli and Nelson (1992) Data on Time Spent in One Residence (yrs)

Oakland RBCA	Israeli and Nelson (1992)		
	All U.S. Households (95th percentile)	Western U.S. Households (95th percentile)	All Urban U.S. Households (95th percentile)
30.0	23.1	17.1	21.7

The Oakland RBCA value for the commercial/industrial land use scenario is 25 years. Again, labor mobility studies indicate that this value is conservative. Table B-34 compares the Oakland RBCA value for the commercial/industrial land use scenario with Bureau of Labor Statistics (1988) data on time spent at a specific job.

Table B-34. Comparison of Oakland RBCA Values for Commercial/Industrial Land Use Scenario Exposure Duration with Bureau of Labor Statistics Data on Time Spent at a Specific Job (yrs)

Oakland RBCA	Bureau of Labor Statistics (50th percentile)	Bureau of Labor Statistics (95th percentile)
25	4	25

B.3.7 Exposure Frequency

The exposure frequency is the number of days per year that an individual is assumed to be exposed to a chemical of concern. Table B-35 compares the Oakland RBCA values for *exposure frequency* with the ASTM (1995) defaults.

Table B-35. Comparison of Oakland RBCA Values for *Exposure Frequency* with ASTM (1995) Defaults (d/yr)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 350 ^a ; Adult: 350 ^a	350
Commercial/Industrial	250 ^a	250

Source:

^aU.S. EPA (1996)

The Oakland RBCA value for *exposure frequency* agrees with the ASTM (1995) default for both the residential and commercial/industrial land use scenarios.

The Oakland RBCA value for the residential land use scenario, for both adult and child, is 350 days/year. This value is based on a two-week vacation scenario. It is conservative because it

assumes that the individual is at home all 24 hours each day and does not take into consideration activities away from home, such as weekend trips, work and errands.

The Oakland RBCA value for the commercial/industrial land use scenario is 250 days/year. This value is based on a five-day work week for fifty weeks of the year. It is conservative because it does not take into account additional holidays and sick days that typically account for anywhere from 10 to 20 fewer work days per year.

B.3.8 Exposure Frequency to Water Used for Recreation

Exposure frequency to water used for recreation is a measure of the number of days per year that an individual is exposed to a chemical of concern through contact with groundwater or surface water. The Oakland RBCA value of 120 days/year is based on a hypothetical, swimming scenario in which water pulled from an extraction well or nearby surface water body is used to fill a pool. It assumes that the exposed individual swims in the contaminated water every day of the swim season, which is assumed to last four months.

ASTM (1995) does not consider this exposure scenario.

B.3.9 Exposure Time to Indoor Air

Exposure time to indoor air is determined by the number of hours per day that an individual is inside a building impacted by contaminated air. ASTM (1995) does not include this input parameter in its RBCA model, effectively assuming 24 hours of exposure per day for both the residential and commercial/industrial land use scenarios. For the residential land use scenario, the Oakland RBCA value is also 24 hours. This is a maximally conservative value that assumes the exposed individual is house-ridden for family obligations or health reasons.

For the commercial/industrial land use scenario, the Oakland RBCA value is 9 hours. This is based on an eight-hour work day with a one-hour lunch taken inside and on-site.

B.3.10 Exposure Time to Outdoor Air

Exposure time to outdoor air is determined by the number of hours per day that an individual is outside at a site with contaminated ambient air. ASTM (1995) does not include this input parameter in its RBCA model, effectively assuming 24 hours of exposure per day for both the residential and commercial/industrial land use scenarios. For the residential land use scenario, the Oakland RBCA value is 16 hours. This is a conservative value that assumes the exposed individual is on-site but outside of the home (e.g., in the yard or garden) the whole day except for eight hours of sleep.

For the commercial/industrial land use scenario, the Oakland RBCA value is 9 hours. This is based on an outdoor, eight-hour work day with a one-hour lunch taken outside and on-site.

B.3.11 Exposure Time to Water Used for Recreation

Exposure time to water used for recreation is a measure of the duration of each exposure to contaminated water used for recreation. The Oakland RBCA values are based on a hypothetical, swimming scenario in which water pulled from an extraction well or nearby surface water body is used to fill a pool. The Oakland RBCA value for an adult assumes one hour of swimming per day; the Oakland RBCA value for a child assumes two hours of swimming per day (Technical Advisory Committee 1997).

ASTM (1995) does not consider this exposure scenario.

B.3.12 Groundwater Ingestion Rate

The groundwater ingestion rate is the amount of impacted groundwater that is ingested by an individual each day. Table B-36 compares the Oakland RBCA values for *groundwater ingestion rate* with the ASTM (1995) defaults.

Table B-36. Comparison of Oakland RBCA *Groundwater Ingestion Rate* Values with ASTM (1995) Defaults (L/d)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 1 ^a ; Adult: 2 ^a	2
Commercial/Industrial	1 ^b	1

Source:

^aU.S. EPA (1996)

^bASTM (1995)

The Oakland RBCA value for *groundwater ingestion rate* deviates from the ASTM (1995) default for the residential land use scenario because the potential for a child receptor is taken into account in the Oakland RBCA model. The Oakland RBCA value for a child under the residential land use scenario is 1 liter/day. This value is based on U.S. EPA (1989b; 1996) data. The Oakland RBCA value for an adult under the residential land use scenario is 2 liters/day. This value is based on both ASTM (1995) and U.S. EPA (1996) data.

Tap water consumption studies indicate that these values are very conservative. Cantor et al. (1987) calculate the mean tap water consumption to be 1.4 liters per day. The same study calculates the 99.99th percentile to be 2.0 liters per day (U.S. EPA 1989b).

The Oakland RBCA value for *groundwater ingestion rate* agrees with the ASTM (1995) default for the commercial/industrial land use scenario.

B.3.13 Indoor Air Exchange Rate

The indoor air exchange rate determines how much fresh air is exchanged with indoor air in buildings. Table B-37 compares the Oakland RBCA values for *indoor air exchange rate* with the ASTM (1995) defaults.

Table B-37. Comparison of Oakland RBCA *Indoor Air Exchange Rate* Values with ASTM Default (ACH*)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	2.0 ^a	0.5
Commercial/Industrial	5.0 ^b	0.83

*Air changes per hour (1 ACH = 0.00028 building volume exchanges/second)

Source:

^aSherman (1997)

^bHydeman (1996)

The Oakland RBCA values for *indoor air exchange rate* deviate from the ASTM (1995) defaults for both the residential and commercial/industrial land use scenarios.

The ASTM (1995) defaults are 0.00014 building volumes/second for the residential land use scenario and 0.00023 building volumes/second for the commercial/industrial land use scenario. These rates translate to 0.5 and 0.83 air changes per hour (ACH), respectively.

Because of Oakland's extremely temperate climate, the Oakland RBCA indoor air exchange rates are set higher than the ASTM (1995) defaults. For a residential land use scenario in California, a value of 2.0 ACH is considered reasonable (Sherman 1997). For a commercial/industrial land use scenario, a value of 5.0 ACH is employed because, when the outside temperature is between 60° F and 70° F, it is most efficient to use 100 percent fresh air for building ventilation (Hydeman 1996). Oakland temperatures are between 60° F and 70° F during the day for about six months of the year (National Climactic Data Center 1982).

B.3.14 Indoor Inhalation Rate

The indoor inhalation rate is the average volume of indoor air breathed per hour. Table B-38 compares the Oakland RBCA values for *indoor inhalation rate* with the ASTM (1995) defaults.

Table B-38. Comparison of Oakland RBCA Values for *Indoor Inhalation Rate* with ASTM (1995) Defaults (m³/d)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 10 ^a ; Adult: 15 ^a	15
Commercial/Industrial	20 ^a	20

Source:

^aU.S. EPA (1996; 1997)

The Oakland RBCA values for *indoor inhalation rate* deviates from the ASTM (1995) default for the residential land use scenario because the potential for a child receptor is taken into account in the Oakland RBCA model. The Oakland RBCA values are based on *Exposure Factors Handbook* (U.S. EPA 1997). They represent average inhalation rates that are supported by several field studies discussed in detail in U.S. EPA (1997).

B.3.15 Ingestion Rate of Water Used for Recreation

The ingestion rate while in water used for recreation is based on a hypothetical, swimming scenario. The U.S. EPA (1989b) recommends assuming an incidental ingestion rate while swimming of 50 ml/hr. U.S. EPA (1989b) advises that workers are not expected to be exposed via this pathway.

ASTM (1995) does not consider this exposure scenario.

B.3.16 Outdoor Inhalation Rate

The outdoor inhalation rate is the average volume of outdoor air breathed per hour. Table B-39 compares the Oakland RBCA values for *outdoor inhalation rate* with the ASTM (1995) defaults.

Table B-39. Comparison of Oakland RBCA Values for *Outdoor Inhalation Rate* with ASTM (1995) Defaults (m³/d)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 10 ^a ; Adult: 15 ^a	15
Commercial/Industrial	20 ^a	20

Source:

^aU.S. EPA (1996)

The Oakland RBCA value for *outdoor inhalation rate* deviates from the ASTM (1995) default for the residential land use scenario because the potential for a child receptor is taken into account. The Oakland RBCA values are based on the *Region 9 PRGs* (U.S. EPA 1996) and the *Exposure Factors Handbook* (U.S. EPA 1997). They represent average inhalation rates that are supported by several field studies discussed in detail in U.S. EPA (1997).

B.3.17 Skin Surface Area Exposed to Soil

The skin surface area exposed to soil is used to estimate how much soil may come in contact with the skin and be absorbed through the skin. Table B-40 compares the Oakland RBCA values for *skin surface area exposed to soil* with the ASTM (1995) defaults.

Table B-40. Comparison of Oakland RBCA Values for *Skin Surface Area Exposed to Soil* with ASTM (1995) Defaults (cm²/d)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 2000 ^a ; Adult: 5000 ^a	3160
Commercial/Industrial	5000 ^a	3160

Source:

^aU.S. EPA (1996)

The Oakland RBCA values for *skin surface area exposed to soil* deviate from the ASTM (1995) defaults for both the residential and commercial/industrial land use scenarios.

The Oakland RBCA values are conservative. U.S. EPA (1989b) reports that a “typical case” scenario for adults (i.e., exposed individual wears long-sleeve shirt, pants and shoes; exposed areas are head and hands) is 2000 cm³ and a “worst case” scenario for adults (i.e., exposed individual wears short-sleeve shirt, shorts and shoes; exposed areas are head, hands, forearms and lower legs) is 5000 cm³.

U.S. EPA (1997) provides a breakdown of skin surface area by body part for both adults and children.

B.3.18 Skin Surface Area Exposed to Water Used for Recreation

Skin surface area exposed to water used for recreation is the surface area of skin that comes in contact with contaminated water during recreational activity. Table B-41 compares the Oakland RBCA values for *skin surface area exposed to water used for recreation* with U.S. EPA (1989b) data on total skin surface area.

Table B-41. Comparison of Oakland RBCA Values for *Skin Surface Area Exposed to Water Used for Recreation* with U.S. EPA (1989b) Data on Total Skin Surface Area (cm²)

Receptor	Oakland RBCA*	U.S. EPA (1989b) (50 th percentile)	U.S. EPA (1989b) (95 th percentile)
Male Adult	20,000 ^a	19,400	22,000
Female Adult	20,000 ^a	16,900	19,800
Male Child	8,000 ^a	7,280	8,420
Female Child	8,000 ^a	7,110	8,790

*no distinction is made in the Oakland RBCA model between male and female receptors

Source:

^aU.S. EPA (1996)

The Oakland RBCA values are conservative. They are based on a hypothetical, swimming scenario in which the exposed individual’s entire body is submerged.

ASTM (1995) does not consider this exposure scenario.

B.3.19 Soil Ingestion Rate

Soil ingestion rate is a measure of the amount of surficial soil intentionally or inadvertently ingested each day. For adults, soil ingestion typically results from oral or nasal contact with dirt on the hands or face. For children, soil ingestion may also result from actually eating dirt. Table B-42 compares the Oakland RBCA values for *soil ingestion rate* with the ASTM (1995) defaults.

Table B-42. Comparison of Oakland RBCA Values for *Soil Ingestion Rate* with ASTM (1995) Defaults (mg/d)

Land Use Scenario	Oakland RBCA	ASTM Default
Residential	Child: 200 ^a ; Adult: 100 ^a	100
Commercial/Industrial	50 ^a	50

Source:

^aU.S. EPA (1996)

The Oakland RBCA value deviates from the ASTM (1995) default for the residential land use scenario because the potential for a child receptor is taken into account. The Oakland RBCA value for the commercial/industrial scenario agrees with the ASTM (1995) default.

The Oakland RBCA values are based on U.S. EPA (1996) recommendations and are very conservative. Various studies have attempted to estimate typical soil ingestion rates by measuring traces of soil elements found in the urine and fecal matter of study participants. Results have varied depending on the trace element measured.

Table B-43 compares the Oakland RBCA values with values calculated by the American Industrial Health Council (AIHC 1994) from data reported by Calabrese and Stanek (1991).

Table B-43. Comparison of Oakland RBCA Values for *Soil Ingestion Rate* with AIHC (1994) Data (mg/d)

Receptor	Oakland RBCA	AIHC*
Child	200	0.1 - 10
Adult	100	16

*extrapolated from Calabrese and Stanek (1991)

B.4 TARGET RISK LEVELS

This section discusses the Oakland RBCA target risk levels for carcinogenic and non-carcinogenic health effects. Table B-44 presents the Oakland RBCA values and indicates which of these diverge from the ASTM (1995) defaults.

Table B-44. Oakland RBCA Target Risk Levels

Input Parameter	Tier 1	Tier 2
Individual Excess Lifetime Cancer Risk (IELCR)	10 ^{-6*}	10 ⁻⁵
Hazard Quotient	1	1

*Oakland-specific value

The following subsections discuss in detail the selection of, and justification for, each of the target risk levels.

B.4.1 Individual Excess Lifetime Cancer Risk

The Oakland Tier 1 IELCR agrees with the ASTM (1995) default.

The Oakland Tier 2 IELCR deviates from the ASTM (1995) default but falls within the range of target risks recommended by ASTM (1995). There is considerable and diverse support for the use of a 1×10^{-5} IELCR target level:

- ▶ Local representatives of the agencies charged with enforcing environmental regulations in Oakland agreed unanimously to 10^{-5} at a meeting of the ULR Program Technical Advisory Committee (1996a).
- ▶ The ULR Program Community Review Panel has approved 10^{-5} . The Panel is made up of Oakland residents representing a cross-section of the Oakland community. The Panel includes individuals from: African American Development Association, GEI Consultants, People United for a Better Oakland, Northern California Minority Business Opportunity Committee, Sierra Club, Urban Habitat and Uribe & Associates Environmental Consulting Services. Their additional experience has included participation with: Alameda Naval Air Station Restoration Advisory Board, Chevron USA Refinery Community Advisory Panel, City of Oakland Planning Commission, Community Assistance Panel for Verdese Carter Park, Regional Brownfields Working Group, Oakland Army Base Restoration Advisory Board, Oakland Sharing the Vision, Oakland General Plan Congress and United Parents Against Lead. The Panel met twelve times between September 1996 and August 1997 to review the ULR Program. In its report, *Consensus Recommendations for Implementing the Oakland Urban Land Redevelopment Program*, the Panel recommends that:

[a] cancer risk level not to exceed 10^{-5} should be employed to calculate cleanup levels, provided that the following conditions are met: (1) the chemicals of concern at the site in question are well-known and well-characterized; (2) the conservatism of the assumptions that are proposed for use in the ULR cleanup calculations (such as those for exposure duration, soil ingestion and drinking water consumption) are maintained, thereby effectively reducing the risk further; (3) whenever possible, engineering controls (such as vapor barriers or asphalt caps) are considered to eliminate exposure through certain pathways; and (4) a comprehensive and effective plan for protecting the public from any remaining concentrations of contaminants is prepared, implemented and enforced (ULR Program Community Review Panel 1997).
- ▶ State Proposition 65 enforcement is based on 10^{-5} . The Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) requires the Governor of California to publish annually a list of chemicals known to the State to cause cancer or reproductive toxicity. All persons who operate a business that might expose individuals to a listed chemical must give a clear and reasonable warning to such individuals, unless there is “no significant risk” posed by the carcinogen(s) in question. The State has defined “no significant risk” as less than one excess case of cancer per 100,000 individuals (i.e., a 10^{-5} risk level).

- ▶ Several states across the nation are using a 10^{-5} target risk level in their RBCA screening level calculations, including: Alabama, Iowa, Michigan, Ohio, South Dakota, Texas and Utah.
- ▶ ASTM (1995) recommends 10^{-5} . The ASTM *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* states:

Actuarial data and risk estimates of common human activities, regulatory precedents, and the relationship between the magnitude and variance of background and incremental risk estimates all provide compelling support for the adoption of the de minimis risk level of 1×10^{-5} for regulatory purposes (ASTM 1995).

- ▶ US EPA closes sites at 10^{-5} . 10^{-5} falls in the middle of the target risk level range used by US EPA on Superfund sites (10^{-4} to 10^{-6}). In addition, the US EPA has selected a single risk level of 10^{-5} in the *Hazardous Waste Management System Toxicity Characteristics Revisions* (1995). In their justification, the US EPA cited the following rationale:

The chosen risk level of 10^{-5} is at the midpoint of the reference risk range for carcinogens (10^{-4} to 10^{-6}) generally used to evaluate CERCLA actions. Furthermore, by setting the risk level at 10^{-5} for TC carcinogens, EPA believes that this is the highest risk level that is likely to be experienced, and most if not all risks will be below this level due to the generally conservative nature of the exposure scenario and the underlying health criteria. For these reasons, the Agency regards a 10^{-5} risk level for Group A, B, and C carcinogens as adequate to delineate, under the Toxicity Characteristics, wastes that clearly pose a hazard when mismanaged.

Like the EPA model, the Oakland RBCA approach for carcinogenic health effects embodies several conservative assumptions, such that the actual risk experienced by an exposed individual is likely to be considerably less than the target level.

B.4.2 Hazard Quotient

For non-carcinogenic health effects, the Oakland RBCA approach applies a target hazard quotient of 1, based on the precedent set in the Risk Assessment Guidance for Superfund (RAGS) (U.S. EPA 1989a).

The RAGS approach estimates the likelihood of non-carcinogenic health effects (e.g., temporary respiratory difficulties or liver toxicity) by use of the threshold/hazard quotient method. Unlike the method used for carcinogenic risk estimation, non-cancer toxicity risk is not based on a probability of occurrence. Rather, the likelihood of an adverse health effect is estimated by establishing a threshold of exposure below which even the most sensitive members of a population will not suffer adverse health effects. (The Oakland RBCA approach assumes that the receptor is always a young child.) This threshold, or “safe” level of exposure, is established experimentally by research on laboratory animals or humans participating in epidemiological investigations. If the hazard quotient ratio is less than one (i.e., if the estimated exposure to the chemical of concern is below the safe threshold for that chemical), then it is assumed that no adverse health effects occur.

The Oakland RBCA approach for non-carcinogenic health effects embodies several conservative assumptions (e.g., that the residential receptor is always a young child), such that the actual risk experienced by an exposed individual is likely to be considerably less than the target level.

B.5 CHEMICAL-SPECIFIC PARAMETERS

Table B-45 presents the chemical-specific parameter values used in the Oakland RBCA calculations (see next page).

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Acenaph- thene	Acenaph- thylene	Acetone	Anthra- cene	Arsenic	Barium	Benz(a)- anthracene	Benzene
CAS Number	-	83-32-9	208-96-8	67-64-1	120-12-7	7440-38-2	7440-39-3	56-55-3	71-43-2
Toxicity Data									
Slope Factor Oral	1/(mg/kg-d)	ND	ND	ND	ND	1.50E+00	ND	1.20E+00	1.00E-01
Slope Factor Inhalation	1/(mg/kg-d)	ND	ND	ND	ND	1.20E+01	ND	3.90E+00	1.00E-01
RfD Oral	mg/kg-d	6.00E-02	6.00E-02	1.00E-01	3.00E-01	3.00E-04	7.00E-02	ND	1.70E-03
RfD Inhalation	mg/kg-d	6.00E-02	6.00E-02	1.00E-01	3.00E-01	ND	1.40E-04	ND	1.70E-03
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-01	1.00E-01	3.00E-02	1.00E-02	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Wat	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.50E-01	9.60E-02	5.69E-04	2.20E-01	1.00E-03	1.00E-03	8.10E-01	2.10E-02
Maximum Contaminant Levels (MCLs)	mg/L	ND	ND	ND	ND	5.00E-02	1.00E+00	ND	1.00E-03
Fate and Transport Parameters									
Solubility	mg/L	4.24E+00	3.93E+00	1.00E+06	4.34E-02	ND	ND	9.40E-03	1.75E+03
Henry's Law Constant (no NDs)	-	6.36E-03	4.67E-03	1.59E-03	2.67E-03	0.00E+00	0.00E+00	1.37E-04	2.28E-01
Koc (for organics, ND for inorganics)	ml/g	7.08E+03	4.79E+03	5.75E-01	2.95E+04	ND	ND	3.98E+05	5.89E+01
Kd (partition coefficient for inorganics)	ml/g	ND	ND	ND	ND	2.90E+01	4.10E+01	ND	ND
Diffusion Coeff. in Air	cm ² /s	4.21E-02	5.40E-02	1.24E-01	3.24E-02	ND	ND	5.10E-02	8.80E-02
Diffusion Coefficient in Water	cm ² /s	7.69E-06	6.60E-06	1.14E-05	7.74E-06	ND	ND	9.00E-06	9.80E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(g,h,i)-perylene	Benzo(k)-fluoranthene	Beryllium	Bis(2-ethylhexyl)phthalate	Butyl benzyl phthalate
CAS Number	-	50-32-8	205-99-2	191-24-2	207-08-9	7440-41-7	117-81-7	85-68-7
Toxicity Data								
Slope Factor Oral	1/(mg/kg-d)	1.20E+01	1.20E+00	ND	1.20E+00	ND	8.40E-03	ND
Slope Factor Inhalation	1/(mg/kg-d)	3.90E+00	3.90E-01	ND	3.90E-01	7.00E+00	8.40E-03	ND
RfD Oral	mg/kg-d	ND	ND	4.00E-03	ND	5.00E-03	2.00E-02	2.00E-01
RfD Inhalation	mg/kg-d	ND	ND	4.00E-03	ND	ND	2.20E-02	ND
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-02	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.20E+00	1.20E+00	1.66E+00	1.10E+00	1.00E-03	3.30E-02	7.40E-02
Maximum Contaminant Levels (MCLs)	mg/L	2.00E-04	ND	ND	ND	4.00E-03	ND	ND
Fate and Transport Parameters								
Solubility	mg/L	1.62E-03	1.50E-03	2.60E-04	8.00E-04	ND	3.40E-01	2.69E+00
Henry's Law Constant (no NDs)	-	4.63E-05	4.55E-03	1.09E-05	3.40E-05	0.00E+00	4.18E-06	5.17E-05
Koc (for organics, ND for inorganics)	ml/g	1.02E+06	1.23E+06	7.76E+06	1.23E+06	ND	1.51E+07	5.75E+04
Kd (partition coefficient for inorganics)	ml/g	ND	ND	ND	ND	7.90E+02	ND	ND
Diffusion Coeff. in Air	cm ² /s	4.30E-02	2.26E-02	4.10E-02	2.26E-02	ND	3.51E-02	3.90E-02
Diffusion Coefficient in Water	cm ² /s	9.00E-06	5.56E-06	4.90E-06	5.56E-06	ND	3.66E-06	7.03E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Cadmium	Carbon Disulfide	Carbon Tetrachloride	Chlorobenzene	Chloroform	Chromium (III)	Chromium (VI)	Chrysene
CAS Number	-	7440-43-9	75-15-0	56-23-5	108-90-7	67-66-3	7440-47-2	7440-47-3	218-01-9
Toxicity Data									
Slope Factor Oral	1/(mg/kg-d)	ND	ND	1.50E-01	ND	3.10E-02	ND	4.20E-01	1.20E-01
Slope Factor Inhalation	1/(mg/kg-d)	1.50E+01	ND	1.50E-01	ND	1.90E-02	ND	5.10E+02	3.90E-02
RfD Oral	mg/kg-d	5.00E-04	1.00E-01	7.00E-04	2.00E-02	1.00E-02	1.00E+00	5.00E-03	ND
RfD Inhalation	mg/kg-d	5.00E-04	2.90E-03	5.71E-04	5.70E-03	1.00E-02	1.00E+00	ND	ND
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-02	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-02	1.00E-02	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.00E-03	2.40E-02	2.20E-02	4.10E-02	8.90E-03	1.30E-03	1.30E-03	8.10E-01
Maximum Contaminant Levels (MCLs)	mg/L	5.00E-03	ND	5.00E-04	7.00E-02	1.00E-01	ND	5.00E-02	ND
Fate and Transport Parameters									
Solubility	mg/L	ND	1.19E+03	7.93E+02	4.72E+02	7.92E+03	ND	ND	1.60E-03
Henry's Law Constant (no NDs)	-	0.00E+00	5.92E-01	1.25E+00	1.52E-01	1.50E-01	0.00E+00	0.00E+00	3.88E-03
Koc (for organics, ND for inorganics)	ml/g	ND	4.57E+01	1.74E+02	2.19E+01	3.98E+01	ND	ND	3.98E+05
Kd (partition coefficient for inorganics)	ml/g	7.50E+01	ND	ND	ND	ND	1.80E+06	1.90E+01	ND
Diffusion Coeff. in Air	cm ² /s	ND	1.04E-01	7.80E-02	7.30E-01	1.04E-01	ND	ND	2.48E-02
Diffusion Coefficient in Water	cm ² /s	ND	1.00E-05	8.80E-06	8.70E-06	1.00E-05	ND	ND	6.21E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Copper	Cresol(-m)	Cresol(-o)	Cresol(-p)	Cyanide	Dibenz(a,h)anthracene	Dichloroethane (1,1-)	Dichloroethane (1,2-) (EDC)
CAS Number	-	7440-50-8	108-39-4	95-48-7	106-44-5	57-12-5	53-70-3	75-34-3	107-06-2
Toxicity Data									
Slope Factor Oral	1/(mg/kg-d)	ND	ND	ND	ND	ND	4.10E+00	5.70E-03	7.00E-02
Slope Factor Inhalation	1/(mg/kg-d)	ND	ND	ND	ND	ND	4.10E+00	5.70E-03	7.00E-02
RfD Oral	mg/kg-d	3.70E-02	5.00E-02	5.00E-02	5.00E-03	4.00E-02	ND	1.00E-01	2.90E-03
RfD Inhalation	mg/kg-d	ND	5.00E-02	5.00E-02	5.00E-03	ND	ND	1.40E-01	2.90E-03
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-02	1.00E-01	1.00E-01	1.00E-01	1.00E-02	1.00E-01	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.00E-03	1.50E-02	1.60E-02	1.80E-02	1.00E-02	2.70E+00	8.90E-03	5.30E-03
Maximum Contaminant Levels (MCLs)	mg/L	1.30E+00	ND	ND	ND	2.00E-01	ND	5.00E-03	5.00E-04
Fate and Transport Parameters									
Solubility	mg/L	ND	2.27E+04	2.60E+04	3.53E+04	ND	2.49E-03	5.06E+03	8.52E+03
Henry's Law Constant (no NDs)	-	0.00E+00	3.55E-05	4.92E-05	4.10E-05	0.00E+00	6.03E-07	2.30E-01	4.01E-02
Koc (for organics, ND for inorganics)	ml/g	ND	8.71E+01	9.12E+01	8.13E+01	ND	3.80E+06	3.16E+01	1.74E+01
Kd (partition coefficient for inorganics)	ml/g	0.00E+00	ND	ND	ND	9.90E+00	ND	ND	ND
Diffusion Coeff. in Air	cm ² /s	ND	7.40E-02	7.40E-02	7.40E-02	ND	2.02E-02	7.42E-02	1.04E-01
Diffusion Coefficient in Water	cm ² /s	ND	1.00E-05	8.30E-06	1.00E-05	ND	5.18E-06	1.05E-05	9.90E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Dichloro ethylene (1,1-)	Dichloro ethylene (cis 1,2-)	Dichloro ethene (trans 1,2)	Dimethyl-benza(a) anthracene (7,12)	Dimethyl phenol (2,4)	di-n-Butyl-phthalate	di-n-octyl phthalate
CAS Number	-	75-34-4	156-59-2	156-60-5	57-97-6	105-67-9	84-74-2	117-84-0
Toxicity Data								
Slope Factor Oral	1/(mg/kg-d)	6.00E-01	ND	ND	ND	ND	ND	ND
Slope Factor Inhalation	1/(mg/kg-d)	1.80E-01	ND	ND	ND	ND	ND	ND
RfD Oral	mg/kg-d	9.00E-03	1.00E-02	2.00E-02	3.00E-02	2.00E-02	1.00E-01	2.00E-02
RfD Inhalation	mg/kg-d	9.00E-03	1.00E-02	2.00E-02	ND	2.00E-02	1.00E-01	2.00E-02
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.60E-02	1.00E-02	1.00E-02	1.20E+00	1.50E-02	3.30E-02	2.70E+01
Maximum Contaminant Levels (MCLs)	mg/L	6.00E-03	6.00E-03	1.00E-02	ND	ND	ND	ND
Fate and Transport Parameters								
Solubility	mg/L	2.25E+03	3.50E+03	6.30E+03	6.10E-02	7.87E+03	1.12E+01	2.90E-01
Henry's Law Constant (no NDs)	-	1.07E+00	1.67E-01	3.85E-01	1.28E-06	8.20E-05	3.85E-08	7.50E-09
Koc (for organics, ND for inorganics)	ml/g	5.89E+01	3.55E+01	5.25E+01	4.80E+05	2.09E+02	8.32E+07	1.10E+05
Kd (partition coefficient for inorganics)	ml/g	ND	ND	ND	ND	ND	ND	ND
Diffusion Coeff. in Air	cm ² /s	9.00E-02	7.36E-02	7.07E-02	4.60E-02	5.84E-02	1.51E-02	3.70E-02
Diffusion Coefficient in Water	cm ² /s	1.04E-05	1.13E-05	1.19E-05	5.00E-06	8.69E-06	3.58E-06	4.00E-05

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Dinitro toluene (2,4)	Dioxane (1,4)	Ethylbenzene	Ethylene Dibromide	Fluoranthene	Fluorene	Indeno-(1,2,3-CD)pyrene
CAS Number	-	121-14-2	123-91-1	100-41-4	106-93-4	206-44-0	86-73-7	193-39-5
Toxicity Data								
Slope Factor Oral	1/(mg/kg-d)	3.10E-01	2.70E-02	ND	3.60E+00	ND	ND	1.20E+00
Slope Factor Inhalation	1/(mg/kg-d)	3.10E-01	2.70E-02	ND	2.50E-01	ND	ND	3.90E-01
RfD Oral	mg/kg-d	ND	ND	1.00E-01	5.70E-05	4.00E-02	4.00E-02	ND
RfD Inhalation	mg/kg-d	ND	ND	2.90E-01	5.70E-05	4.00E-02	4.00E-02	ND
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	3.80E-03	3.60E-04	7.40E-02	3.30E-03	3.60E-01	3.60E-01	1.90E+00
Maximum Contaminant Levels (MCLs)	mg/L	ND	ND	7.00E-01	5.00E-05	ND	ND	ND
Fate and Transport Parameters								
Solubility	mg/L	2.70E+02	1.10E-02	1.69E+02	4.30E+03	2.06E-01	1.98E+00	2.20E-05
Henry's Law Constant (no NDs)	-	3.80E-06	1.10E-02	3.23E-01	2.89E-02	6.60E-04	2.61E-03	6.56E-05
Koc (for organics, ND for inorganics)	ml/g	9.55E+01	1.70E+01	3.63E+02	4.37E+01	1.07E+05	1.38E+04	3.47E+06
Kd (partition coefficient for inorganics)	ml/g	ND	ND	ND	ND	ND	ND	ND
Diffusion Coeff. in Air	cm ² /s	2.03E-01	2.30E-01	7.50E-02	5.00E-02	3.02E-02	3.63E-02	1.90E-02
Diffusion Coefficient in Water	cm ² /s	7.06E-06	1.00E-05	7.80E-06	9.60E-06	6.35E-06	7.88E-06	5.66E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Mercury	Methanol	Methyl ethyl ketone	Methylene Chloride	Methyl-naphthalene (2-)	MTBE	Naphthalene
CAS Number	-	7439-97-6	67-56-1	78-93-3	75-09-2	91-57-6	1634-04-4	91-20-3
Toxicity Data								
Slope Factor Oral	1/(mg/kg-d)	ND	ND	ND	1.40E-02	ND	ND	ND
Slope Factor Inhalation	1/(mg/kg-d)	ND	ND	ND	3.50E-03	ND	ND	ND
RfD Oral	mg/kg-d	1.00E-04	5.00E-01	6.00E-01	6.00E-02	4.00E-02	5.00E-03	4.00E-02
RfD Inhalation	mg/kg-d	8.57E-05	5.00E-01	2.90E-01	8.60E-01	4.00E-02	8.57E-01	4.00E-02
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.67E-03	3.50E-04	5.00E-03	4.50E-03	1.80E-01	3.08E-03	6.90E-02
Maximum Contaminant Levels (MCLs)	mg/L	2.00E-03	ND	ND	5.00E-03	ND	1.30E-02	2.00E-02
Fate and Transport Parameters								
Solubility	mg/L	ND	1.00E+06	2.12E+05	1.30E+04	2.46E+01	4.80E+04	3.10E+01
Henry's Law Constant (no NDs)	-	4.67E-01	1.87E-04	2.33E-03	8.98E-02	2.12E-02	2.04E-02	1.98E-02
Koc (for organics, ND for inorganics)	ml/g	ND	0.00E+00	4.50E+00	1.17E+01	8.50E+03	1.20E+01	2.00E+03
Kd (partition coefficient for inorganics)	ml/g	5.20E+01	ND	ND	ND	ND	ND	ND
Diffusion Coeff. in Air	cm ² /s	3.07E-02	1.55E-01	8.08E-02	1.01E-01	5.80E-02	7.10E-02	5.90E-02
Diffusion Coefficient in Water	cm ² /s	6.30E-06	1.64E-05	9.80E-06	1.17E-05	7.37E-06	9.04E-06	7.50E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Nickel	Nitro benzene	PCBs	Phenan-threne	Phenol	Pyrene	Pyridine	Selenium
CAS Number	-	7440-02-0	98-95-3	1336-36-3	85-01-8	108-95-2	129-00-0	110-86-1	7782-49-2
Toxicity Data									
Slope Factor Oral	1/(mg/kg-d)	ND	5.00E-04	7.70E+00	ND	ND	ND	1.00E-03	ND
Slope Factor Inhalation	1/(mg/kg-d)	9.10E-01	5.70E-04	7.70E+00	ND	ND	ND	1.00E-03	ND
RfD Oral	mg/kg-d	2.00E-02	ND	2.00E-05	3.00E-01	6.00E-01	3.00E-02	ND	5.00E-03
RfD Inhalation	mg/kg-d	ND	ND	2.00E-05	3.00E-01	6.00E-01	3.00E-02	ND	ND
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-02	1.00E-01	6.00E-02	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-02
Absorption Adjustment Factor: Dermal-Wat	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	1.00E-03	7.00E-03	1.30E+00	2.70E-01	5.50E-03	3.24E-01	1.80E-03	1.00E-03
Maximum Contaminant Levels (MCLs)	mg/L	1.00E-01	ND	5.00E-04	ND	ND	ND	ND	5.00E-02
Fate and Transport Parameters									
Solubility	mg/L	1.73E+05	2.09E+03	4.20E-01	1.29E+00	8.28E+04	1.35E-01	1.00E+06	ND
Henry's Law Constant (no NDs)	-	0.00E+00	9.84E-04	1.11E-02	1.60E-03	1.63E-05	4.51E-04	4.51E-04	0.00E+00
Koc (for organics, ND for inorganics)	ml/g	ND	6.46E+01	3.09E+05	2.29E+04	2.88E+01	1.05E+05	5.38E+01	ND
Kd (partition coefficient for inorganics)	ml/g	6.50E+01	ND	ND	ND	ND	ND	ND	5.00E+00
Diffusion Coeff. in Air	cm ² /s	ND	7.60E-02	1.04E-01	5.17E-02	8.20E-02	2.72E-02	9.10E-02	ND
Diffusion Coefficient in Water	cm ² /s	ND	8.60E-05	1.00E-05	5.90E-06	9.10E-06	7.24E-06	7.60E-06	ND

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Silver	Stryene	Tetrachloroethane (1,1,2,2-)	Tetrachloroethylene (PCE)	Tetraethyl Lead	Toluene	Trichloroethane (1,1,1-)
CAS Number	-	7440-22-4	100-42-5	79-34-5	127-18-4	78-00-2	108-88-3	71-55-6
Toxicity Data								
Slope Factor Oral	1/(mg/kg-d)	ND	ND	2.70E-01	5.10E-02	ND	ND	ND
Slope Factor Inhalation	1/(mg/kg-d)	ND	ND	2.70E-01	2.10E-02	ND	ND	ND
RfD Oral	mg/kg-d	5.00E-03	2.00E-01	2.60E-02	1.00E-02	1.00E-07	2.00E-01	3.50E-02
RfD Inhalation	mg/kg-d	ND	2.86E-01	2.60E-02	1.00E-02	ND	1.14E-01	2.90E-01
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-02	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	6.00E-04	5.50E-02	9.00E-03	4.80E-02	3.60E-02	4.50E-02	1.70E-02
Maximum Contaminant Levels (MCLs)	mg/L	1.00E-01	1.00E-01	1.00E-03	5.00E-03	1.50E-02	1.50E-01	2.00E-01
Fate and Transport Parameters								
Solubility	mg/L	ND	3.10E+02	2.97E+03	2.00E+02	2.10E-01	5.26E+02	1.33E+03
Henry's Law Constant (no NDs)	-	0.00E+00	1.13E-01	1.41E-02	7.54E-01	2.33E+01	2.72E-01	7.05E-01
Koc (for organics, ND for inorganics)	ml/g	ND	7.76E+02	9.33E+01	1.55E+02	4.90E+03	1.82E+02	1.10E+02
Kd (partition coefficient for inorganics)	ml/g	8.30E+00	ND	ND	ND	ND	ND	ND
Diffusion Coeff. in Air	cm ² /s	ND	7.10E-02	7.10E-02	7.20E-02	5.70E-02	8.70E-02	7.80E-02
Diffusion Coefficient in Water	cm ² /s	ND	8.00E-06	7.90E-06	8.20E-06	6.40E-06	8.60E-06	8.80E-06

Table B-45. Oakland RBCA Chemical Properties

Parameter	Units	Trichloroethane (1,1,2-)	Trichloroethylene (TCE)	Vanadium	Vinyl Chloride	Xylenes	Zinc
CAS Number	-	79-00-5	79-01-6	7440-62-2	75-01-4	1330-20-7	7440-66-6
Toxicity Data							
Slope Factor Oral	1/(mg/kg-d)	7.20E-02	1.50E-02	ND	2.70E-01	ND	ND
Slope Factor Inhalation	1/(mg/kg-d)	7.20E-02	1.00E-02	ND	2.70E-01	ND	ND
RfD Oral	mg/kg-d	4.00E-03	6.00E-03	7.00E-03	ND	2.00E+00	3.00E-01
RfD Inhalation	mg/kg-d	4.00E-03	6.00E-03	ND	ND	2.00E-01	ND
Absorption Adjustment Factor: Oral-Soil	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Oral-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Dermal-Soil	-	1.00E-01	1.00E-01	1.00E-02	1.00E-01	1.00E-01	1.00E-02
Absorption Adjustment Factor: Dermal-Water	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Absorption Adjustment Factor: Inhalation	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Skin Permeability Coefficient	cm/hr	8.40E-03	2.30E-01	1.00E-03	7.30E-03	8.00E-02	6.00E-04
Maximum Contaminant Levels (MCLs)	mg/L	5.00E-03	5.00E-03	ND	5.00E-04	1.75E+00	ND
Fate and Transport Parameters							
Solubility	mg/L	4.42E+03	1.10E+03	ND	2.67E+03	1.98E+02	ND
Henry's Law Constant (no NDs)	-	3.74E-02	4.22E-01	0.00E+00	1.11E+00	2.90E-01	0.00E+00
Koc (for organics, ND for inorganics)	ml/g	5.01E+01	1.66E+02	ND	1.86E+01	2.40E+02	ND
Kd (partition coefficient for inorganics)	ml/g	ND	ND	1.00E+03	ND	ND	6.20E+01
Diffusion Coeff. in Air	cm ² /s	7.80E-02	7.90E-02	ND	1.06E-01	7.20E-02	ND
Diffusion Coefficient in Water	cm ² /s	8.80E-06	9.10E-06	ND	1.23E-05	8.50E-06	ND

The following subsections present the source(s) for each of the chemical-specific parameter values.

B.5.1 Slope Factors

For oral and inhalation slope factors, data from the following sources are used (in order of preference):

1. *California Cancer Potency Factors* (California Environmental Protection Agency 1994)
2. *Region 9 Preliminary Remediation Goals* (U.S. EPA 1996)

For all chemicals, the dermal slope factor is assumed to be equal to the oral slope factor.

B.5.2 Reference Doses

For oral and inhalation reference doses, data from the *Region 9 PRGs* (U.S. EPA 1996) are used. The dermal reference dose is assumed to be equal to the oral reference dose.

B.5.3 Absorption Adjustment Factors

For absorption adjustment factors for dermal contact with soil, data from the *Region 9 PRGs* (U.S. EPA 1996) are used. The absorption adjustment factor for dermal contact with soil is 0.1 for all organics, with the exception of arsenic (0.03) and PCBs (0.06), and 0.01 for all inorganics.

All other absorption adjustment factors are set equal to 1.

B.5.4 Skin Permeability Coefficients

For skin permeability coefficients, data from *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA 1992) are used.

B.5.5 Maximum Contaminant Levels

For MCLs, the California Department of Health Services (1999) values are used.

B.5.6 Solubility

For solubility, data from the following sources are used (in order of preference):

1. *Soil Screening Guidance* (U.S. EPA 1996)
2. *Handbook of Physical Properties of Organic Chemicals* (Howard and Meylan 1997)

B.5.7 Henry's Law Constant

For Henry's Law Constant, data from the following sources are used (in order of preference):

1. *Soil Screening Guidance* (U.S. EPA 1996)
2. *Handbook of Physical Properties of Organic Chemicals* (Howard and Meylan 1997)
3. *Handbook of Fate and Exposure Data for Organic Chemicals (Volumes 1 - 3)* (Howard 1989)

B.5.8 Organic Carbon Partition Coefficient

For the organic carbon partition coefficient, K_{oc} , data from the following sources are used (in order of preference):

1. *Soil Screening Guidance* (U.S. EPA 1996)
2. *Handbook of Fate and Exposure Data for Organic Chemicals (Volumes 1 - 3)* (Howard 1989)

B.5.9 Partition Coefficient for Inorganics

For inorganic chemicals, although the K_{oc} is set equal to zero, sorption is still accounted for by employing the partition coefficient, K_s (also commonly written as K_d). Data for K_s are from *Soil Screening Guidance* (U.S. EPA 1996) and are based on a pH value of 6.8. For chemicals not listed therein, the K_s is assumed to be zero (i.e., no sorption occurs).

B.5.10 Diffusion Coefficients

For diffusion coefficients in air and water, data from the following sources are used (in order of preference):

1. *Soil Screening Guidance* (U.S. EPA 1996)
2. *Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) –Air Emission Models* (U.S. EPA 1987)

APPENDIX C
SENSITIVITY ANALYSIS OF INPUT PARAMETERS

This appendix presents a sensitivity analysis for all the input parameters employed in the Oakland RBCA equations. The tables contained herein identify:

- (1) the exposure pathway(s) that each input parameter affects
- (2) the mathematical relationship between the input parameter value and the RBCA level

For purposes of this discussion, a “parallel” relationship means that the higher or lower the input parameter value, the higher or lower the resultant RBCA level. An “inverse” relationship means that the higher the input parameter value, the lower the resultant RBCA level, and vice versa.

C.1 SOIL-SPECIFIC TRANSPORT PARAMETERS

Table C-1 presents the exposure pathways affected by each of the Oakland RBCA soil-specific transport parameters and their mathematical relationship to the calculated RBCA level.

Table C-1. Sensitivity Analysis of Soil-Specific Transport Parameters

Input Parameter	Affected Pathways	Relationship
<i>Capillary fringe air content</i>	▶ Groundwater: inhalation of indoor and outdoor air	Inverse
<i>Capillary fringe water content</i>	▶ Groundwater: inhalation of indoor and outdoor air	Parallel
<i>Capillary fringe thickness</i>	▶ Groundwater: inhalation of indoor and outdoor air	Parallel
<i>Fraction organic carbon in soil (F_{oc}^*)</i>	▶ Surficial soil and subsurface soil: all ▶ Groundwater: inhalation of indoor and outdoor air	Parallel
<i>Groundwater Darcy velocity</i>	▶ Subsurface soil: ingestion of groundwater impacted by leachate	Parallel
<i>Groundwater mixing zone thickness</i>	▶ Subsurface soil: ingestion of groundwater impacted by leachate	Parallel
<i>Infiltration rate through the vadose zone</i>	▶ Subsurface soil: ingestion of groundwater impacted by leachate	Inverse
<i>Soil bulk density</i>	▶ Surficial and subsurface soil: all	Inverse
<i>Soil to skin adherence factor</i>	▶ Surficial soil	Inverse
<i>Total soil porosity</i>	▶ Surficial soil and subsurface soil: all	NA ^a
<i>Vadose zone air content</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Inverse
<i>Vadose zone water content</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Parallel
<i>Vadose zone thickness</i>	▶ Groundwater: inhalation of indoor and outdoor air	Parallel

^aNot applicable: total soil porosity does not affect the RBCA levels—air and water content do.

C.2 NON-SOIL-SPECIFIC TRANSPORT PARAMETERS

Table C-2 presents the exposure pathways affected by each of the Oakland RBCA non-soil-specific transport parameters and their mathematical relationship to the calculated RBCA level.

Table C-2. Sensitivity Analysis of Non-Soil-Specific Transport Parameters

Input Parameter	Affected Pathways	Relationship
<i>Areal fraction of cracks in building foundation</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Inverse
<i>Foundation cracks air content</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Inverse
<i>Foundation cracks water content</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Parallel
<i>Foundation thickness</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Parallel
<i>Lower depth of surficial soil zone</i>	▶ Surficial soil	Inverse ^a
<i>Depth to subsurface soil sources</i>	▶ Subsurface soil: inhalation of indoor air	Parallel
<i>Depth to groundwater</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Parallel
<i>Width of source area parallel to wind or groundwater flow direction</i>	▶ Surficial soil, subsurface soil and groundwater: all pathways	Inverse
<i>Outdoor air mixing zone height</i>	▶ Subsurface soil and groundwater: inhalation of outdoor air	Parallel
<i>Particulate emission rate</i>	▶ Surficial soil	Inverse
<i>Wind speed above ground surface in outdoor air mixing zone</i>	▶ Subsurface soil and groundwater: inhalation of outdoor air	Parallel

^aAffects RBCA level only for highly-volatile chemicals

C.3 RECEPTOR-SPECIFIC PARAMETERS

Table C-3 presents the exposure pathways affected by each of the Oakland RBCA receptor-specific parameters and their mathematical relationship to the calculated RBCA level.

Table C-3. Sensitivity Analysis of Receptor-Specific Parameters

Input Parameter	Affected Pathways	Relationship
<i>Averaging time for carcinogenic effects</i>	▶ All pathways	Inverse ^a
<i>Averaging time for non-carcinogenic effects</i>	▶ All pathways	NA ^b
<i>Averaging time for vapor flux</i>	▶ Surficial soil	Parallel
<i>Body weight</i>	▶ All pathways	Parallel
<i>Building air volume/floor area</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Parallel
<i>Exposure duration</i>	▶ All pathways	Inverse ^c
<i>Exposure frequency</i>	▶ All pathways	Inverse
<i>Exposure frequency to water used for recreation</i>	▶ Water used for recreation	Inverse
<i>Exposure time to indoor air</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Inverse
<i>Exposure time to outdoor air</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of outdoor air	Inverse
<i>Exposure time to water used for recreation</i>	▶ Water used for recreation	Inverse
<i>Groundwater ingestion rate</i>	▶ Groundwater: ingestion	Inverse
<i>Indoor air exchange rate</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Parallel
<i>Indoor inhalation rate</i>	▶ Subsurface soil and groundwater: inhalation of indoor air	Inverse
<i>Ingestion rate of water used for recreation</i>	▶ Water used for recreation	Inverse
<i>Outdoor inhalation rate</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of outdoor air	Inverse
<i>Skin surface area exposed to soil</i>	▶ Surficial soil	Inverse
<i>Skin surface area exposed to water used for recreation</i>	▶ Water used for recreation	Inverse
<i>Soil ingestion rate</i>	▶ Surficial soil	Inverse

^aThe input value for *averaging time for carcinogenic effects* is effectively fixed since all toxicity data is based on 70 years.

^bNot applicable; *averaging time for non-carcinogenic effects* cancels out with *exposure duration*.

^cApplies only to RBCA levels for carcinogens; for non-carcinogens, the input value for *exposure duration* cancels out with the input value for *averaging time for non-carcinogenic effects*.

C.4 TARGET RISK LEVELS

Table C-4 presents the exposure pathways affected by each of the Oakland RBCA target risk levels parameters and their mathematical relationship to the calculated RBCA level.

Table C-4. Sensitivity Analysis of Target Risk Levels

Input Parameter	Affected Pathways	Relationship
<i>Individual Excess Lifetime Cancer Risk (IELCR)</i>	▶ All	Parallel
<i>Hazard Quotient</i>	▶ All	Parallel

C.5 CHEMICAL-SPECIFIC PARAMETERS

Table C-5 presents the exposure pathways affected by each of the Oakland RBCA chemical-specific parameters and their mathematical relationship to the calculated RBCA level.

Table C-5. Sensitivity Analysis of Chemical-Specific Parameters

Input parameter	Affected Pathways	Relationship
<i>Slope factors</i>	▶ All	Inverse
<i>Reference doses</i>	▶ All	Parallel
<i>Absorption adjustment factors</i>	▶ Surficial soil ^a	Inverse
<i>Skin permeability coefficient</i>	▶ Water used for recreation	Inverse
<i>Maximum Contaminant Level (MCL)</i>	▶ Subsurface soil: ingestion of groundwater impacted by leachate ▶ Groundwater: ingestion	Parallel ^b
<i>Solubility</i>	▶ Subsurface soil, groundwater and water used for recreation: all	NA ^c
<i>Henry's Law constant</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Inverse
<i>Organic carbon partition coefficient (K_{oc})</i>	▶ Surficial and subsurface soil: all	Parallel
<i>Partition coefficient for inorganics (K_s)</i>	▶ Surficial and subsurface soil: all	Parallel
<i>Diffusion coefficient in air</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Inverse
<i>Diffusion coefficient in water</i>	▶ Surficial soil ▶ Subsurface soil and groundwater: inhalation of indoor and outdoor air	Inverse

^aDermal contact with soil is the only absorption adjustment factor for which the Oakland RBCA approach employs chemical-specific values; all others are set equal to one.

^bRisk-based calculations are replaced with MCLs when MCLs are more stringent.

^cNot applicable; solubility is employed to check if the RBCA level is above the saturation limit.

APPENDIX D SPREADSHEET VALIDATION RESULTS

This appendix compares the output of the Oakland RBCA *Excel* spreadsheet (see [Table D-1](#)) with the ASTM (1995) example Tier 1 table (see [Table D-2](#)) to verify that the algorithms for the Oakland RBCA model are entered correctly in the spreadsheet.

The default input parameter values from ASTM (1995) were employed in the Oakland RBCA spreadsheet. The output compares favorably with the ASTM (1995) example Tier 1 RBSLs, with the following exceptions:

- (1) The RBSL calculated for Xylenes for surficial soil under the residential land use scenario (1.45E+05 mg/kg) does not match the value presented in the ASTM (1995) example Tier 1 table (1.45E+06 mg/kg). We believe that the ASTM (1995) value is a typo because (a) it is exactly one order of magnitude different from the value calculated by the Oakland RBCA spreadsheet, and (b) it is higher than the ASTM (1995) value presented for the same pathway under the commercial/industrial land use scenario.
- (2) The RBSLs presented for benzo(a)pyrene for ingestion of groundwater impacted by leachate, using maximum contaminant levels (MCLs), do not match the ASTM (1995) value of 9.42E+00 mg/kg. This is because, although the Oakland RBCA spreadsheet also calculates a value of 9.42E+00, this value is recognized by the spreadsheet to be above the saturated soil concentration and “SAT” is entered. Because the Oakland RBCA spreadsheet results match the ASTM (1995) values for all other chemicals for this exposure pathway, we believe that the ASTM (1995) spreadsheet failed to recognize that the saturated soil concentration had been exceeded.

Please note that we were unable to perform a spreadsheet validation study for the “water used for recreation” exposure pathway since it is unique to the Oakland RBCA approach and is not considered by ASTM (1995).

Table D-1. Oakland RBCA Spreadsheet Validation Results

Medium	Exposure Pathway	Land Use	Type of Risk	Benzene	Benzo(a)-pyrene	Ethyl-benzene	Naphthalene	Toluene	Xylenes	
Surficial Soil [mg/kg]	Ingestion/ Dermal/ Inhalation	Residential	Carcinogenic	5.82E+00	1.30E-01					
			Hazard			7.84E+03	9.77E+02	1.33E+04	1.45E+05	
		Commercial/ Industrial	Carcinogenic	1.00E+01	3.04E-01					
			Hazard			1.15E+04	1.50E+03	1.87E+04	2.08E+05	
Subsurface Soil [mg/kg]	Inhalation of Outdoor Air Vapors	Residential	Carcinogenic	2.73E-01	SAT					
			Hazard			SAT	SAT	SAT	SAT	
	Commercial/ Industrial	Carcinogenic	4.59E-01	SAT						
		Hazard			SAT	SAT	SAT	SAT		
	Inhalation of Indoor Air Vapors	Residential	Carcinogenic	5.38E-03	SAT					
			Hazard			4.29E+02	4.07E+01	2.08E+01	SAT	
	Commercial/ Industrial	Carcinogenic	1.69E-02	SAT						
		Hazard			1.12E+03	1.06E+02	5.45E+01	SAT		
	Ingestion of Groundwater Impacted by Leachate	Residential	Carcinogenic	2.93E-02	SAT	1.10E+02			1.77E+01	3.05E+02
			Hazard	2.93E-02	SAT	1.10E+02	2.29E+01	1.77E+01	3.05E+02	
Commercial/ Industrial	Carcinogenic	2.93E-02	SAT	1.10E+02			1.77E+01	3.05E+02		
	Hazard	2.93E-02	SAT	1.10E+02	6.43E+01	1.77E+01	3.05E+02			
Groundwater [mg/l]	Ingestion of Groundwater	Residential	Carcinogenic	5.00E-03	2.00E-04	7.00E-01		1.00E+00	1.00E+01	
			Hazard	5.00E-03	2.00E-04	7.00E-01	1.46E-01	1.00E+00	1.00E+01	
	Commercial/ Industrial	Carcinogenic	5.00E-03	2.00E-04	7.00E-01			1.00E+00	1.00E+01	
		Hazard	5.00E-03	2.00E-04	7.00E-01	4.09E-01	1.00E+00	1.00E+01		
	Inhalation of Indoor Air Vapors	Residential	Carcinogenic	2.40E-02	>Sol					
			Hazard			7.78E+01	4.70E+00	3.24E+01	>Sol	
	Commercial/ Industrial	Carcinogenic	7.52E-02	>Sol						
		Hazard			>Sol	1.23E+01	8.48E+01	>Sol		
	Inhalation of Outdoor Air Vapors	Residential	Carcinogenic	1.10E+01	>Sol					
			Hazard			>Sol	>Sol	>Sol	>Sol	
Commercial/ Industrial	Carcinogenic	1.85E+01	>Sol							
	Hazard			>Sol	>Sol	>Sol	>Sol			

Table D-2. ASTM (1995) Example Tier 1 Table



TABLE X2.1 Example Tier 1 Risk-Based Screening Level (RBSL) Look-up Table^A

NOTE—This table is presented here only as an example set of Tier 1 RBSLs. It is not a list of proposed standards. The user should review all assumptions prior to using any values. Appendix X2 describes the basis of these values.

Exposure Pathway	Receptor Scenario	Target Level	Benzene	Ethylbenzene	Toluene	Xylenes (Mixed)	Napthalenes	Benzo (a)pyrene
Air								
Indoor air screening levels for inhalation exposure, μm^3	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	3.92E-01 3.92E+01					1.86E-03 1.86E-01
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	4.93E-01 4.93E+01	1.39E+03	5.56E+02	9.73E+03	1.95E+01	2.35E-03 2.35E-01
Outdoor air screening levels for inhalation exposure, $\mu\text{g}/\text{m}^3$	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	2.94E-01 2.94E+01					1.40E-03 1.40E-01
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	4.93E-01 4.93E+01	1.04E+03	4.17E+02	7.30E+03	1.46E+01	2.35E-03 2.35E-01
OSHA TWA PEL, $\mu\text{g}/\text{m}^3$			3.20E+03	4.35E+05	7.53E+05	4.35E+06	5.00E+04	2.00E+02 ^A
Mean odor detection threshold, $\mu\text{g}/\text{m}^3$ ^B			1.95E+05		6.00E+03	8.70E+04	2.00E+02	
National indoor background concentration range, $\mu\text{g}/\text{m}^3$ ^C			3.25E+00 to 2.15E+01	2.20E+00 to 9.70E+00	6.00E+03 2.91E+01	8.70E+04 4.76E+01		
Soil								
Soil volatilization to outdoor air, mg/kg	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	2.72E-01 2.73E+01					RES ^D RES
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	4.57E-01 4.57E+01	RES	RES	RES	RES	RES RES
Soil-vapor intrusion from soil to buildings, mg/kg	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	5.37E-03 5.37E-01					RES RES
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	1.69E-02 1.69E+00	4.27E+02	2.06E+01	RES	4.07E+01	RES RES
Surficial soil (0 to 3 ft) (0 to 0.9 m) ingestion/dermal/inhalation, mg/kg	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	5.82E+00 5.82E+02					1.30E-01 1.30E+01
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	1.00E+01 1.00E+03	7.83E+03	1.33E+04	1.45E+06	9.77E+02	3.04E-01 3.04E+01
Soil-leachate to protect ground water ingestion target level, mg/kg	residential	MCLs cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	2.93E-02 1.72E-02 1.72E+00	1.10E+02	1.77E+01	3.05E+02	N/A	9.42E+00 5.50E-01 RES
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	5.78E-02 5.78E+00	5.75E+02	1.29E+02	RES	2.29E+01	1.85E+00 RES
				1.61E+03	3.61E+02	RES	6.42E+01	
Ground Water								
Ground water volatilization to outdoor air, mg/L	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	1.10E+01 1.10E+03					>S ^E >S
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	1.84E+01 >S	>S	>S	>S	>S	>S >S
Ground water ingestion, mg/L	residential	MCLs cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	5.00E-03 2.94E-03 2.94E-01	7.00E-01	1.00E+00	1.00E+01	N/A	2.00E-04 1.17E-05 1.17E-03
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	9.87E-03 9.87E-01	3.65E+00	7.30E+00	7.30E+01	1.46E-01	3.92E-05 >S
Ground water—vapor intrusion from ground water to buildings, mg/L	residential	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	2.38E-02 2.38E+00					>S >S
	commercial/ industrial	cancer risk = 1E-06 cancer risk = 1E-04 chronic HQ = 1	7.39E-02 7.39E+00	7.75E+01	3.28E+01	>S	4.74E+00	>S >S
				>S	8.50E+01	>S	1.23E+01	

^A As benzene soluble coal tar pitch volatiles.

^B See Ref (22).

^C See Refs (23–25).

^D RES—Selected risk level is not exceeded for pure compound present at any concentration.

^E >S—Selected risk level is not exceeded for all possible dissolved levels (\leq pure component solubility).

REFERENCES

- American Industrial Health Council. 1994. *Exposure Factors Sourcebook*. (Available from Update Coordinator, American Industrial Health Council, Suite 760, 2001 Pennsylvania Avenue, NW, Washington, DC 20006-1807.)
- American Society for Testing and Materials. 1995. *Standard Guide to Risk-Based Corrective Action Applied at Petroleum Release Sites*. ASTM E1739-95.
- American Society of Heating, Refrigerating, and Air Conditioning Engineering. 1981. *ASHRAE Handbook: 1981 Fundamentals*.
- Bay Area Air Quality Management District. 1997. Oakland wind rose data. *Facsimile to Mark Gomez*, December 11.
- Bureau of Labor Statistics. 1988. *Labor Force Statistics Derived from the Current Population Survey, 1948-1987*. Washington, D.C.: U.S. Department of Labor.
- Calabrese, E.J. and E.J. Stanek, III. 1991. "A guide to interpreting soil ingestion studies II: qualitative and quantitative evidence of soil ingestion". *Regulatory Toxicology and Pharmacology* (13:278-292).
- California Building Code. 1998. Sacramento, CA: California Building Standards Commission.
- California Department of Health. 1999. Maximum Contaminant Levels.
- California Environmental Protection Agency. 1994. *California Cancer Potency Factors*. Office of Environmental Health Hazard Assessment, Department of Pesticide Regulation (DPR) and Department of Toxic Substances Control.
- City of Oakland. 2000. *Oakland Urban Land Redevelopment Program: Guidance Document*. Public Works Agency, Environmental Services Division.
- Community Review Panel, Oakland Urban Land Redevelopment Program. 1997. *Consensus Recommendations for Implementing the Oakland Urban Land Redevelopment Program*. (Available from the City of Oakland Environmental Services Division.)
- Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*. New Jersey: Prentice-Hall, Inc.
- Gomez, M.M. 1999. Review of Phase II environmental site assessments available in City of Oakland Environmental Services Division library.
- Guymon, G. L. 1994. *Unsaturated Zone Hydrology*. New Jersey: Prentice-Hall, Inc.
- Heath, R.C. 1982. "Classification of Ground-water Systems of the United States". *Ground Water*. Vol. 20: 4.
- _____. 1989. *Basic Ground-Water Hydrology*. Third Edition. United States Government Printing Office for the USGS. (Available from U.S. Geological Survey Federal Center, Box 25425 Denver, CO 80225.)

- Hiatt, Gerry. 199?.
- Howard, P. H. 1989. *Handbook of Fate and Exposure Data for Organic Chemicals*. Volumes I, II, and III. Michigan: Lewis Publishers.
- _____ and W.M. Meylan. 1997. *Handbook of Physical Properties of Organic Chemicals*. Boca Raton, FL: CRC Press.
- Hydeman, M. PG&E Energy Center – San Francisco. 1996. Telephone conversation with Lynn Spence, December.
- Knox, R.C., Sabatini, D.A., and Canter, L.W. 1993. *Subsurface Transport and Fate Processes*. Michigan: Lewis Publishers.
- Lyman, W.J., Reidy, P.J., and Levy, B. 1992. *Mobility and Degradation of Organic Contaminants in Subsurface Environments*. Prepared for the U.S. EPA. Michigan: C. K. Smoley, Inc.
- National Climactic Data Center. 1982. *Daily Normals of Temperature, Heating and Cooling Degree Days and Precipitation 1951-80*. Washington: United States Department of Commerce.
- Radbruch, D. 1957. *Areal and Engineering Geology of the Oakland West Quadrangle, California*. United States Geological Survey.
- Sherman, M. Lawrence Berkeley Laboratories. 1997. *E-mail message to Lynn Spence*, January 3.
- Spence, L.R. and M.M. Gomez. 1999. *Oakland Benzene Partitioning Study: Synopsis*. Available from the City of Oakland Environmental Services Division.
- State of California. *Safe Drinking Water and Toxic Enforcement Act (California State Proposition 65)*. 1986.
- Technical Advisory Committee, Oakland Urban Land Redevelopment Program. 1996a. *Meeting*, February 13.
- _____. 1996b. *Meeting*, May 31.
- _____. 1997. *Meeting*, February 11.
- U.S. Environmental Protection Agency. 1987. *Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) – Air Emission Models*. EPA Office of Air and Radiation. EPA-540/3-87-026.
- _____. 1989a. *Risk Assessment Guidance for Superfund*. Vol. I. Human Health Evaluation Manual (Part A). Office of Emergency and Remedial Response. EPA/540/1-89/002.

- _____. 1989b. *Exposure Factors Handbook*. Office of Health and Environmental Assessment. EPA/600/8-89/043.
- _____. 1992. *Dermal Exposure Assessment: Principles and Applications*. Interim Report. Office of Research and Development. EPA/600/8-91/011B.
- _____. 1995. *Hazardous Waste Management System Toxicity Characteristics Revisions*. Washington, D.C.: US EPA. 55 FR 11798-11863.
- _____. 1996. *Soil Screening Guidance: Technical Background Document*. Office of Solid Waste and Emergency Response. EPA/540/R-95/128.
- _____. 1997. *Exposure Factors Handbook*. Office of Research and Development. EPA/600/P-95/002Fc.
- Walton, W.C. 1988. *Practical Aspects of Groundwater Modeling—Third Edition*. Reprint: originally published by National Water Well Association.
- Woodward-Clyde. 1992. *Limited Phase II Environmental Site Assessment: “Taldan Property” Block, Oakland, California*.