ERID-221588

LA-UR-12-22799
July 2012
EP2012-0147

Technical Approach for Calculating Recreational Soil Screening Levels for Chemicals, Revision 2

Prepared by the Environmental Programs Directorate

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Author Rich Mirenda	**Signature**	**Date** 7/17/12
Reviewer Tracy McFarland	**Signature**	**Date** 7/17/12
Approver Alan MacGregor	**Signature**	**Date** 7-17-12

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1.0 INTRODUCTION

The chemical soil screening levels (SSLs) used in the human health risk-based screening assessments are based on the current and reasonably foreseeable future land use(s) for a site. Four types of land use can be evaluated: residential, industrial, construction, and recreational. The screening assessments use the SSLs for one or more particular land use/receptors. For residential and recreational scenarios, a child is evaluated for noncarcinogenic effects and an individual from childhood through adulthood for carcinogenic effects that are cumulative over time. Only adult receptors are evaluated for the industrial and construction scenarios.

The SSLs used by the Environmental Programs (EP) Directorate have been developed by the New Mexico Environment Department (NMED) for chemicals based on residential, industrial, and construction worker exposures (NMED 2012, 219971, or as updated). However, neither NMED nor the U.S. Environmental Protection Agency (EPA) has developed recreational SSLs. Recreational SSLs for potential human health risk were originally presented by Los Alamos National Laboratory (LANL or the Laboratory) in 2004 (LANL 2004, 087800); were updated in 2007 (LANL 2007, 094496); were revised in 2010 (LANL 2010, 108613); and are further revised in this document. The recreational SSLs presented in this document have been updated to reflect new exposure parameters, equations, and toxicity values presented in NMED's most recent version of the guidance for developing SSLs (NMED 2012, 219971) and EPA's regional screening tables, available at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm. For the recreational scenario, the receptors are an adult and a child who walk, hike, or play in Los Alamos County.

The chemical SSLs (for all scenarios) are based on chronic toxicity and represent the concentration of a chemical associated with either a lifetime excess cancer risk of 1 in 100,000 (1×10^{-5}) for carcinogens or a hazard quotient of 1 for noncarcinogens. These target levels are in agreement with NMED guidance (NMED 2012, 219971). The recreational SSL calculation methodology uses toxicity values and physical and chemical parameters provided in NMED guidance (NMED 2012, 219971) or EPA's regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm. The information provided in this document includes the exposure parameter values and assumptions used to calculate the recreational SSLs.

The technical approach described in this document is intended to ensure that recreational SSLs are derived in a manner consistent with the methodology described in NMED guidance (NMED 2012, 219971). Any deviations from the procedure described in NMED guidance must have NMED's approval.

2.0 RECREATIONAL SCENARIO

The recreational scenario pertains to individuals who may be exposed as a result of spending a limited amount of time engaged in outdoor activities on or near an area impacted by releases from a solid waste management unit or area of concern (including time spent in the canyons). Two primary recreational activities are represented by this scenario: an adult trail user/hiker and a child playing outdoors. The child is evaluated under an extended backyard scenario, originally developed for individual sites, which borders a residential development on canyons and the canyon area is accessible to pre-teen children for outdoor play. This document expands that scenario to include a 6- to less than 12-yr-old child walking or playing in any part of the canyon that is accessible for an extended period of time. For noncarcinogenic chemicals, the duration of the chronic exposure period does not affect the likelihood or severity of effects. Therefore, the recreational SSLs are based on the child extended backyard exposure scenario because the SSLs for these chemicals are lower for the child than for the adult trail user. For carcinogenic

chemicals, the recreational SSLs are based on the combined exposure of the child and the adult trail user because the risk of carcinogenic effects is proportional to the length of the exposure period. If exposure at a site is expected to be limited to only a child or only an adult, the recreational SSLs may be recalculated to consider only that receptor with proper justification. The exposure pathways evaluated for this scenario include incidental ingestion of soil, inhalation of volatiles and fugitive dusts, and skin contact with soil.

The exposure parameters for each of the pathways for the recreational scenario are presented in Table 1. The upper bound estimate of the total daily soil ingestion rate for a child (200 mg/d) is obtained from NMED guidance (NMED 2012, 219971) and the 2011 EPA *Exposure Factors Handbook* (EPA 2011, 208374, Chapter 5, Table 5-1, p. 5-5). The total daily soil ingestion rate for an adult (100 mg/d) is the mean soil and dust ingestion rate for ages 6 to less than 21 yr (EPA 2011, 208374, Chapter 5, Table 5-1, p. 5-5) and is also the adult value used by NMED (2012, 219971) and presented in the EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm. The value of 100 mg/d is twice the recommended adult soil ingestion rate presented in the exposure factors handbook (EPA 2011, 208374, Chapter 5, Table 5-1, p. 5-5). These upper bound daily total soil ingestion values are recommended for the reasonable maximum exposure (RME) because they reflect conditions in this area of the country where vegetation is sparse, winds are prevalent, and incidental soil ingestion may therefore occur to a greater extent than is generally the case in other regions. The child and adult total daily ingestion rates are prorated based upon the ratio of exposure time on-site to the overall time spent outdoors (Appendix A).

The values presented for dermal exposures to soil are EPA default values, including the exposed skin surface area (SA), soil adherence factors (AFs), and skin absorption factors (ABS) (EPA 2004, 090800; NMED 2012, 219971). The surface area value assumes the adult is wearing a short-sleeved shirt, shorts, and shoes. The surface area value for children assumes the same situation as the adult; the child (age 6 to less than 12 yr) is wearing a short-sleeved shirt, shorts, and shoes (Appendix A). The EPA's dermal risk assessment guidance (EPA 2004, 090800) provides information from studies on the total mean body surface area of children for various age groups and the percentage of total body surface area by body part for different age groups, respectively.

Assumptions were made with respect to exposure time (1 h/d) and exposure frequency (200 d/yr) for the recreational RME values. The exposure time represents the total amount of time spent walking per day (90th percentile) in the western U.S. for all age groups (EPA 2011, 208374, Chapter 16, Table 16-26, p. 16-75). The exposure frequency is based on best professional judgment and is equivalent to 4 d/wk for 50 wk/yr.

3.0 DERIVATION OF RECREATIONAL SSLS FOR CHEMICALS

The toxicity values [reference doses (RfDs), reference concentrations (RfCs), inhalation unit risk (IUR), and slope factors (SFs)] and physical and chemical parameters are consistent with those provided in NMED guidance (NMED 2012, 219971). For chemicals not included in NMED's document, physical, chemical, and toxicity information are obtained from EPA's regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm or the hierarchy of sources cited in NMED guidance (NMED 2012, 219971).

The recreational SSL for inorganic lead is not derived from the risk equations used for other chemicals because EPA toxicity values for lead have not been published. The recreational lead SSL for a child was calculated using Version 1.1 Build 11 of EPA's Integrated Exposure Uptake Biokinetic (IEUBK) model (http://www.epa.gov/superfund/lead/products.htm). This model can be used to derive soil criteria for exposure of children from birth to 7 yr of age. The recreational SSL for lead is based on a soil lead level

that limits exposure of a child to no more than a 5% chance of exceeding a 10 µg/dL blood lead level (EPA 1994, 059509) and includes the contribution of exposures from diet, tap water, and background levels of lead in house dust to total lead exposure. Details on the calculation of the recreational SSL for lead are provided in Appendix B. Because the IEUBK model applies to a population of children up to 7 yr of age, the use of it for ages 6 to less than 12 yr is protective.

3.1 Physical and Chemical Parameters and Toxicity Values

The recommended hierarchy of sources for RfDs, RfCs, IURs, and SFs used by NMED (2012, 219971) to derive its SSLs is described in EPA guidance (EPA 2003, 086554). The preferred source of toxicity values is EPA's Integrated Risk Information System (IRIS), located at http://www.epa.gov/iris. In addition, provisional peer reviewed toxicity values (PPRTVs) may be obtained for some chemicals and routes of exposure from EPA's Office of Superfund Remediation and Technology Innovation (http://hhpprtv.ornl.gov/). However, the PPRTVs have not been subjected to rigorous scientific review and, therefore, cannot be used with the confidence of values obtained from IRIS. The PPRTVs are used in calculating SSLs for performing screening assessments because they (1) reflect the state of knowledge within EPA at the time of its publication and incorporate a level of peer review, and (2) comply with EPA methodologies and practices for developing toxicity values. If provisional values are used in calculating SSLs for chemicals that are potential risk-drivers, the consequences to the confidence of the screening decision may be discussed in the uncertainty analysis of the screening assessment. Lower-tier sources of toxicity values include California EPA's Office of Environmental and Health Hazard Assessment values, New Jersey Department of Environmental Protection, Agency for Toxic Substances and Disease Registry minimal risk levels, and EPA's Health Effects Assessment Summary Table (EPA 1997, 058968). The toxicity information used to calculate the recreational SSLs are provided in the workbook on a CD (Appendix C).

Some cancer-causing chemicals operate by a mutagenic mode of action for carcinogenesis. There is reason to surmise that some chemicals with a mutagenic mode of action, which would be expected to cause irreversible changes to the deoxyribonucleic acid (DNA), would exhibit a greater effect in early-life versus later-life exposure. Cancer risk to children in the context of the EPA's cancer guidelines includes both early-life exposures that may result in the occurrence of cancer during childhood and early-life exposures that may contribute to cancers later in life. Based on this guidance, separate cancer risk equations are presented for mutagens. Equations 1 through 9 (section 3.4) are appropriate for all chemicals, with the exception of those carcinogens exhibiting mutagenic toxicity. Equations 10 through 15 (section 3.4.4) show the derivation of the SSLs for carcinogenic chemicals exhibiting mutagenic properties.

Chemical-specific physical parameters used in the calculation of SSLs include the organic carbon-water partition coefficient for organic compounds (K_{oc}), the soil-water partition coefficient for organic and inorganic constituents (K_d), the solubility of a chemical in water (S), the Henry's law constant (H), air diffusivity (D_a), water diffusivity (D_w), and the chemical molecular weight. The physical and chemical information is presented in the workbook on CD (Appendix C). A variety of sources for these values are cited in NMED guidance (NMED 2012, 219971) with publication dates ranging from 1986 to 2009.

To maintain consistency between the SSLs calculated for the recreational scenario and those published by NMED for other scenarios, the physical and chemical parameters provided in Table B-2 and the toxicity values provided in Table C-1 of NMED guidance (NMED 2012, 219971) were used to calculate the recreational SSLs (Appendix D). Toxicity values and physical and chemical parameters for chemicals not included in NMED's SSLs were preferentially obtained from documentation of EPA's regional screening levels at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm or from the same sources of

information cited by NMED for its SSLs. The toxicity values and physical and chemical parameters used to calculate the recreational SSLs are provided on CD (Appendix C). Consistent with current EPA methodology, NMED SSLs and Laboratory recreational SSLs for chemicals do not employ route-to-route extrapolation of toxicity criteria.

Table 1
Recreational Exposure Parameters Used in the Recreational SSL Equations

Symbol	Definition	Adult Trail User	Outdoor Child[a]
C	Chemical SSL in soil (mg/kg)		
THQ	Target hazard quotient	1	1
TR	Target cancer risk	10^{-5}	10^{-5}
AT_c	Averaging time (carcinogen)	70 yr × 365 d/yr	6 yr × 365 d/yr
AT_n	Averaging time (noncarcinogen)	ED × 365 d/yr	ED × 365 d/yr
CSF_o	Cancer slope factor–oral	Chemical-specific $(mg/kg\text{-}d)^{-1}$	Chemical-specific $(mg/kg\text{-}d)^{-1}$
IUR	Inhalation unit risk	Chemical-specific $(mg/kg\text{-}d)^{-1}$	Chemical-specific $(mg/kg\text{-}d)^{-1}$
RfD_o	Reference dose–oral	Chemical-specific (mg/kg-d)	Chemical-specific (mg/kg-d)
RfC	Reference concentration–inhalation	Chemical-specific (mg/kg-d)	Chemical-specific (mg/kg-d)
BW	Body weight	70 kg[b]	31 kg[c] (value for male and female)
ED	Exposure duration	30 yr[d]	6 yr (6 to <12 yr of age)
EF	Exposure frequency	200 d/yr	200 d/yr
ET	Exposure time	1 h/d	1 h/d
IRS	Soil ingestion rate	28 mg/d [100 mg/d × (1 h/3.6 h)][e]	91 mg/d [200 mg/d × (1 h/2.2 h)][f]
AF	Adherence factor	0.07 mg/cm^2	0.2 mg/cm^2
GIABS	Gastrointestinal absorption factor	Default to 1 for most chemicals, chemical-specific for others	Default to 1 for most chemicals, chemical-specific for others
ABS	Skin absorption factor	Semivolatile organic compounds = 0.1. Chemical-specific for others	Semivolatile organic compounds = 0.1. Chemical-specific for others
SA	Exposed surface area	5700 cm^2 (head, hands, forearms, lower legs)	3790 cm^2 (head, hands, forearms, lower legs)[g]
PEF	Particulate-emission factor	6.61×10^9 m^3/kg	6.61×10^9 m^3/kg
VF	Volatilization factor for soil	Chemical-specific (m^3/kg)	Chemical-specific (m^3/kg)

[a] Based on extended backyard scenario.

[b] Adult body weight from NMED (2012, 219971).

[c] Body weight for a 6- to <11-yr-old child from EPA (2011, 208374, Table 8-10).

[d] Exposure duration for lifetime resident is 30 yr. For carcinogens, the exposures are combined for child (6 yr) and adult (24 yr).

[e] Assumes 1 h of trail use per day, with potential exposure to contaminants occurring over all of that time out of an average of 3.6 h spent outdoors per day for an adult (12 to 35 yr) (EPA 2011, 208374, Table 16-1, p. 16-58). See Appendix A for more details.

[f] Assumes 1 h of trail use per day, with potential exposure to contaminants occurring over all of that time out of an average of 2.2 h spent outdoors per d for a 6- to <11-yr-old child (EPA 2011, 208374, Table 16-1, p. 16-58). See Appendix A for more details.

[g] The exposed skin surface area for this child receptor was calculated using the body-part-specific surface areas for ages 6 to <7 yr through 11 to <12 yr given in Exhibit C-1 of Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final (EPA 2004, 090800).

Some chemicals routinely analyzed and detected in environmental media do not have published toxicity values in any of the sources described in the hierarchy above. The approach in these cases is to identify a similar chemical for which toxicity values are available and incorporate it into the screening assessment as a surrogate. The similarity may be based on whether their chemical structures are similar or one chemical is a degradation product of another. Identification of an appropriate surrogate chemical and whether the evaluation is performed within the context of a screening assessment or a risk assessment, is a chemical-specific and assessment-specific decision beyond the scope and purpose of this document.

3.2 Exposure Scenarios, Media, and Pathways

The SSLs represent exposure for a recreational scenario as described above. Exposure pathways for chemical SSLs include incidental ingestion of soil, inhalation of volatiles and fugitive dusts, and skin absorption of chemicals in soil. Exposure equations and parameter values for recreational SSL calculations are provided (Equations 1 to 5 and Table 1, respectively). The primary source of exposure parameters used in the recreational SSL calculations is NMED guidance (NMED 2012, 219971). The exposure parameter values provide estimates of the RME for a receptor incorporating the pathways listed above. For the skin absorption exposure route, exposure parameter values are from EPA's dermal risk assessment guidance (EPA 2004, 090800). The gastrointestinal and skin-absorption factors used in the dermal exposure route were obtained from NMED guidance (NMED 2012, 219971) or from the EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm.

The risk assessment equations are consistent with the calculation of SSLs by NMED and EPA for other scenarios; only the exposure parameters were changed to reflect recreational rather than residential exposure. This approach is consistent with the methods for developing SSLs described by both NMED (2012, 219971) and EPA (available at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm).

3.3 Modeling Inhalation and Dermal Pathways

3.3.1 Inhalation—Volatile Organic Compounds

The concentration of volatile organic compound (VOC) vapors in the ambient-air breathing zone associated with VOCs in site soil is calculated using a steady-state volatilization model. The model used is Hwang and Falco's volatilization factor (VF) model, originally described by EPA (1991, 058234). The version of the VF model used to calculate NMED SSLs and LANL recreational SSLs is presented in the user's guide and technical background document of EPA's soil screening guidance documents (EPA 1996, 059902) and in NMED guidance (NMED 2012, 219971). VOC status for calculating recreational SSLs was based on the definition provided in section 3.1 of NMED guidance (NMED 2012, 219971); those chemicals having a Henry's law constant greater than 10^{-5} atm-m^3/mole-°K and a molecular weight less than 200 g/mole.

The VF model is valid for sites where a VOC is present at concentrations below soil particle, pore water, and pore air saturation levels. For conditions in which soil is saturated with one or more organic chemicals, an SSL calculated using the VF model output is not reliable. Both NMED guidance (NMED 2012, 219971) and EPA guidance (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm) recommend the same protocol for establishing SSLs when an SSL for a VOC calculated using the VF model exceeds the saturation value (C_{sat}). For VOCs that are solids at ambient temperatures, the SSL is computed using only the soil ingestion and skin absorption exposure pathways if the SSL calculated using the VF model exceeds the value of C_{sat}. For liquid VOCs which have an SSL calculated using the VF model that exceeds the value of C_{sat}, the C_{sat} value is used as the SSL. However, the C_{sat} value for liquid phase VOCs is not a risk-based screening level based on toxicological endpoints; it is used to identify the

possible presence of nonaqueous phase VOCs with a greater likelihood of off-site migration. The SSLs presented in Appendix D are risk-based values that include inhalation risks because of volatilization from soil regardless of the magnitude of the inhalation pathway SSL. The SSLs are footnoted to indicate whether the SSL for a liquid VOC exceeds the C_{sat} concentration.

The VF and C_{sat} model equations and parameter values for SSL calculations are documented in Equations 6 and 7 and Tables 2 and 3, respectively. Parameter values for site-related factors such as soil porosities, density, and amount of organic carbon are the default values recommended in NMED guidance (NMED 2012, 219971). Chemical-specific parameter values are required for chemical diffusivity in air and water, Henry's law constant, solubility in water, and organic carbon partition coefficient. The values used in calculating recreational SSLs are the same as those used in NMED guidance to calculate SSLs for residential and industrial exposures (NMED 2012, 219971). The sources used to obtain these values for additional chemicals not included in NMED's SSLs are described in section 3.1.

3.3.2 Inhalation—Fugitive Dust

The concentration of dust suspended in air above contaminated soil and sediment is calculated using EPA's particulate-emission factor (PEF) model, which is a screening-level soil resuspension model. This model was originally described in "Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites" (EPA 1985, 059903). The version of the PEF model used to calculate recreational SSLs is consistent with NMED guidance for residential and industrial exposures (NMED 2012, 219971).

The PEF model used for screening the dust inhalation pathway is from wind erosion of surfaces that have an unlimited reservoir of particles. The model calculates the long-term concentration of respirable particles in the breathing zone as a result of wind erosion. Depending on site soil conditions, an unlimited supply of particles of this size may not be available throughout the exposure period and may overestimate the intake by dust inhalation. The PEF model equations and parameter values for SSL calculations are presented below (Equation 8; Table 4). Parameter values for the PEF model, including the dispersion term (Q/C), vegetative cover, and wind speeds, are default values recommended in NMED guidance for residential and industrial exposures (NMED 2012, 219971).

3.3.3 Dermal Absorption

The amount of soil residing on a unit area of skin is described using an AF. A layer of soil is assumed to cover 100% of a specified body surface area corresponding to the AF. The literature on AFs recognizes that AFs are dependent upon body part, soil type, particle size, soil moisture content, and other variables. Because information for quantifying these variables is often not available, single default values are used for the AFs when SSLs are calculated (0.2 mg/cm^2 for a child and 0.07 mg/cm^2 for an adult) (NMED 2012, 219971).

Skin absorption from soil is evaluated using an ABS to model desorption of a chemical from soil, absorption through skin, and transfer to the bloodstream. Consistent with NMED guidance (NMED 2012, 219971) and EPA guidance (EPA 2004, 090800), a default ABS value of 0.1 is used for semivolatile organic compounds. For gastrointestinal absorption, a default value of 1 is used unless a chemical-specific value is available in NMED guidance (NMED 2012, 219971) or EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm. ABS values from NMED guidance (NMED 2012, 219971) or EPA regional screening tables at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm are used in calculating the recreational SSLs.

3.4 SSL Equations and Parameter Values

Equations 1 through 3 are used to calculate recreational SSLs for noncarcinogenic effects through direct soil ingestion, inhalation of volatiles and fugitive dusts, and skin absorption from soil. Equations 4 through 6 are used to calculate recreational SSLs for carcinogenic effects. Table 1 gives the parameters for Equations 1 through 6.

3.4.1 Exposures for Noncarcinogenic Chemicals in Soil

$$C(\text{soil ingestion}) = \frac{THQ \times RfD_o \times BW_c \times AT_n}{EF \times ED_c \times \frac{IRS_c}{10^6\ mg/kg}} \qquad \textbf{Equation 1}$$

$$C(\text{inhalation}) = \frac{THQ \times RfC \times AT_n \times 24hr/day}{EF \times ED_c \times ET_c \times \frac{1}{(VF \text{ or } PEF)}} \qquad \textbf{Equation 2}$$

$$C(\text{dermal}) = \frac{THQ \times RfD_o \times GIABS \times BW_c \times AT_n}{EF \times ED_c \times \frac{SA_c \times AF_c \times ABS}{10^6\ mg/kg}} \qquad \textbf{Equation 3}$$

Note: VF used for volatile chemicals and PEF used for all other chemicals.

where THQ is the target hazard quotient

AT_n is the averaging time for noncarcinogens

EF is the exposure frequency

RfD_o is the oral reference dose

RfC is the inhalation reference concentration

GIABS is the gastrointestinal absorption factor

ABS is the skin-absorption factor

BW_c, ED_c, IRS_c, SA_c, AF_c, and ET_c are the child exposure parameters for body weight, exposure duration, soil ingestion rate, skin surface area, soil adherence factor, and exposure time, respectively

VF is the volatilization factor

PEF is the particulate-emission factor

3.4.2 Exposures for Carcinogenic Chemicals in Soil

$$C(\text{soil ingestion}) = \frac{TR \times AT_c}{CSF_o \times EF \times \frac{IFS_{adj}}{10^6\ mg/kg}} \qquad \textbf{Equation 4}$$

$$C(\text{inhalation}) = \frac{TR \times AT_c \times 24hr/day}{IUR \times 1000 \times EF \times ED \times ET \times \frac{1}{(VF \text{ or } PEF)}} \qquad \textbf{Equation 5}$$

$$C\,(\text{dermal}) = \frac{TR \times AT_c}{CSF_o \Big/ GIABS \times EF \times \dfrac{ABS \times SFS_{adj}}{10^6\,\text{mg/kg}}} \qquad \textbf{Equation 6}$$

Note: VF used for volatile chemicals and PEF used for all other chemicals.

where TR is the target cancer risk

AT_c is the averaging time for carcinogens

EF is the exposure frequency

IFS_{adj} is the age-adjusted soil ingestion factor

SFS_{adj} is the age-adjusted skin contact factor

GIABS is the gastrointestinal absorption factor

ABS is the skin-absorption factor

CSF_o is the oral cancer slope factor

IUR is the inhalation unit risk factor

VF is the volatilization factor

PEF is the particulate-emission factor

Because contact rates may be different for children and adults, carcinogenic risks during the 30-yr exposure period are calculated using age-adjusted factors (Equations 7 and 8). Age-adjusted factors are especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposures across pathways, an additional age-adjusted factor is used for skin exposures. Under site-specific conditions (e.g., if the area is within Laboratory property), either an adult trail user or a child under the extended backyard scenario may be appropriate. If such a condition exists, SSLs may be calculated for the individual receptor with proper justification. Table 1 gives the parameters for Equations 7 and 8.

Equation 7 (mg-yr)/(kg-d) is used for ingestion:

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{(ED_r - ED_c) \times IRS_a}{BW_a} \qquad \textbf{Equation 7}$$

Equation 8 (mg-yr)/(kg-d) is used for skin contact:

$$SFS_{adj} = \frac{ED_c \times AF_c \times SA_c}{BW_c} + \frac{(ED_r - ED_c) \times AF_a \times SA_a}{BW_a} \qquad \textbf{Equation 8}$$

where IFS_{adj} is the age-adjusted soil ingestion factor

SFS_{adj} is the age-adjusted skin contact factor

ED_r is the recreational exposure duration (30 yr)

ED_c, IRS_c, BW_c, AF_c, and SA_c, are the child exposure parameters for exposure duration, soil ingestion rate, body weight, soil adherence factor, and skin surface area, respectively

IRS_a, BW_a, AF_a, and SA_a are the adult exposure parameters for soil ingestion rate, body weight, soil adherence factor, and skin surface area, respectively

3.4.3 Combined Exposures for Chemicals in Soil

The SSL for combined exposures from all pathways is calculated as

$$C\,(\text{combined}) = \frac{1}{1/C_{\text{ing}} + 1/C_{\text{inh}} + 1/C_{\text{dermal}}} \qquad \textbf{Equation 9}$$

where C is the concentration for combined exposures

C_{ing} is the concentration for soil ingestion

C_{inh} is the concentration for inhalation

C_{dermal} is the concentration for skin exposure

3.4.4 Equations for Carcinogens Acting by a Mutagenic Mode of Action

Because exposure to mutagenic chemicals may pose particularly high cancer risk when exposures occur for infants and young children, EPA has developed guidance to adjust cancer potency estimates for childhood exposures for carcinogens that have a mutagenic mode of action (http://www.epa.gov/oswer/risk assessment/sghandbook/index.htm). Equations 10 through 12 are used to calculate recreational SSLs for mutagenic chemicals. The equations have been modified for the recreational scenario to include the 6 to 12 yr old as a child and the 12 to 16 yr old as an adult rather than a 6 to 16 yr old as an adult in NMED guidance (NMED 2012, 219971) and EPA guidance (available at http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm). These guidance documents also contain separate equations for the mutagen vinyl chloride, for which EPA has published oral and inhalation SFs applicable to lifetime exposure beginning at birth. However, the age range of the recreational scenario child receptor (6 to <12 yr) begins well past birth and lies largely outside the age range of a child (0 to 6 yr) that NMED and EPA guidance apply in their vinyl chloride equations. Therefore, vinyl chloride cancer potency estimates for the child receptor in the recreational scenario are adjusted using the same equations as for other mutagens.

$$C\,(\text{soil ingestion}) = \frac{TR \times AT_c}{CSF_o \times EF \times IFSM_{adj} \times 10^{-6}} \qquad \textbf{Equation 10}$$

Equation 11

$$C\,(\text{inhalation}) = \frac{TR \times AT_c}{(EF \times ET \times 1000) \times [(ED_{6\text{-}12} \times IUR \times 3) + (ED_{12\text{-}16} \times IUR \times 3) + (ED_{16\text{-}30} \times IUR \times 1)] \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

$$C\,(\text{dermal}) = \frac{TR \times AT}{\frac{CSF_o}{GIABS} \times EF \times DFSM_{adj} \times ABS \times 10^{-6}} \qquad \textbf{Equation 12}$$

Note: VF used for volatile chemicals and PEF used for all other chemicals.

where TR is the target cancer risk

AT_c is the averaging time for carcinogens

EF is the exposure frequency

$ED_{6–12}$ is the child exposure duration from 6 to 12 yr

$ED_{12–16}$ is the adult exposure duration from 12 to 16 yr

$ED_{16–30}$ is the adult exposure duration from 16 to 30 yr

ET is the exposure time

$IFSM_{adj}$ is the age-adjusted soil ingestion factor mutagens

$DFSM_{adj}$ is the age-adjusted skin contact factor mutagens

GIABS is the fraction absorbed in gastrointestinal tract

ABS is the skin-absorption factor

CSF_o is the oral cancer slope factor

IUR is the inhalation unit risk factor

VF is the volatilization factor

PEF is the particulate-emission factor

As noted above for other carcinogenic chemicals, contact rates may be different for children and adults. Mutagenic risks are also calculated using age-adjusted soil ingestion and skin absorption factors (Equations 13 and 14).The equations have been modified to include the 6 to 12 yr old as a child and the 12 to 16 yr old as an adult rather than a 6 to 16 yr old as an adult.

Equation 13 is used for ingestion:

$$\mathrm{IFSM_{adj}} = \frac{\mathrm{ED_{6–12}} \times \mathrm{IRS_c} \times 3}{\mathrm{BW_c}} + \frac{\mathrm{ED_{12–16}} \times \mathrm{IRS_a} \times 3}{\mathrm{BW_a}} + \frac{\mathrm{ED_{16–30}} \times \mathrm{IRS_a} \times 1}{\mathrm{BW_a}} \qquad \textbf{Equation 13}$$

Equation 14 is used for skin contact:

Equation 14

$$\mathrm{DFSM_{adj}} = \frac{\mathrm{ED_{6\text{-}12}} \times \mathrm{AF_c} \times \mathrm{SA_c} \times 3}{\mathrm{BW_c}} + \frac{\mathrm{ED_{12\text{-}16}} \times \mathrm{AF_a} \times \mathrm{SA_a} \times 3}{\mathrm{BW_a}} + \frac{\mathrm{ED_{16\text{-}30}} \times \mathrm{AF_a} \times \mathrm{SA_a} \times 1}{\mathrm{BW_a}}$$

where $ED_{6\text{-}12}$ is the child exposure duration from 6 to 12 yr

$ED_{12\text{-}16}$ is the adult exposure duration from 12 to 16 yr

$ED_{16\text{-}30}$ is the adult exposure duration from 16 to 30 yr

BW_c is the child body weight

BW_a is the adult body weight

IRS_c is the child soil ingestion rate

IRS_a is the adult soil ingestion rate

SA_c is the child surface area

SA_a is the adult surface area

AF_c is the child soil adherence factor

AF_a is the adult soil adherence factor

$IFSM_{adj}$ is the age-adjusted soil ingestion factor mutagens

$DFSM_{adj}$ is the age-adjusted skin contact factor mutagens

VF is the volatilization factor

PEF is the particulate-emission factor

The mutagen SSL for combined exposures from all pathways is calculated as per Equation 15.

$$C(\text{combined}) = \frac{1}{1/C_{\text{mu-ing}} + 1/C_{\text{mu-inh}} + 1/C_{\text{mu-dermal}}} \qquad \textbf{Equation 15}$$

3.5 Derivation of the VF

Equation 16 is used to derive the VF for VOCs; the parameters are presented in Table 2.

$$VF_s = \left(\frac{Q}{C}\right) \times \frac{\left(3.14 \times D_A \times T\right)^{1/2}}{2 \times \rho_b \times D_A} \times 10^{-4}\left(m^2/cm^2\right) \qquad \textbf{Equation 16}$$

where

$$D_A = \frac{\left(\Theta_a^{10/3} D_i H' + \Theta_w^{10/3} D_w\right)/n^2}{\rho_b K_d + \Theta_w + \Theta_a H'}$$

Table 2
Parameters Used to Derive the VF

Symbol	Definition	Value (Unit)
VF_s	Volatilization factor	Chemical-specific (m^3/kg)
D_A	Apparent diffusivity	Chemical-specific (cm^2/s)
Q/C	Inverse of mean concentration at the center of a 0.5-ac^2 source	68.18 g/m^2-s per kg/m^3
T	Exposure interval	9.5×10^8 s
ρ_b	Dry soil bulk density	1.5 g/cm^3
Θ_a	Air-filled soil porosity (L_{air}/L_{soil})	0.17 or n – Θ_w
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.26
D_i	Diffusivity in air	Chemical-specific (cm^2/s)
H' *	Dimensionless Henry's law constant	Chemical-specific
D_w	Diffusivity in water	Chemical-specific (cm^2/s)
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 – (ρ_b/ρ_s)
ρ_s	Soil-particle density	2.65 g/cm^3
K_d	Soil-water partition coefficient	$K_{oc} \times f_{oc}$ (chemical-specific) (cm^3/g)
K_{oc}	Soil organic carbon/water partition coefficient	Chemical-specific (L/kg)
f_{oc}	Fraction organic carbon content of soil	0.0015 (g/g)

*H' = Henry's law constant ÷ (universal gas constant x absolute temperature).

3.6 Derivation of the Soil Saturation Concentration

Equation 17 is used to derive the C_{sat} for organic chemicals; the parameters are presented in Table 3.

$$C_{sat} = \frac{S}{\rho_b}\left(K_d \rho_b + \Theta_w + H'\Theta_a\right) \qquad \textbf{Equation 17}$$

Table 3
Parameters Used to Derive the Soil Saturation Concentration

Symbol	Definition	Value (Unit)
C_{sat}	Soil-saturation concentration	Chemical-specific (mg/kg)
S	Solubility in water	Chemical-specific (mg/L)
K_d	Soil-water partition coefficient	K_{oc}*f_{oc} (chemical-specific) (cm^3/g)
K_{oc}	Soil organic carbon/water partition coefficient	Chemical-specific (L/kg)
f_{oc}	Fraction organic carbon content of soil	0.0015 (g/g)
ρ_b	Dry soil bulk density	1.5 g/cm^3
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.26
H' *	Dimensionless Henry's law constant	Chemical-specific
Θ_a	Air-filled soil porosity (L_{air}/L_{soil})	0.17 or n – Θ_w

*H' = Henry's law constant ÷ (universal gas constant x absolute temperature).

3.7 Derivation of the PEF

Equation 18 is used to derive the PEF for non-VOCs and inorganic chemicals; the parameters are presented in Table 4.

$$PEF\left(m^3/kg\right) = \frac{Q}{C} \times \frac{3{,}600 \text{sec/h}}{0.036 \times (1 - V) \times \left(U_m/U_t\right)^3 \times F(x)} \qquad \textbf{Equation 18}$$

Table 4
Parameters Used to Derive the PEF

Symbol	Definition	Value (Unit)
PEF	Particulate-emission factor	6.61×10^9 m^3/kg
Q/C	Inverse of mean concentration at the center of a 0.5-ac^2 source	81.85 g/m^2-s per kg/m^3
V	Fraction of vegetative cover	0.5 (unitless)
U_m	Mean annual wind speed	4.02 m/s
U_t	Equivalent threshold value of wind speed at 7 m	11.32 m/s
F(x)	Function dependent on U_m/U_t (derived using EPA 1985, 059903)	0.0553 (unitless)

3.8 Recreational SSLs

The recreational SSLs for soil (Appendix D) were calculated using the toxicity values, physical and chemical parameter values, and methodological guidance described in NMED guidance (NMED 2012, 219971) and the exposure parameters presented in Table 1. The recreational SSLs presented in the second column of the table in Appendix D are the lower (more protective) of the carcinogenic SSLs and the noncarcinogenic SSLs. Footnotes indicate whether the SSL exceeds the C_{sat} (for liquid VOCs only) or the ceiling or "maximum" concentration (100,000 mg/kg) when calculated SSLs are above 10% of the soil by mass (NMED 2012, 219971). The Excel spreadsheet, which presents the exposure parameters, toxicity values, and physical and chemical information used to calculate the recreational SSLs, is provided on CD (Appendix C). This workbook provides pathway-specific screening criteria, and the SSLs integrating exposure pathways for carcinogenic and noncarcinogenic endpoints for each chemical.

4.0 REFERENCES

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Appendix A

Basis of Exposure Parameters
Used to Calculate Recreational Soil Screening Levels

A-1.0 ADULT ON-SITE SOIL INGESTION RATE

In developing the exposure parameter for incidental soil ingestion through recreational exposures, the conservative assumption was made that all adult soil ingestion occurs during the time the adult is outdoors. The outdoor time at the site is set at 1 h/d based on the total amount of time spent walking per day (90^{th} percentile) in the west (EPA 2011, 208374, Table 16-26, p. 16-75). The total time spent outdoors per day for the adult is set at 214 min (3.6 h/d), which is the total mean time outdoors as an adult for an individual with a 30-yr exposure duration beginning at age 6 yr (12 to 35 yr as an adult) (EPA 2011, 208374, Table 16-1). The adult outdoor exposure time is calculated as a weighted average based on three exposure periods (11 to less than 16 yr, 16 to less than 21 yr, and 18 to less than 65 yr) for which information is recorded in the Exposure Factors Handbook (EPA 2011 208374, Table 16-1). A total time of 214 min (3.6 h) is calculated as (4 yr/24 yr × 100 min/d + (5 yr/24 yr × 102 min/d) + (15 yr/24 yr × 281 min/d). It is assumed soil ingestion is proportional to the time outdoors (not just time in physical activity). The recreational scenario soil ingestion rate for the adult is calculated as (100 mg/d) × (1 h/d on-site /3.6 h/d) = 28 mg/d of soil ingested during on-site recreational activities.

A-2.0 CHILD SOIL INGESTION RATE

In developing the exposure parameter for incidental soil ingestion through recreational exposures, the conservative assumption was made that all soil ingestion by the child occurs when the child is outdoors. The outdoor time at the site is set at 1 h/d based on the total amount of time spent walking per day (90th percentile) in the west (EPA 2011, 208374, Table 16-26, p. 16-75). The time outdoors per day (2.2 h/d) is the total mean time outdoors for a 6- to less than 11-yr-old child (EPA 2011, 208374, Table 16-1, p. 16-3). The upper percentile value for soil ingestion for children of 200 mg/d was used to reflect conditions in this area of the country where vegetation is sparse, winds are prevalent, and incidental soil ingestion may occur to a greater extent than is generally the case. Therefore, the on-site soil ingestion for the child was set to (200 mg/d) × (1 h/d on-site/2.2 h/d) = 91 mg/d of soil ingested.

A-3.0 SURFACE AREA FOR SKIN EXPOSURE TO SOIL

The skin surface area to which soil may adhere for the adult recreational receptor is the same as that used for residential exposure (NMED 2012, 219971), which includes the head, hands, forearms, and lower legs. This value corresponds to an adult wearing shorts, a short-sleeved shirt, and shoes. For consistency, the skin surface area to which soil may adhere for the child was set to a value matching an average child between 6 to less than 12 yr of age, wearing shorts, a short-sleeved shirt, and shoes. The exposed skin surface area for this child receptor was calculated using the body-part-specific surface areas for this age group given in Exhibit C-1 of Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final (EPA 2004, 090800).

A-4.0 REFERENCES

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Appendix B

Derivation of the Recreational Soil Screening Levels for Lead

Lead is a naturally occurring metal in the environment, but human uses such as leaded gasoline and lead-based paints have resulted in increased concentrations, particularly in urban areas. Industrial releases may also contribute to locally elevated environmental lead concentrations. Exposure to inorganic forms of lead is associated with health effects, including neurotoxicity, developmental delays, hypertension, impaired hearing acuity, impaired hemoglobin synthesis, and male reproductive impairment (http://www.epa.gov/iris/subst/0277.htm). Lead exposure is of particular concern for children, whose physiology and behavior cause them to be more susceptible to the effects of lead in environmental media such as soil and dust (http://www.atsdr.cdc.gov/toxprofiles/tp13.pdf).

The U.S. Environmental Protection Agency (EPA) has not established toxicity criteria such as the reference dose and reference concentration for lead. Potential health risks related to childhood lead exposure are evaluated by modeling blood lead concentrations using the Integrated Exposure Uptake Biokinetic (IEUBK) model. The IEUBK model was used to develop the residential lead soil screening level (SSL) of 400 mg/kg cited in NMED guidance (NMED 2012, 219971) and EPA's regional screening tables (http://www.epa.gov/region06/6pd/rcra_c/pd-n/screen.htm). A target blood lead threshold of a 5% probability of a child having a blood lead level exceeding 10 μg/dL is generally used as the criterion to determine whether potential blood lead levels are of concern (EPA 1994, 059509). This threshold is associated with the 400 mg/kg standard. Site-related residential exposures contributing to the 400 mg/kg screening level include soil ingestion from the yard and indoor ingestion of house dust contaminated with soil. In addition to these site-related exposures, the 400 mg/kg screening level incorporates background levels of lead exposure from nonsite-related sources (e.g., ambient air, drinking water, and diet). For the calculation of the 400 mg/kg screening level, these background exposures were defined using national averages or typical values where suitable (EPA 1994, 059509).

The recreational lead SSL for a child was calculated using Version 1.1 Build 11 of the IEUBK model (http://www.epa.gov/superfund/lead/products.htm). This model can be used to derive soil criteria for exposure of children of various age ranges from birth through 7 yr of age. To compute the recreational SSL, Los Alamos-specific values were employed for several model parameters including the

- indoor dust lead concentration,
- time spent outdoors,
- lead concentration in drinking water, and
- age group.

When using all default values, Version 1.1 Build 11 of the IEUBK model produces an SSL of 418 mg/kg, which is approximately equivalent to the original value of 400 mg/kg calculated in 1994 using version 0.99d of the IEUBK model. The Version 1.1 Build 11 IEUBK model input values that were altered for the recreational scenario calculations are described in the following paragraphs. All other IEUBK model inputs, including food lead concentrations and all media-specific ingestion rates, were left as default values.

The indoor dust lead concentration was defined based on the mean ambient soil lead level (12.7 mg/kg) for Los Alamos (LANL 1998, 059730). The default soil ingestion to indoor dust ingestion weighting factor of 0.45 was used. If this ratio is used, the lead SSL is relatively insensitive to changes in the indoor dust lead concentration. Doubling the value to 25 mg/kg has a negligible impact (approximately a 1% change) on the calculated SSL.

Time spent outdoors was defined as the recreational scenario outdoor exposure time (1 hr/d) in the area of elevated soil lead concentrations. In principle, the daily time spent outdoors for the IEUBK model input

should be lowered by the recreational exposure frequency fraction (200 d/yr per 365 d/yr) because the IEUBK model presumes daily exposure. However, the outdoor time parameter is used in the IEUBK model only in calculating the contribution of the ambient dust inhalation exposure pathway. This exposure pathway was determined to have a negligible impact on the SSL; varying the exposure time input value between 0.5 and 5 h/d did not affect the calculated SSL.

The lead drinking water concentration used in the recreational SSL calculation was based on the 2010 Drinking Water Quality Report published by the Los Alamos Department of Public Utilities (http://www.losalamosnm.us/utilities/DPUDocuments/DPU_BR10drinkingwaterqualityrpt.pdf). A value of 0.5 µg/L (0.5 ppb) was used in the IEUBK model to represent drinking water lead concentrations. According to the 2010 Drinking Water Quality Report published by the Los Alamos Department of Public Utilities, water samples are analyzed for lead at 3-yr intervals. Of home tap water tested for lead in 2008, the last year for which data have been published, 98.7% were lower than the detection limit of 0.5 ppb (http://www.losalamosnm.us/utilities/DPUDocuments/DPU_BR10drinkingwaterqualityrpt.pdf).

The age group selected for displaying the IEUBK output was related to the recreational exposure model, which specifies a child receptor between the ages of 6 to less than 12 yr. As noted above, the IEUBK model applies to children from birth up to an age of 7 yr (84 m). Therefore, an age group of 72 m (6 yr) to 84 m (7 yr) was selected in the IEUBK model. The selection of age group was a relatively sensitive parameter for the IEUBK output. Recreational SSLs for lead for age groups of 6–7 yr, 5–7 yr, and 4–7 yr calculated using the IEUBK model are as follows:

- 6–7 yr: 1350 mg/kg
- 5–7 yr: 1250 mg/kg
- 4–7 yr: 1110 mg/kg

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Appendix C

Exposure Parameters, Toxicity Values, Physical and Chemical Information, and Soil Screening Level Calculations (on CD included with this document)

Appendix D

Recreational Soil Screening Levels for Chemicals

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
Acenaphthene	1.78E+04	1.78E+04	no data[b]	not applicable
Acetaldehyde	1.02E+04	1.02E+04	1.21E+04	1.75E+05
Acetone	5.51E+05[c,d]	5.51E+05	no data	1.77E+05
Acrylonitrile	6.76E+01	1.68E+03	6.76E+01	1.41E+04
Acetophenone	6.19E+04	6.19E+04	no data	not applicable
Acrolein	1.61E+01	1.61E+01	no data	1.75E+05
Aldrin	1.33E+00	1.01E+01	1.33E+00	not applicable
Aluminum	6.19E+05[c]	6.19E+05	no data	not applicable
Aniline	2.37E+03	2.37E+03	4.02E+03	not applicable
Anthracene	8.92E+04[c]	8.92E+04	no data	not applicable
Antimony	2.48E+02	2.48E+02	no data	not applicable
Arsenic	2.38E+01	1.49E+02	2.38E+01	not applicable
Barium	1.24E+05[c]	1.24E+05	no data	not applicable
Benzene	3.96E+02	1.86E+03	3.96E+02	7.49E+02
Benzidine (M)[e]	4.33E-02	1.01E+03	4.33E-02	not applicable
Benzo(a)anthracene (M)	1.19E+01	no data	1.19E+01	not applicable
Benzo(a)pyrene (M)	1.19E+00	no data	1.19E+00	not applicable
Benzo(b)fluoranthene (M)	1.19E+01	no data	1.19E+01	not applicable
Benzo(k)fluoranthene (M)	1.19E+02	no data	1.19E+02	not applicable
Benzoic acid	1.35E+06[c]	1.35E+06	no data	not applicable
Benzyl alcohol	3.38E+04	3.38E+04	no data	not applicable
Beryllium	1.24E+03	1.24E+03	2.80E+06	not applicable
alpha-Benzene hexachloride (BHC)	3.64E+00	2.70E+03	3.64E+00	not applicable
beta-BHC	1.27E+01	no data	1.27E+01	not applicable
gamma-BHC (Lindane)	3.00E+01	1.39E+02	3.00E+01	not applicable
1,1-Biphenyl	2.24E+03[d]	2.24E+03	5.85E+03	5.46E+01
Bis(2-chloroethyl) ether	3.53E+01	no data	3.53E+01	3.81E+03
Bis(2-chloroisopropyl) ether	6.68E+02	no data	6.68E+02	not applicable
Bis(2-ethylhexyl)phthalate	1.64E+03	6.76E+03	1.64E+03	not applicable
Bis(chloromethyl) ether	1.32E-01	no data	1.32E-01	4.15E+03
Boron	1.24E+05[c]	1.24E+05	no data	not applicable
Bromobenzene	4.30E+03[d]	4.30E+03	no data	2.39E+02
Bromodichloromethane	1.81E+02	1.24E+04	1.81E+02	6.99E+02
Bromomethane	4.19E+02	4.19E+02	no data	3.37E+03
1,3-Butadiene	1.12E+01	1.52E+02	1.12E+01	4.20E+02
2-Butanone (Methyl ethyl ketone)	3.54E+05[c,d]	3.54E+05	no data	4.02E+04
Butylbenzylphthalate	1.21E+04	6.76E+04	1.21E+04	not applicable
tert-Butyl methyl ether (MBTE)	1.71E+04[d]	1.68E+06	1.71E+04	9.86E+03
n-Butylbenzene	2.92E+04[d]	2.92E+04	no data	6.23E+01

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
sec-Butylbenzene	5.81E+04[d]	5.81E+04	no data	1.95E+02
tert-Butylbenzene	5.46E+04[d]	5.46E+04	no data	5.92E+01
Cadmium	4.65E+02	4.65E+02	3.73E+06	not applicable
Carbazole	2.34E+03	no data	2.34E+03	not applicable
Carbon disulfide	3.48E+04[d]	3.48E+04	no data	3.20E+02
Carbon tetrachloride	2.90E+02[d]	2.09E+03	2.90E+02	2.89E+02
Chlordane	9.44E+01	2.32E+02	9.44E+01	not applicable
2-Chloroacetophenone	8.54E+06[c]	8.54E+06	no data	not applicable
4-Chloroaniline	1.15E+02	1.35E+03	1.15E+02	not applicable
2-Chloro-1,3-butadiene	7.04E+00[d]	1.58E+03	7.04E+00	4.59E+02
1-Chloro-1,1-diflouroethane	4.43E+06[c,d]	4.43E+06	no data	7.19E+02
Chlorobenzene	7.75E+03[d]	7.75E+03	no data	2.69E+02
1-Chlorobutane	2.48E+04	2.48E+04	no data	not applicable
Chlorodifluoromethane	4.27E+06[c,d]	4.27E+06	no data	1.13E+03
Chloroethane	1.29E+06[c,d]	1.29E+06	no data	1.50E+03
Chloroform	2.16E+02	4.94E+03	2.16E+02	1.89E+03
Chloromethane	1.15E+04[d]	1.15E+04	no data	1.25E+03
β-Chloronaphthalene	4.95E+04	4.95E+04	no data	not applicable
o-Chloronitrobenzene	7.64E+01	1.01E+03	7.64E+01	not applicable
ρ-Chloronitrobenzene	3.38E+02	3.38E+02	3.64E+03	not applicable
2-Chlorophenol	3.10E+03	3.10E+03	no data	not applicable
2-Chloropropane	2.76E+05[c,d]	2.76E+05	no data	5.97E+02
o-Chlorotoluene	1.24E+04	1.24E+04	no data	not applicable
Chromium(III)	9.27E+05[c]	9.27E+05	no data	not applicable
Chromium(VI) (M)	3.87E+01	1.86E+03	3.87E+01	not applicable
Chrysene (M)	1.19E+03	no data	1.19E+03	not applicable
Cobalt	1.86E+02	1.86E+02	7.49E+05	not applicable
Copper	2.48E+04	2.48E+04	no data	not applicable
o-Cresol (2-Methylphenol)	1.69E+04	1.69E+04	no data	not applicable
p-Cresol (4-Methylphenol)	1.69E+03	1.69E+03	no data	not applicable
Crotonaldehyde	2.46E+01	6.19E+02	2.46E+01	not applicable
Cumene (Isopropylbenzene)	4.36E+04[d]	4.36E+04	no data	7.83E+01
Cyanide	3.72E+02	3.72E+02	no data	not applicable
Cyanogen	2.48E+04	2.48E+04	no data	not applicable
Cyanogen bromide	5.57E+04	5.57E+04	no data	not applicable
Cyanogen chloride	3.10E+04	3.10E+04	no data	not applicable
4,4'-DDD	9.55E+01	no data	9.55E+01	not applicable
4,4'-DDE	6.74E+01	no data	6.74E+01	not applicable
4,4'-DDT	1.05E+02	2.48E+02	1.05E+02	not applicable

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
Dibenz(a,h)anthracene (M)	1.19E+00	no data	1.19E+00	not applicable
Dibenzofuran	6.19E+02	6.19E+02	no data	not applicable
1,2-Dibromo-3-chloropropane (M)	2.42E+01	1.24E+02	2.42E+01	not applicable
Dibromochloromethane	2.73E+02	6.76E+03	2.73E+02	not applicable
1,2-Dibromoethane	1.32E+01	3.09E+03	1.32E+01	9.22E+02
1,4-Dichloro-2-butene	4.06E+00	no data	4.06E+00	2.17E+02
1,2-Dichlorobenzene	4.01E+04[d]	4.01E+04	no data	6.05E+01
1,3-Dichlorobenzene	3.73E+04[d]	3.73E+04	no data	7.94E+01
1,4-Dichlorobenzene	1.18E+03[d]	4.00E+04	1.18E+03	6.08E+01
3,3-Dichlorobenzidine	5.09E+01	no data	5.09E+01	not applicable
Dichlorodifluoromethane	6.71E+03[d]	6.71E+03	no data	5.14E+02
1,1-Dichloroethane	2.12E+03[d]	1.24E+05	2.12E+03	1.25E+03
1,2-Dichloroethane	2.15E+02	1.63E+03	2.15E+02	1.21E+03
cis-1,2-Dichloroethene	1.24E+03	1.24E+03	no data	not applicable
trans-1,2-Dichloroethene	6.48E+03[d]	6.48E+03	no data	8.81E+02
1,1-Dichloroethene	1.26E+04[d]	1.26E+04	no data	8.28E+02
2,4-Dichlorophenol	1.01E+03	1.01E+03	no data	not applicable
1,2-Dichloropropane	4.53E+02	1.17E+03	4.53E+02	7.77E+02
1,3-Dichloropropene	4.04E+02	6.58E+03	4.04E+02	8.00E+02
Dicyclopentadiene	1.13E+03	1.13E+03	no data	1.42E+02
Dieldrin	1.43E+00	1.69E+01	1.43E+00	not applicable
Diethyl phthalate	2.70E+05[c]	2.70E+05	no data	not applicable
Dimethyl phthalate	3.37E+06[c]	3.37E+06[c]	no data	not applicable
Di-n-butyl phthalate	3.38E+04	3.38E+04	no data	not applicable
Di-n-octyl phthalate	6.76E+03	6.76E+03	no data	not applicable
2,4-Dimethylphenol	6.76E+03	6.76E+03	no data	not applicable
1,3-Dinitrobenzene	3.38E+01	3.38E+01	no data	not applicable
4,6-Dinitro-o-methylphenol	2.70E+01	2.70E+01	no data	not applicable
2,4-Dinitrophenol	6.76E+02	6.76E+02	no data	not applicable
2,4-Dinitrotoluene	7.40E+01	6.76E+02	7.40E+01	not applicable
2,6-Dinitrotoluene	3.38E+02	3.38E+02	no data	not applicable
2,4 and 2,6–Dinitrotoluene	3.37E+01	no data	3.37E+01	not applicable
2-Amino-4,6-Dinitrotoluene	1.18E+03	1.18E+03	no data	not applicable
4-Amino-2,6-Dinitrotoluene	1.15E+03	1.15E+03	no data	not applicable
1,4-Dioxane	2.29E+02	1.01E+04	2.29E+02	not applicable
1,2-Diphenylhydrazine	2.87E+01	no data	2.87E+01	not applicable
Endosulfan	2.03E+03	2.03E+03	no data	not applicable
Endosulfan sulfate	1.01E+02	1.01E+02	no data	not applicable
Endrin	1.01E+02	1.01E+02	no data	not applicable

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
Epichlorohydrin	1.25E+03	1.25E+03	4.18E+03	1.24E+04
Ethyl acetate	5.57E+05[c]	5.57E+05	no data	not applicable
Ethyl acrylate	9.74E+02	no data	9.74E+02	not applicable
Ethyl chloride	1.24E+06[c,d]	1.24E+06	no data	1.73E+03
Ethyl ether	1.24E+05[c]	1.24E+05	no data	not applicable
Ethyl methacrylate	5.05E+04[d]	5.05E+04	no data	1.07E+03
Ethylbenzene	1.84E+03[d]	5.25E+04	1.84E+03	1.49E+02
Ethylene oxide	8.80E+01	2.39E+04	8.80E+01	1.79E+05
Fluoranthene	1.19E+04	1.19E+04	no data	not applicable
Fluorene	1.19E+04	1.19E+04	no data	not applicable
Fluoride	2.48E+04	2.48E+04	no data	not applicable
Furan	6.19E+02	6.19E+02	no data	not applicable
Heptachlor	5.09E+00	1.69E+02	5.09E+00	not applicable
Heptachlor epoxide	2.52E+00	4.39E+00	2.52E+00	not applicable
Hexachlorobenzene	1.43E+01	2.70E+02	1.43E+01	not applicable
Hexachloro-1,3-butadiene	2.94E+02	3.38E+02	2.94E+02	not applicable
Hexachlorocyclopentadiene	2.03E+03	2.03E+03	no data	not applicable
Hexachloroethane	2.37E+02	2.37E+02	5.73E+02	not applicable
n-Hexane	2.11E+04[d]	2.11E+04	no data	8.30E+01
2-Hexanone	2.88E+03	2.88E+03	no data	3.38E+03
HMX (also 1,3,5,7-Tetranitro-1,3,5,7-tetrazocine)	3.10E+04	3.10E+04	no data	not applicable
Hydrazine anhydride	1.56E+01	8.54E+06	1.56E+01	1.74E+05
Hydrogen cyanide	2.26E+02	2.26E+02	no data	not applicable
Indeno(1,2,3-c,d)pyrene (M)	1.19E+01	no data	1.19E+01	not applicable
Iron	4.33E+05[c]	4.33E+05	no data	not applicable
Isobutanol (Isobutyl alcohol)	1.86E+05[c]	1.86E+05	no data	not applicable
Isophorone	2.41E+04	6.76E+04	2.41E+04	not applicable
Lead	1.35E+03[f]	1.35E+03[f]	no data	not applicable
Lead (tetraethyl-)	3.38E-02	3.38E-02	no data	not applicable
Maleic hydrazide	1.69E+05[c]	1.69E+05	no data	not applicable
Manganese	1.48E+04	1.48E+04	no data	not applicable
Mercury (elemental)	7.40E+07	7.40E+07	no data	not applicable
Mercury (inorganic)	1.86E+02	1.86E+02	no data	not applicable
Mercury (methyl)	6.19E+01	6.19E+01	no data	not applicable
Methacrylonitrile	5.55E+01	5.55E+01	no data	4.93E+03
Methomyl	8.45E+03	8.45E+03	no data	not applicable
4,4'-Methoxychlor	1.69E+03	1.62E+03	no data	not applicable
Methyl acetate	6.19E+05[c]	6.19E+05	no data	not applicable

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
Methyl acrylate	1.86E+04	1.86E+04	no data	not applicable
Methyl isobutyl ketone (4-Methyl-2-pentanone)	4.88E+04[d]	4.88E+04	no data	3.66E+03
Methyl methacrylate	3.26E+05[c,d]	3.26E+05	no data	2.83E+03
Methyl styrene (alpha)	4.33E+04	4.33E+04	no data	not applicable
Methyl styrene (mixture)	3.27E+03[d]	3.27E+03	no data	1.12E+02
Methylcyclohexane	2.35E+05[c,d]	2.35E+05	no data	3.59E+01
Methylene bromide (Dibromomethane)	1.68E+03	1.68E+03	no data	2.50E+03
Methylene chloride	3.62E+03[d]	3.62E+03	2.24E+04	2.87E+03
2-Methylnaphthalene	2.48E+03	2.48E+03	no data	not applicable
Molybdenum	3.10E+03	3.10E+03	no data	not applicable
Naphthalene	1.80E+03[d]	3.38E+03	1.80E+03	7.74E+01
Nickel	1.24E+04	1.24E+04	2.47E+07	not applicable
Nitrate	9.89E+05[c]	9.89E+05	no data	not applicable
Nitrite	6.19E+04	6.19E+04	no data	not applicable
Nitrobenzene	1.20E+03[d]	1.20E+03	2.23E+03	1.07E+03
Nitroglycerin	3.38E+01	3.38E+01	1.35E+03	not applicable
N-Nitrosodiethylamine (M)	6.64E-02	no data	6.64E-02	not applicable
N-Nitrosodimethylamine (M)	1.95E-01	2.70E+00	1.95E-01	not applicable
N-Nitrosodi-n-butylamine	4.10E+00	no data	4.10E+00	1.96E+03
N-Nitrosodiphenylamine	4.68E+03	no data	4.68E+03	not applicable
N-Nitrosopyrrolidine	1.09E+01	no data	1.09E+01	not applicable
m-Nitrotoluene	6.19E+01	6.19E+01	no data	not applicable
o-Nitrotoluene	2.13E+02	5.57E+02	2.13E+02	not applicable
p-Nitrotoluene	1.35E+03	1.35E+03	1.43E+03	not applicable
Pentachlorobenzene	2.70E+02	2.70E+02	no data	not applicable
Pentachlorophenol	3.25E+01	1.00E+03	3.25E+01	not applicable
Perchlorate	4.34E+02	4.34E+02	no data	not applicable
Phenanthrene	1.01E+04	1.01E+04	no data	not applicable
Phenol	1.01E+05[c]	1.01E+05	no data	not applicable
Polychlorinated Biphenyls				
Aroclor 1016	2.00E+01	2.00E+01	2.72E+02	not applicable
Aroclor 1221	9.52E+00	no data	9.52E+00	not applicable
Aroclor 1232	9.52E+00	no data	9.52E+00	not applicable
Aroclor 1242	9.52E+00	no data	9.52E+00	not applicable
Aroclor 1248	9.52E+00	no data	9.52E+00	not applicable
Aroclor 1254	5.72E+00	5.72E+00	9.52E+01	not applicable
Aroclor 1260	9.52E+00	no data	9.52E+00	not applicable

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170)	1.46E+00	no data	1.46E+00	not applicable
2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	1.46E+01	no data	1.46E+01	not applicable
2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	4.88E+00	no data	4.88E+00	not applicable
2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	4.88E+00	no data	4.88E+00	not applicable
2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	4.88E+00	no data	4.88E+00	not applicable
2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156)	4.88E+00	no data	4.88E+00	not applicable
3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	4.88E-03	no data	4.88E-03	not applicable
2',3,4,4',5-Pentachlorobiphenyl (PCB 123)	4.88E+00	no data	4.88E+00	not applicable
2',3',4,4',5-Pentachlorobiphenyl (PCB 118)	4.88E+00	no data	4.88E+00	not applicable
2',3,3',4,4'-Pentachlorobiphenyl (PCB 105)	4.88E+00	no data	4.88E+00	not applicable
2,3,4,4',5-Pentachlorobiphenyl (PCB 114)	4.88E+00	no data	4.88E+00	not applicable
3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	1.46E-03	no data	1.46E-03	not applicable
3,3',4,4'-Tetrachlorobiphenyl (PCB 77)	1.46E+00	no data	1.46E+00	not applicable
3,4,4',5-Tetrachlorobiphenyl (PCB 81)	4.88E-01	no data	4.88E-01	not applicable
n-Propylbenzene	3.12E+04[d]	3.12E+04	no data	7.52E+01
Propylene oxide	1.90E+02	3.37E+04	1.90E+02	1.07E+05
Pyrene	8.92E+03	8.92E+03	no data	not applicable
RDX (also Hexahydro-1,3,5-trinitro-1,3,5-triazine)	4.25E+02	1.86E+03	4.25E+02	not applicable
Selenium	3.10E+03	3.10E+03	no data	not applicable
Silver	3.10E+03	3.10E+03	no data	not applicable
Strontium	3.71E+05[c]	3.71E+05	no data	not applicable
Styrene	1.02E+05[c,d]	1.02E+05	no data	2.65E+02
2,3,7,8-TCDD (Dioxin)	2.74E-04	4.95E-04	2.74E-04	not applicable
2,3,7,8-TCDF	2.74E-03	no data	2.74E-03	not applicable
1,2,4,5-Tetrachlorobenzene	1.01E+02	1.01E+02	no data	not applicable
1,1,1,2-Tetrachloroethane	7.79E+02[d]	1.86E+04	7.79E+02	3.36E+02
1,1,2,2-Tetrachloroethane	1.54E+02	1.24E+04	1.54E+02	9.10E+02
Tetrachloroethene	7.73E+01[d]	5.50E+03	7.73E+01	8.19E+01
Tetryl (Trinitrophenylmethylnitramine)	1.35E+03	1.35E+03	no data	not applicable
Thallium	6.19E+01	6.19E+01	no data	not applicable
Toluene	4.79E+04[d]	4.79E+04	no data	2.92E+02

Chemical	Recreational SSL[a] (mg/kg)	Noncarcinogenic SSLs (mg/kg)	Carcinogenic SSLs (mg/kg)	C_{sat} SSL (mg/kg)
Toxaphene	2.08E+01	no data	2.08E+01	not applicable
Tribromomethane (Bromoform)	2.90E+03	6.76E+03	2.90E+03	not applicable
1,1,2-Trichloro-1,2,2-trifluoroethane	2.65E+06[c,d]	2.65E+06	no data	4.96E+02
1,2,4-Trichlorobenzene	1.61E+03[d]	2.18E+03	1.61E+03	1.08E+02
1,1,1-Trichloroethane	4.57E+05[c,d]	4.57E+05	no data	4.12E+02
1,1,2-Trichloroethane	1.13E+02	1.13E+02	4.21E+02	2.95E+02
Trichloroethene (M)	1.68E+02	1.68E+02	2.52E+02	3.97E+02
Trichlorofluoromethane	4.69E+04[d]	4.69E+04	no data	7.59E+02
2,4,5-Trichlorophenol	3.38E+04	3.38E+04	no data	not applicable
2,4,6-Trichlorophenol	3.38E+02	3.38E+02	2.08E+03	not applicable
1,1,2-Trichloropropane	3.10E+03	3.10E+03	no data	not applicable
1,2,3-Trichloropropane (M)	6.46E-01	2.95E+02	6.46E-01	6.11E+02
1,2,3-Trichloropropene	5.08E+01	5.08E+01	no data	2.08E+02
Triethylamine	9.21E+03	9.21E+03	no data	1.84E+04
1,2,4-Trimethylbenzene	3.29E+03[d]	3.29E+03	no data	6.40E+01
1,3,5-Trimethylbenzene	6.19E+03[d]	6.19E+03	no data	2.13E+02
1,3,5-Trinitrobenzene	1.60E+04	1.60E+04	no data	not applicable
2,4,6-Trinitrotoluene	3.10E+02	3.10E+02	1.56E+03	not applicable
Uranium (total)	1.86E+03	1.86E+03	no data	not applicable
Vanadium	3.10E+03	3.10E+03	no data	not applicable
Vinyl acetate	9.35E+04[d]	9.35E+04	no data	3.68E+03
Vinyl bromide	9.85E+01	4.05E+02	9.85E+01	1.34E+03
Vinyl chloride (M)	2.46E+01	1.54E+03	2.46E+01	2.95E+03
m-Xylene	2.67E+04[d]	2.67E+04	no data	1.24E+02
o-Xylene	3.01E+04[d]	3.01E+04	no data	8.18E+01
Xylenes	2.78E+04[d]	2.78E+04	no data	8.18E+01
Zinc	1.86E+05[c]	1.86E+05	no data	not applicable

Notes: Several chemicals are assessed using surrogate soil screening levels (SSLs) for similar chemicals, which have toxicity values. The similarity may be based on whether the chemical structures are similar or one chemical is a degradation product of another. Chemicals for which surrogates are used include acenaphthylene, benzo(g,h,i)perylene, chlordane[alpha/gamma-], endosulfan sulfate, endrin aldehyde, endrin ketone, and isopropyltoluene[4-] (NMED 2003, 081172).

[a] The SSL used is the lower of either the noncarcinogenic and carcinogenic SSLs; if an analyte has both noncarcinogenic and carcinogenic effects, both may be included in the screening assessment, if appropriate.

[b] "no data" indicates that a toxicity criterion for the endpoint is not available for an analyte.

[c] SSL exceeds the ceiling limit or maximum of 100,000 mg/kg (NMED 2012, 219971). The values presented are the calculated SSLs.

[d] SSL exceeds the soil saturation limit (C_{sat}) value, above which the chemicals may occur as nonaqueous phase liquids in soil and the volatilization model is unreliable. The values presented are the risk-based SSLs; the C_{sat} value is provided in the last column.

[e] (M) indicates the chemical is classified as a mutagen; SSL values are calculated with an adjustment to account for increased sensitivity to mutagenic effects from childhood exposures.

[f] The SSL for lead is derived using the U.S. Environmental Protection Agency's Integrated Exposure Uptake Biokinetic model (http://www.epa.gov/superfund/lead/products.htm).

REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

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