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SUPPLEMENTAL GUIDANCE FOR DEVELOPING SOIL SCREENING LEVELS FOR SUPERFUND SITES

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Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
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Disclaimer

This document provides guidance to EPA Regions concerning how the Agency intends to exercise its discretion in implementing one aspect of the CERCLA remedy selection process. The guidance is designed to implement national policy on these issues.

The statutory provisions and EPA regulations described in this document contain legally binding requirements. However, this document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it cannot impose legally-binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. Any decisions regarding a particular remedy selection decision will be made based on the statute and regulations, and EPA decisionmakers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. EPA may change this guidance in the future.

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LIST OF ACRONYMS

ABS	Absorption fraction
AF	Skin-soil Adherence Factor
ARAR	Applicable or Relevant and Appropriate Requirement
ASTM	American Society for Testing and Materials
AT	Averaging Time
ATSDR	Agency for Toxic Substances and Disease Registry
BW	Body Weight
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
C/I	Commercial/Industrial
C_{sat}	Soil Saturation Limit
CSF	Cancer Slope Factor
CSGWPP	Comprehensive State Ground Water Protection Plan
CSM	Conceptual Site Model
DAF	Dilution Attenuation Factor
DDT	p,p'-Dichlorodiphenyltrichloroethane
DOD	Department of Defense
DOE	Department of Energy
DQO	Data Quality Objectives
Eco-SSLs	Ecological Soil Screening Levels
ED	Exposure Duration
EF	Exposure Frequency
EPA	Environmental Protection Agency
EV	Event Frequency
HBL	Health Based Level
HEAST	Health Effects Assessment Summary Tables
HELP	Hydrologic Evaluation of Landfill Performance
HI	Hazard Index
HQ	Hazard Quotient
IC	Institutional Control
IF	Age-adjusted Soil Ingestion Factor
IR	Soil Ingestion Rate
IRIS	Integrated Risk Information System
ISC3	Industrial Source Complex Dispersion Model
MCL	Maximum Contaminant Level (in water)
MCLG	Maximum Contaminant Level Goal (in water)
MRL	Minimal Risk Level
NAPL	Nonaqueous Phase Liquid
NPDWR	National Primary Drinking Water Regulations
NPL	National Priorities List
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response

LIST OF ACRONYMS
(Continued)

PAH	Polycyclic Aromatic Hydrocarbon
PA/SI	Preliminary Assessment/Site Inspection
PCB	Polychlorinated biphenyl
PEF	Particulate Emission Factor
PRG	Preliminary Remediation Goal
QA/QC	Quality Assurance/Quality Control
Q/C	Site-Specific Dispersion Factor
RAGS	Risk Assessment Guidance for Superfund
RAS	Regulatory Analytical Services
RBCA	Risk-based Corrective Action
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
SA	Surface Area
SAP	Sampling and Analysis Plan
SCDM	Superfund Chemical Data Matrix
SCS	Soil Classification System
SPLP	Synthetic Precipitation Leachate Procedure
SSG	Soil Screening Guidance
SSL	Soil Screening Level
TBD	Technical Background Document
TC	Soil-to-dust Transfer Coefficient
THQ	Target Hazard Quotient
TR	Target Cancer Risk
TRW	Technical Review Workgroup for Lead
UCL	Upper Confidence Limit
URF	Unit Risk Factor
VF	Volatilization Factor
VOC	Volatile Organic Compound

1.0 INTRODUCTION

In 1996, EPA issued the *Soil Screening Guidance (SSG)*, a tool developed by the Agency to help standardize and accelerate the evaluation and cleanup of contaminated soils at sites on the National Priorities List (NPL). The *SSG* provides site managers with a tiered framework for developing risk-based, site-specific soil screening levels (SSLs).[1] SSLs are not national cleanup standards; instead, they are used to identify areas, chemicals, and pathways of concern at NPL sites that need further investigation (i.e., through the Remedial Investigation/Feasibility Study) and those that require no further attention under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[2] The three-tiered framework includes a set of conservative, generic SSLs; a simple site-specific approach for calculating SSLs; and a detailed site-specific modeling approach for more comprehensive consideration of site conditions in establishing SSLs. The *SSG* emphasizes the simple site-specific approach as the most useful method for calculating SSLs.

In developing the 1996 *SSG*, EPA chose to focus exclusively on future residential use of NPL sites. At the time the guidance was developed, defining levels that would be safe for residential use was very important because of the significant number of NPL sites with people living on-site or in close proximity. In addition, the assumptions needed to calculate SSLs for residential use were better established and more widely accepted than those for other land uses.

One of the most prevalent suggestions made during the public comment period on the 1996 *SSG* was that EPA should develop additional screening approaches for non-residential land uses. This concern reflected the large number of NPL sites with anticipated non-residential future land uses and the desire on the part of site managers to develop SSLs that are not overly conservative for these sites.

Another concern raised during public comment addressed the risk to workers and others from exposures to soil contaminants during construction activity. In the 1996 *SSG*, EPA presented equations for developing SSLs for the inhalation of volatiles and fugitive dusts assuming that a site was undisturbed by anthropogenic processes. This is likely to be a reasonable assumption for many potential future activities at these sites, but not for construction that may be required to redevelop a site. Activities such as excavation and traffic on unpaved roads can result in extensive soil

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[1] EPA uses the term "site manager" in this guidance to refer to the primary user of this document. However, EPA encourages site managers to obtain technical support from risk assessors, site engineers, and others during all steps of the soil screening process.

[2] SSLs also can be incorporated into the framework for risk assessment planning, reporting, and review that EPA has described in the *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual Part D (RAGS, Part D)* (U.S. EPA, 1998). Specifically, SSLs can be incorporated into Standard Table 2 within this guidance, which is designed to compile data to support the identification of chemicals of concern at sites.

disturbance and dust generation that may lead to increased emissions of volatiles and particulates for the duration of the construction project. Such increased short-term exposures are not addressed by the 1996 *SSG*.

With this guidance document, EPA addresses the development of SSLs for residential land use, non-residential land use, and construction activities.

1.1 Purpose and Scope

This document is intended as companion guidance to the 1996 *SSG* for residential use scenarios at NPL sites. It builds upon the soil screening framework established in the original guidance, adding new scenarios for soil screening evaluations. It also updates the residential scenario in the 1996 *SSG*, adding exposure pathways and incorporating new modeling data. The following specific changes included in this document supersede the 1996 *SSG*:

- New methods for developing SSLs based on non-residential land use[3] and construction activities;
- New residential SSL equations for combined exposures via ingestion and dermal absorption[4];
- Updated dispersion modeling data for the soil screening guidance air exposure model; and
- New methods to develop residential and non-residential SSLs for the migration of volatiles from subsurface sources into indoor air.

RELATIONSHIP OF NON-RESIDENTIAL SSL FRAMEWORK TO *RAGS*

EPA has previously provided guidance on evaluating exposure and risk for non-residential use scenarios at NPL sites in the following documents:

- *Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual (HHEM), Supplemental Guidance, Standard Default Exposure Factors, Interim Guidance* (U.S. EPA, 1991a).
- *Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual (HHEM), Part B, Development of Risk-based Preliminary Remediation Goals* (U.S. EPA, 1991b).

These two documents include default values and exposure equations for a generic commercial/industrial exposure scenario that have been widely used and that form the basis of many state site cleanup programs, as well as RCRA's *Risk Based Corrective Action (RBCA) Provisional Standard for Chemical Releases.* However, the approaches detailed in these documents may not always account for the full range of activities and exposures within commercial and industrial land uses. The models, equations, and default assumptions presented in this guidance supersede those presented in the *RAGS Supplemental Guidance* and *RAGS Part B* documents for evaluating exposures under non-residential land use assumptions.

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[3] A detailed discussion of EPA's recommended practices for identifying reasonably anticipated future land use can be found in the EPA directive *Land Use in the CERCLA Remedy Selection Process* (1995a).

[4] This document may be used in conjunction with the draft *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) - Interim Guidance* (U.S. EPA, 2001)

Except for these new equations and updated modeling data, the soil screening process remains the same as the one presented in the 1996 *SSG*. Therefore, this document presents the process in less detail than the original guidance and focuses instead on the specific elements of soil screening evaluation that differ for residential, non-residential, and construction scenarios. Users of this guidance should refer to the *SSG User's Guide* and *Technical Background Document* (U.S. EPA, 1996c and 1996b) for additional information on modeling approaches, data sources, and other important details of conducting soil screening evaluations at NPL sites.

Although certain exposure pathways can be addressed using generic assumptions, this document emphasizes the simple site-specific approach for developing SSLs. EPA believes that this approach provides the best combination of site-specificity and ease of use. Exhibits 1-1 and 1-2 summarize the simple site-specific screening approaches discussed in this document. They address three soil exposure scenarios: residential, non-residential (commercial/industrial), and construction. Exhibit 1-1 describes the exposure characteristics and pathways of concern for each of the receptors under these scenarios, and Exhibit 1-2 presents the relevant exposure factors. Pathways and exposure factors listed in bold typeface under the residential scenario indicate changes from the residential soil screening scenario originally presented in the 1996 *SSG*. These changes reflect updates to EPA's method for evaluating exposures via the dermal contact and inhalation of indoor vapors pathways. (See Chapter 3 for a detailed explanation of these methods.)

This document also discusses the detailed site-specific modeling approach to developing SSLs. This approach can be used to conduct a more in-depth evaluation of any residential or commercial/industrial scenario, but also is needed to develop SSLs for exposure scenarios associated with additional non-residential land uses, such as recreational or agricultural use. These land uses may involve exposure pathways that are not included in the generic and simple site-specific approaches (e.g., ingestion of contaminated foods) and, therefore, require detailed site-specific modeling.

The flowchart in Exhibit 1-3 provides an overview of the residential, commercial/industrial, and construction exposure scenarios, illustrating the relationships among them and indicating the sections of this document relevant to developing SSLs under each of the scenarios. As shown in the flowchart, a soil screening evaluation involves identifying the likely anticipated future land use of a site; selecting an approach to SSL development; developing SSLs according to EPA's seven-step process; calculating supplemental construction SSLs (if necessary); and comparing site soil concentrations to all applicable SSLs. In addition, because SSLs are based on conceptual site models comprised of a complex set of assumptions about future land use and exposure scenarios, care should be taken to ensure that future site activities are consistent with these assumptions (e.g., through the use of institutional controls).

This guidance document focuses solely on risks to humans from exposure to soil contamination; it does not address ecological risks. For any soil screening evaluation (residential or non-residential), an ecological assessment should be performed, independently of the soil screening process for human health, to evaluate potential risks to ecological receptors. Assumptions about human exposure pathways under specific land use scenarios are not relevant to assessing ecological risks. Therefore, site managers should conduct a separate evaluation of risks to ecological receptors.

Exhibit 1-1
SUMMARY OF EXPOSURE SCENARIO CHARACTERISTICS AND PATHWAYS OF CONCERN FOR SIMPLE SITE-SPECIFIC SOIL SCREENING EVALUATIONS

Scenario[1]	**Residential**[2]	**Non-Residential (Commercial/Industrial)**		**Construction**	
Receptor	**On-site Resident**	**Outdoor Worker**	**Indoor Worker**	**Construction Worker**	**Off-site Resident**
Exposure Characteristics	C Substantial soil exposures (esp. children) C Significant time spent indoors C Long-term exposure	C Substantial soil exposures C Long-term exposure	C Minimal soil exposures (no direct contact with outdoor soils, potential for contact through ingestion of soil tracked in from outside) C Long-term exposure	C Exposed during construction activities only C Potentially high ingestion and inhalation exposures to surface and subsurface soil contaminants C Short-term exposure	C Located at the site boundary C Exposed during and post-construction C Potentially high inhalation exposures to soil contaminants C Short- and long-term exposure
Pathways of Concern	C Ingestion (surface and shallow sub-surface soils) C **Dermal absorption (surface and shallow sub-surface soils)**[2] C Inhalation (fugitive dust, outdoor vapors) C **Inhalation (indoor vapors)** C Migration to ground water	C Ingestion (surface and shallow sub-surface soils) C Dermal absorption (surface and shallow sub-surface soils) C Inhalation (fugitive dust, outdoor vapors) C Migration to ground water	C Inhalation (indoor vapors) C Ingestion (indoor dust) C Migration to ground water	C Ingestion (surface and subsurface soil) C Dermal absorption (surface and subsurface soil) C Inhalation (fugitive dust, outdoor vapors)	C Inhalation (fugitive dust)

[1] This exhibit presents information on simple site-specific soil screening evaluations for three exposure scenarios -- residential, commercial/industrial, and construction. Additional exposure scenarios (e.g., agricultural and recreational) may be appropriate for certain sites. Given the lack of generic information available for these scenarios, site managers typically will need to use detailed site-specific modeling to develop SSLs for them.

[2] Bold typeface indicates residential pathways that have changed since the 1996 *SSG*.

Exhibit 1-2
SUMMARY OF DEFAULT EXPOSURE FACTORS FOR SIMPLE SITE-SPECIFIC SOIL SCREENING EVALUATIONS

Scenario[1]	**Residential**	**Non-Residential (Commercial/Industrial)**		**Construction**	
Receptor	**On-site Resident**[2]	**Outdoor Worker**	**Indoor Worker**	**Construction Worker**	**Off-site Resident**
Exposure Frequency (d/yr)	350	225	250	site-specific	site-specific
Exposure Duration (yr)	30 [6 (child)[4] for non-cancer effects]	25	25	site-specific	site-specific
Event Frequency (events/d)	**1**	1	NA	1	NA
Soil Ingestion Rate (mg/d)	200 (child) 100 (adult)	100	50	330	NA
Ground Water Ingestion Rate[3] (L/d)	2	2	2	NA	NA
Inhalation Rate (m^3/d)	20[5]	20	20	20	20
Surface Area Exposed (cm^2)	**2,800 (child)** **5,700 (adult)**	3,300	NA	3,300	NA
Adherence Factor (mg/cm^2)	**0.2 (child)** **0.07 (adult)**	0.2	NA	0.3	NA
Body Weight (kg)	15 (child) 70 (adult)	70	70	70	70
Lifetime (yr)	70	70	70	70	70

[1] This exhibit presents information on simple site-specific soil screening evaluations for three exposure scenarios -- residential, commercial/industrial, and construction. Additional exposure scenarios (e.g., agricultural and recreational) may be appropriate for certain sites. Given the lack of generic information available for these scenarios, site managers will typically need to use detailed site-specific modeling to develop SSLs for them.

[2] Items in bold represent changes to the residential soil screening exposure scenario presented in the 1996 *SSG*.

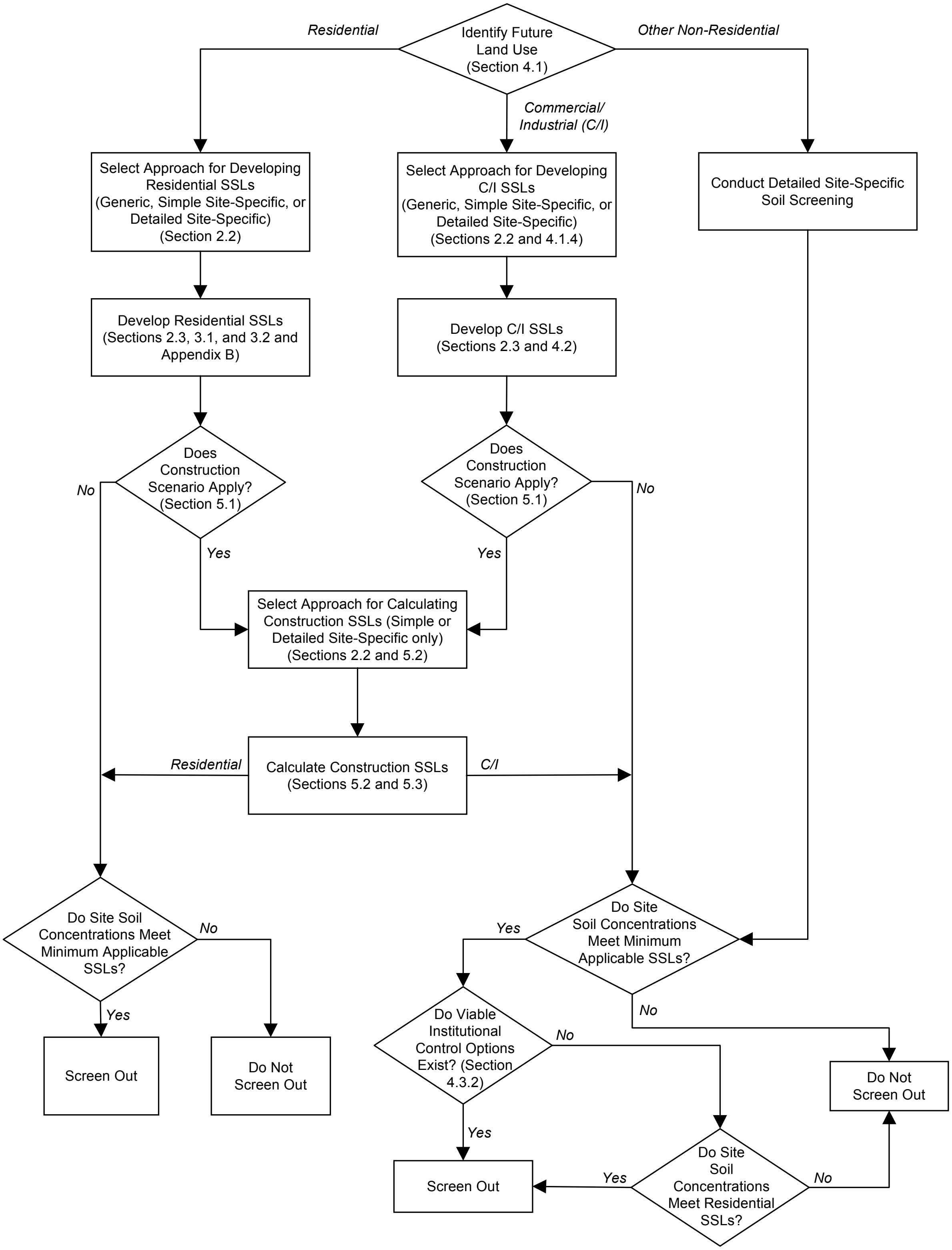
[3] SSLs for the migration to ground water pathway are based on acceptable ground water concentrations, which are, in order of preference: a non-zero Maximum Contaminant Level Goal (MCLG), a Maximum Contaminant Level (MCL), or a health-based level (HBL) based on a 1×10^{6} incremental lifetime cancer risk or a hazard quotient of one due to ingestion of contaminated ground water. When an HBL is used, it is based on these ground water ingestion rate values.

[4] A child is defined as an individual between one and six years of age.

[5] We evaluate residential inhalation exposure to children and adults using the RfC toxicity criterion, which is based on an inhalation rate of 20 m^3 /day. No comparable toxicity criterion specific to childhood exposures is currently available. EPA has convened a workgroup to identify suitable default values for modeling childhood inhalation exposures, as well as possible approaches for adjusting toxicity values for application to such exposures.

Exhibit 1-3

SOIL SCREENING OVERVIEW



EPA is currently working with a multi-stakeholder workgroup to develop scientifically sound, ecologically-based soil screening levels. The workgroup includes representatives from EPA, Environment Canada, Department of Energy (DOE), Department of Defense (DOD), academia, states, industry, and private consulting. This collaborative project will result in a Superfund guidance document that includes a look-up table of generic ecological soil screening levels (Eco-SSLs) for up to 24 chemicals that frequently are of ecological concern at Superfund sites. These Eco-SSLs will be soil concentrations that are expected to be protective of the mammalian, avian, plant, and invertebrate populations or communities that could be exposed to these chemicals.

1.2 Organization of Document

The remainder of this document is organized into four major chapters. Chapter 2 presents a brief overview of soil screening evaluations. It discusses the soil screening concept, the three-tiered screening framework, and the seven-step soil screening process. Chapter 3 focuses on the exposure pathways considered in soil screening evaluation. It lists the key exposure pathways for the three soil screening scenarios (residential, commercial/industrial, and construction) and presents new methods for calculating SSLs for two exposure pathways — dermal absorption (which addresses the potential for concurrent exposure via the direct ingestion and dermal pathways) and the migration of volatiles into indoor air. Chapter 4 addresses the development of non-residential SSLs. It discusses approaches to identifying future land use, presents a non-residential exposure framework, and provides equations for calculating site-specific non-residential SSLs. In addition, Chapter 4 also discusses issues related to the derivation and application of non-residential SSLs, including the importance of involving community representatives in identifying future land uses; the selection and implementation of institutional controls to ensure that future site activities are consistent with non-residential land use assumptions; and the relative roles of SSLs and OSHA standards in protecting future workers from exposure to residual contamination at non-residential sites. Finally, Chapter 5 describes methods for the development of construction SSLs that address exposures due to construction activities occurring during site redevelopment.

Five appendices to this document provide supporting information for the development of SSLs. Appendix A presents generic SSLs for residential and non-residential exposure scenarios. The generic residential SSLs in Appendix A have been updated to reflect the changes discussed in this document and supersede all previously published generic SSLs. Appendix B presents the complete set of simple site-specific SSL equations for the residential exposure scenario that incorporates changes to the 1996 *SSG*. Appendix C consists of chemical-specific information on chemical and physical properties, as well as human health toxicity values for use in developing SSLs. Appendix D provides tables of coefficients for calculating site-specific dispersion factors for inclusion in the air dispersion equations used to calculate simple site-specific SSLs for the inhalation pathway. Finally, Appendix E describes suggested modeling approaches that can be used to develop detailed site-specific inhalation SSLs for the non-residential and construction scenarios.

2.0 OVERVIEW OF SOIL SCREENING

This chapter of the guidance document provides a brief overview of soil screening evaluations for sites on the NPL. It begins with a definition of the soil screening concept and a discussion of its applicability and limitations, then describes three approaches to conducting soil screening evaluations, and concludes with a review of EPA's seven-step soil screening process. For a more in-depth and comprehensive discussion of these topics, please refer to Chapter 1.0 of EPA's 1996 *SSG*.

2.1 The Screening Concept

As used in this guidance, screening refers to the process of identifying and defining areas, contaminants, and conditions at a site that do not warrant further federal attention under CERCLA. Site managers make these determinations by comparing measured soil contaminant concentrations to soil screening levels (SSLs). SSLs are soil contaminant concentrations below which no further action or study regarding the soil at a site is warranted under CERCLA, provided that conditions associated with the SSLs are met. In general, areas with measured concentrations of contaminants below SSLs may be screened from further federal attention; if actual concentrations in the soil are at or above SSLs, further study, though not necessarily cleanup action, is warranted.[4] Exhibit 2-1 summarizes the definition and the applicability of the soil screening process and the associated SSLs.

SSLs are risk-based soil concentrations derived for individual chemicals of concern from standardized sets of equations. These equations combine EPA chemical toxicity data with parameters defined by assumed future land uses and exposure scenarios, including receptor characteristics and potential exposure pathways. Residential SSLs, initially described in the 1996 *SSG* and updated in this document, are based on exposure scenarios associated with residential activities, while non-residential SSLs are based on scenarios associated with non-residential activities.

For each chemical, SSLs are back-calculated from target risk levels. For the inhalation pathway and for the combined direct ingestion/dermal absorption pathway (see Section 3.2), target risk levels for soil exposures are a one-in-a-million ($1x10^{-6}$) excess lifetime cancer risk for carcinogens and a hazard quotient (HQ) of one for non-carcinogens. SSLs for the migration to ground water pathway are back-calculated from the following ground water concentration limits (in order of preference): non-zero maximum contaminant level goals (MCLGs); maximum contaminant levels (MCLs); or health-based limits (based on a cancer risk of $1x10^{-6}$ or an HQ of one).

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[4] Areas meeting federal SSLs may still warrant further study. Some EPA Regional Offices and states have developed separate soil screening levels and/or preliminary remediation goals (PRGs) that may be more stringent than those presented in this guidance (though these alternative levels are based on the same general methodology described in this guidance). It is important that site managers confer with regional and state risk assessors when conducting soil screening evaluations to ensure that any SSLs developed will be consistent with their accepted soil levels.

Exhibit 2-1

A GENERAL GUIDE TO THE SCREENING AND SSL CONCEPTS

Screening **Is:**	Screening **Is Not:**
• A method for identifying and defining areas, contaminants, and conditions at a site that generally do not warrant further federal attention; • A means of focusing the Remedial Investigation/ Feasibility Study (RI/FS) and site risk assessment; • A means for gathering data for later phases of the Superfund site remediation process.	• Mandatory; • A substitute for an RI/FS or risk assessment; • Valid unless conditions associated with SSLs (e.g., assumed future land use and site activities) are met.
SSLs **Are:**	SSLs **Are Not:**
• Human health risk-based concentrations; • Levels below which no further action or study is warranted under CERCLA, provided conditions concerning potential exposures and receptors (e.g., future land use) are met; • Specific to assumed exposures and site conditions; C Potentially suitable for use as PRGs.	• National cleanup standards; • Uniform across all sites; • Applicable to radioactive contaminants.

Although SSLs are “risk-based,” the soil screening process does not eliminate the need to conduct site-specific risk assessments as part of the Superfund cleanup process. However, the screening process can help focus the risk assessment for a site on specific areas, contaminants, and pathways, and data collected during the screening process can be used in the risk assessment. Similarly, SSLs are not national cleanup standards, and exceedances of SSLs do not trigger the need for response actions at NPL sites.

In addition, because SSLs are based on a set of assumptions about likely future land use and site activities, they are only pertinent to the extent that future activities are consistent with these assumptions. Institutional controls may serve to limit future land uses and associated exposures to those assumed in a non-residential screening analysis, helping to ensure that the non-residential SSLs (which may be based on less conservative exposure assumptions than residential SSLs) are adequately protective. Institutional controls are not generally necessary for sites screened using residential SSLs because the conservative assumptions incorporated in the residential exposure scenario yield SSLs that are protective of non-residential uses as well. Further discussion of these issues can be found in *Land Use in the CERCLA Remedy Selection Process* (U.S. EPA 1995a).

The use of SSLs for screening purposes during site investigation at CERCLA sites is not mandatory. However, it is recommended by EPA as a tool to focus the RI/FS and site risk assessment by identifying the contaminants and areas of concern, and to gather necessary information for later phases of the RI/FS process.[5]

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[5] SSLs developed in accordance with this guidance can also be applied to Resource Conservation and Recovery Act (RCRA) corrective action sites as “action levels,” where appropriate, since the RCRA corrective action program currently views the role of action levels as generally serving the same purpose as soil screening levels. For more information, see 61 *Federal Register* 19432, 19439, and 19446 (May 1, 1996).

SSLs also can be used as Preliminary Remediation Goals (PRGs) provided conditions found during subsequent investigations at a specific site are the same as the conditions assumed in developing the SSLs. EPA recognizes, however, that certain conservative assumptions built into the generic and simple site-specific approaches to SSL development, while appropriate for a screening analysis, may be overly conservative for setting PRGs and, ultimately, site cleanup levels. For example, as described in the 1996 *SSG*, EPA chose to base generic and simple site-specific SSLs for non-carcinogenic contaminants via soil ingestion on a conservative, childhood-only, six-year exposure duration because several studies suggest that inadvertent soil ingestion is common among children age 6 and younger (Calabrese et al., 1989; Davis et al., 1990; and VanWinjen et al., 1990). The SAB noted that the combination of the six-year childhood exposure with a chronic RfD may be appropriate for chemicals with toxic endpoints specific to children or with steep dose-repsonse curves, but is likely to be overly protective for most contaminants (U.S. EPA, 1993). EPA believes this protectiveness is appropriate for soil screening evaluations, but such conservatism may not be necessary for developing PRGs and cleanup levels for many contaminants. Therefore, site managers wishing to use SSLs as a basis for developing PRGs should carefully consider the assumptions built into the SSLs and whether it may be appropriate to relax any of these assumptions for calculating PRGs.

2.2 The Tiered Screening Framework /Selecting a Screening Approach

EPA's framework for soil screening assessment provides site managers with three approaches to establish SSLs for comparison to soil contaminant concentrations:

- Apply **generic** SSLs developed by EPA;
- Develop SSLs using a **simple site-specific** methodology; or
- Develop SSLs using a more **detailed site-specific** modeling approach.

These approaches involve using increasingly detailed site-specific information to replace generic assumptions, thereby tailoring the screening model to more accurately reflect site conditions, potential exposure pathways, and receptor characteristics. Additionally, progression from generic to detailed site-specific methods generally results in less stringent screening levels because conservative assumptions are often replaced with site-specific information while maintaining a constant target risk level.

The first approach for developing screening levels is the simplest and least site-specific. This approach assumes a generic exposure scenario, intended to be broadly protective under a wide array of site conditions. The site manager simply compares measured soil concentrations to chemical-specific SSLs derived by EPA based on the conservative generic scenario and provided in a look-up table. (These tables, together with additional guidance on applying the generic SSLs to individual sites, are presented in Appendix A of this document.) While this approach offers the benefits of simplicity and ease of use, the generic SSLs are calculated using conservative assumptions about site conditions and are thus likely to be more stringent than SSLs developed using more site-specific approaches. Where site conditions differ substantially from the scenario used to derive the generic SSLs, generic levels may not be appropriate for identifying areas that can be "screened out." The specific assumptions underlying the generic SSLs are identified in the equations presented in Section 4.2.3 (non-residential exposure scenario) and in Appendix B (residential exposure scenario).

The second approach, the simple site-specific methodology, allows site managers to calculate SSLs using the same equations used to derive the generic SSLs. Unlike the generic approach, the simple site-specific methodology offers some flexibility in the use of site-specific data for developing SSLs. Though the target risk for SSLs remains the same, some of the generic default input values may be replaced by site-specific information such as data on hydrological, soil, and meteorological conditions. Thus, the simple site-specific approach retains much of the ease and simplicity of the generic approach, while providing site managers increased freedom to replace the conservative assumptions of the generic approach with data that more accurately reflect site conditions. The result will be more tailored SSLs that are likely to be less stringent than the generic values. As site managers change the assumptions used in developing the SSLs to reflect site-specific information, they should have the changes reviewed by the regional risk assessor associated with the site. Site managers should also document any changes they make to the exposure parameters from the default values in order to develop simple site-specific SSLs.

As the name suggests, the detailed site-specific modeling approach is the most rigorous of the three approaches and incorporates site-specific data to the greatest extent. This approach is useful for developing SSLs that take into account more complex site conditions than those assumed in the simple site-specific approach. The detailed approach may be appropriate, for example, to demonstrate that the migration of soil contaminants to ground water does not apply at a particular site, or to model distinct or unusual site conditions. Technical details supporting the use of this approach can be found in Appendices D and E of this document and in the *Technical Background Document* (*TBD*) for the 1996 *SSG*.

The decision regarding which of the three approaches is most appropriate for a given site must balance the need for accuracy with considerations of cost and timeliness. While progression from generic SSLs to a detailed site-specific modeling approach increases the accuracy of the screening process, it also generally involves an increase in the resources, time, and costs required. Deciding which option to use typically requires balancing the increased investigation effort with the potential savings associated with higher (but still protective) SSLs. In general, EPA believes the most useful approach to apply is the simple site-specific methodology, which provides a reasonable compromise in terms of effort and site-specificity.

Although the simple site-specific approach is generally expected to be the most useful, there are times when the generic or the detailed site-specific modeling approaches may be more appropriate. The former can be used as an initial screening tool or as a “crude yardstick” to quickly identify those areas which clearly do not pose threats to human health or the environment. In such cases where exclusion appears clearly warranted, there is little need for more site-specific information to justify this decision. The generic approach can also be used to quickly screen out chemicals and focus the subsequent investigation on the key chemicals of concern. Generally, detailed site-specific modeling is most useful in cases where: 1) the ability to conduct sophisticated analyses, incorporating mostly site-specific data, could result in substantial savings in site investigation and cleanup costs due to an increase in the site area "screened out" of the remedial process under CERCLA; or 2) site conditions are unique. For example, the detailed approach could be used to assess unusual exposure pathways or conditions or to conduct fate and transport analyses that describe the leaching of contaminants to ground water in a specific hydrogeologic setting.

2.3 The Seven-Step Soil Screening Process

Regardless of the screening approach chosen, the soil screening analysis consists of the seven steps discussed in this section. EPA emphasizes that the overall seven-step site screening process is not changing, and the same process is applied to residential and non-residential scenarios. However, the evaluation of the non-residential and construction exposure scenarios described in this guidance requires modifications to the steps of the screening process, especially to Steps 1, 2, and 5. These modifications are described in Section 4.2 and Section 5.3 of this document for the non-residential and construction scenarios, respectively.

The seven-step soil screening process established in the 1996 *SSG* was designed to evaluate the significance of soil contaminant concentrations at residential sites. Although some of the default values and assumptions of the residential approach do not apply to commercial/industrial or construction exposure scenarios, the same overall screening framework can be used to evaluate sites under these scenarios. The basic elements of the seven steps are described below. Exhibit 2-2 presents a useful one-page summary of the full soil screening process. Please refer to the 1996 *SSG* for additional information on the soil screening steps.

Step 1: Develop Conceptual Site Model

Developing a conceptual site model (CSM) is a critical step in properly implementing the soil screening process at a site. The CSM is a comprehensive representation of the site that documents current site conditions. It characterizes the distribution of contaminant concentrations across the site in three dimensions and identifies all potential exposure pathways, migration routes, and potential receptors. The CSM is initially developed from existing site data. This site data should include input from community members about their site knowledge, concerns, and interests. The CSM is a key component of the RI/FS and EPA's Data Quality Objectives (DQO) process, and should be continually revised as new site investigations produce updated or more accurate information. CSM summary forms and detailed information on the development of CSMs are presented in Attachment A of the 1996 *SSG User's Guide*.

In addition, *RAGS Part D*, which is intended to assist site managers in standardizing risk assessment planning, reporting, and review at CERCLA sites, provides a template that site mangers can use to summarize and update data on the CSM. This template is the first in a series of standard tables that EPA has developed to document important parameters, data, calculations, and conclusions from all stages of Superfund human health risk assessments.

Exhibit 2-2

SOIL SCREENING PROCESS

Step 1: **Develop Conceptual Site Model**

- Collect existing site data (historical records, aerial photographs, maps, PA/SI data, available background information, state soil surveys, etc.)
- Collect community input
- Organize and analyze existing site data
  - Identify known sources of contamination
  - Identify affected media
  - Identify potential migration routes, exposure pathways, and receptors
- Construct a preliminary diagram of the CSM
- Perform site reconnaissance
  - Confirm and/or modify CSM
  - Identify remaining data gaps

Step 2: **Compare CSM to SSL Scenario**

- Identify sources, pathways, and receptors likely to be present at the site and addressed by the soil screening scenario
- Identify additional sources, pathways, and receptors likely to be present at the site but not addressed by the soil screening scenario

Step 3: **Define Data Collection Needs for Soils**

- Develop hypothesis about distribution of soil contamination
- Develop sampling and analysis plan for determining soil contaminant concentrations
  - Sampling strategy for surface soils following Data Quality Objectives (DQOs)
  - Sampling strategy for subsurface soils following Data Quality Objectives (DQOs)
  - Sampling strategy to measure soil characteristics (bulk density, moisture and organic carbon content, porosity, pH)
- Determine appropriate field methods and establish QA/QC protocols

Step 4: **Sample and Analyze Soils**

- Identify contaminants
- Delineate area and depth of sources
- Determine soil characteristics
- Revise CSM, as appropriate

Step 5: **Calculate Site- and Pathway-Specific SSLs**

- Identify SSL equations for relevant pathways
- Identify chemicals of concern for dermal exposure
- Obtain site-specific input parameters from CSM summary
- Replace variables in SSL equations with site-specific data gathered in Step 4
- Calculate SSLs
  - Account for exposure to multiple contaminants

Step 6: **Compare Site Soil Contaminant Concentrations to Calculated SSLs**

- For surface soils characterized using composite samples, screen out exposure areas where all composite samples do not exceed SSLs by a factor of two
- For surface soils characterized using discrete samples, screen out areas where the 95 percent upper confidence limit (UCL_{95}) on the mean concentration for each contaminant does not exceed the corresponding SSL
- For subsurface soils with indirect exposures, screen out source areas where the mean concentration of each contaminant in each soil boring does not exceed the applicable SSL
- For subsurface soils with direct exposures, screen out source areas where the highest soil boring concentration for each contaminant does not exceed the applicable SSL
- Evaluate whether background levels exceed SSLs

Step 7: **Address Areas Identified for Further Study**

- Consider likelihood that additional areas can be screened out with more data
- Integrate soil data with other media in the baseline risk assessment to estimate cumulative risk at the site
- Determine the need for action
- Use SSLs as PRGs, if appropriate

Step 2: Compare CSM to SSL Scenario

In this step, the CSM for a site is compared to the SSL scenario and assumptions for calculating generic and simple site-specific SSLs. This comparison should determine whether the CSM is sufficiently similar to the SSL scenario so that use of the generic or simple site-specific SSL scenario is appropriate. If the CSM contains sources, pathways, or receptors not covered by the general SSL scenario, comparison to generic or simple site-specific SSLs alone may not be sufficient to fully evaluate the site, suggesting the need to conduct detailed site-specific modeling. However, it may be sufficient to eliminate some pathways or chemicals from further consideration. It is crucial to engage in these efforts at this early stage in order to identify areas or conditions where generic or simple site-specific SSLs are not sufficiently informative, so that other characterization and response efforts can be considered when planning the sampling strategy (Step 3).

Step 3: Define Data Collection Needs for Soils

Upon initiating a soil screening evaluation, a site manager develops a Sampling and Analysis Plan (SAP). The SAP should identify sampling strategies for filling any data gaps in the CSM requiring collection of site-specific information. These strategies typically address contaminant concentrations in surface and subsurface soil, as well as soil characteristics.

Before developing the SAP, the site manager should define the specific areas(s) to which the soil screening process will be applied. Existing data can be used to determine what level and type of investigation may be appropriate. Areas with known contamination will be thoroughly investigated and characterized in the RI/FS. Areas that are unlikely to be contaminated based on good historical documentation of the location of current and past storage, handling, or disposal of hazardous materials at the site may generally be screened out at this stage; however, samples should be taken to confirm this hypothesis. The remaining areas, those with uncertain contamination levels and historical activities, are most appropriate for the soil screening sampling strategy outlined in the 1996 *SSG*.

For purposes of soil screening analyses, EPA distinguishes between surface and subsurface soils as follows: surface soils are located within two centimeters of the ground surface, and subsurface soils are located more than two centimeters below the surface. Because exposure to contaminants in these two soil regions may occur via different mechanisms, sampling plans for these two categories of soil should be designed to collect reliable data appropriate to the exposure models involved. For example, the surface soil strategy should collect data appropriate for evaluating exposure via direct ingestion, dermal contact, and inhalation of fugitive dusts as individuals move randomly around a site. Typically, this requires a reliable estimate of the arithmetic mean of contaminant concentrations in surface soils in exposure areas of concern. In general, the subsurface soil sampling strategy should provide data to model the types of indirect exposure to subsurface contamination that occurs when chemicals migrate up to the soil surface or down to an underlying aquifer. Modeling these pathways usually requires an estimate of the average contaminant concentration through each source, estimates of the dimensions of the source, and average soil properties within the source. However, as discussed below, at some sites a sampling plan designed to evaluate direct contact exposures may be appropriate for some subsurface soils.

Site managers have two options for developing an SAP for surface soils: composite sampling or discrete sampling. Either approach should allow you to calculate a reliable estimate of the arithmetic mean of contaminant concentrations in surface soils. Composite sampling involves the physical mixing of soils from multiple locations and then collecting one or more sub-samples from the mixture. Details of a composite-based SAP are presented in the 1996 *SSG*. The maximum contaminant concentration from composite sampling is a conservative estimate of the mean concentration and can be used for soil screening evaluations. This approach can be an effective way to estimate the mean contaminant concentration with lower sampling costs, because fewer samples are needed. However, the mixing of soils in composite samples may disperse volatile contaminants and also may dilute concentrations of other contaminants, resulting in less sensitivity to hot spots and to other variations in contaminant concentrations. Alternatively, site managers can collect discrete un-composited samples using a simple random sampling scheme (SRS), a stratified SRS[6], or systematic grid sampling with a random starting point. Details of alternative SAPs for discrete sampling can be found in *Guidance for Choosing a Sampling Design for Environmental Data Collection* (EPA 2000a). Because there is no spatial averaging of soil concentrations with this method, a much larger number of soil samples is required to produce a reliable estimate of the mean contaminant concentration. As a result, EPA recommends estimating the 95th percentile upper confidence limit (UCL_{95}) on the mean contaminant concentration as a conservative estimate of the mean when performing a soil screening evaluation with data sets of un-composited samples.[7]

The 1996 *SSG* subsurface soil sampling strategy addresses exposure to subsurface contamination that occurs when chemicals migrate up to the soil surface or down to an underlying aquifer. It focuses on collecting the data required for modeling volatilization and migration to ground water. As a result, the goals of this strategy are to measure the area and depth of contamination, the average contaminant concentration in each source area, and the characteristics of the soil. Accurately determining the mean concentration of subsurface soils using current investigative techniques and statistical methods would require a costly and intensive sampling program that is beyond the level of effort required for a screening analysis. Therefore, EPA recommends that conservative assumptions be used to develop hypotheses on likely contaminant distributions. EPA recommends taking 2 or 3 soil borings located in the areas suspected of having the highest contaminant concentrations within each source. Because the subsurface sampling approach is likely to be less comprehensive than the surface soil SAP, the soil screening analysis focuses on the highest mean soil boring contaminant concentration within the source as a conservative estimate of the mean contaminant concentration for the entire source area. The subsurface SAP also should include the collection of site characteristics needed to determine site-specific SSLs, including the following soil parameters: Soil Classification System (SCS) soil type, dry bulk density (ρ_b), soil organic carbon content (f_{oc}), and pH. Additional detail on this approach can be found in the 1996 *SSG User's Guide* and *Technical Background Document*.

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[6] Stratified SRS allows for random sample collection within sampling blocks designed to reflect anticipated site activity patterns; thus, it more effectively targets areas where exposures are expected to occur.

[7] EPA's *Calculating Upper Confidence Limits For Exposure Point Concentrations at Hazardous Waste Sites*, provides a survey of statistical methods that may be used by site managers to estimate UCL_{95} values (U.S. EPA,2002a).

For some CSMs, these three sampling approaches will suffice to characterize exposures to contaminants in soil. However, other CSMs may feature residential activities (e.g., gardening) or commercial/industrial (e.g., outdoor maintenance or landscaping) or construction activities that may disturb soils to a depth of up to two feet, potentially exposing receptors to contaminants in subsurface soil via direct contact pathways such as ingestion and dermal absorption. In such cases, EPA anticipates that site managers will need to characterize contaminant levels by taking shallow subsurface borings where appropriate. The specific locations of such borings should be determined by the likelihood of direct contact with these subsurface soils and by the likelihood that soil contamination is present at that depth. Given that contamination in these deeper soils is unlikely to be characterized to the same extent as contamination in surface soils, the maximum measured concentration of each contaminant in these borings should used as a conservative estimate of the mean contaminant concentration for purposes of the soil screening evaluation.

Alternatively, if available evidence strongly indicates that contaminated subsurface soils will be disturbed and brought to the surface (e.g., as the result of redevelopment activities), site managers will need to characterize subsurface contamination more thoroughly and should collect a sufficient number of samples to develop a UCL_{95} value for use in the soil screening evaluation.

For both surface and subsurface soils, site managers should use the Data Quality Objectives (DQO) process in developing SAPs to ensure that sufficient data are collected to properly assess site contamination and support decision-making concerning future Superfund site activities. The DQO process is a systematic planning process designed to ensure that sufficient data are collected to support EPA decision-making. Section 2.3 of the 1996 *SSG* describes this process in detail.

Step 4: Sample and Analyze Site Soils

Once sampling strategies have been developed and implemented, the samples are analyzed according to the methods specified in the SAP. The analytic results provide the concentration data for contaminants of concern that are used in the comparison to SSLs (Step 6). Soil analysis also helps to define the areal extent and depth of contamination, as well as soil characteristics data. This information is needed to calculate site-specific SSLs for the inhalation of volatiles and migration to ground water pathways.

The analyses of soil contaminants and characteristics may reveal new information about site conditions. It is critical that the CSM be updated to reflect this information.

Step 5: Calculate Site- and Pathway-Specific SSLs

Using the data collected in Step 4 above, site-specific soil screening levels can be calculated according to the methods presented under this step of the *SSG*. (If generic SSLs are used for comparison with site contaminant concentrations, this step may be omitted.) Both the 1996 *SSG* and this guidance document provide equations necessary to develop simple site-specific SSLs. Also, an interactive SSL calculator for simple site-specific equations is available online at http://risk.lsd.ornl.gov/calc_start.htm.[8] Descriptions of how these equations were developed and background information on underlying assumptions and limitations are available in the *TBD* for the 1996 *SSG* as well as in Chapters 3, 4, and 5 of this document. The default exposure assumptions and equations for calculating residential SSLs can be found in Chapter 3 and in Appendix B of this document. Additional information on default residential assumptions can be found in the 1996 *SSG User's Guide* and *TBD*. The default assumptions and equations for calculating non-residential SSLs are presented in Chapter 4. (Alternatively, tables of generic SSLs for these two scenarios are presented in Appendix A.) The equations used to calculate SSLs based on construction activities are presented in Chapter 5.

All SSL equations in the 1996 *SSG* were designed to be consistent with the concept of Reasonable Maximum Exposure (RME) in the residential setting. In following the Superfund program's approach for estimating RME, EPA uses reasonably conservative defaults for intake and exposure duration, combined with values for site-specific parameters (e.g., for soil or hydrologic conditions) that reflect average or typical site conditions, to develop risk-based SSLs. EPA bases SSLs on RME assumptions rather than central tendency conditions because this approach results in a conservative (though not a worst case) estimate of long-term exposure that is protective of the majority of the population.

The 1996 *SSG* quantitatively addresses four exposure pathways — direct ingestion, inhalation of fugitive dusts, inhalation of volatiles in outdoor air, and ingestion of ground water contaminated by the migration of contaminants through soil to an underlying potable aquifer. This guidance includes these four pathways plus dermal contact exposures and inhalation of volatiles in indoor air from vapor intrusion.

Step 6: Compare Site Soil Contaminant Concentrations to Calculated SSLs

Once site-specific SSLs have been calculated (or the appropriate generic SSLs from Appendix A have been identified), they are compared to the measured concentrations of contaminants of concern. At this point, it is important to review the CSM to confirm its accuracy in light of the actual site data that have been collected in previous steps of the soil screening process. This also will help to ensure that the SSL scenarios are applicable to the site.

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[8] The SSL calculator currently includes default values for residential exposures; however, users can adjust these defaults to reflect non-residential exposure scenarios.

The following are four methods for deciding whether an exposure area can be screened from further investigation — two for surface soil contamination and two for subsurface soil contamination. Each method specifies a particular estimator of the true mean concentration to be used in a screening evaluation, as well as the screening level to which the estimate is compared.

- **Compare Maximum Composite Concentration to 2 x SSL (Surface Soils).** For surface soils that have been sampled using composite samples in accordance with the DQOs discussed in the 1996 *SSG*, the maximum composite sample concentration is compared to two times the SSL; areas where the maximum composite sample concentration is less than two times the SSL can be screened out. Further study is needed for areas where any composite sample concentration equals or exceeds twice the applicable SSL for one or more contaminants.[9] The 1996 *SSG* notes that the surface soil max test strategy that employs composites is applicable for semivolatiles, inorganics, and pesticides only.

- **Compare 95 Percent Upper Confidence Limit on the Mean to SSL (Surface Soils).** For data sets consisting of discrete samples or data sets of limited sample size, EPA uses statistical methods to calculate a conservative estimate of the arithmetic mean concentration for each contaminant in an exposure area. This estimate, the 95 percent upper confidence limit (UCL_{95}) on the mean is used to avoid underestimating the true mean (and thereby ensure that the screening process is protective of human health). The UCL_{95} may be estimated by a variety of statistical methods depending on the characteristics of the data set (e.g., the Chebyshev inequality, the bootstrap method, and the jackknife method); these methods are described in *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (U.S. EPA, 2002a).

- **Compare Mean Concentration in Soil Borings to SSL (Subsurface Soils/Indirect Exposure).** Where direct contact exposure to subsurface soil is not an issue, subsurface soil sampling under the SSL DQOs is generally limited to two or three borings *per source area*. As discussed in Step 3, subsurface soil sampling strategies focus on the collection of data for modeling the volatilization and migration to ground water pathways (i.e., the area and depth of contamination, soil characteristics, and the average contaminant concentration in each source area. Because the expense and level of effort involved in a precise determination of these values for a subsurface contamination source is well beyond the level of effort generally

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[9] Given the sampling approach described in the 1996 *SSG*, which focused on a strategy of collecting composite samples, two times the SSL was determined to be a reasonable upper limit for comparison that would still be protective of human health. See the 1996 *SSG TBD* for a complete discussion of the protectiveness of this level (U.S. EPA, 1996b).

appropriate for a screening evaluation, these soils tend not to be characterized to the same extent as surface soils. Therefore, for these soils, the *SSG* adopts a conservative approach for soil screening decisions of comparing mean concentrations from each boring directly to the SSL. In areas where the mean concentrations of all borings fall below the SSL, the area may be screened out. In all other areas, further study is required.[10]

- **Compare Maximum Concentration in Soil Borings to SSL (Subsurface Soils/Direct Exposure).** At sites where activities may disturb subsurface soils and result in direct contact exposures to contaminants in those soils, EPA anticipates that site managers will characterize contaminant levels by taking samples from additional subsurface borings in areas of soil likely to be disturbed. Given that contamination in these deeper soils is unlikely to be characterized to the same extent as contamination in surface soils, the maximum measured concentration of each contaminant in these borings should used as a conservative estimate of the mean contaminant concentration and compared directly with the appropriate SSL. If the maximum concentration of each contaminant in a given area falls below its SSL, the area may be screened out. For all other areas, additional study is required.[11]

Exposures to Multiple Chemicals

Exposures to multiple chemicals are treated similarly for non-residential and residential soil screening evaluations. The project manager should coordinate with the risk assessor to determine the health end points caused by each chemical and combinations of several chemicals. EPA believes that the $1\text{x}10^{-6}$ target cancer risk level for individual chemicals and pathways generally will lead to cumulative site risks within the $1\text{x}10^{-4}$ to $1\text{x}10^{-6}$ risk range for the combinations of chemicals typically found at NPL sites. For non-carcinogens, EPA recommends that non-carcinogenic contaminants be grouped according to the critical effect listed as the basis for the RfD/RfC. If more than one chemical detected at a site affects the same target organ or organ system, SSLs for those chemicals should be divided by the number of chemicals present in the group

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[10] The SSL DQO sampling approach will not yield sufficient data for calculating a 95 percent UCL for the arithmetic mean contaminant concentration in subsurface soil. However, should there be sufficient data for this calculation, site managers have the option of comparing either the 95 UCL value for the site or the contaminant concentrations in each boring to the SSL.

[11] Alternatively, if available evidence indicates that contaminated subsurface soils will be disturbed and brought to the surface (e.g., as the result of redevelopment activities), site managers will need to characterize subsurface contamination more thoroughly and should collect a sufficient number of samples to develop a UCL_{95} value for comparison to the SSL.

Step 7: Address Areas Identified for Further Study

Areas that have been identified for further study become the subject of the RI/FS. The results of the baseline risk assessment, which is part of the RI/FS, will establish the basis for taking any remedial action; however, the threshold for initiating this action differs from the screening criteria. As outlined in *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (U.S. EPA, 1991c), remedial action at NPL sites is generally warranted where cumulative risks (i.e., total risk from exposure to multiple contaminants at a site) for a current or future land use exceed $1x10^{-4}$ for carcinogens or a hazard index (HI) of one for non-carcinogens. The data collected for soil screening evaluations will be useful in developing the baseline risk assessment. However, site managers will probably need to collect additional data during future site investigations conducted as part of the RI/FS. These additional data will allow site managers to better define the risks at a site and could ultimately indicate that no action is required. If a decision is made to initiate remedial action, the SSLs may then serve as PRGs. For further guidance on this issue, please consult Sections 1.2 and 2.7 of the 1996 *SSG*.

3.0 EXPOSURE PATHWAYS

The 1996 *SSG* provides quantitative methods to derive SSLs for the following exposure pathways under a residential soil exposure scenario:

- Direct ingestion,
- Inhalation of volatiles outdoors,
- Inhalation of fugitive dust outdoors, and
- Ingestion of ground water contaminated by the migration of soil leachate to an underlying aquifer.

In addition, that document qualitatively addressed dermal absorption of contaminants from soil exposure. Together, these five pathways formed the basis for EPA's generic and simple site-specific approaches to residential soil screening evaluations.

This chapter updates the 1996 *SSG* in three ways. First, it presents a list of key exposure pathways for three soil screening exposure scenarios: residential, commercial/industrial, and construction. Second, it presents equations for a combined soil ingestion/dermal absorption SSL that includes a new quantitative approach for evaluating dermal absorption. Third, it presents a new quantitative approach for evaluating the inhalation of volatile contaminants present in indoor air as the result of vapor intrusion.

3.1 Exposure Pathways by Exposure Scenario

Exhibit 3-1 lists default soil exposure pathways for each of three soil screening exposure scenarios: residential, commercial/industrial, and construction. The list of pathways for each scenario is not intended to be exhaustive; instead, each list represents a set of typical exposure pathways likely to account for the majority of exposure to soil contaminants at a site. The actual exposure pathways evaluated in a soil screening evaluation depend on the contaminants present, the site conditions, and the expected receptors and site activities described in the CSM. A CSM may include additional receptors or exposure pathways not addressed by this document or by the 1996 *SSG* (e.g., ingestion of contaminated fish by subsistence anglers). Conversely, not all the pathways listed in Exhibit 3-1 for a particular scenario may apply to a given site. As a result, it is important to compare the CSM with the assumptions and limitations associated with each applicable exposure scenario to identify whether additional or more detailed assessments are needed for particular exposure pathways. Early identification of the need for additional analysis is important because it facilitates development of a comprehensive sampling strategy.

Exhibit 3-1

RECOMMENDED EXPOSURE PATHWAYS FOR SOIL SCREENING EXPOSURE SCENARIOS

	Residential		Commercial/Industrial				Construction			
			Outdoor Worker		Indoor Worker		Construction Worker		Off-Site Resident	
Potential Exposure Pathways	**Surface Soil[1]**	**Subsurface Soil**	**Surface Soil**	**Subsurface Soil**	**Surface Soil**	**Subsurface Soil**	**Surface Soil**	**Subsurface Soil**	**Surface Soil**	**Subsurface Soil**
Direct ingestion	T	T	T	T	T		T	T		
Dermal absorption	T	T	T	T			T	T		
Inhalation of volatiles outdoors		T		T				T		
Inhalation of fugitive dust outdoors	T		T				T		T	
Migration of volatiles into indoor air		T				T				
Ingestion of ground water contaminated by the migration of leachate to an underlying aquifer		T		T		T				

[1] For the purposes of soil screening evaluations, EPA defines surface soil as consisting of the top two centimeters of soil, and subsurface soil as soils located beneath the top two centimeters. However, at sites where the CSM suggests that receptors will frequently come into direct contact with soils at depths greater than two centimeters, contaminant concentrations in these soils should be compared to SSLs developed for surface soils.

The methods for evaluating exposures via the inhalation of volatiles outdoors, the inhalation of fugitive dust outdoors, and the ingestion of leachate-contaminated ground water under the residential scenario have not changed since the publication of the 1996 *SSG*; detailed information about the modeling approaches for these exposure pathways can be found in the 1996 *SSG User's Guide* and *Technical Background Document.* Section 3.2 of this document discusses new methods for developing SSLs for combined exposures via soil ingestion and dermal absorption and for the migration of volatiles into indoor air. It also presents residential SSL equations for the soil ingestion/dermal absorption pathway and directs readers to the spreadsheet models that can be used to evaluate the indoor air pathway. For convenience, the complete set of residential SSL equations and default assumptions has been reproduced in Appendix B. (SSL equations for the commercial/industrial and construction scenarios are presented in Chapters 4 and 5, respectively.) In addition, an interactive SSL calculator is available online at http://risk.lsd.ornl.gov/calc_start.htm.

In general, each exposure scenario uses a similar modeling approach for a given exposure pathway. Differences in exposure scenarios are reflected primarily in the specific default model input values associated with the different types of exposures. However, in the case of the migration to ground water pathway, both the modeling approach and model inputs for the residential and commercial/industrial scenarios are identical, and hence so are the associated SSLs.[10] This approach is consistent with EPA's policy to protect potentially potable ground water resources. The treatment of migration to ground water SSLs for commercial/industrial scenarios is discussed further in Section 4.2.3.

3.2 Exposure Pathway Updates

Since publishing the 1996 *SSG*, EPA has developed new technical approaches for two exposure pathways relevant to soil screening evaluations: dermal absorption and inhalation of volatiles present in indoor air as the result of vapor intrusion. In addition, although EPA has not changed the way it models soil ingestion exposures, this guidance provides site managers with new SSL equations that combine soil ingestion and dermal absorption. This section presents an overview of these new approaches to SSL development and includes the associated SSL equations for residential exposure scenarios. (The residential SSL equations presented in this guidance supersede the equations described in the 1996 *SSG*.) Chapter 4 of this document includes a discussion of the application of these methods to non-residential exposure scenarios, and Chapter 5 addresses the application of the ingestion/dermal approach for construction scenarios.

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[10] This pathway is not evaluated under the construction exposure scenario. Since the construction scenario supplements either the residential or commercial/industrial scenario, migration to ground water SSLs from either of those chronic exposure scenarios are expected to be protective of subchronic exposures via this pathway during construction.

3.2.1 Direct Ingestion and Dermal Absorption of Soil Contaminants

EPA has developed an approach that site managers can use to calculate SSLs for concurrent exposures to contaminants via the direct ingestion and dermal absorption pathways. This approach consists of a set of equations that allows a site manager to estimate the soil contaminant concentration for which the combined potential exposure via these two pathways is equivalent to an incremental lifetime cancer risk of 1×10^{-6} or an HQ of one — the same target risks used for other pathways. This yields SSLs that are protective of exposures that occur via these pathways simultaneously. EPA developed this approach because concurrent exposures via these two pathways are very likely during activities such as gardening, outdoor work, children's outdoor play, and excavation.[11]

Equations 3-1 and 3-2 present EPA's approach to developing combined SSLs for the ingestion and dermal pathways. Equation 3-1 is appropriate for addressing exposure to carcinogenic compounds, and Equation 3-2 covers exposure to non-carcinogenic compounds. Site data may be used to derive site-specific input values for the model parameters that appear in bold typeface. EPA provides default values for these parameters that can be used when site-specific data are not available. Appendix A presents generic ingestion/dermal SSLs for the residential exposure scenario that were calculated using these equations and the specified default values.

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[11] Although these activities also may lead to exposure via inhalation, EPA will continue to evaluate these exposures separately because of the potential for different health effects via the inhalation route. Differences in health effects can be associated with differences in metabolic processes for contaminants entering the body via the ingestion/dermal and inhalation exposure routes. As a result, EPA recommends developing separate SSLs for exposures via inhalation.

Equation 3-1
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Carcinogenic Contaminants in Soil
- Residential Scenario

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365\,\text{d/yr}}{(EF \times 10^{-6}\,\text{kg/mg})\,[(SF_o \times IF_{soil/adj}) + (SF_{ABS} \times SFS \times ABS_d \times EV)]}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (years)	70
EF/exposure frequency (days/year)	350
SF_{ABS}/dermally adjusted cancer slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific (Equation 3-3)
SFS/age-adjusted dermal factor (mg-yr/kg-event)	**360 (Equation 3-5)**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
EV/event frequency (events/day)	1
SF_o/oral cancer slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific (Appendix C)
$IF_{soil/adj}$/age-adjusted soil ingestion factor (mg-yr/kg-d)	114[a]

[a] Calculated per *RAGS, PART B* Equation 3. (U.S. EPA, 1991b)

Direct Ingestion

The components of Equations 3-1 and 3-2 that reflect modeling of exposures via soil ingestion remain unchanged from the approach used in the 1996 *SSG*. For carcinogens, Equation 3-1 assumes a high end exposure duration (30 years) and incorporates a time-weighted average soil ingestion rate for children and adults (incorporated in the soil ingestion factor, $IF_{soil/adj}$), because exposure is higher during childhood and decreases with age. For non-carcinogens, Equation 3-2 focuses on childhood ingestion exposures only, a conservative approach that EPA believes is appropriate for a screening analysis and is consistent with RME exposure.

Equation 3-2
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Non-Carcinogenic Contaminants in Soil - Residential Scenario

$$\text{Screening Level (mg/kg)} = \frac{THQ \times BW \times AT \times 365\,\text{d/yr}}{(EF \times ED \times 10^{-6}\,\text{kg/mg})\left[\left(\frac{1}{RfD_o} \times IR\right) + \left(\frac{1}{RfD_{ABS}} \times AF \times ABS_d \times EV \times SA\right)\right]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	15
AT/averaging time (years)	6[a]
EF/exposure frequency (days/year)	350
ED/exposure duration (years)	6
RfD_o/oral reference dose (mg/kg-d)	chemical-specific (Appendix C)
IR/soil ingestion rate (mg/d)	200
RfD_{ABS}/dermally-adjusted reference dose (mg/kg-d)	chemical-specific (Equation 3-4)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.2**
ABS_d/dermal absorption factor (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
EV/event frequency (events/day)	1
SA/skin surface area exposed-child (cm^2)	**2,800**

[a] For non-carcinogens, averaging time equals exposure duration.

Dermal Absorption

Although the 1996 *SSG* acknowledged that contaminant exposure through dermal absorption could be a significant source of human health risks at contaminated sites, data limitations precluded the development of broadly applicable simple site-specific equations for this pathway. EPA's original approach recommended that dermal screening levels be calculated by dividing ingestion SSLs in half for those compounds exhibiting significant (i.e., greater that ten percent) dermal absorption. EPA based this approach on the assumption that exposures via the dermal route would be roughly equivalent to the ingestion route when dermal absorption from soil exceeds ten percent.[12] At the time, only pentachlorophenol had been shown to exceed the ten percent absorption threshold; for all other compounds, the dermal route did not need to be considered.

Since 1996, EPA has expanded its dermal absorption database to include more contaminants. This information can be found in EPA's *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part E, Supplemental Guidance for Dermal Risk Assessment* (*RAGS Part E - Interim Guidance,* U.S. EPA, 2001). The modeling approach presented in this soil screening guidance is derived from the risk assessment methodology presented in *RAGS Part E*. This revised approach provides a consistent and more broadly applicable methodology for assessing the dermal pathway for Superfund human health risk assessments.

Exhibit 3-2

SOIL CONTAMINANTS EVALUATED FOR DERMAL EXPOSURES

- Arsenic
- Benzo(*a*)pyrene
- Cadmium
- Chlordane
- DDT
- Lindane
- PAHs
- Pentachlorophenol
- Semi-volatile organic compounds

The dermal pathway should be evaluated for both residential and non-residential soil exposure scenarios depending on the types of activities occurring at a site (e.g., landscaping) and on the contaminants of concern present. The approach to modeling dermal absorption in this guidance supersedes EPA's original approach and should therefore be used instead of the dermal absorption method presented in the 1996 *SSG*. Exhibit 3-2 presents a list of contaminants for which data are available to develop dermal SSLs.[13] This exhibit includes seven individual compounds and two classes of compounds — polycyclic aromatic hydrocarbons (PAHs) and semi-volatile organic compounds — demonstrating significant dermal absorption potential in EPA's dermal absorption database. EPA will provide updates to this list as adequate absorption data are developed for additional chemicals.

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[12] Dermal absorption efficiency is a function of the length of time that contaminated soils (or other media) contact the skin of a receptor. Consistent with EPA's RAGS Part E interim guidance document for evaluating dermal exposures to contaminants (U.S. EPA, 2001), all dermal absorption efficiency values reported in this document assume 24-hour exposure events.

[13] Dermal absorption data are also available for PCBs and for 2,3,7,8-tetrachlorodibenzodioxin (TCDD); however, EPA is developing separate guidance to address risks from release of these compounds. For PCBs, EPA is in the process of updating its 1990 *Guidance on Remedial Actions for Superfund Sites with PCB Contamination*. For TCDD and other chlorinated dioxins and furans, please consult the *Draft Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds* (U.S. EPA, 2000c).

Because no toxicity data are presently available for directly evaluating dermal exposures to contaminants, EPA has developed a method to extrapolate oral toxicity values for use in dermal risk assessments. This extrapolation method, shown in Equations 3-3 and 3-4, is necessary because most oral RfDs and cancer slope factors are based on an administered dose (e.g., in food or water) while dermal exposure equations estimate an absorbed dose. Specifically, dermal exposure equations account for the relative ability of a given contaminant to pass through the skin and into the bloodstream. The extrapolation method applies a gastro-intestinal absorption factor (ABS_{GI}) to the available oral toxicity values to account for the absorption efficiency of an administered dose across the gastro-intestinal tract and into the bloodstream. Oral toxicity values should be adjusted when the gastro-intestinal absorption of the chemical in question is significantly less than 50 percent; this cutoff reflects the intrinsic variability in the analysis of absorption studies. A list of chemical-specific ABS_{GI} factors for specific compounds is presented as Exhibit C-7 in Appendix C.

Equation 3-3
Calculation of Carcinogenic
Dermal Toxicity Values

$$SF_{ABS} = \frac{SF_O}{ABS_{GI}}$$

Parameter/Definition (units)	Default
SF_{ABS}/dermally adjusted slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific
SF_O/oral slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific (Appendix C)
ABS_{GI}/gastro-intestinal absorption factor (unitless)	chemical-specific (Appendix C)

Equation 3-4
Calculation of Non-Carcinogenic
Dermal Toxicity Values

$$RfD_{ABS} = RfD_O \times ABS_{GI}$$

Parameter/Definition (units)	Default
RfD_{ABS}/dermally adjusted reference dose (mg/kg-d)	chemical-specific
RfD_O/oral reference dose (mg/kg-d)	chemical-specific (Appendix C)
ABS_{GI}/gastro-intestinal absorption factor (unitless)	chemical-specific (Appendix C)

To be protective of exposures to carcinogens in a residential setting, Superfund focuses on individuals who may live in an area for an extended period of time (e.g., 30 years) from childhood through adulthood. Equation 3-1 uses an age-adjusted dermal factor (SFS) to account for changes in skin surface area, body weight, and adherence factor. The SFS, presented in Equation 3-5, is a time-weighted average of these parameters for receptors exposed from age one to 31. EPA recommends that a default SFS of 360 mg-yr/kg-event be used. For more information regarding the derivation of this time-weighted average value, please consult *RAGS, Part E* Section 3.2.2.5, Equation 3.20.

Equation 3-5
Derivation of the Age-Adjusted Dermal Factor

$$SFS = \left[\frac{SA_{1-6} \times AF_{1-6} \times ED_{1-6}}{BW_{1-6}}\right] + \left[\frac{SA_{7-31} \times AF_{7-31} \times ED_{7-31}}{BW_{7-31}}\right]$$

Parameter/Definition (units)	Default
SFS/age-adjusted dermal factor (mg-yr/kg-event)	360
SA_{1-6}/skin surface area exposed-child (cm^2)	**2,800**
SA_{7-31}/skin surface area exposed-adult (cm^2)	**5,700**
AF_{1-6}/skin-soil adherence factor-child (mg/cm^2 - event)	**0.2**
AF_{7-31}/skin-soil adherence factor-adult (mg/cm^2 - event)	**0.07**
ED_{1-6}/exposure duration-child (years)	6
ED_{7-31}/exposure duration-adult (years)	24
BW_{1-6}/body weight-child (kg)	15
BW_{7-31}/body weight-adult (kg)	70

Although children will have a smaller total skin surface area (SA) exposed than adult receptors, they are assumed to have a much higher soil to skin adherence factor (AF). Recent data provide evidence to demonstrate that: 1) soil properties influence adherence, 2) soil adherence varies considerably across different parts of the body, and 3) soil adherence varies with activity (Kissel *et al.,* 1996, Kissel *et al.,*1998, Holmes *et al.,* 1999). Because children are assumed to have additional, more sensitive body parts exposed (e.g., feet) and to engage in higher soil contact activities (e.g., playing in wet soil), this guidance recommends the use of a body part-weighted AF of 0.2 for children and 0.07 for adults in residential exposure scenarios. In order to remain adequately protective, EPA bases SSLs for residential exposures to non-carcinogenic contaminants via the ingestion/dermal absorption pathways on a conservative "childhood only" scenario in which the receptor is assumed to be between ages one through six. This is the approach reflected in Equation 3-2. For more information regarding the calculation of body part-weighted adherence factors, please refer to Section 3.2.2 in *RAGS, Part E.*

Suggested default RME values in *RAGS, Part E* are appropriate for the dermal absorption-related inputs to Equations 3-1, 3-2, and 3-5. The default values for these inputs are also consistent with the residential scenario presented in the 1996 *SSG*. In addition to those inputs described above, default values have been developed for event frequency (EV) and skin surface area exposed (SA). Event frequency (EV, the number of events per day) is assumed to be equal to one. Children are assumed to have 2,800 cm^2 of exposed skin surface area (face, forearms, hands, lower legs, and feet), while adults are assumed to have 5,700 cm^2 exposed (face, forearms, hands, and lower legs). These SA values represent the median (50th percentile) values for all children and adults (U.S. EPA, 1997a).

The last input needed to calculate the dermal portion of the ingestion/dermal SSLs is the chemical-specific dermal absorption fraction (ABS_d). Values for seven individual compounds and two classes of compounds are presented in Exhibit 3-3.[14] For those compounds that are classified as both semi-volatile and as a PAH, the ABS_d default for PAHs should be applied.

Exhibit 3-3

RECOMMENDED DERMAL ABSORPTION FRACTIONS

Compound	Dermal Absorption Fraction (ABS_d)
Arsenic	0.03
Benzo(*a*)pyrene	0.13
Cadmium	0.001
Chlordane	0.04
DDT	0.03
Lindane	0.04
PAHs	0.13
Pentachlorophenol	0.25
Semi-volatile organic compounds	0.1

Source: U.S. EPA, *RAGS, Part E, Supplemental Guidance for Dermal Risk Assessment, Interim Guidance, 2001.*

3.2.2 Migration of Volatiles Into Indoor Air

Subsurface contamination in either soil or ground water may adversely affect indoor air quality through the infiltration of contaminant vapors into the basement or ground floor of an on-site building. The potential for inhalation exposure via this pathway elicited substantial comment during the development of the 1996 *SSG*.

In this update, EPA is incorporating vapor intrusion and the subsequent inhalation of volatiles in indoor air into the soil screening process. This pathway may apply to both residential and non-residential scenarios. A site manager's decision to evaluate this pathway should be based

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[14] The U.S. Environmental Protection Agency is developing separate guidance documents which address the dermal risk from exposure to PCBs (*Guidance on Remedial Actions for Superfund Sites with PCB Contamination*, U.S. EPA 1990, currently being updated) and dioxins (*Draft Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds*, U.S. EPA, 2000c).

on current and expected future site conditions (i.e., the current and/or potential future existence of a building on or near a source area) and on the contaminants of concern at the site. Compounds most likely to pose a significant risk via this pathway include volatile organic compounds (VOCs), such as benzene, trichloroethylene, and vinyl chloride. This pathway may also apply to mercury, the only metal that has an appreciable vapor pressure.

EPA recommends that this pathway be evaluated at sites where volatile contaminants have been detected in subsurface soil or soil gas, or in groundwater above MCLs, and where buildings either currently exist or are expected to be developed above or near the contamination. OSWER has developed a draft guidance document that includes a tiered approach to help site managers identify whether the vapor intrusion exposure pathway is complete at a given site, and if so, whether it results in exposures above levels of concern (U.S. EPA, 2002b). We recommend site managers consult this document if uncertain about the applicability of this exposure pathway at a given site.

The Johnson and Ettinger (1991) vapor intrusion model can by used by site managers if the inhalation of volatile contaminants in indoor air is an exposure pathway of concern. This model simulates both convective and diffusive transport of contaminant vapors from a contaminated source area into a building directly above the source. The model may be used for buildings with basements or with slab-on-grade foundations. The model treats the entire building as a single chamber, and therefore does not consider room to room variation in ventilation. It uses chemical-specific data, soil characteristics, and the structural properties of the building to generate an attenuation coefficient that relates the indoor air contaminant concentration to the contaminant vapor concentration at the source area. The output is a risk-based soil-screening concentration derived from a steady-state concentration indoors that represents either a 1×10^{-6} individual lifetime cancer risk or a hazard quotient of one for non-cancer effects, whichever yields the more stringent SSL.

EPA has developed a series of computer spreadsheets that allow for site-specific application of the Johnson and Ettinger model (1991). Because there is substantial variation in the values for the parameters used in the Johnson and Ettinger model, it is very difficult to identify suitable default values for inputs such as building dimensions and the distance between contamination and a building's foundation. As a result, EPA has not developed generic values for soil or other media for this pathway. Instead, site managers are encouraged to calculate site-specific values for this pathway using the spreadsheets provided and site-specific values for key input parameters (e.g. building size and ventilation rate).

The vapor intrusion spreadsheets are available for calculating risk or risk-based concentrations for contaminants in soil, soil gas, or ground water. Each medium-specific spreadsheet is available in two versions: one designed for a simple site-specific screening approach (e.g., SL-SCREEN) and one designed for a detailed site-specific modeling approach (e.g., SL-ADV). The simple site-specific version employs conservative default values for many model input parameters but allows the user to define values for several key variables (e.g., soil porosity, depth of contamination). The detailed modeling version allows the user to select values for all model variables and define multiple soil strata between the area of contamination and the building.

Although EPA provides Johnson and Ettinger model spreadsheets for the calculation of risk-based soil concentrations, these values are likely to be characterized by significant uncertainty. As noted in EPA's draft vapor intrusion guidance document (2002b), this uncertainty arises from both measurement error associated with the analysis of volatile compounds in soil samples and from uncertainties in modeling the partitioning of volatile compounds in soil. If the CSM for a site indicates that vapor intrusion may be an exposure pathway of concern, EPA recommends that the pathway be evaluated using measured soil gas data and, if applicable, ground water data. These data may be used in conjunction with the advanced versions of the Johnson and Ettinger model as part of a site-specific analysis of the vapor intrusion pathway.

The model includes default input values based on a review of data for existing hazardous waste sites. Although the default values used are conservative, because of the natural variation in key parameters across sites, EPA recommends taking a range of outcomes into consideration, as opposed to a single value, when conducting a soil screening evaluation. The site manager can assess a range of values after focusing on the most sensitive input variables. In general, the default inputs will yield conservative values. The vapor intrusion SSL spreadsheets and a user's guide that describes the Johnson and Ettinger model in greater detail can be downloaded from the EPA web site at http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm.[15]

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[15] Revised spreadsheets consistent with the draft vapor intrusion guidance are currently being developed, and are expected to be posted to the EPA website in January 2003.

4.0 DEVELOPING SSLS FOR NON-RESIDENTIAL EXPOSURE SCENARIOS

This chapter of the guidance document presents soil screening procedures for developing SSLs for sites with non-residential future land use. It first discusses approaches to identifying and categorizing future non-residential land use and presents EPA's framework for developing non-residential SSLs. Next, it presents the specific modifications to the soil screening process required to calculate non-residential SSLs. Finally, it highlights key issues to be considered when conducting a non-residential soil screening assessment.

4.1 Identification of Non-Residential Land Use

The appropriate characterization of future land use at a site during the development of the conceptual site model (CSM) enables a site manager to identify or calculate proper soil screening levels for the site. It also enables future site investigations, such as the baseline risk assessment and feasibility study, to focus on the development of practical and cost-effective remedial alternatives that are consistent with the anticipated future land use. This section discusses the process for identifying anticipated future site land uses and describes the implications of the results for the soil screening process. It begins with a brief discussion of factors to consider when identifying future land use, then provides an overview of the types of land uses included in the "non-residential" universe, and concludes with a description of EPA's approach to integrating non-residential land use into the soil screening framework.

4.1.1 Factors to Consider in Identifying Future Land Use

A detailed discussion of EPA's recommended practices for identifying reasonably anticipated future land use can be found in the EPA directive *Land Use in the CERCLA Remedy Selection Process* (1995a).[1] In brief, that document stresses the importance of developing realistic assumptions about the likely future uses of NPL sites through community involvement, including early discussions with local land use planning authorities, local officials, and the public. The Community Contact Coordinator could facilitate these discussions with the community. The directive also provides examples of information sources that can be useful in identifying likely future land uses such as: current land use, zoning laws and maps, population growth patterns, existing institutional controls and land use designations, presence of endangered or threatened species, and adjacent and nearby land uses.

Identification of future land use in the context of soil screening evaluations goes beyond simply making assumptions about categories of use. It involves identifying the kinds of human receptors that may be present (e.g., workers) and the types of activities they are likely to engage in at the site. Risk from contamination at a site is a function of the specific activities that receptors

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[1] This document may be obtained from the EPA web site at: http://www.epa.gov/superfund/resources/landuse.htm.

undertake and the exposures to contaminants that are associated with those activities. The activities can vary considerably, even across sites that fall within the same land use category; thus, when developing the CSM, the assumptions about receptor activities at a site are as critical to the screening process as assumptions about land use.

4.1.2 Categories of Non-Residential Land Use and Exposure Activities

The term "non-residential land use" encompasses a broad range of possible site uses, including commercial, industrial, agricultural, and recreational. The commercial and industrial categories are each individually quite broad as well; commercial uses range from churches and day care centers to automobile repair shops and large-scale warehouse operations, and industrial uses can include public utilities, transportation services, and a wide range of manufacturing activities.

The range of human activities at sites with non-residential uses may also vary considerably in terms of location (e.g., indoors versus outdoors), physical exertion, frequency, and the potential for contact with site contamination. These differences determine the types and intensity of exposures likely to be experienced by receptors. For example, an indoor office worker is generally not engaged in physically strenuous labor during the work day and experiences minimal exposures to potentially contaminated site soil compared to a construction worker performing excavation work. The office worker, however, may inhale volatilized compounds that migrate from contaminated soil or ground water into the office space. Activities may vary even between sites within the same land use category. For example, activities (and receptors) at a day care center are quite different from activities at a store, though both would be considered commercial establishments. Thus, as mentioned earlier, careful identification of activities associated with the likely future use of a site is critical to proper assessment of potential exposure.

4.1.3 Framework for Developing SSLs for Non-Residential Land Uses

The non-residential screening framework focuses on a single non-residential land use category that encompasses both commercial and industrial land uses. EPA selected this approach for two reasons. First, as discussed in Section 3.2, it can be difficult to distinguish between commercial and industrial sites on the basis of exposure potential. A wide range of potential exposure levels (as determined by the range of potential site activities) characterizes both the commercial and industrial categories, and because these ranges overlap, one category can not be considered to have a consistently higher exposure potential than the other. Second, the screening process focuses on *future* land use, and for many NPL sites, considerable uncertainty exists about the specific activities likely to occur in the future. Therefore, the non-residential soil screening framework includes one set of generic SSLs and SSL equations that apply to both commercial and industrial land uses. In addition, the simple site-specific approach allows site managers to differentiate between commercial and industrial sites when calculating SSLs by focusing on the receptors and activities specific to the assumed future use.

Normally, under the generic and simple site-specific screening methodologies, the receptors for the commercial/industrial scenario are limited to workers. EPA does not warrant evaluation of exposures to members of the public under a non-residential land use scenario for two reasons. First, because public access is generally restricted at industrial sites, workers are the sole on-site receptor. Second, even though the public usually has access to commercial sites (e.g., as customers), SSLs that are protective of workers, who have a much higher exposure potential because they spend substantially more time at a site, will also be protective of customers. **However, if a future commercial or industrial land use is likely to involve substantial exposure to the public (e.g., nursing homes, day care centers), the site should be evaluated using the residential soil screening framework or a detailed site-specific screening methodology.**

As shown in Exhibit 4-1, two potential worker receptors are addressed under the commercial/industrial scenario. They are characterized by the intensity and location of their activities, and by the frequency and duration of their exposures.

- **Outdoor Worker.** This is a long-term receptor exposed during the work day who is a full time employee of the company operating on-site and who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface and shallow subsurface soils (at depths of zero to two feet). The outdoor worker is expected to have an elevated soil ingestion rate (100 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, dermal absorption of contaminants from soil, inhalation of fugitive dust, inhalation of volatiles outdoors, and ingestion of ground water contaminated by leachate.[2, 3] The outdoor worker is expected to be the most highly exposed receptor in the outdoor environment under commercial/industrial conditions. Thus, SSLs for this receptor are protective of other reasonably anticipated outdoor activities at commercial/industrial facilities.

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[2] The soil ingestion rate of 100 mg per day for the outdoor worker is equal to the default residential adult ingestion rate recommended in *RAGS Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors,* OSWER Directive 9285.6-03 (U.S. EPA, 1991a). The document recommends an ingestion rate of 50 mg per day for a commercial/industrial worker and 100 mg per day for an adult resident. EPA selected the latter value to reflect the increased ingestion exposures experienced by outdoor workers during landscaping or other soil disturbing activities. Research is ongoing to gain better information on soil ingestion rates. The recommended default values are subject to change as better data become available.

[3] The ingestion of contaminated ground water exposure pathway for non-residential receptors is addressed by SSLs for the migration of contaminants from soil into an underlying potable aquifer. The SSL equations and default values used to model this pathway are identical to those used for residential exposure scenarios (See Section 3.1). In addition, the rationale for a consistent set of migration to ground water SSLs across residential and commercial/industrial uses is described in detail on page 4-24.

Exhibit 4-1

SUMMARY OF THE COMMERCIAL/INDUSTRIAL EXPOSURE FRAMEWORK FOR SOIL SCREENING EVALUATIONS

	Receptors	
	Outdoor Worker	**Indoor Worker**
Exposure Characteristics	C Substantial soil exposures C Long-term exposure	C Minimal soil exposures (little or no direct contact with outdoor soils, potential for contact through ingestion of soil tracked in from outside) C Long-term exposure
Pathways of Concern	C Ingestion (surface and shallow subsurface soils) C Dermal absorption (surface and shallow subsurface soils) C Inhalation (fugitive dust, outdoor vapors) C Ingestion of contaminated ground water[1]	C Ingestion (indoor dust) C Inhalation (indoor vapors) C Ingestion of contaminated ground water[1]
Default Exposure Factors		
Exposure Frequency (d/yr)	225	250
Exposure Duration (yr)	25	25
Soil Ingestion Rate (mg/d)	100	50
Inhalation Rate (m^3/d)	20	20
Body Weight (kg)	70	70
Lifetime (yr)	70	70

[1] The same equations and default inputs (e.g., ground water ingestion rates) are used to calculate both residential and commercial/industrial SSLs for this pathway because of concern for off-site residents who may be exposed to contaminated ground water that migrates off-site.

- **Indoor Worker.** This receptor spends most, if not all, of the workday indoors. Thus, an indoor worker has no direct contact with outdoor soils. This worker may, however, be exposed to contaminants through ingestion of contaminated soils that have been incorporated into indoor dust, ingestion of contaminated ground water, and the inhalation of contaminants present in indoor air as the result of vapor intrusion.[4] SSLs calculated for this receptor

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[4] The soil ingestion rate for the indoor worker, 50 mg per day, reflects decreased soil exposures relative to the outdoor worker and is consistent with the default commercial/industrial soil ingestion rate recommended in *RAGS Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors,* OSWER directive 9285.6-03 (U.S. EPA, 1991a). Research is ongoing to gain better information on soil ingestion rates. The recommended default values are subject to change as better data become available.

are expected to be protective of both workers engaged in low intensity activities such as office work and those engaged in more strenuous activity (e.g., factory or warehouse workers).

The commercial/industrial scenario does not include exposures during construction activities. However, EPA recognizes that construction is likely to occur at many NPL sites and that it may lead to significant short-term exposures. A separate soil screening scenario and SSL methodology for construction activities designed to supplement either the residential or commercial/industrial SSL is presented in Chapter 5.

4.1.4 Land Use and the Selection of a Screening Approach

The assumptions about future land use and future site activities may influence the selection of a soil screening approach. In general, sites where the reasonably anticipated future use is either commercial or industrial may be evaluated using any of the three screening approaches: the generic approach, the simple site-specific approach, or the detailed site-specific modeling approach. However, commercial sites with exposures akin to residential scenarios (i.e., where the future use involves the housing, education, and/or care of children, the elderly, the infirm, or other sensitive subpopulations) should be evaluated using the residential soil screening framework, if appropriate, or using a detailed site-specific screening approach. Examples of such uses include, but are not limited to: schools or other educational facilities, day care centers, nursing homes, elder care facilities, hospitals, and churches.

Sites where the anticipated future land use is agricultural or recreational typically require site managers to apply the detailed site-specific modeling approach for developing SSLs. For example, agricultural sites may require site-specific modeling to address exposure pathways that are not included in the generic and simple site-specific approaches (e.g., ingestion of contaminated foods). In other situations, such as an evaluation of future recreational use, exposure scenarios may be analogous to residential exposures, and application of residential SSLs to the site may be a reasonable alternative to the detailed site-specific modeling approach.

Lastly, a soil screening evaluation of a construction scenario, which is described separately in Chapter 5, should be conducted using either the simple site-specific or detailed site-specific modeling approaches. Because of the difficulty of establishing default input values for a "standard" construction project, these screenings can not be conducted using the generic approach.

4.2 Modifications to the Soil Screening Process for Sites With Non-Residential Exposure Scenarios

To conduct a soil screening evaluation for a non-residential exposure scenario, a site manager should employ the same basic seven-step soil screening process outlined in Section 2.3. However, there are some fundamental differences in the potential for exposure under non-residential scenarios that necessitate modifications to certain steps of the framework. This section describes in detail the key differences in these steps for the non-residential soil screening process.

Of the seven steps in the screening process, three must be adjusted for a non-residential soil screening evaluation — Step 1: Develop Conceptual Site Model (CSM); Step 2: Compare CSM to SSL Scenario; and Step 5: Calculate Site- and Pathway-specific SSLs. The remaining steps, consisting of Step 3: Define Data Collection Needs for Soils; Step 4: Sample and Analyze Site Soils; Step 6: Compare Site Soil Contaminant Concentrations to Calculated SSLs; and Step 7: Address Areas Identified for Further Study, are essentially unchanged. For detailed guidance on performing these latter steps, please consult the 1996 *SSG*.

Regarding Step 3, EPA recommends that site managers develop a sampling plan for surface soil that will provide a reliable estimate of the arithmetic mean of contaminant concentrations. Section 2.3.2 of the 1996 *SSG* describes such a sampling plan utilizing composite samples. Guidance on developing other sampling plans using discrete samples can be found in *Guidance for Choosing a Sampling Design for Environmental Data Collection* (U.S. EPA 2000a). Although there may be differences in the activities and exposures likely to occur under non-residential and residential use scenarios, EPA is not recommending specific changes to the surface soil sampling approach when performing non-residential soil screening evaluations. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to have random exposure to surface soils at both residential and non-residential sites.

However, as in the 1996 *SSG*, EPA emphasizes that the depth over which soils are sampled should reflect the type of exposures expected. Activities typical for non-residential site uses (e.g., landscaping and other outdoor maintenance activities) may result in direct contact exposure for certain receptors to contaminants in shallow subsurface soils at depths of up to two feet. EPA expects that site managers will characterize contaminant levels in the top two feet of the soil column by taking shallow subsurface borings where appropriate. The specific locations of such borings should be determined by the likelihood of direct contact with these subsurface soils and by the likelihood that soil contamination is present at that depth. Given that these deeper soils are not characterized to the same extent as the top two centimeters of soil, the maximum measured contaminant concentration in the borings in a given exposure area should be compared directly with the SSLs, as described in Section 2.3, Step 6. Alternatively, if available evidence indicates that contaminated subsurface soils will be disturbed and brought to the surface (e.g., as the result of redevelopment activities), site managers will need to characterize subsurface contamination more thoroughly and should collect a sufficient number of samples to develop a UCL_{95} value for use in the soil screening evaluation.

4.2.1 Step 1: Develop Conceptual Site Model

The process of developing a CSM — a comprehensive representation of a site that illustrates contaminant distributions in three dimensions, along with release mechanisms, exposure pathways, migration routes, and potential receptors — is similar for non-residential and residential soil screening evaluations. The key differences in developing a CSM for a site with anticipated non-residential future land use are:

- **Identification of Land Use.** Identifying the reasonably anticipated future land use for an NPL site is critical to the development of the CSM. It is the first step toward identifying the future site receptors and activities that determine the key exposure pathways of concern. Future land use may also influence the selection of a screening approach by a site manager. Future industrial or commercial sites may be evaluated using any of the three screening approaches (generic, simple site-specific, or detailed site-specific modeling); sites with other non-residential future land uses (e.g., agriculture, recreation) are appropriately addressed using a detailed site-specific modeling approach.

- **Receptors for Non-Residential Uses.** When developing CSMs for commercial or industrial sites, the focus should be on worker receptors, unless anticipated future site activities are expected to result in substantial exposures to members of the public and/or children visiting the site (see Section 4.1.3). CSMs for commercial or industrial sites should include long-term receptors (e.g., indoor workers and outdoor workers) and, if appropriate, short-term, high intensity receptors (e.g., construction workers). For sites with future agricultural or recreational uses, CSMs should address a wider range of potential receptors (e.g., farm workers and children/adults exposed to contamination through consumption of agricultural products or children/adults engaged in recreational activities).

- **Activities for Non-Residential Uses.** In order to identify the exposure pathways pertinent to future exposures, site managers should consider the potential future site activities that may contribute to exposure. Examples of activities likely to occur at commercial/industrial sites include: outdoor maintenance work and landscaping, indoor commercial activities (e.g. wholesale or retail sales) and office work.

A key part of CSM development for all soil screening evaluations is the identification of ground water use. Site managers should consult EPA's policy on ground water classification (presented in Section 4.2.3) and should coordinate with state or local authorities responsible for ground water use and classification to determine whether the aquifer beneath or adjacent to the site is a potential source of drinking water. The migration to ground water pathway is applicable to all potentially potable aquifers, regardless of current or future land use.

4.2.2 Step 2: Compare Conceptual Site Model to SSL Scenario

The non-residential soil screening scenario used in the generic and simple site-specific screening approaches is likely to be appropriate for a wide range of commercial and industrial sites. However, the CSM for agricultural or recreational sites, as well as for some commercial or industrial sites, may include sources, exposure pathways, and receptors not covered by the commercial/industrial scenario described in this document. Comparison of the CSM with this scenario enables site managers to determine whether additional or more detailed assessments are needed to address specific site contaminants or characteristics.

Six exposure pathways are included in the commercial/industrial soil screening scenario. These pathways, as well as the relevant receptors for each pathway, are listed below:

<u>Surface soil pathways</u>:

- Incidental direct ingestion — indoor worker and outdoor worker.
- Dermal absorption — outdoor worker.
- Inhalation of fugitive dusts — outdoor worker.

<u>Subsurface soil pathways</u>:

- Inhalation of volatiles resulting from vapor intrusion into indoor air — indoor worker.
- Inhalation of volatiles migrating from soil to outdoor air — outdoor worker.
- Ingestion of contaminated ground water caused by migration of chemicals through soil to an underlying potable aquifer — indoor worker and outdoor worker.

Site managers should consider these pathways and make thoughtful determinations about whether receptors are likely to be exposed via each pathway.

It is important to carefully consider each of the possible pathways as part of the screening process, even though a site manager may quickly decide that one or more specific pathways are not relevant for a site. If, based on an analysis of reasonably anticipated future site activities, the site manager identifies pertinent exposure pathways other than those listed above, these additional pathways should be addressed using a detailed site-specific modeling approach.

The commercial/industrial soil screening scenario does not evaluate exposures to off-site receptors, except via the ingestion of ground water contaminated by soil leachate. In general, off-site receptors are assumed to have very limited or no access to the site, which precludes direct exposures. Indirect exposure to off-site residents (e.g., outdoor exposure to soil vapors and to particulates due to wind erosion) is possible. Modeling results indicate that the on-site outdoor worker is exposed to higher particulate and vapor concentrations than an off-site receptor located at the site property line. As a result, outdoor worker SSLs for the inhalation of volatiles and particulates outdoors should be protective of an off-site worker with similar exposure frequency and duration. Off-site residents, however, have a higher exposure frequency and duration than workers, and therefore SSLs based on modeling for these off-site receptors could be slightly lower than SSLs based on outdoor worker exposures.

An analysis of these pathways that used very conservative (i.e., health protective) assumptions to model emissions and transport of vapors and particulates to an off-site receptor indicates that for most contaminants, SSLs calculated for on-site receptors would be protective of indirect exposures to off-site residents.[5] For some compounds, the modeled SSL for indirect off-site exposure is less than the most protective SSL for commercial/industrial on-site receptors; however, for most of these, the off-site SSL is within 30 percent of the on-site value.[6] The significance of this difference depends on several factors that need to be evaluated on a site-specific basis, such as the nature and toxicity of the chemicals of concern, source characteristics, and the actual distance to off-site receptors. Also, if the migration to ground water pathway is being evaluated at a site (assuming a DAF of 20), on-site SSLs will likely be protective of indirect inhalation exposures to off-site residents for nearly all contaminants in Appendix A, even using conservative modeling assumptions.[7] Given the results of this analysis, the Agency does not recommend evaluating volatile or particulate exposures to off-site residents under the simple site-specific commercial/industrial scenario.[8] If a CSM suggests that off-site receptors may experience significant exposures to site contaminants via pathways other than ingestion of ground water, these exposures should be evaluated using a detailed site-specific modeling approach.

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[5] The conservative assumptions include the presence of an infinite source, the presence of volatiles in surface soils, and the location of the off-site receptor just beyond the site boundary.

[6] Exceptions for the inhalation of volatiles pathway include 1,1,2-trichloroethane (36 percent lower for off-site receptor), hexachlorobenzene (37 percent lower for off-site receptor), mercury (94 percent lower for off-site receptor), and tetrachloroethylene (32 percent lower for off-site receptor). Chromium (VI) was the lone exception for the inhalation of particulates pathway (50 percent lower for off-site receptor). If the migration to ground water pathway is being evaluated, on-site SSLs would be sufficiently protective (using the conservative default assumptions) for all but hexachlorobenzene, mercury, and chromium (VI).

[7] The only four contaminants for which on-site SSLs would not be protective under this scenario are chloroform (27 percent lower for off-site receptor), hexachlorobenzene (37percent lower for off-site receptor), hexachloropentadiene (6 percent lower for off-site receptor), and mercury (94 percent lower for off-site receptor).

[8] As discussed in Chapter 5, exposures to an off-site resident receptor may need to be evaluated if a future construction event is reasonably likely.

4.2.3 Step 5: Calculate Site- and Pathway-Specific SSLs

This section presents equations appropriate for calculating SSLs for the generic and simple site-specific soil screening approaches for each pathway in the commercial/industrial soil screening scenario (with the exception of the indoor vapor intrusion pathway, which requires a spreadsheet model to calculate SSLs). These equations and the default input values are designed to reflect reasonable maximum exposure (RME) for chronic exposures in a commercial or industrial setting. They incorporate reasonably conservative values for intake and duration and average or typical values for all site-specific inputs describing soil, aquifer, and meteorologic characteristics.

For each equation, site-specific input parameters are indicated in bold.[9] Where possible, default values are provided for these parameters for use when site-specific data are not available. These defaults were not selected to represent worst case conditions; however, they are conservative. The generic SSLs for the commercial/industrial scenario were calculated using these equations and the specified default values. Generic commercial/industrial SSLs are presented in Appendix A. In addition, an interactive SSL calculator for the simple site-specific equations is available on-line at http://risk.lsd.ornl.gov/calc_start.htm.[10] The SSL calculator is updated periodically to reflect changes in Agency guidance (e.g., additional pathways, updated toxicity values); users should confirm that the calculator's chemical-specific inputs are consistent with the latest values available.

Chemical-specific data, including toxicity values, for use in developing simple site-specific SSLs are provided in Appendix C. **Prior to calculating SSLs at a site, each relevant chemical-specific value in Appendix C should be checked against the most recent version of its source and updated, if necessary.** Toxicity values for the inhalation exposure route are not available for all chemicals. The *TBD* to the 1996 *SSG* presents the results of EPA's review of methods for extrapolating inhalation toxicity values from oral values. EPA found that route-to-route extrapolations are not necessary if migration to ground water is considered, because the SSLs for that pathway are sufficiently protective to address any underestimation of risk resulting from the lack of inhalation toxicity data. If the migration to ground water pathway is not applicable to the site, oral-to-inhalation extrapolations should be considered on a case-by-case basis. For information on extrapolation methods, please consult EPA's *Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry* (U.S. EPA, 1994).

In general, the basic forms of the SSL equations presented here are the same as those used for the residential scenario; however, EPA has developed the following default input values that reflect a commercial/industrial RME scenario:

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[9] The use of distributions for exposure factors (in a probabilistic risk assessment) is reserved for a detailed site-specific modeling approach. Refer to EPA's *Guiding Principles for Monte Carlo Analysis* (U.S. EPA, 1997b) and *Policy for Use of Probabilistic Analysis in Risk Assessment* (U.S. EPA, 1997d) for further information.

[10] The SSL calculator currently includes default values for residential exposure scenarios; however, users can adjust these defaults to reflect the non-residential exposure scenarios.

- **Exposure frequency.** For outdoor workers, EPA has established a default exposure frequency of 225 days/year. This value is based on data from the U.S. Census Bureau's *1990 Earnings by Occupation and Education Survey* and represents the average number of days worked per year by male and female workers engaged in activities likely to be similar to those of the outdoor worker receptor.[11] Because we assume exposure frequency is equal to the number of days worked per year, we recognize that this value may overestimate exposures for receptors in regions of the U.S. where extreme winters preclude exposure to site soils for extended periods during the year. Similarly, the default may potentially underestimate exposures in more temperate climates. Therefore, site managers conducting simple or detailed site-specific soil screening evaluations may propose alternative, site-specific values for this parameter that are supported by specific information on climatic influences. For indoor workers, EPA has established a default exposure frequency of 250 days/year. This value is based on a work scenario of five days per week for 50 weeks per year (assuming two weeks of vacation).

- **Exposure duration.** Exposure duration is assumed to be equivalent to job tenure for receptors in the non-residential soil screening scenario. EPA has selected a value of 25 years as the default for this exposure factor. This is the same value used in *RAGS Part B* (U.S. EPA, 1991b). It is supported by an analysis of Bureau of Labor Statistics data which shows that the 95th percentile value for job tenure for men and women in the manufacturing sector are 25 years and 19 years, respectively (Burmaster, 1999). Job tenure for non-industrial workers varies widely. The 95th percentile job tenure values for workers in the transportation/utility and wholesale sectors are only somewhat less than manufacturing workers — 22 years and 18 years for men and women, respectively. Values are lower for other non-industrial sectors — approximately 13 years for workers in the finance and service sectors, and seven years for retail workers. Thus, the 25-year default value is protective of workers across a wide spectrum of industrial and commercial sectors. Site managers conducting simple or detailed site-specific screening evaluations may propose alternative exposure durations supported by job tenure data and the anticipated site use.

Other changes to default exposure factors that apply to individual pathways are discussed below, along with their respective SSL equations.

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[11] The exposure frequency value of 225 days/year for outdoor workers assumes an eight-hour workday and is based on data from the following occupational categories in the U.S. Census Bureau's *1990 Earnings by Occupation and Education Survey:* groundskeepers and gardeners, except farm; specified mechanics and repairers, not elsewhere classified; not specified mechanics and repairers; painters, construction and maintenance; and construction laborers.

SSL Equations for Surface Soils

The relevant pathways for exposure to surface soils for the commercial/industrial use scenarios include direct ingestion, dermal absorption, and inhalation of fugitive dusts. As in the residential soil screening process, the SSL equations for direct ingestion and dermal absorption have been combined to reflect the concurrent nature of these exposures. The combined direct ingestion/dermal absorption exposure pathway should be routinely considered in screening evaluations that use the commercial/industrial scenario, though dermal absorption can not be evaluated currently for all contaminants. (Where dermal absorption data are not available, the ingestion/dermal SSL equations can be used to calculate an SSL based on the ingestion pathway only.)

Typical activities for commercial/industrial site use, such as landscaping and outdoor maintenance, may result in direct exposure to soils at depths of up to two feet. Thus, site managers may need to extend the analysis of exposure through the direct ingestion, dermal absorption, and inhalation of fugitive dusts pathways to include contaminants found in these subsurface soils. The likelihood of these receptor activities occurring at a site should be addressed in the CSM and reflected in the development of site-specific SSLs.

Direct Ingestion and Dermal Absorption. Equations 4-1 and 4-2 are appropriate for addressing chronic ingestion and dermal absorption exposure of commercial/industrial receptors to carcinogens and non-carcinogens, respectively. The equations produce SSLs protective of concurrent exposures to these receptors via these two pathways.

As mentioned in Section 4.1.3, the commercial/industrial scenario does not evaluate exposures to children. Thus, unlike the residential SSLs, the commercial/industrial direct ingestion/dermal absorption SSLs for non-carcinogens are based on exposures to adults only.

The default recommended soil ingestion rate for workers depends on the type of activity being performed. EPA recommends a 50 mg/day dust ingestion rate for indoor workers, as suggested in *RAGS Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*, OSWER directive 9285.6-03 (U.S. EPA, 1991a). The soil ingestion SSLs for indoor employees protect against the ingestion of contaminants in indoor dust that are derived from contaminated outdoor soil. In setting a default ingestion rate for outdoor workers, we follow the same rationale as EPA's Technical Review Workgroup for Lead (TRW); we assume that a higher ingestion rate is reasonable for a commercial/industrial worker engaged in contact-intensive activities. Because outdoor workers are likely to experience more significant exposures to surface soils than their indoor counterparts, EPA has adopted a default soil ingestion rate of 100 mg/day for this receptor.

SSLs for chronic exposures to contaminants via dermal absorption under the commercial/industrial scenario are calculated based on the same methodology discussed in Section 3.2.1. The suggested default input values for the dermal exposure portion of the direct ingestion/dermal absorption equations are consistent with those recommended in EPA's *RAGS, Part E* with the exception of exposure frequency (U.S. EPA, 2001). This soil screening guidance recommends that a default of 225 days per year be used for workers at commercial or industrial sites as opposed to the 250 days per year suggested in *RAGS, Part E*. As described above, this recommendation is based on occupational data from the U.S. Census Bureau. Event frequency (EV, the number of events per day) is assumed to be equal to one. Adults are assumed to have their face, forearms, and hands exposed. Therefore, this guidance recommends that a value of 3,300 cm^2 be used as an estimate of the skin surface area exposed (SA). We also assume a default adherence factor (AF) of 0.2 mg soil per square centimeter of exposed skin. Both the SA and AF default values represent the median (50th percentile) values for all adult workers at commercial and industrial sites based on EPA studies (U.S. EPA, 1997a). The chemical-specific dermal absorption fractions (ABS_d) are presented in Appendix C. For those compounds classified as both semi-volatile and as a PAH, the ABS_d default for PAHs should be applied.

Equation 4-1
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Carcinogenic Contaminants in Soil
- Commercial/Industrial Scenario

$$\text{Screening Level (mg/kg)} = \frac{TR \times BW \times AT \times 365\,\text{d/yr}}{(EF \times ED \times 10^{-6}\,\text{kg/mg})\left((SF_o \times IR) + (SF_{ABS} \times AF \times ABS_d \times SA \times EV)\right)}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
BW/body weight (kg)	70
AT/averaging time (years)	70
EF/exposure frequency (days/year)	
outdoor worker	**225**
indoor worker	250
ED/exposure duration (years)	
outdoor worker	**25**
indoor worker	25
SF_o/oral cancer slope factor $(\text{mg/kg-d})^{-1}$	chemical-specific (Appendix C)
IR/soil ingestion rate (mg/d)	
outdoor worker	100
indoor worker	50
SF_{ABS}/dermally-adjusted cancer slope factor $(\text{mg/kg-d})^{-1}$	chemical-specific (Equation 3-3)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.2**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
SA/skin surface exposed (cm^2)	**3,300**
EV/event frequency (events/day)	
outdoor worker	**1**
indoor worker	**0**

Equation 4-2
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Non-Carcinogenic Contaminants in Soil
- Commercial/Industrial Scenario

$$\text{Screening Level (mg/kg)} = \frac{THQ \times BW \times AT \times 365\,\text{d/yr}}{(EF \times ED \times 10^{-6}\,\text{kg/mg})\left[\left(\frac{1}{RfD_o} \times IR\right) + \left(\frac{1}{RfD_{ABS}} \times AF \times ABS_d \times SA \times EV\right)\right]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	70
AT/averaging time (years)	25[a]
EF/exposure frequency (days/year)	
outdoor worker	**225**
indoor worker	250
ED/exposure duration (years)	
outdoor worker	**25**
indoor worker	25
RfD_o/oral reference dose (mg/kg-d)	chemical-specific (Appendix C)
IR/soil ingestion rate (mg/d)	
outdoor worker	100
indoor worker	50
RfD_{ABS}/dermally-adjusted reference dose (mg/kg-d)	chemical-specific (Equation 3-4)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.2**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
SA/skin surface exposed (cm^2)	**3,300**
EV/event frequency (events/day)	
outdoor worker	**1**
indoor worker	**0**

[a] For non-carcinogens, averaging time equals exposure duration.

Inhalation of Fugitive Dusts. Inhalation of fugitive dusts generated by wind erosion may be of concern under the commercial/industrial scenario for semi-volatile organic compounds and metals in surface soils. However, as in the residential scenario, the fugitive dust exposure route need not be routinely considered for semi-volatile organics under the commercial/industrial scenario for two reasons: (1) the default ingestion/dermal absorption SSLs for these compounds are often several orders of magnitude lower (i.e., more stringent) than the corresponding default fugitive dust SSLs; and (2) EPA believes the ingestion/dermal absorption route always should be evaluated when screening surface soils. Thus, EPA considers ingestion/dermal absorption SSLs to be adequately protective of fugitive dust exposures to semi-volatile organic chemicals in surface soils under typical commercial/industrial conditions.

Similarly, generic ingestion/dermal absorption SSLs for most metals are more conservative than the fugitive dust SSLs. Thus, fugitive dust SSLs do not need to be calculated for most metals with the exception of chromium. The carcinogenicity of the hexavalent form of chromium (Cr^{+6}) via the inhalation route results in a generic fugitive dust SSL that is more stringent than the ingestion/dermal absorption SSL. As a result the fugitive dust pathway should be evaluated routinely for chromium.

The fugitive dust pathway should be considered carefully when developing the CSM at sites with future commercial/industrial land use. The above rules of thumb for fugitive dust SSLs may not be valid for site conditions or activities at sites that are expected to result in particularly high fugitive dust emissions. Examples of conditions that contribute to potentially high fugitive dust emissions include dry soils (moisture content less than approximately eight percent), finely divided or dusty soils (high silt or clay content); high average annual wind speeds (greater than approximately 5.3 m/s); and less than 50 percent vegetative cover. Examples of activities likely to generate high dust levels include heavy truck traffic on unpaved roads and other construction-related activities. Chapter 5 presents a method for addressing increased particulate exposures during construction. For other scenarios characterized by high fugitive dust calculations, EPA recommends using a detailed site-specific modeling approach to develop fugitive dust SSLs (see Appendix E).

Equations 4-3 and 4-4 are appropriate for calculating fugitive dust SSLs for carcinogens and non-carcinogens. These equations are unchanged from the 1996 *SSG*. However, different default values are provided that reflect appropriate exposure frequency, exposure duration, and averaging time (for exposures to non-carcinogens) for workers.

Equation 4-5 is used to calculate the particulate emission factor (PEF). This factor represents an estimate of the relationship between soil contaminant concentrations and the concentration of these contaminants in air as a consequence of particle suspension. Equation 4-5 is unchanged and includes the same defaults as those provided in the 1996 *SSG*, with the exception of the dispersion factor for wind erosion, Q/C_{wind}, which has been modified slightly to reflect updated dispersion modeling.

Equation 4-3
Screening Level Equation for Inhalation of Carcinogenic Fugitive Dusts - Commercial/Industrial Scenario

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ (\text{mg/kg})\end{array} = \frac{TR \times AT \times 365\,\text{d/yr}}{URF \times 1{,}000\,\mu\text{g/mg} \times EF \times ED \times \frac{1}{PEF}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor ($\mu g/m^3)^{-1}$	chemical-specific (Appendix C)
EF/exposure frequency (d/yr)	
Outdoor Worker	**225**
ED/exposure duration (yr)	
Outdoor Worker	**25**
PEF/particulate emission factor (m^3/kg)	**1.36×10^9** **(Equation 4-5)**

Equation 4-4
Screening Level Equation for Inhalation of Non-carcinogenic Fugitive Dusts - Commercial/Industrial Scenario

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ (\text{mg/kg})\end{array} = \frac{THQ \times AT \times 365\text{d/yr}}{EF \times ED \times [\frac{1}{RfC} \times \frac{1}{PEF}]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (yr)	
Outdoor Worker	**25**[a]
EF/exposure frequency (d/yr)	
Outdoor Worker	**225**
ED/exposure duration (yr)	
Outdoor Worker	**25**
RfC/inhalation reference concentration (mg/m^3)	chemical-specific (Appendix C)
PEF/particulate emission factor (m^3/kg)	**1.36×10^9** **(Equation 4-5)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation 4-5
Derivation of the Particulate Emission Factor
- Commercial/Industrial Scenario

$$\mathrm{PEF}\ '\ Q/C_{wind} \times \frac{3{,}600\,\mathrm{s/h}}{0.036\times(1\&V)\times(U_m/U_t)^3\times F(x)}$$

Parameter/Definition (units)	Default
PEF/particulate emission factor (m^3/kg)	1.36 × 10^9
Q/C_{wind}/inverse of the ratio of the geometric mean air concentration to the emission flux at the center of a square source (g/m^2-s per kg/m^3)	**93.77[a]**
V/fraction of vegetative cover (unitless)	**0.5 (50%)**
U_m/mean annual windspeed (m/s)	**4.69**
U_t/equivalent threshold value of windspeed at 7m (m/s)	**11.32**
F(x)/function dependent on U_m/U_t derived using Cowherd et al. (1985) (unitless)	**0.194**

[a] Assumes a 0.5 acre emission source; for site-specific values, consult Appendix D.

As a result of the updated modeling, Q/C_{wind} can now be derived for any source size between 0.5 and 500 acres using the equation and look-up table in Appendix D, Exhibit D-2. (The default Q/C_{wind} factor assumes a 0.5 acre source size, the size of a typical exposure unit.) The look-up table in Exhibit D-2 provides the three constants for the Q/C_{wind} equation (A, B, and C) for each of 29 cities selected to be representative of the range of meteorologic conditions across the country. The Q/C_{wind} constants for each city were derived from the results of EPA's Industrial Source Complex (ISC3) dispersion model run in short-term mode using five years of hourly meteorological data.

To calculate a site-specific Q/C_{wind} factor, the site manager must first identify the climatic zone and city most representative of meteorological conditions at the site. Appendix D includes a map of climatic zones to help site managers select the appropriate Q/C_{wind} equation constants for the site. Once the equation constants have been identified, Q/C_{wind} can be calculated for any source size between 0.5 and 500 acres and input into Equation 4-5 to derive a site-specific PEF.

SSL Equations for Subsurface Soils

This guidance addresses three exposure pathways that are pertinent to contamination in subsurface soils. These pathways include:

- Inhalation of volatiles migrating from soil to indoor air;
- Inhalation of volatiles migrating from soil to outdoor air; and

- Ingestion of contaminated ground water resulting from the leaching of chemicals from soil and their migration to an underlying potable aquifer.

Because the equations developed to calculate SSLs for the last two of these three pathways assume an infinite source, they can violate mass-balance considerations, especially for small sources. To address this concern, the guidance also includes SSL equations for these pathways that allow for mass-limits. These equations can be used only when the volume (i.e., area and depth) of the contaminated soil source is known or can be estimated with confidence.

Exhibit 4-2 lists site-specific parameters necessary to calculate SSLs for the outdoor inhalation of volatiles and the ingestion of ground water pathways, along with recommended sources and measurement methods. The exhibit includes both key parameters used directly in the SSL equations (solid dots) and supporting data or assumptions (hollow dots) used to estimate key parameter values. Site-specific parameters for the migration of volatiles into indoor air pathway are described in spreadsheets developed by EPA (described below).

Inhalation of Volatiles — Indoors. As discussed in Section 3.2.2, vapors resulting from the volatilization of contaminants in soil may be transported into indoor spaces through cracks or gaps in a building's foundation. The inhalation of these vapors by indoor workers may be an important exposure pathway at sites with current or future commercial/industrial land use. To facilitate the development of SSLs for this pathway, EPA has constructed a series of spreadsheets that allow for the site-specific application of a screening-level model for indoor vapor intrusion developed by Johnson and Ettinger (1991). These spreadsheets are available from the EPA web site at http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm.

The vapor intrusion spreadsheets are available for calculating risk or risk-based concentrations for contaminants in soil, soil gas, or ground water. Each medium-specific spreadsheet is available in two versions: one designed for a simple site-specific screening approach (e.g., SL-SCREEN) and one designed for a detailed site-specific modeling approach (e.g., SL-ADV). The simple site-specific version employs conservative default values for many model input parameters but allows the user to define values for several key variables (e.g., soil porosity, depth of contamination). The detailed modeling version allows the user to select values for all model input parameters and define multiple soil strata between the area of contamination and the building. Thus, site managers wanting to develop vapor intrusion SSLs using site-specific building parameters should use the SL-ADV spreadsheets.

These spreadsheets employ toxicity values (inhalation unit risk values for cancer and reference concentrations for non-cancer effects) based on an adult inhalation rate of 20 m^3/day to calculate SSLs for indoor vapor intrusion. This is the same rate used to develop residential SSLs for this pathway. Because workers are typically exposed via this pathway for shorter periods than residents, (eight to 10 hours each day versus up to 24 hours) the 20 m^3/day inhalation rate is likely to be a conservative estimate for some workers. However, data on worker activity levels and

Exhibit 4-2

SITE-SPECIFIC PARAMETERS FOR CALCULATING SUBSURFACE SSLs

	SSL Pathway			
Parameter	**Inhalation of Volatiles - Outdoors**	**Ingestion of Ground Water**	**Data Source**	**Method for Estimating Parameter**
Source Characteristics				
Source area (A)	!		Sampling data	Measure total area of contaminated soil.
Source length (L)	!	!	Sampling data	Measure length of source parallel to ground water flow.
Source depth	!	!	Sampling data	Measure depth of contamination or use conservative assumption.
Soil Characteristics				
Soil texture	"	"	Lab measurement	Particle size analysis (Gee & Bauder, 1986) and USDA classification; used to estimate θ_W & I
Dry soil bulk density (ρ_b)	!	!	Field measurement	All soils: ASTM D 2937; shallow soils: ASTM D 1556, ASTM D 2167, ASTM D 2922
Soil moisture content (w)	"	"	Lab measurement	ASTM D 2216; used to estimate dry soil bulk density
Soil organic carbon (f_{oc})	!	!	Lab measurement	Nelson and Sommers (1982)
Soil pH	"	"	Field measurement	McLean (1982); used to select pH-specific K_{OC} (ionizable organics) and K_d (metals)
Moisture retention exponent (b)	"	"	Look-up	Attachment A to 1996 SSG; used to calculate θ_W
Saturated Hydraulic conductivity (K_S)	"	"	Look-up	Attachment A to 1996 SSG; used to calculate θ_W
Avg. soil moisture content (θ_W)	!	!	Calculated	Attachment A to 1996 SSG
Meteorological Data				
Air dispersion factor (Q/C)	!		Q/C tables (Appendix D)	Select value corresponding to source area, climatic zone, and city with conditions similar to site.
Hydrogeologic Characteristics (DAF)				
Hydrogeologic setting		"	Conceptual site model	Place site in hydrogeologic setting from Aller et al. (1987) for estimation of parameters below (see Attachment A to 1996 TBD).
Infiltration/recharge (I)		!	HELP model; Regional estimates	HELP (Schroeder et al., 1984) may be used for site-specific infiltration estimates; recharge estimates also may be taken from Aller et al. (1987) or may be based on knowledge of local meteorologic and hydrogeologic conditions.
Hydraulic conductivity (K)		!	Field measurement; Regional estimates	Aquifer tests (i.e., pump tests, slug tests) preferred; estimates also may be taken from Aller et al. (1987) or Newell et al. (1990) or may be based on knowledge of local hydrogeologic conditions.
Hydraulic gradient (i)		!	Field measurement; Regional estimates	Measured on map of site's water table (preferred); estimates also may be taken from Newell et al. (1990) or may be based on knowledge of local hydrogeologic conditions.
Aquifer thickness (d)		!	Field measurement; Regional estimates	Site-specific measurement (i.e., from soil boring logs) preferred; estimates also may be taken from Newell et al. (1990) or may be based on knowledge of local hydrogeologic conditions.

! Indicates key parameters used in the SSL equation for each pathway.
" Indicates supporting data/assumptions used to develop estimates of the values of the key parameters.

inhalation rates reveal two distinct sets of indoor workers: those working primarily in an office setting (daily inhalation rates ranging from 5.4 m^3/day to 12.6 m^3/day, with an average of 9.3 m^3/day), and those engaged in physically demanding tasks for roughly half of their work day (daily inhalation rates ranging from 13.6 m^3/day to 18.5 m^3/day, with an average of 16.2 m^3/day) (U.S. Department of Commerce, 1985; US EPA, 1989a; US EPA, 1997a). Thus, EPA believes that the 20 m^3/day rate is a reasonable estimate of RME that is protective of indoor workers engaged in strenuous workday activities associated with elevated breathing rates.

As noted in Section 3.2.2, risk-based concentrations for contaminants in soil calculated using the Johnson and Ettinger spreadsheets may be highly uncertain. If the CSM for a site indicates that vapor intrusion may be an exposure pathway of concern, EPA recommends that the pathway be evaluated using measured soil gas data and, if applicable, ground water data. These data may be used in conjunction with the advanced versions of the Johnson and Ettinger model as part of a site-specific analysis of the vapor intrusion pathway.

Inhalation of Volatiles — Outdoors. Equations 4-6 through 4-9 are appropriate for calculating SSLs for the outdoor inhalation of volatiles pathway using the simple site-specific approach. (A detailed site-specific modeling approach to this pathway is discussed in Appendix E).

EPA recommends evaluating this pathway at sites where volatile contaminants have been detected in subsurface source areas and where the surface soils covering those sources are undisturbed (e.g. a covered lagoon). Equations 4-6 and 4-7 calculate the SSLs for the inhalation of carcinogenic and non-carcinogenic volatile compounds, respectively. Each of these equations incorporates a soil-to-air volatilization factor (VF) that relates the concentration of a contaminant in soil to the concentration of the contaminant in air resulting from volatilization. Equation 4-8 is appropriate for calculating the VF. Finally, to ensure that the VF model is applicable to soil contaminant conditions at a site, a soil saturation limit (C_{sat}) must be calculated for each volatile compound. Equation 4-9 is appropriate for calculating this value.

Relative to the inhalation modeling for the residential exposure scenario, the only differences for commercial/industrial soil screening evaluations are the default values for exposure frequency, exposure duration, and averaging time (for non-carcinogenic exposures) in Equations 4-6 and 4-7. The toxicity values used in these equations (inhalation unit risk factors for cancer and reference concentrations for non-cancer effects) are based on an adult inhalation rate of 20 m^3/day, the same rate used to evaluate the migration of volatiles into indoor air. As discussed in the previous section, use of this value for outdoor workers is supported by data on the activity levels and associated inhalation rates for different classes of workers (U.S. Department of Commerce, 1985; US EPA, 1989a; US EPA, 1997a) and is protective of workers engaged in strenuous activities.

Equation 4-6
Screening Level Equation for Inhalation of Carcinogenic Volatile Contaminants in Soil - Commercial/Industrial Scenario

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365\,\text{d/yr}}{URF \times 1{,}000\,\mu\text{g/mg} \times EF \times ED \times \frac{1}{VF}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor $(\mu g/m^3)^{-1}$	chemical-specific (Appendix C)
EF/exposure frequency (d/yr)	
Outdoor Worker	**225**
ED/exposure duration (yr)	
Outdoor Worker	**25**
VF/soil-to-air volatilization factor (m^3/kg)	**chemical-specific** **(Equation 4-8)**

Equation 4-7
Screening Level Equation for Inhalation of Non-carcinogenic Volatile Contaminants in Soil - Commercial/Industrial Scenario

$$\text{Screening Level (mg/kg)} = \frac{THQ \times AT \times 365\,d/yr}{EF \times ED \times [\frac{1}{RfC} \times \frac{1}{VF}]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (yr)	
Outdoor Worker	**25**[a]
EF/exposure frequency (d/yr)	
Outdoor Worker	**225**
ED/exposure duration (yr)	
Outdoor Worker	**25**
RfC/inhalation reference concentration (mg/m^3)	chemical-specific (Appendix C)
VF/soil-to-air volatilization factor (m^3/kg)	**chemical-specific (Equation 4-8)**

[a] For non-carcinogens, averaging time equals exposure duration.

The VF equation for the commercial/industrial scenario (Equation 4-8) is identical to the one included in the 1996 *SSG* for screening sites with future residential land use and is based on the model developed by Jury et al. (1984). However, the dispersion factor (Q/C_{vol}) can now be derived for any source size between 0.5 and 500 acres using the equation and look-up table in Appendix D, Exhibit D-3. (The default Q/C_{vol} factor assumes a 0.5 acre source size. As reported in Appendix A to the 1996 *SSG*, SSLs for a 0.5 acre source calculated under the infinite source assumption are protective of uniformly contaminated 30-acre source areas of significant depth — up to 21 meters depending on contaminant and pathway, approximately 10 meters on average.) The look-up table in Exhibit D-3 provides the three constants for the Q/C_{vol} equation (A, B, and C) for each of 29 cities selected to be representative of a range of meteorologic conditions across the country. The Q/C_{vol} constants for each city were derived from the results of modeling runs of EPA's ISC3 dispersion model run in short-term mode using five years of hourly meteorological data.

Equation 4-8
Derivation of the Volatilization Factor - Commercial/Industrial Scenario

$$VF = \frac{Q/C_{vol} \times (3.14 \times D_A \times T)^{1/2} \times 10^{-4} (m^2/cm^2)}{(2 \times \rho_b \times D_A)}$$

where:

$$D_A = \frac{[(\theta_a^{10/3} D_i H' + \theta_w^{10/3} D_w)\ /n^2]}{\rho_b K_d + \theta_w + \theta_a H'}$$

Parameter/Definition (units)	Default
VF/volatilization factor (m^3/kg)	chemical-specific
D_A/apparent diffusivity (cm^2/s)	chemical-specific
Q/C_{vol} /inverse of the ratio of the geometric mean air concentration to the volatilization flux at center of a square source (g/m^2-s per kg/m^3)	**68.18**[a]
T/exposure interval (s)	9.5×10^8
ρ_b/dry soil bulk density (g/cm^3)	**1.5**
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n-\theta_w$
n/total soil porosity (L_{pore}/L_{soil})	$1-(\rho_b/\rho_s)$
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
ρ_s/soil particle density (g/cm^3)	2.65
D_i/diffusivity in air (cm^2/s)	chemical-specific[b]
H′/dimensionless Henry's law constant	chemical-specific[b]
D_w/diffusivity in water (cm^2/s)	chemical-specific[b]
K_d/soil-water partition coefficient (cm^3/g)	for organics: $K_d = K_{oc} \times f_{oc}$ for inorganics: see Appendix C[c]
K_{oc}/soil organic carbon partition coefficient (cm^3/g)	chemical-specific[b]
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**

[a] Assumes a 0.5 acre emission source; for site-specific values, consult Appendix D.

[b] See Appendix C.

[c] Assume a pH of 6.8 when selecting default K_d values for metals.

To calculate a site-specific Q/C_{vol} factor, site managers must first identify the climatic zone and city most representative of meteorological conditions at the site. Appendix D includes a map of climatic zones to help site managers select the appropriate Q/C_{vol} equation constants for the site. The site manager should also consult with the site hydrogeologist to determine Q/C_{vol} inputs. Once the Q/C_{vol} equation constants have been identified, a dispersion factor can be calculated for any source size between 0.5 and 500 acres and input into Equation 4-8 to derive a site-specific VF.

The C_{sat} equation (Equation 4-9) is also unchanged from the residential guidance; it measures the contaminant concentration at which all soil pore space (both air- and water-filled) is saturated with the compound and the adsorptive limits of the soil particles have been reached.

Equation 4-9
Derivation of the Soil Saturation Limit

$$C_{sat} = \frac{S}{\rho_b}(K_d\rho_b + \theta_w + H'\theta_a)$$

Parameter/Definition (units)	Default
C_{sat}/soil saturation concentration (mg/kg)	chemical-specific[a]
S/solubility in water (mg/L-water)	chemical-specific[a]
ρ_b/dry soil bulk density (kg/L)	**1.5**
K_d/soil-water partition coefficient (L/kg)	organics = $K_{oc} \times f_{oc}$ inorganics = see Appendix C[b]
K_{oc}/organic carbon partition coefficient (L/kg)	chemical-specific[a]
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
H'/dimensionless Henry's law constant	chemical-specific[a]
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n - \theta_w$
n/total soil porosity (L_{pore}/L_{soil})	$1 - (\rho_b/\rho_s)$
ρ_s/soil particle density (kg/L)	2.65

[a] See Appendix C.

[b] Assume a pH of 6.8 when selecting default K_d values for metals.

C_{sat} represents an upper bound on the applicability of the VF model, because compounds exceeding C_{sat} may be present in free phase, which would violate a key principle of the model (i.e., that Henry's Law applies). C_{sat} values should be calculated using the same site-specific soil characteristics used to calculate SSLs. Because VF-based inhalation SSLs are reliable only if they are less than or equal to C_{sat}, these SSLs should be compared to C_{sat} concentrations before they are used in a soil screening evaluation. If the calculated SSL exceeds C_{sat} and the contaminant is liquid at typical soil temperatures (see Appendix C, Exhibit C-3), the SSL is set at C_{sat}. If an organic compound is liquid at soil temperature, concentrations exceeding C_{sat} indicate the potential for nonaqueous phase liquid (NAPL) to be present in soil. This poses a possible risk to ground water, and more investigation may be warranted. For organic compounds that are solid at soil temperatures, concentrations above C_{sat} do not pose a significant inhalation risk nor are they indicative of NAPL contamination. Soil screening decisions for these compounds should be based on SSLs for other exposure pathways. For more information on C_{sat} and the proper selection of SSLs, please refer to the 1996 *SSG*.

Migration to Ground Water.

This guidance calculates commercial/industrial SSLs for the ingestion of leachate-contaminated ground water using the same set of equations and default input values presented in the 1996 *SSG*. Thus, the generic SSLs for this pathway are the same under commercial/industrial and residential land use scenarios.

EPA has adopted this approach for two reasons. First, it protects off-site receptors, including residents, who may ingest contaminated ground water that migrates from the site. Second, it protects potentially potable ground water aquifers that may exist beneath commercial/ industrial properties. (See text box for EPA's policy on ground water classification). Thus, this approach is appropriate for protecting ground water resources and human health; however, it may necessitate that sites meet stringent SSLs if the migration to ground water pathway applies, regardless of future land use.

The simple site-specific ground water approach consists of two steps. First, it employs a simple linear equilibrium soil/water partition equation to estimate the contaminant concentration in soil leachate. Alternatively, the synthetic precipitation leachate procedure (SPLP) can be used to estimate this concentration. Next, a simple water balance equation is used to calculate a dilution factor to account for reduction of soil leachate concentration from mixing in an aquifer. This calculation is based on conservative, simplified assumptions about the release and transport of contaminants in the subsurface (see Exhibit 4-3). These assumptions should be reviewed for consistency with the CSM to determine the applicability of SSLs to the migration to ground water pathway.

Ground Water Classification

In order to demonstrate that the ingestion of ground water exposure pathway is not applicable for a site, site managers may either perform a detailed fate and transport analysis (as discussed in the *TBD* to the 1996 *SSG*), or may show that the underlying ground water has been classified as non-potable. EPA's current policy regarding ground water classification for Superfund sites is outlined in an OSWER directive (U.S. EPA, 1997e). EPA evaluates ground water at a site according to the federal ground water classification system, which includes four classes:

1 - sole source aquifers;
2A - currently used for drinking water;
2B - potentially usable for drinking water; and
3 - not usable for drinking water.

Generally, this pathway applies to all potentially potable water (i.e., classes 1, 2A, and 2B), unless the state has made a different determination through a process analogous to the Comprehensive State Ground Water Protection Plan (CSGWPP). Through this process, ground water classification is based on an aquifer or watershed analysis of relevant hydrogeological information, with public participation, in consultation with water suppliers, and using a methodology that is consistently applied throughout the state. If a state has no CSGWPP or similar plan, EPA will defer to the state's ground water classification only if it is more protective than EPA's. As of February 2001, 11 states (AL, CT, DE, GA, IL, MA, NH, NV, OK, VT, and WI) have approved CSGWPP plans.

Equation 4-10 is the soil/water partition equation; it is appropriate for calculating SSLs corresponding to target leachate contaminant concentrations in the zone of contamination. Equations 4-11 and 4-12 are appropriate for determining the dilution attenuation factor (DAF) by which concentrations are reduced when leachate mixes with a clean aquifer. Because of the wide variability in subsurface conditions that affect contaminant migration in ground water, default values are not provided for input parameters for these dilution equations. Instead, EPA has developed two possible default DAFs (DAF=20 and DAF=1) that are appropriate for deriving generic SSLs for this pathway. The selection of a default DAF is discussed in Appendix A, and the derivation of these defaults is described in the *TBD* to the 1996 *SSG*. The default DAFs also can be used for calculating simple site-specific SSLs, or the site manager can develop a site-specific DAF using equations 4-11 and 4-12.

To calculate SSLs for the migration to ground water pathway, the acceptable ground water concentration is multiplied by the DAF to obtain a target soil leachate concentration (C_w).[12] For example, if the DAF is 20 and the acceptable ground water concentration is 0.05 mg/L, the target soil leachate concentration would be 1.0 mg/L. Next, the partition equation is used to calculate the total soil concentration (i.e., SSL) corresponding to this soil leachate concentration. Alternatively, if a leach test is used, the target soil leachate concentration is compared directly to extract concentrations from the leach tests.

Exhibit 4-3

Simplifying Assumptions for the SSL Migration to Ground Water Pathway

- Infinite source (i.e., steady-state concentrations are maintained over the exposure period)
- Uniformly distributed contamination from the surface to the top of the aquifer
- No contaminant attenuation (i.e., adsorption, biodegradation, chemical degradation) in soil
- Instantaneous and linear equilibrium soil/water partitioning
- Unconfined, unconsolidated aquifer with homogeneous and isotropic hydrologic properties
- Receptor well at the downgradient edge of the source and screened within the plume
- No contaminant attenuation in the aquifer
- No NAPLs present (if NAPLs are present, the SSLs do not apply)

For more information on the development of SSLs for this pathway, please consult the 1996 *SSG*.

Mass-Limit SSLs. Equations 4-13 and 4-14 present models for calculating mass-limit SSLs for the outdoor inhalation of volatiles and migration to ground water pathways, respectively. These models can be used only if the depth and area of contamination are known or can be estimated with confidence. These equations are identical to those in the 1996 *SSG*. Please consult that guidance for information on using mass-limit SSL models.

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[12] The acceptable ground water concentration is, in order of preference: a non-zero Maximum Contaminant Level Goal (MCLG), a Maximum Contaminant Level (MCL), or a health-based level (HBL) calculated based on an ingestion rate of 2L/day and a target cancer risk of $1x10^{-6}$ or an HQ of 1. These values are presented in Appendix C.

Equation 4-10
Soil Screening Level Partitioning Equation for Migration to Ground Water

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{in Soil (mg/kg)}\end{array} = C_w\left[K_D + \frac{(\theta_w + \theta_a H')}{\rho_b}\right]$$

Parameter/Definition (units)	Default
C_w/target soil leachate concentration (mg/L)	(nonzero MCLG, MCL, or HBL)[a] × dilution factor
K_d/soil-water partition coefficient (L/kg)	for organics: $K_d = K_{oc} \times f_{oc}$ for inorganics: see Appendix C[b]
K_{oc}/soil organic carbon/water partition coefficient (L/kg)	chemical-specific[c]
f_{oc}/fraction organic carbon in soil (g/g)	**0.002 (0.2%)**
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.3**
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n - \theta_w$
ρ_b/dry soil bulk density (kg/L)	**1.5**
n/soil porosity (L_{pore}/L_{soil})	$1 - (\rho_b/\rho_s)$
ρ_s/soil particle density (kg/L)	2.65
H'/dimensionless Henry's law constant	chemical-specific[c] (assume to be zero for inorganic contaminants except mercury)

[a] Chemical-specific (see Appendix C).

[b] Assume a pH of 6.8 when selecting default K_d values for metals.

[c] See Appendix C.

Equation 4-11
Derivation of Dilution Attenuation Factor

$$\begin{array}{c}\text{Dilution}\\ \text{Attenuation}\\ \text{Factor (DAF)}\end{array} = 1 + \frac{K \times i \times d}{I \times L}$$

Parameter/Definition (units)	Default
DAF/dilution attenuation factor (unitless)	**20 or 1 (0.5-acre source)**
K/aquifer hydraulic conductivity (m/yr)	**Site-specific**
i/hydraulic gradient (m/m)	**Site-specific**
I/infiltration rate (m/yr)	**Site-specific**
d/mixing zone depth (m)	**Site-specific**
L/source length parallel to ground water flow (m)	**Site-specific**

Equation 4-12
Estimation of Mixing Zone Depth

$$d \;\text{'}\; (0.0112L^{2})^{0.5} \;\%\; d_a(1 \,\&\, \exp[(\&L \times I)/(K \times i \times d_a)])$$

Parameter/Definition (units)	**Default**
d/mixing zone depth (m)	**Site-specific**
L/source length parallel to ground water flow (m)	**Site-specific**
I/infiltration rate (m/yr)	**Site-specific**
K/aquifer hydraulic conductivity (m/yr)	**Site-specific**
i/hydraulic gradient (m/m)	**Site-specific**
d_a/aquifer thickness (m)	**Site-specific**

Equation 4-13
Mass-Limit Volatilization Factor - Commercial/Industrial Scenario

$$VF \;\text{'}\; Q/C_{vol} \times \frac{[T\times\;(3.15\times10^{7}\text{s/yr})]}{(\rho_b\times d_s\times10^{6}\text{g/Mg})}$$

Parameter/Definition (units)	**Default**
d_s/average source depth (m)	**site-specific**
T/exposure interval (yr)	**30**
Q/C_{vol}/inverse of the ratio of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)	**68.18[a]**
ρ_b/dry soil bulk density (kg/L or Mg/m^3)	**1.5**

[a] Assumes a 0.5 acre emission source

Equation 4-14
Mass-Limit Soil Screening Level for Migration to Ground Water

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{in Soil (mg/kg)}\end{array} \;\text{'}\; \frac{(C_w\times I\times ED)}{\rho_b\times d_s}$$

Parameter/Definition (units)	**Default**
C_w/target soil leachate concentration (mg/L)	(nonzero MCLG, MCL, or HBL)[a] × dilution factor
d_s/depth of source (m)	**site-specific**
I/infiltration rate (m/yr)	**0.18**
ED/exposure duration (yr)	70
ρ_b/dry soil bulk density (kg/L)	**1.5**

[a] Chemical-specific, see Appendix C.

4.3 Additional Considerations for the Evaluation of Non-Residential Exposure Scenarios

As described in this guidance document, conducting soil screening evaluations for non-residential land use scenarios involves making well-reasoned assumptions about site use, potential exposure pathways, and potential receptors. These decisions raise the following issues about the derivation and application of non-residential SSLs:

- The importance of involving community representatives in identifying the likely future land use (and associated activities) at sites;
- The selection and implementation of institutional controls to ensure that future site uses and activities will be consistent with the non-residential land use assumptions used to derive SSLs; and
- The relative roles of SSLs and OSHA standards in protecting future workers from exposure to residual contamination at non-residential sites.

This section provides guidance on these issues, outlining EPA policy and highlighting useful resources.

4.3.1 Involving the Public in Identifying Future Land Use at Sites

The potential for site managers to apply non-residential land use assumptions in developing SSLs is most useful when the likely future land use for a site can be identified early in the Superfund process. As discussed in Section 3.1, community representatives (including local land use planners, local officials and members of the general public) can provide a great deal of insight about the reasonably anticipated future land use of sites. This can be one of the most important aspects of overall community involvement, especially for sites that have been abandoned by previous owners or sites where land use is likely to change. Site managers should look to the community as a source of information about both current and reasonably anticipated future site activities, which can help identify relevant exposure pathways that should be reflected in the CSM.

Early interaction with community representatives and local government officials can help to ensure that the assumptions used in the soil screening evaluation will be supported by the community. This also may lead to greater community support of subsequent Superfund activities at a site, such as the baseline risk assessment and selection of remedies, which may be based, in part, on these assumptions. EPA has developed guidance, *Community Involvement in Superfund Risk Assessments, A Supplement to RAGS Part A*, to assist site managers in working with communities and soliciting their input (U.S. EPA, 1999b). Site managers also can consult the

OSWER directive, *Land Use in the CERCLA Remedy Selection Process* (U.S. EPA, 1995a) for information on community involvement in the identification of future land use.[13]

4.3.2 Institutional Controls

Non-residential SSLs are based on specific assumptions about land use and access. These assumptions are typically less conservative than those used to develop residential SSLs; thus, non-residential SSLs may be less stringent than the corresponding residential values. These non-residential SSLs can be protective of the key receptors associated with reasonably anticipated future non-residential land uses, but they may not be universally protective of all receptors and activities. Therefore, ensuring that contaminant levels are protective of exposures at sites or areas of sites that are screened out under these less stringent SSLs depends on site use, activities, and accessibility remaining consistent with the conceptual site model upon which screening decisions are based. Effective, enforceable institutional controls (ICs) may be a very important tool for preventing inappropriate land uses and activities that may result in unacceptable exposures. EPA defines ICs as "non-engineered instruments such as administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource use" (U.S. EPA, 2000b).[14]

A non-residential screening assessment should include an evaluation of the implementability and potential effectiveness of ICs for areas that are screened out. This evaluation, which may consider multiple IC options, allows the site manager to identify the best available means (if any) to ensure long-term protectiveness at areas of sites screened out under less stringent, non-residential SSLs. It should provide sufficient evidence to conclude that effective implementation of ICs is feasible and can serve to "prevent an unanticipated change in land use that could result in unacceptable exposures to residual contamination or, at a minimum, alert future users to residual risks and monitor for any changes in use" (U.S. EPA, 1995a). If it does not appear likely that such ICs can be established in the future, then it is inappropriate to screen out a site or area of a site under non-residential SSLs. Instead, site managers may compare soil contaminant concentrations to residential SSLs that would be protective given unrestricted land use.

A variety of ICs exist that can be used to prevent or limit exposure at a site. In general, these fall into the four major categories summarized below (U.S. EPA, 2000b).

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[13] See http://www.epa.gov/oerrpage/superfund/resources/landuse.htm.

[14] EPA also stresses that ICs are generally to be used in conjunction with engineering measures; that they can be used during all stages of the cleanup process; and that they should ideally be "layered" (i.e. the simultaneous application of multiple ICs) or implemented in series to provide overlapping assurances of protection from contamination (U.S. EPA, 2000b).

- **State and Local Government Controls**. Government controls are usually implemented and enforced by a state or local government and can include zoning restrictions, ordinances, statutes, building permits, or other provisions that restrict land or resource use at a site. Since this category of ICs is put in place under local jurisdiction, they may be changed or terminated with little notice to EPA, and EPA generally has no authority to enforce such controls.

- **Proprietary Controls**. These controls have their basis in property law and are unique in that they generally create legal property interests. In other words, proprietary controls involve legal instruments placed in the chain of title of the site or property. Common examples include covenants or easements restricting future land use or prohibiting activities that may compromise specific engineering remedies. The benefit of proprietary controls is that they can be binding on subsequent purchasers of the property (successors in title) and transferable, which may make them more reliable in the long term than other types of ICs. However, property law is complex, and variations in property laws across states can make it difficult to establish and enforce appropriate proprietary controls.

- **Enforcement Tools with IC Components**. Under section 106(a) of CERCLA, EPA has the authority to issue administrative orders to compel land owners to limit certain site activities at both Federal and private sites. Although this tool is frequently used by site managers, it may have significant shortcomings that should be thoroughly evaluated. For example, property restrictions that are part of an enforcement action are binding only on the signatories and are not transferred through a property transaction, which limits their long-term protectiveness.

- **Informational Devices**. Informational tools provide information or notification that residual or capped contamination may remain on site. Common examples include state registries of contaminated properties, deed notices, and advisories. Because such devices are not legally enforceable, it is important to carefully consider the objective of this category of IC. Informational devices are most likely to be used as a secondary "layer" to help ensure the overall reliability of other ICs.

Early and careful consideration of ICs can be valuable for soil screening evaluations because it focuses attention on land use assumptions that can be maintained over time. In the context of soil screening analyses, the IC evaluation should identify the types of ICs available, the existence of the authority necessary to implement an IC, the willingness and ability of the appropriate entity to effectively implement and enforce the IC in both the short and long term, and the relative cost associated with the implementation and maintenance of any IC. Incorporating such considerations as a part of the screening assessment allows site managers to anticipate and consider potential barriers to the implementation of ICs.

In addition, early consideration of IC options assists site managers in identifying those parties (e.g., local government agencies) who would be instrumental in ensuring the effective implementation and management of any IC selected. For example, a local government's ability to effectively maintain or enforce an IC may affect not only the type of IC selected, but also the decision of whether it is appropriate to utilize ICs to help achieve protection of human health. Consideration of IC options is thus a valuable tool for increasing the overall reliability of screening decisions and should not be viewed as an afterthought to the soil screening process.

For more detailed information on how to evaluate and implement ICs, please consult the following publications:

> *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups.* Office of Solid Waste and Emergency Response. EPA 540-F-00. OSWER 9355-0-24-FS-P. September 2000.
>
> *Land Use in the Remedy Selection Process*. OSWER Directive No. 9355.7-04. May 1995.

4.3.3 Applicability of OSHA Standards at NPL Sites

Conducting soil screening evaluations at sites where workers are the primary receptors of concern raises questions about the roles of commercial/industrial SSLs and OSHA standards in protecting these receptors. Although both OSHA standards and SSLs protect the health of workers exposed to toxic substances, the conditions of exposure implicit in each set of values differ. As a result, OSHA standards are not suitable substitutes for SSLs.

The key distinctions between OSHA standards and commercial/industrial SSLs include the underlying assumptions about the context of workplace exposures, the characteristics of the workers being protected, and the level of protection afforded to workers (U.S. EPA, 1995b).

- **Context of Workplace Exposure.** OSHA standards assume that workers are exposed to hazardous chemicals used in or generated as a result of routine work activities. These workers are assumed to be aware of the chemicals to which they are exposed and can obtain information on them through Right-to-Know laws. Further, they tacitly accept certain risks associated with exposure because they receive a benefit (i.e., higher wages) to compensate them for additional hazard. On the other hand, commercial/industrial SSLs address worker exposures to general environmental pollution — contaminants whose presence at a site may be independent of any current or future work activity (though work activities, such as excavation, may lead to exposure).

- **Characteristics of Worker Receptors.** OSHA standards protect workers who are likely, through self-selection, to be less sensitive to the chemicals to which they are exposed; a worker who finds that he or she is highly sensitive to a compound that is used during daily work activities would be able to proactively seek other jobs or alternative job responsibilities that do not involve exposure to that compound. Thus, unlike SSLs, which are based on an RME scenario, OSHA standards are not designed to protect against exposures to sensitive sub-populations.

- **Level of Protection Afforded to Workers.** OSHA standards assume not only that workers are knowingly exposed to specific chemicals in the workplace, but also that they receive additional protection and training to mitigate exposures. OSHA requires workers to be trained to control or prevent exceedances of its exposure standards (including the use of personal protective clothing and gear to help prevent excessive exposures). OSHA also requires periodic worker health monitoring to ensure that excessive exposures are not occurring. In contrast, *RAGS Part A* (U.S. EPA, 1989b) indicates that a Superfund risk assessment is an analysis of potential adverse health effects (current or future) caused by hazardous substances released from a site *in the absence of any actions or controls to mitigate exposures*.

5.0 CALCULATION OF SSLS FOR A CONSTRUCTION SCENARIO

Construction is likely to occur as part of the redevelopment process at many NPL sites, regardless of the anticipated future land use. Although construction is typically of relatively short duration (a year or less), it may lead to significant exposures to construction workers and off-site residents as a result of soil-disturbing activities that include excavation and vehicle traffic on unpaved roads. To help address this potential concern, EPA has developed a construction soil screening scenario that site managers can use to develop construction SSLs.

EPA designed the construction scenario to supplement the residential and non-residential screening scenarios. When appropriate, site managers should calculate construction SSLs *in addition to* the SSLs for the appropriate land use scenario. This chapter of the guidance explains when construction SSLs should be calculated, presents the exposure framework for the construction scenario, and provides equations for calculating simple site-specific SSLs that reflect potential exposure during construction activities. Information on using more detailed site-specific modeling to develop construction SSLs is presented in Appendix E.

5.1 Applicability of the Construction Scenario

The construction scenario assumes that one or more residential or commercial buildings will be erected on a site and that construction will occur within areas of residual soil contamination. Because the activities associated with such a project are likely to result in significant direct contact soil exposures (i.e., ingestion and dermal absorption) to construction workers and are likely to increase emissions of both volatiles and particulate matter from contaminated soils during the construction period, EPA recommends that site managers evaluate the construction exposure scenario whenever major construction is anticipated at a site. However, EPA realizes that developing SSLs based on a construction scenario may be difficult, especially if there is considerable uncertainty surrounding the details of future construction. In such cases, site managers can evaluate several plausible construction scenarios representing a range of activities, areal extents, and durations. The results of these evaluations can provide valuable information to help guide and focus future construction activities.

EPA anticipates that the potential for increased exposure during construction will be a concern at many sites. While we recognize that the construction scenario may produce SSLs that are more stringent than those for the other scenarios, we emphasize that SSLs are not cleanup levels; rather they are used to assist site managers in scoping the analyses that comprise the Superfund process. In addition, construction SSLs can be used to inform future construction plans, highlighting areas and construction activities that may pose significant risks to construction workers or other receptors in the absence of mitigating measures.

There are conditions under which site managers may choose not to evaluate the construction scenario. These include:

- **No Redevelopment Currently Anticipated.** If there are no existing plans for redeveloping a site, the site manager may opt not to evaluate the construction scenario at the time of the initial soil screening evaluation. However, in this case, the soil screening evaluation should be accompanied by an analysis that demonstrates the feasibility of implementing institutional controls in the future to restrict activities that would disturb residual site contamination, such as excavation or digging a well, unless screened out site areas are re-evaluated.

- **Construction Will Not Disturb Contamination.** If a site manager can demonstrate that the proposed excavation does not include any areas of soil contamination and that any unpaved roads created on-site for construction vehicle traffic will not cross areas of surficial soil contamination, the construction scenario need not be evaluated. Again, the soil screening evaluation should identify effective institutional controls that can be implemented in the future to restrict activities in the event that subsequent construction would disturb residual soil contamination.

5.2 Soil Screening Exposure Framework for Construction Scenario

The construction soil screening scenario evaluates exposures to construction workers present throughout a construction project, as well as exposures to nearby off-site residents. These receptors are potentially subject to higher contaminant exposures via increased volatile and fugitive dust emissions during construction activities.

Exhibit 5-1 summarizes the exposure framework for construction workers and off-site residents.

- **Construction Worker.** This is a short-term adult receptor who is exposed to soil contaminants during the work day for the duration of a single construction project (typically a year or less). If multiple non-concurrent construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial on-site exposures to surface and subsurface soils. The construction worker is expected to have a very high soil ingestion rate and is assumed to be exposed to contaminants via the following direct and indirect pathways: incidental soil ingestion, dermal absorption, inhalation of volatiles outdoors, and inhalation of fugitive dust.

Exhibit 5-1

SUMMARY OF THE CONSTRUCTION SCENARIO EXPOSURE FRAMEWORK FOR SOIL SCREENING

	Receptors	
	Construction Worker	**Off-site Resident**
Exposure Characteristics	C Exposed during construction activities only C Potentially high ingestion and inhalation exposures to surface and subsurface soil contaminants C Short-term (subchronic) exposure	C Resides at the site boundary C Exposed both during and post-construction C Potentially high inhalation exposures to contaminants in fugitive dust C Long-term (chronic) exposure
Pathways of Concern[1]	C Ingestion (surface and subsurface soil) C Dermal contact (surface and subsurface soil) C Inhalation of volatiles outdoors (subsurface soil) C Inhalation of fugitive dust due to traffic on unpaved roads (surface soil)[2]	C Inhalation of fugitive dust due to traffic on unpaved roads and wind erosion (surface soil)
Default Exposure Factors		
Exposure Frequency (d/yr)	250	350
Exposure Duration (yr)	1	30
Soil Ingestion Rate[3] (mg/d)	330	NA
Inhalation Rate (m^3/d)	20	20[4]
Body Weight (kg)	70	70
Lifetime (yr)	70	70

[1] The inhalation of volatiles is not included as a pathway of concern for off-site residents because SSLs developed for this pathway for the construction worker (short-term) and for the on-site worker receptor under the commercial/industrial scenario (long-term) were shown to be protective for this receptor.

[2] Analyses of the inhalation of fugitive dust pathway suggest that the most significant contribution to exposure comes from disturbance of surface soil by traffic on unpaved roads. Therefore, the framework for simple site-specific soil screening evaluation for this pathway focuses on surface soil. If a site manager determines that excavation of subsurface soil or other earth-moving activities may lead to significant exposure to fugitive dust, it may be appropriate to use a more detailed site-specific modeling approach to develop a construction SSL for this pathway. Appendix E provides guidance on conducting such modeling.

[3] The soil ingestion rate is revised from the previous default ingestion rate of 480 mg/d. See the discussion of ingestion rate in section 5.3.2.

[4] Residential inhalation exposure to children and adults is evaluated using the RfC toxicity criterion, which is based on an inhalation rate of 20 m^3/day. No comparable toxicity criterion specific to childhood exposures is currently available. EPA has convened a workgroup to identify suitable default values for modeling childhood inhalation exposures, as well as possible approaches for adjusting toxicity values for application to such exposures.

C **Off-site Resident.** This receptor is similar to the one evaluated in the residential soil screening scenario but is located at the site boundary.[21] The off-site resident is exposed to contaminants both during and after construction, for a total of 30 years. This receptor has no direct contact with on-site soils. Under this framework, the only exposure pathway evaluated for this receptor is the inhalation of fugitive dust, which is likely to be exacerbated during construction as a result of dust generated by truck traffic on unpaved roads.

EPA's recommendations for focusing on specific exposure pathways and receptors are based on analyses of the potential exposure levels resulting from different activities. EPA's analysis of the impacts of different construction activities on fugitive dust emissions demonstrated that vehicle traffic on contaminated unpaved roads typically accounts for the majority of emissions, with wind erosion, excavation soil dumping, dozing, grading, and filling operations contributing lesser emissions. Based on this analysis, EPA has focused the simple site-specific construction scenario on fugitive dust emissions from traffic on contaminated unpaved roads. Information on evaluating fugitive dust emissions resulting from other construction activities as part of a detailed site-specific approach can be found in Appendix E.

In the case of volatile contaminants, excavation during construction can increase volatile emissions by unearthing soil contamination and bringing it into direct contact with the air; this increases the flux of volatile contaminants from the soil into the air. The equations for developing simple site-specific SSLs for both the commercial/industrial and construction scenarios are based on the assumption that contaminants are present at the soil surface. The complexity of modeling the volatilization of contaminants from buried waste precludes the development of SSLs for this situation under the simple site-specific approach. SSLs that reflect buried contamination can be calculated for any scenario using the detailed site-specific approach (see Appendix E). Under the conservative assumptions of the simple site-specific approach, SSLs for volatiles developed for the outdoor worker receptor under the commercial/industrial scenario (or for a resident) should be protective of the off-site resident under the construction scenario. (See discussion of the relative exposures for on- and off-site receptors in Section 4.2.2).

EPA also conducted an analysis comparing the subchronic exposure levels to volatile contaminants for on-site construction workers with those for off-site residents and found little difference between the resulting SSLs for the two receptors. The difference in SSLs for these receptors is less than 20 percent, well within the uncertainty associated with emissions modeling.[22]

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[21] This is a conservative assumption, since the highest exposure concentrations for off-site residents occur at the site boundary.

[22] Modeling results indicate that a construction worker, who is located on-site, is exposed to higher concentrations of volatiles than an off-site resident. However, an off-site resident is assumed to have a higher exposure frequency than a construction worker during the construction period (i.e., seven days per week versus five days per week). The net result is a slightly lower SSL for an off-site resident, approximately 18 percent lower than the SSL for a construction worker. This difference is small relative to the uncertainty in the emission, dispersion, and exposure modeling; thus, EPA believes that the construction worker SSL is sufficiently protective of subchronic exposures to off-site residents.

Therefore, EPA recommends that only construction workers be evaluated for subchronic exposure to volatiles during construction activities.

In some cases, site managers also may wish to evaluate direct ingestion and dermal contact exposures of off-site residents to contaminated dust that is deposited on an off-site property during construction activities. For sites where contaminant concentrations meet residential SSLs, this pathway is unlikely to result in significant risks, due to the reduction of contaminant concentrations expected to occur as deposited dust mixes with uncontaminated soils. For sites meeting commercial/industrial SSLs, this may be a pathway of concern for some contaminants, especially metals, for which the commercial/industrial SSL for ingestion/dermal contact exposure is significantly higher than the corresponding residential SSL that would apply to the off-site exposure. For these contaminants, off-site deposition could potentially lead to concentrations that exceed residential direct contact SSLs. However, the complexity of modeling off-site deposition of contaminated dusts precludes EPA from developing an average default factor for estimating the off-site concentration resulting from deposition, relative to on-site contamination levels. Therefore, this pathway should be addressed on a site-specific basis.

5.3 Calculating SSLs for the Construction Scenario

This section presents EPA's recommended approach to calculating SSLs for construction-related exposures. First, it describes key differences between the calculation of construction SSLs and the calculation of residential or commercial/industrial SSLs. Then, it presents the equations used to calculate construction SSLs using the simple site-specific soil screening approach.

5.3.1 Calculation of Construction SSLs - Key Differences

Besides differences in receptors and exposure factors, there are three key differences between construction SSLs and residential or commercial/industrial SSLs:

- **Absence of Generic SSLs.** EPA does not present generic SSLs for the construction scenario. This decision reflects the difficulty of developing standardized default exposure assumptions and other model input parameters for a construction scenario. Construction-related exposures depend on many parameters including, but not limited to: the size of the site; the size of the contaminated source area; the dimensions of the building(s) being constructed and its location relative to the source area and to the site boundary; the type of building being constructed (e.g., a slab-on-grade structure versus a building with a basement); and the overall duration of the construction project. These parameters can vary considerably from project to project, and current data do not allow EPA to identify a reasonable set of generic default values (either central tendency or high end) for all of them.

Therefore, EPA has not established generic SSLs for construction activities, and the equations presented below do not include suggested default values for all model input parameters. Site managers having difficulty determining a site-specific value may wish to calculate SSLs using a range of plausible values.

C **Subchronic Exposures.** Under the guidelines established by the Superfund program, exposures to construction workers of one year or less are classified as subchronic exposures.[23] This short exposure duration affects how site managers use toxicity values in calculating SSLs for non-carcinogenic effects. Specifically, calculations of SSLs based on non-carcinogenic effects associated with *subchronic* exposures should incorporate toxicity values for subchronic, not chronic, effects.[24] Subchronic toxicity values are not as widely available as chronic values, and unlike chronic RfDs and RfCs, no EPA work group exists to review and verify subchronic RfDs or RfCs. Subchronic toxicity values for a limited number of compounds are available from EPA's *Health Effects Assessment Summary Tables* (HEAST).[25] We recommend that site managers seek assistance from EPA's regional risk assessors and from EPA's Superfund Technical Support Center when researching appropriate subchronic toxicity values. In addition, the Agency for Toxic Substances and Disease Registry (ATSDR) publishes Minimal Risk Levels (MRLs) that may be suitable for use as subchronic toxicity values.[26] The SSL equations for the construction worker use the generic term "Health Based Level" (HBL) to refer to these subchronic toxicity values. When calculating SSLs for this receptor, site managers can use a subchronic RfD or RfC from HEAST, a value recommended by the Superfund Technical Support Center, an MRL, or another suitable subchronic value (accompanied by appropriate documentation) as the HBL, as opposed to chronic or acute toxicity values.

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[23] EPA defines subchronic exposures for Superfund purposes as exposures lasting between two weeks and seven years. See U.S. EPA., 1989b, Chapters 6, 7, and 8.

[24] There is no change with respect to SSLs based on carcinogenic effects, because the methodology averages exposures over a lifetime.

[25] HEAST presents tables of chemical-specific toxicity information and values based on data from Health Effects Assessments, Health and Environmental Effects Documents, Health and Environmental Effects Profiles, Health Assessment Documents, or Ambient Air Quality Criteria Documents. HEAST summarizes interim (and some verified) RfDs and RfCs, as well as other toxicity information for specific chemicals. Although the HEAST data do not have the agency-wide consensus of the IRIS data, the information contained in HEAST represents current toxicity data generated by EPA. The most recent printed version of HEAST was printed in 1997.

[26] ATSDR MRLs were developed in response to a CERCLA mandate and represent the highest exposure levels that would not lead to the development of non-cancer health effects in humans based on acute (1-14 days), subchronic (15-364 days), and chronic (365 days and longer) exposures via oral and inhalation pathways. MRLs are based on non-cancer health effects only. MRLs are available from ATSDR'S website, http://atsdr1.atsdr.cdc.gov:8080/mrls.html.

- **Focus on Subsurface Soil.** Construction SSLs for the combined direct ingestion/dermal absorption exposure pathway should be used to evaluate contaminant concentrations in both surface and subsurface soils. The focus on subsurface soils is appropriate because excavation and other earth-moving activities could result in substantial exposures to soils at depths greater than two centimeters (the 1996 *SSG* definition of surface soils).

5.3.2 SSL Equations for the Construction Scenario

This section presents the equations used to calculate construction SSLs for surface and subsurface soils using the simple site-specific soil screening approach. As noted above, a generic approach is not appropriate for evaluating the construction scenario. As an alternative to the simple site-specific approach, site managers can perform detailed site-specific modeling to evaluate this scenario; Appendix E presents suggestions for modeling inhalation pathways under construction conditions using the detailed site-specific approach.

For each equation, site-specific input parameters are indicated in bold. Where possible, default values for these parameters are provided for use when site-specific data are not available. As in the other exposure scenarios, all site-specific inputs describing soil, aquifer, and meteorologic characteristics should represent average or typical site conditions in order to produce risk-based SSLs that reflect reasonable maximum exposure (RME).

Chemical-specific data, including chronic toxicity criteria, for use in developing simple site-specific SSLs are provided in Appendix C. Prior to calculating SSLs, each relevant chemical-specific value in Appendix C should be checked against the most recent version of its source and updated, if necessary.

In general, the basic forms of the SSL equations for the construction scenario are similar to those used for the other scenarios. Changes to default exposure parameters that apply to individual pathways are discussed below, along with their respective SSL equations.

SSL Equations for Surface Soils

The relevant pathways for exposure to surface soils under the construction scenario include direct ingestion and dermal absorption for construction workers, and inhalation of fugitive dusts by both construction workers and off-site residents.

Direct Ingestion and Dermal Absorption. Equations 5-1 and 5-2 are appropriate for addressing subchronic ingestion and dermal absorption exposure of construction workers to carcinogens and non-carcinogens, respectively. These equations produce SSLs for combined exposure of construction workers via these pathways.

Equation 5-1
Screening Level Equation for Combined Subchronic Ingestion and Dermal Absorption
Exposure to Carcinogenic Contaminants in Soil
Construction Scenario - Construction Worker

$$\text{Screening Level (mg/kg)} = \frac{TR \times BW \times AT \times 365\ \text{d/yr}}{(EF \times ED \times 10^{-6}\ \text{kg/mg})\,[(SF_o \times IR) + (SF_{ABS} \times AF \times ABS_d \times SA \times EV)]}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
BW/body weight (kg)	70
AT/averaging time (years)	70
EF/exposure frequency (days/year)	**site-specific**
ED/exposure duration (years)	**site-specific**
SF_o/oral cancer slope factor $(\text{mg/kg-d})^{-1}$	chemical-specific (Appendix C)
IR/soil ingestion rate (mg/d)	330
SF_{ABS}/dermally adjusted cancer slope factor $(\text{mg/kg-d})^{-1}$	chemical-specific (Equation 3-3)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.3**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
SA/skin surface area exposed (cm^2)	**3,300**
EV/event frequency (events/day)	**1**

Equation 5-2
Screening Level Equation for Combined Subchronic Ingestion and Dermal Absorption Exposure to Non-Carcinogenic Contaminants in Soil
Construction Scenario - Construction Worker

$$\text{Screening Level (mg/kg)} = \frac{THQ \times BW \times AT \times 365\,\text{d/yr}}{(EF \times ED \times 10^{-6}\,\text{kg/mg})\left[\left(\frac{1}{HBL_{sc}} \times IR\right) + \left(\frac{1}{HBL_{ABS}} \times AF \times ABS_{d} \times SA \times EV\right)\right]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	70
AT/averaging time (years)	**site specific**[a]
EF/exposure frequency (days/year)	**site specific**
ED/exposure duration (years)	**site specific**
HBL_{sc}/subchronic health-based limit (mg/kg-d)	chemical-specific
IR/soil ingestion rate (mg/d)	330
HBL_{ABS}/dermally-adjusted subchronic health-based limit (mg/kg-d)	chemical-specific (Equation 3-4)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.3**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Exhibit 3-3 and Appendix C)
SA/skin surface exposed (cm^2)	**3,300**
EV/event frequency (events/day)	**1**

[a] For non-carcinogens, averaging time equals to exposure duration.

Data on soil ingestion rates for adults engaged in outdoor work are not currently available. However, EPA believes construction workers are likely to experience substantial exposures to soils during excavation and other work activities; therefore, a high-end soil ingestion rate has been selected to estimate exposures under this scenario. The default value of 330 mg/day (Stanek et al., 1997) listed in Equations 5-1 and 5-2 replaces the previous default ingestion rate of 480 mg/day (Hawley, 1985). While the Hawley value was based on a theoretical calculation for adults engaged in outdoor physical activity, the revised default ingestion rate is based on the 95th percentile value for adult soil intake rates reported in a soil ingestion mass-balance study.[27]

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[27] Research is on-going to refine our knowledge about adult soil ingestion and to produce better ingestion rate estimates for individuals engaged in strenuous activities. This default is therefore subject to change as better data become available.

The dermal absorption components of Equations 5-1 and 5-2 are based on the same methodology discussed in Section 3.2.1, and they can be used to calculate SSLs for the same seven compounds and two compound classes discussed in that section. The suggested default input values for the dermal exposure equations are consistent with those recommended in EPA's interim dermal guidance (U.S. EPA, 2001). Event frequency (EV, the number of events per day) is assumed to be one. Construction workers are assumed to have their face, forearms, and hands exposed. Therefore, this guidance recommends that a value of 3,300 cm^2 be used as an estimate of the skin surface area exposed (SA). We also assume a default adherence factor (AF) of 0.3 mg soil per square centimeter of exposed skin. The SA default value is the same as that used for commercial/industrial outdoor worker receptors; the AF value represents the 95th percentile value for construction workers. The chemical-specific dermal absorption fractions (ABS_d) are presented in Appendix C. For those compounds that are classified as both semi-volatiles and as PAHs, the ABS_d default for PAHs should be applied. Subchronic oral toxicity values used to calculate this SSL should be adjusted in the same manner as chronic oral RfDs (see Equation 3-4).

Inhalation of Fugitive Dusts. Under a construction scenario, fugitive dusts may be generated from surface soils by wind erosion, construction vehicle traffic on temporary unpaved roads and other construction activities. Inhalation of these dusts containing semi-volatile organic compounds and metals may be of concern to construction workers and off-site residents. As described in Section 4.2.3, site managers need only evaluate the fugitive dust pathway for a single contaminant, hexavalent chromium (Cr^{+6}) under the residential and commercial/industrial scenarios; however, due to the potential for increased dust exposure from truck traffic on unpaved roads during construction, EPA recommends that SSLs for the construction scenario be calculated for semi-volatile compounds and for all metals.[28]

Equations 5-3 and 5-4 are appropriate for calculating fugitive dust SSLs for carcinogens and non-carcinogens for subchronic construction worker exposure. These equations are similar to the fugitive dust SSL equations for other scenarios, with the exception of the health based limit subchronic toxicity value term (HBL_{sc}). In addition, the equation to calculate the subchronic particulate emission factor (PEF_{sc}, Equation 5-5) is significantly different from the residential and non-residential PEF equations. The PEF_{sc} in Equation 5-5 focuses exclusively on emissions from truck traffic on unpaved roads, which typically contribute the majority of dust emissions during construction. This equation requires estimates of parameters such as the number of days with at least 0.01 inches of rainfall, the mean vehicle weight, and the sum of fleet vehicle distance traveled during construction.

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[28] For purposes of this guidance, semi-volatile compounds are defined as those listed on EPA's Contract Laboratory Program list of target semi-volatile compounds (see http://www.epa.gov/superfund/programs/clp/target.htm). These compounds are identified on the exhibits in Appendix A. In addition, metals are listed at the bottom of each exhibit in Appendix A.

Equation 5-3
Screening Level Equation for Subchronic Inhalation of Carcinogenic Fugitive Dusts Construction Scenario - Construction Worker

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365\,\text{d/yr}}{URF \times 1{,}000\,\mu\text{g/mg} \times EF \times ED \times \frac{1}{PEF_{sc}}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (years)	70
URF/inhalation unit risk factor $(\mu g/m^3)^{-1}$	chemical -specific (Appendix C)
EF/exposure frequency (days/year)	**site-specific**
ED/exposure duration (years)	**site-specific**
PEF_{sc}/subchronic road particulate emission factor (m^3/kg)	**site-specific (Equation 5-5)**

Equation 5-4
Screening Level Equation for Subchronic Inhalation of Non-carcinogenic Fugitive Dusts Construction Scenario - Construction Worker

$$\text{Screening Level (mg/kg)} = \frac{THQ \times AT \times 365\,\text{d/yr}}{EF \times ED \times \left(\frac{1}{HBL_{sc}} \times \frac{1}{PEF_{sc}} \right)}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (years)	**site-specific**[a]
EF/exposure frequency (days/year)	**site-specific**
ED/exposure duration (years)	**site-specific**
HBL_{sc}/subchronic health-based limit (mg/m^3)	chemical-specific
PEF_{sc}/subchronic road particulate emission factor (m^3/kg)	**site-specific (Equation 5-5)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation 5-5
Derivation of the Particulate Emission Factor
Construction Scenario - Construction Worker

$$PEF_{sc} = Q/C_{sr} \times \frac{1}{F_D} \times \left[\frac{T \times A_R}{556 \times (W/3)^{0.4} \times \frac{(365d/yr - p)}{365d/yr} \times \Sigma VKT} \right]$$

Parameter/Definition (units)	Default
PEF_{sc}/subchronic road particulate emission factor (m^3/kg)	**site-specific**
Q/C_{sr}/ inverse of the ratio of the 1-h geometric mean air concentration to the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3)	**23.02[a] (Equation 5-6)**
F_D/dispersion correction factor (unitless)	0.185 (Appendix E)
T/total time over which construction occurs (s)	**site-specific**
A_R/surface area of contaminated road segment (m^2) L_R/length of road segment (ft) W_R/width of road segment (ft)	**274.213 ($A_R = L_R \times W_R \times 0.092903 m^2/ft^2$)**
W/mean vehicle weight (tons)	**site-specific**
p/number of days with at least 0.01 inches of precipitation (days/year)	**site-specific (Exhibit 5-2)**
ΣVKT/sum of fleet vehicle kilometers traveled during the exposure duration (km)	**site-specific**

[a] Assumes a 0.5 acre site

The number of days with at least 0.01 inches of rainfall can be estimated using Exhibit 5-2. Mean vehicle weight (W) can be estimated by assuming the numbers and weights of different types of vehicles. For example, assuming that the daily unpaved road traffic consists of 20 two-ton cars and 10 twenty-ton trucks, the mean vehicle weight would be:

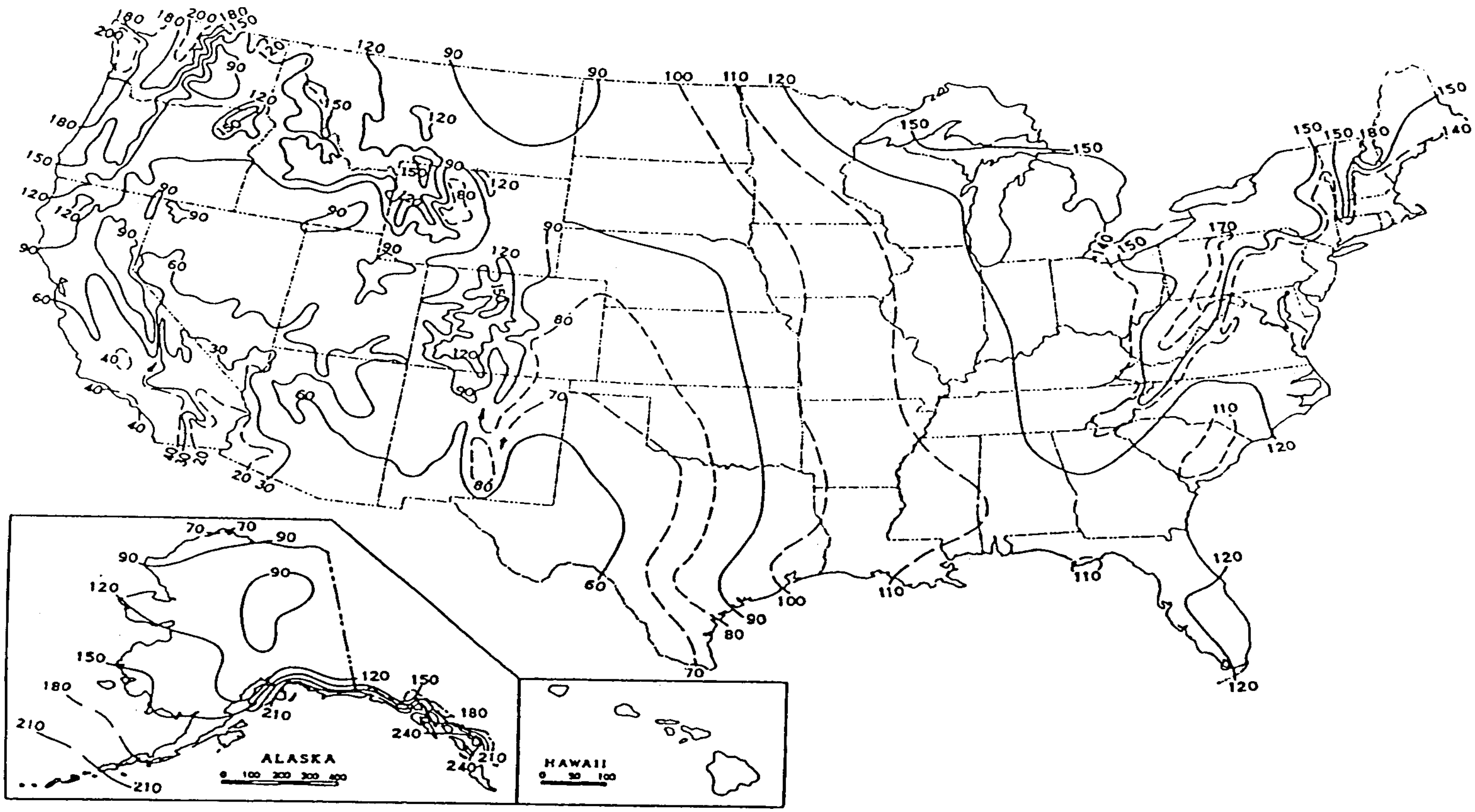
W = [(20 cars x 2 tons/car) + (10 trucks x 20 tons/truck)]/30 vehicles = 8 tons

The sum of the fleet vehicle kilometers traveled during construction (ΣVKT) can be estimated based on the size of the area of surface soil contamination, assuming the configuration of the unpaved road, and the amount of vehicle traffic on the road. For example, if the area of surface soil contamination is 0.5 acres (or 2,024 m^2), and one assumes that this area is configured as a square with the unpaved road segment dividing the square evenly, the road length would be equal to the square root of 2,024 m^2, 45 m (or 0.045 km). Assuming that each vehicle travels the length of the road once per day, 5 days per week for a total of 6 months, the total fleet vehicle kilometers traveled would be:

ΣVKT = 30 vehicles x 0.045 km/day x (52 wks/yr ÷ 2) x 5 days/wk = 175.5 km

Exhibit 5-2

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF ANNUAL PRECIPITATION



The equation for the subchronic dispersion factor for dust generated by unpaved road traffic, Q/C_{sr}, is presented in Equation 5-6. Q/C_{sr} was derived using EPA's ISC3 dispersion model for a hypothetical site under a wide range of meteorological conditions. Unlike the Q/C values for the other scenarios, the Q/C_{sr} for the construction scenario's simple site-specific approach can be modified only to reflect different site sizes between 0.5 and 500 acres; it cannot be modified for climatic zone. Users conducting a detailed site-specific analysis for the construction scenario can develop a site-specific Q/C_{sr} value by running the ISC3 model. Further details on the derivation of Q/C_{sr} can be found in Appendix E.

Equation 5-6
Derivation of the Dispersion Factor for Particulate Emissions from Unpaved Roads - Construction Scenario

$$Q/C_{sr} = A \times \exp\left[\frac{(\ln A_s - B)^2}{C}\right]$$

Parameter/Definition (units)	Default
Q/C_{sr}/inverse of the ratio of the 1-h geometric mean air concentration to the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3)	**23.02[a]**
A/constant (unitless)	**12.9351**
A_s/areal extent of site surface soil contamination (acres)	**0.5**
B/constant (unitless)	**5.7383**
C/constant (unitless)	**71.7711**

[a] Assumes a 0.5 acre site

Equations 5-7 and 5-8 are appropriate for calculating fugitive dust SSLs for carcinogens and non-carcinogens based on chronic exposure to off-site residents. The fugitive dust SSL is calculated for off-site residents who are exposed both during construction and after construction is complete. During site construction, off-site residents are assumed to be exposed to fugitive dust emissions from site traffic on temporary unpaved roads. After construction, receptors are assumed to be exposed to emissions from wind erosion. Although the construction exposure duration is considerably shorter than the post-construction exposure duration, the magnitude of emissions due to unpaved road traffic may be substantially higher than that due to wind erosion. For this reason, we evaluate chronic exposure to off-site residents by combining the total mass emitted from both unpaved road traffic during construction and wind erosion post-construction, normalizing this value over the total exposure duration.

Equation 5-7
Screening Level Equation for Chronic Inhalation of Carcinogenic Fugitive Dust Construction Scenario - Off-Site Resident

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365\text{d/yr}}{URF \times 1{,}000\mu\text{g/mg} \times EF \times ED \times \frac{1}{PEF_{off}}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (years)	70
URF/inhalation unit risk factor ($\mu g/m^3$)$^{-1}$	chemical-specific (Appendix C)
EF/exposure frequency (days/year)	**350**
ED/exposure duration (years)	**30**
PEF_{off}/off-site particulate emission factor (m^3/kg)	**4.40×10^8** **(Equation 5-9)**

Equation 5-8
Screening Level Equation for Chronic Inhalation of Non-carcinogenic Fugitive Dust Construction Scenario - Off-Site Resident

$$\text{Screening Level (mg/kg)} = \frac{THQ \times AT \times 365\text{d/yr}}{EF \times ED \times \left[\frac{1}{RfC} \times \frac{1}{PEF_{off}}\right]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (years)	**30**[a]
EF/exposure frequency (days/year)	**350**
ED/exposure duration (years)	**30**
RfC/inhalation reference concentration (mg/m^3)	chemical-specific (Appendix C)
PEF_{off}/off-site particulate emission factor (m^3/kg)	**4.40×10^8** **(Equation 5-9)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation 5-9 calculates the particulate emission factor for off-site residents (PEF_{off}). Because it normalizes the mass of fugitive dust emitted over 30 years, this equation requires separate estimates of the mass of dust emitted by traffic on unpaved roads during construction and the mass of dust emitted by wind erosion. These are calculated using Equation 5-10 (based on U.S. EPA, 1985) and Equation 5-11 (based on Cowherd et al., 1985), respectively.

Q/C_{off} can be derived for any source size between 0.5 and 500 acres using the equation and look-up table in Appendix D, Exhibit D-4. (The default Q/C_{off} factor assumes a 0.5 acre source size.) The look-up table in Exhibit D-4 provides the three coefficients for the Q/C_{off} equation (A, B, and C) for each of 29 cities selected to be representative of the range of meteorologic conditions across the country. The Q/C_{off} equation for each city was derived from the results of modeling runs of EPA's ISC3 dispersion model using five years of meteorological data. To calculate a site-specific Q/C_{off} factor, the site manager must first identify the climatic zone and city most representative of meteorological conditions at the site. Appendix D includes a map of climatic zones to help site managers select the appropriate Q/C_{off} coefficients. Once the coefficients have been identified, Q/C_{off} can be calculated for any source size between 0.5 and 500 acres and input into Equation 5-9 to derive a site-specific PEF_{off}.

Equation 5-9
Derivation of the Particulate Emission Factor
Construction Scenario - Off-Site Resident

$$PEF_{off} = Q/C_{off} \times \frac{1}{J_T}$$

where:

$$J_T = \frac{M_{road} + M_{wind}}{A_{site} \times ED \times (3.1536 \times 10^7 s/yr)}$$

Parameter/Definition (units)	Default
PEF_{off}/off-site particulate emission factor (m^3/kg)	4.40×10^8
Q/C_{off}/inverse of ratio of the geometric mean air concentration to the emission flux at the boundary of a square source (g/m^2-s per kg/m^3)	**89.03[a] (Appendix D, Appendix E)**
J_T/total time-averaged emission flux (g/m^2-s)	**site-specific**
M_{road}/unit mass emitted from unpaved road traffic (g)	**site-specific (Equation 5-10)**
M_{wind}/unit mass emitted from wind erosion (g)	**site-specific (Equation 5-11)**
A_{site}/areal extent of site (m^2)	**2,024**
ED/exposure duration (year)	**30**

[a] Assumes a 0.5 acre emission source

Equation 5-10
Mass of Dust Emitted by Road Traffic
Construction Scenario - Off-Site Resident

$$M_{road} \; ' \; 556(W/3)^{0.4} \times \left[\frac{(365d/yr \, \& \, p)}{365d/yr} \right] \times \Sigma VKT$$

Parameter/Definition (units)	Default
M_{road}/unit mass emitted from unpaved road traffic (g)	**site-specific**
W/mean vehicle weight (tons)	**site-specific**
p/number of days per year with at least 0.01 inches of precipitation (days/year)	**site-specific (Exhibit 5-2)**
' VKT/sum of fleet vehicle kilometers traveled during construction (km)	**site-specific**

Equation 5-11
Mass of Dust Emitted by Wind Erosion
Construction Scenario - Off-Site Resident

$$M_{wind} \; ' \; 0.036 \times (1 \, \& \, V) \times \left(\frac{U_m}{U_t} \right)^3 \times F(x) \times A_{surf} \times ED \times 8{,}760hr/yr$$

Parameter/Definition (units)	Default
M_{wind}/unit mass emitted from wind erosion (g)	1.32E+05
V/fraction of vegetative cover (unitless)	**0.5**
U_m/mean annual windspeed (m/s)	**4.69**
U_t/equivalent threshold value of windspeed at 7m (m/s)	**11.32**
F(x)/function dependent on U_m/U_t derived from Cowherd, et al., 1985 (unitless)	**0.194**
A_{surf}/areal extent of site with undisturbed surface soil contamination (m^2)	**2,024**
ED/exposure duration (years)	**30**

SSL Equations for Subsurface Soils

The relevant pathways for exposure to subsurface soils for the construction scenario include direct ingestion, dermal absorption, and inhalation of volatiles outdoors. As noted above, these pathways are evaluated for construction workers only. SSLs for ingestion and dermal absorption exposure to subsurface soils are calculated in the same way as those for surface soils and as described in the previous section.

Inhalation of Volatiles. Equations 5-12 through 5-15 are appropriate for calculating SSLs for subchronic outdoor inhalation of volatiles by construction workers. These equations are appropriate for the simple site-specific approach; the detailed site-specific modeling approach to this pathway is discussed in Appendix E. Equations 5-12 and 5-13 calculate the SSLs for the subchronic inhalation of carcinogenic and non-carcinogenic volatile compounds, respectively. Equation 5-14 is appropriate for calculating the soil-to-air volatilization factor (VF_{sc}) that relates the concentration of a contaminant in soil to the concentration in air resulting from volatilization. The equation for the subchronic dispersion factor for volatiles, Q/C_{sa}, is presented in Equation 5-15. Q/C_{sa} was derived using EPA's SCREEN3 dispersion model for a hypothetical site under a wide range of meteorological conditions. Unlike the Q/C values for the other scenarios, the Q/C_{sa} for the construction scenario's simple site-specific approach can be modified only to reflect different site sizes between 0.5 and 500 acres; it cannot be modified for climatic zone. Site managers conducting a detailed site-specific analysis for the construction scenario can develop a site-specific Q/C value by running the SCREEN3 model. Further details on the derivation of Q/C_{sa} can be found in Appendix E.

Equation 5-12
Screening Level Equation for Subchronic Inhalation of Carcinogenic Volatile Contaminants in Soil
Construction Scenario - Construction Worker

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{(mg/kg)}\end{array} = \frac{TR \times AT \times 365\,\text{d/yr}}{URF \times 1{,}000\,\mu\text{g/mg} \times EF \times ED \times \frac{1}{VF_{sc}}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (years)	70
URF/inhalation unit risk factor $(\mu g/m^3)^{-1}$	chemical-specific (Appendix C)
EF/exposure frequency (days/year)	**site-specific**
ED/exposure duration (years)	**site-specific**
VF_{sc}/subchronic soil-to-air volatilization factor (m^3/kg)	**chemical-specific (Equation 5-14)**

Equation 5-13
Screening Level Equation for Subchronic Inhalation of Non-Carcinogenic Volatile Contaminants in Soil Construction Scenario - Construction Worker

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{(mg/kg)}\end{array} = \frac{THQ \times AT \times 365\,\text{d/yr}}{EF \times ED \times \left(\frac{1}{HBL_{sc}} \times \frac{1}{VF_{sc}} \right)}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (years)	**site-specific**[a]
EF/exposure frequency (days/year)	**site-specific**
ED/exposure duration (years)	**site-specific**
HBL_{sc} /subchronic health-based limit (mg/m^3)	chemical-specific
VF_{sc}/subchronic soil-to-air volatilization factor (m^3/kg)	**chemical-specific (Equation 5-14)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation 5-16 is appropriate for calculating the soil saturation limit (C_{sat}) for each volatile compound. As discussed in Section 4.2.3, C_{sat} represents an upper bound on SSLs calculated using the VF model. If the calculated SSL exceeds C_{sat} and the contaminant is liquid at soil temperatures (see Appendix C, Exhibit C-3), the SSL should be set at C_{sat}. Soil screening decisions for organic compounds that are solid at soil temperatures should be based on SSLs for other exposure pathways.

Because the equations developed to calculate SSLs for the inhalation of volatiles outdoors assume an infinite source, they can violate mass-balance considerations, especially for small sources. To address this concern, a mass-limit SSL equation for this pathway may be used (Equation 5-17). This equation can be used only when the volume (i.e., area and depth) of the contaminated soil source is known or can be estimated with confidence.

As discussed above, the simple site-specific approach for calculating construction scenario SSLs uses the same emission model for volatiles as that used in the residential and non-residential scenarios. However, the conservative nature of this model (i.e., it assumes all contamination is at the surface) makes it sufficiently protective of construction worker exposures to volatiles. The toxicity values used in these equations (inhalation unit risk factors for cancer and subchronic reference concentrations for non-cancer effects) are based on an adult inhalation rate of 20 m^3/day. This is consistent with the rate used for residential and commercial/industrial SSLs. Although construction worker receptors are exposed for shorter periods each day than residents (generally eight to 10 hours versus 24 hours), data on worker-related activity levels and associated inhalation rates suggest that the 20 m^3/day rate is a reasonable estimate of RME for these workers (see Section 4.2.3 for a more complete discussion of these data).

Equation 5-14
Derivation of the Subchronic Volatilization Factor
Construction Scenario - Construction Worker

$$VF_{sc} = \left[\frac{(3.14 \times D_A \times T)^{1/2}}{2 \times \rho_b \times D_A}\right] \times 10^{-4}\, m^2/cm^2 \times Q/C_{sa} \times \frac{1}{F_D}$$

where:

$$D_A = \frac{[(\theta_a^{10/3} D_i H' + \theta_w^{10/3} D_w)/n^2]}{\rho_b K_d + \theta_w + \theta_a H'}$$

Parameter/Definition (units)	Default
VF_{sc}/subchronic volatilization factor (m^3/kg)	chemical-specific[a]
D_A/apparent diffusivity (cm^2/s)	chemical-specific[a]
T/total time over which construction occurs (s)	**site-specific**
ρ_b/dry soil bulk density (g/cm^3)	1.5
Q/C_{sa}/inverse of the ratio of the 1-h geometric mean air concentration to the volatilization flux at the center of a square site (g/m^2-s per kg/m^3)	**14.31[b] (Equation 5-15)**
F_D/dispersion correction factor (unitless)	0.185
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n-\theta_w$
n/total soil porosity (L_{pore}/L_{soil})	$1-(\rho_b/\rho_s)$
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
ρ_s/soil particle density (g/cm^3)	2.65
D_i/diffusivity in air (cm^2/s)	chemical-specific[a]
H′/dimensionless Henry's law constant	chemical-specific[a]
D_w/diffusivity in water (cm^2/s)	chemical-specific[a]
K_d/soil-water partition coefficient (cm^3/g)	for organics: $K_d = K_{oc} \times f_{oc}$ for inorganics: see Appendix C[c]
K_{oc}/soil organic carbon partition coefficient (cm^3/g)	chemical-specific[a]
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**

[a] See Appendix C

[b] Assumes a 0.5 acre site

[c] Assume a pH of 6.8 when selecting default K_d values

Equation 5-15
Derivation of the Dispersion Factor for Subchronic Volatile Contaminant Emissions Construction Scenario - Construction Worker

$$Q/C_{sa} = A \times \exp\left[\frac{(\ln A_c - B)^2}{C}\right]$$

Parameter/Definition (units)	Default
Q/C_{sa}/inverse of the ratio of the 1-h geometric mean air concentration to the volatilization flux at the center of the square source (g/m^2-s per kg/m^3)	**14.31**[a]
A/constant (unitless)	**2.4538**
A_c/areal extent of site soil contamination (acres)	**0.5**
B/constant (unitless)	**17.5660**
C/constant (unitless)	**189.0426**

[a] Assumes a 0.5 acre emission source

Equation 5-16
Derivation of the Soil Saturation Limit

$$C_{sat} = \frac{S}{\rho_b}(K_d\rho_b + \theta_w + H'\theta_a)$$

Parameter/Definition (units)	Default
C_{sat}/soil saturation concentration (mg/kg)	chemical-specific
S/solubility in water (mg/L-water)	chemical-specific (Appendix C)
ρ_b/dry soil bulk density (kg/L)	**1.5**
K_d/soil-water partition coefficient (L/kg)	organic = K_{oc} x f_{oc} inorganic = see Appendix C[a]
K_{oc}/organic carbon partition coefficient (L/kg)	chemical-specific (Appendix C)
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
H'/dimensionless Henry's law constant	chemical-specific (Appendix C)
θ_a/air-filled soil porosity (L_{air}/L_{soil})	n - θ_w
n/total soil porosity (L_{pore}/L_{soil})	1 - (ρ_b/ρ_s)
ρ_s/soil particle density (kg/L)	2.65

[a] Assume a pH of 6.8 when selecting default K_d values

Equation 5-17
Mass-Limit Volatilization Factor
Construction Scenario - Construction Worker

$$VF_{sc} = Q/C_{sa} \times \frac{1}{F_D} \times \frac{T \times (3.15 \times 10^7 s/yr)}{\rho_b \times d_s \times 10^6 g/Mg}$$

Parameter/Definition (units)	Default
VF_{sc}/volatilization factor (m^3/kg)	--
Q/C_{sa}/inverse of the ratio of the 1-h geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)	**14.31**[a] **(Equation 5-15)**
F_D/dispersion correction factor (unitless)	0.185 (Appendix E)
T/exposure interval (year)	**site-specific (=ED)**
ρ_b/dry soil bulk density (kg/L or Mg/m^3)	**1.5**
d_s/average source depth (m)	**site-specific**

[a] Assumes a 0.5 acre emission source

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APPENDIX A

GENERIC SSLs FOR THE RESIDENTIAL AND COMMERCIAL/INDUSTRIAL SCENARIOS

This appendix provides generic SSLs for 109 chemicals under residential and non-residential (i.e., commercial/industrial) exposure scenarios. Exhibit A-1 presents updated generic SSLs for the residential exposure scenario. The generic SSLs for three of the pathways in this exhibit — inhalation of volatiles in outdoor air, inhalation of fugitive dust, and migration to ground water — were calculated using the same equations and default values for exposure assumptions found in the 1996 *SSG* (and reproduced in Appendix B of this document). However, they incorporate updated values for dispersion factors, for toxicity, and for other chemical-specific parameters presented in Appendix C. The exhibit also presents new SSLs for concurrent exposures via soil ingestion and dermal absorption that are based, in part, on a new quantitative approach for evaluating dermal absorption. SSLs for combined direct ingestion and dermal absorption exposures to contaminants were calculated according to the method described in Section 3.2.1 of this document. The generic residential SSLs in Exhibit A-1 supersede those published in the 1996 *SSG*.

Exhibits A-2 and A-3 present commercial/industrial SSLs for the outdoor worker and indoor worker receptors, respectively. These SSLs have been calculated using the equations and the default values for exposure assumptions and other input parameters presented in Section 4.2.3 of this guidance document. All generic SSLs presented in this appendix, both residential and commercial/industrial, are rounded to two significant figures, with the exception of values less than 10 mg/kg, which are rounded to one significant figure.

As noted above, the values in this Appendix are based on chemical-specific physical and toxicological parameters presented in Appendix C. The values in Appendix C represent the most recent values available and are current as of the date of publication of this guidance. However, physical/chemical and toxicological data are subject to revision and should therefore be confirmed before referencing screening levels in the following tables. Trichloroethylene, in particular, is based on a draft risk assessment, and because the document is still undergoing review, the health benchmark values should be considered provisional.

EPA does not present generic SSLs for the construction exposure scenario because the complexity and variability of exposure conditions for construction activities precludes the development of such values. For information on developing SSLs for exposures during construction activities, users should refer to Chapter 5 or Appendix E of the guidance document.

The generic residential and non-residential SSLs are not necessarily protective of all known human exposure pathways or ecological threats. Before applying SSLs, it is therefore necessary to compare the conceptual site model (developed in Step 1 of the soil screening process) with the assumptions underlying the generic SSLs to ensure that site conditions and exposure pathways are consistent with these assumptions (See Exhibit A-4.) If this comparison indicates that the site is more complex than the generic SSL scenario, or that there are significant exposure pathways not accounted for by the SSL scenario, then generic SSLs alone are **not** sufficient to evaluate the site, and additional, more detailed site-specific investigation is necessary.

In each exhibit, the first column presents SSLs based on the combined soil ingestion and dermal absorption exposure pathway. When data on dermal absorption from soil are unavailable, these SSLs are based on ingestion exposures only. SSLs for this pathway may be updated in the future as dermal absorption data become available for other contaminants.

The second column in Exhibits A-1 and A-2 presents SSLs for the outdoor inhalation of volatiles pathway. Although residential receptors and indoor workers are potentially exposed to volatiles in indoor air as well, EPA has not calculated generic SSLs for migration of volatiles into indoor air because it is very difficult to identify suitable standardized default values for inputs such as dimensions of commercial buildings and the distance between contamination and a building's foundation. EPA provides spreadsheet models that can be used to calculate SSLs for this pathway using the simple site-specific or detailed site-specific approaches.[1] The third column in Exhibit A-1 and A-2 lists SSLs for the inhalation of fugitive dusts pathway. Because inhalation of fugitive dust is typically not a concern for organic compounds, SSLs for this pathway are presented only for inorganic compounds, which are listed at the end of each exhibit. Conversely, with the exception of mercury, no SSLs for the inhalation of volatiles pathway are provided for inorganic compounds because these chemicals exhibit extremely low volatility.

The user should note that several of the generic SSLs for the inhalation of volatiles pathway are determined by the chemical-specific soil saturation limit (C_{sat}) which is used to screen for the presence of non-aqueous phase liquids (NAPLs). As indicated in Section 4.2.3, in situations where the residual concentration of a compound that is a liquid at ambient soil temperature exceeds C_{sat}, the compound may exist as free-phase liquid (see Exhibit C-3 in Appendix C for a list of those compounds present in liquid phase at typical ambient soil temperatures). In these cases, further investigation will be required.

The final two columns in Exhibits A-1 through A-3 present generic SSLs for the migration to ground water pathway. The generic commercial/industrial SSLs for this pathway are the same as those for residential use and are unchanged from the 1996 *SSG*. As discussed in Section 4.2.3, this approach protects potential potable ground water resources that may be present beneath sites with commercial/industrial uses and protects off-site residents who may ingest ground water contaminated by the site. The migration to ground water SSLs are back-calculated from an acceptable target soil leachate concentration using a dilution-attenuation factor (DAF). The first of the two columns of SSLs for this pathway presents levels calculated using a DAF of 20 to account for reductions in contaminant concentration due to natural processes occurring in the subsurface. The second column presents SSL values for the migration to ground water pathway calculated assuming a DAF of one (i.e., no dilution or attenuation between the source and the receptor well). These levels should be used at sites where little or no dilution or attenuation of soil leachate concentrations is expected; this will be the case at sites with characteristics such as shallow water tables, fractured media, karst topography, or source size greater than 30 acres.

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[1] The vapor intrusion spreadsheets can be found on EPA's web site at http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm.

After all possible SSLs for all potential receptors at a site have been identified from the tables in Exhibits A-1 through A-3, the site manager should select the lowest applicable SSL for each exposure pathway to be used for comparison to site contaminant concentrations in soil. Generally, where the relevant SSL for a given pathway of concern is not exceeded, the user may eliminate the pathway from further investigation. If all pathways of concern are eliminated for an area of the site based on comparison with residential SSLs, that area can be eliminated from further investigation. However, if commercial/industrial SSLs are used in soil screening evaluations, elimination of an area from further consideration is contingent on an analysis of institutional control options. Users should consult Section 4.3.2 of the guidance document for more information.

The final exhibit in this appendix (Exhibit A-4) presents the default values for physical site characteristics that are used in calculating SSLs (both residential and commercial/industrial) for the inhalation and migration to ground water pathways. These values describe the nature of the contaminant source area, the characteristics of site soil, meteorologic conditions, and hydrogeologic characteristics, and serve either as direct input parameters for SSL equations or as assumptions for developing input parameters for the equations.

This appendix does not include SSLs for lead, dioxin, or PCBs, because EPA has issued separate documents that specify risk-based concentrations for these contaminants in soil. For guidance on addressing soil contaminated with lead, dioxin, or PCBs, please refer to the following sources:

Lead:

- U.S. EPA, 1994. *Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities*, EPA/540/F-94/043, Office of Solid Waste and Emergency Response, Washington, D.C. Directive 9355.4-12.

- U.S. EPA, 1996. *Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil*, Technical Review Workgroup for Lead (TRW), Washington, D.C.

- US EPA, 1999. *Frequently Asked Questions on the Adult Lead Model: Guidance Document*. Technical Review Workgroup for Lead (TRW), Washington, D.C. http://www.epa.gov/oerrpage/superfund/programs/lead/adfaqs.htm

PCBs:

- US EPA, 1990. *Guidance on Remedial Actions for Superfund Sites with PCB Contamination*. Office of Solid Waste and Emergency Response, Washington, D.C. NTIS PB91-921206CDH. (Currently being updated by the EPA PCB work group.)

Dioxin:

- U.S. EPA. 1998. *Approach for Addressing Dioxin in Soil at CERCLA and RCRA Sites*. OSWER Directive 9200.4-26.
- U.S. EPA. 2000. *Draft Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo*-p-*Dioxin (TCDD) and Related Compounds*. Office of Research and Development, Washington, D.C. EPA/600/P-00/001Bg. September.

Analysis of Effects of Source Size on Generic SSLs

The generic SSLs presented have been developed assuming an infinite source and a 0.5 acre source size. For an analysis of the sensitivity of generic SSLs to changes in source size and the depths to which infinite source SSLs are protective at larger sites, please refer to Attachment A and Table A-3 in the *Technical Background Document* of the 1996 *SSG*. Additional detail is also provided in the guidance documents specifically addressing screening levels for soils contaminated with lead, dioxin, or PCBs (listed above).

Exhibit A-1

GENERIC SSLs FOR RESIDENTIAL SCENARIO[a]

Compound	CAS No.	Ingestion-Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Ground Water	
Organics					DAF=20 (mg/kg)	DAF=1 (mg/kg)
Acenaphthene	83-32-9	3,400[b]	---[c]	---	570[b]	29[b]
Acetone (2-Propanone)	67-64-1	7,800[b,c]	---[c]	---	16[b]	0.8[b]
Aldrin	309-00-2	0.04[c,e]	3[e]	---	0.5[e]	0.02[e]
Anthracene	120-12-7	17,000[b]	---[c]	---	12,000[b]	590[b]
Benz(a)anthracene	56-55-3	0.6[e]	---[c]	---	2[e]	0.08[e,f]
Benzene	71-43-2	12[c,e]	0.8[e]	---	0.03	0.002[f]
Benzo(b)fluoranthene	205-99-2	0.6[e]	---[c]	---	5[e]	0.2[e,f]
Benzo(k)fluoranthene	207-08-9	6[e]	---[c]	---	49[e]	2[e]
Benzoic acid	65-85-0	310,000[b,c]	---[c]	---	400[b,k]	20[b,k]
Benzo(a)pyrene	50-32-8	0.06[e,f]	---[c]	---	8	0.4
Bis(2-chloroethyl)ether	111-44-4	0.4[e]	0.2[e,f]	---	0.0004[e,f]	0.00002[e,f]
Bis(2-ethylhexyl)phthalate	117-81-7	35[e]	---[c]	---	3,600	180
Bromodichloromethane	75-27-4	10[c,e]	---[c]	---	0.6	0.03
Bromoform (tribromomethane)	75-25-2	81[c,e]	52[e]	---	0.8	0.04
Butanol	71-36-3	7,800[b,c]	---[c]	---	17[b]	0.9[b]
Butyl benzyl phthalate	85-68-7	12,000[b]	---[c]	---	930[d]	810[b]
Carbazole	86-74-8	24[e]	---[c]	---	0.6[e]	0.03[e,f]
Carbon disulfide	75-15-0	7,800[b,c]	720[d]	---	32[b]	2[b]
Carbon tetrachloride	56-23-5	5[c,e]	0.3[e]	---	0.07	0.003[f]
Chlordane	57-74-9	2[e]	72[e]	---	10	0.5
p-Chloroaniline	106-47-8	240[b]	---[c]	---	0.7[b]	0.03[b,f]
Chlorobenzene	108-90-7	1,600[b,c]	380[b]	---	1	0.07
Chlorodibromomethane	124-48-1	8[c,e]	---[c]	---	0.4	0.02
Chloroform	67-66-3	780[b,c]	---[c]	---	0.6	0.03
2-Chlorophenol	95-57-8	310[b]	---[c]	---	4[b,k]	0.2[b,f,k]
Chrysene	218-01-9	62[e]	---[c]	---	160[e]	8[e]
DDD	72-54-8	3[c,e]	---[c]	---	16[e]	0.8[e]
DDE	72-55-9	2[c,e]	---[c]	---	54[e]	3[e]
DDT	50-29-3	2[e]	---[g]	---	32[e]	2[e]
Dibenz(a,h)anthracene	53-70-3	0.06[e,f]	---[c]	---	2[e]	0.08[e,f]
Di-n-butyl phthalate	84-74-2	6,100[b]	---[c]	---	2,300[d]	270[b]
1,2-Dichlorobenzene	95-50-1	5,500[b]	600[d]	---	17	0.9
1,4-Dichlorobenzene	106-46-7	20[e]	---[g]	---	2	0.1[f]
3,3-Dichlorobenzidine	91-94-1	1[e]	---[c]	---	0.007[e,f]	0.0003[e,f]
1,1-Dichloroethane	75-34-3	7,800[b,c]	1,200[b]	---	23[b]	1[b]
1,2-Dichloroethane	107-06-2	7[c,e]	0.4[e]	---	0.02	0.001[f]
1,1-Dichloroethylene	75-35-4	3900[b,c]	290[b]	---	0.06	0.003[f]
cis-1,2-Dichloroethylene	156-59-2	780[b,c]	---[c]	---	0.4	0.02
trans-1,2-Dichloroethylene	156-60-5	1,600[b,c]	---[c]	---	0.7	0.03
2,4-Dichlorophenol	120-83-2	180[b]	---[c]	---	1[b,k]	0.05[b,f,k]
2,4-Dichlorophenoxy-acetic acid	94-75-7	690[b]	---[c]	---	0.4[b,k]	0.02[b,k]
1,2-Dichloropropane	78-87-5	9[c,e]	15[b]	---	0.03	0.001[f]
1,3-Dichloropropene	542-75-6	6[c,e]	1[e]	---	0.004[e]	0.0002[e]

Exhibit A-1 (continued)

GENERIC SSLs FOR RESIDENTIAL SCENARIO[a]

Compound				Inhalation of Fugitive Particulates (mg/kg)	Migration to Ground Water	
***Organics** (continued)*	**CAS No.**	**Ingestion-Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**		**DAF=20 (mg/kg)**	**DAF=1 (mg/kg)**
Dieldrin	60-57-1	0.04[c,e]	1[e]	---	0.004[e]	0.0002[e,f]
Diethylphthalate	84-66-2	49,000[b]	---[c]	---	470[b]	23[b]
2,4-Dimethylphenol	105-67-9	1,200[b]	---[c]	---	9[b]	0.4[b]
2,4-Dinitrophenol	51-28-5	120[b]	---[c]	---	0.2[b,f,k]	0.008[b,f,k]
2,4-Dinitrotoluene	121-14-2	0.7[e]	---[c]	---	0.0008[e,f]	0.00004[e,f]
2,6-Dinitrotoluene	606-20-2	0.7[e]	---[c]	---	0.0007[e,f]	0.00003[e,f]
Di-n-octyl phthalate	117-84-0	1,200[b]	---[c]	---	10,000[d]	10,000[d]
Endosulfan	115-29-7	470[b,c]	---[c]	---	18[b]	0.9[b]
Endrin	72-20-8	23[b,c]	---[c]	---	1	0.05
Ethylbenzene	100-41-4	7,800[b,c]	400[d]	---	13	0.7
Fluoranthene	206-44-0	2,300[b]	---[c]	---	4,300[b]	210[b]
Fluorene	86-73-7	2,300[b]	---[c]	---	560[b]	28[b]
Heptachlor	76-44-8	0.1[c,e]	4[e]	---	23	1
Heptachlor Epoxide	1024-57-3	0.07[c,e]	5[e]	---	0.7	0.03
Hexachlorobenzene	118-74-1	0.3[e]	1[e]	---	2	0.1[f]
Hexachloro-1,3-butadiene	87-68-3	6[e]	8[e]	---	2	0.1[f]
α-HCH (α-BHC)	319-84-6	0.1[c,e]	0.7[e]	---	0.0005[e,f]	0.00003[e,f]
β-HCH(β-BHC)	319-85-7	0.4[c,e]	6[e]	---	0.003[e]	0.0001[e,f]
γ-HCH(Lindane)	58-89-9	0.4[e]	---[c]	---	0.009	0.0005[f]
Hexachlorocyclopentadiene	77-47-4	370[b]	29[b]	---	400	20
Hexachloroethane	67-72-1	35[e]	54[e]	---	0.5[e]	0.02[e,f]
Indeno(1,2,3-cd)pyrene	193-39-5	0.6[e]	---[c]	---	14[e]	0.7[e]
Isophorone	78-59-1	510[e]	---[c]	---	0.5[e]	0.03[e,f]
Methoxychlor	72-43-5	390[b,c]	---[c]	---	160	8
Methyl bromide	74-83-9	110[b,c]	9[b]	---	0.2[b]	0.01[b,f]
Methylene chloride	75-09-2	85[c,e]	13[e]	---	0.02[e]	0.001[e,f]
2-Methylphenol (o-cresol)	95-48-7	3,100[b]	---[c]	---	15[b]	0.8[b]
Naphthalene	91-20-3	1,100[b]	170[c]	---	84[b]	4[b]
Nitrobenzene	98-95-3	31[b]	90[b]	---	0.1[b,f]	0.007[b,f]
N-Nitrosodiphenylamine	86-30-6	99[e]	---[c]	---	1[e]	0.06[e,f]
N-Nitrosodi-n-propylamine	621-64-7	0.07[e,f]	---[c]	---	0.0000[e,f]	0.000002[e,f]
Pentachlorophenol	87-86-5	3[e]	---[c]	---	0.03[f,k]	0.001[f,k]
Phenol	108-95-2	18,000[b]	---[c]	---	100[b]	5[b]
Pyrene	129-00-0	1,700[b]	---[c]	---	4,200[b]	210[b]
Styrene	100-42-5	16,000[b,c]	1,500[d]	---	4	0.2
1,1,2,2-Tetrachloroethane	79-34-5	3[c,e]	0.6[e]	---	0.003[e,f]	0.0002[e,f]
Tetrachloroethylene	127-18-4	1[c,e]	1[e]	---	0.06	0.003[f]
Toluene	108-88-3	16,000[b,c]	650[d]	---	12	0.6
Toxaphene	8001-35-2	0.6[c,e]	87[e]	---	31	2
1,2,4-Trichlorobenzene	120-82-1	610[b]	3,200[d]	---	5	0.3[f]
1,1,1-Trichloroethane	71-55-6	---[c]	1,200[d]	---	2	0.1
1,1,2-Trichloroethane	79-00-5	11[c,e]	1[e]	---	0.02	0.0009[f]
Trichloroethylene[^]	79-01-6	2[c,e]	0.07[e]	---	0.06	0.003[f]
2,4,5-Trichlorophenol	95-95-4	6,100[b]	---[c]	---	270[b,k]	14[b,k]
2,4,6-Trichlorophenol	88-06-2	44[e]	200[e]	---	0.2[e,f,k]	0.008[e,f,k]

Exhibit A-1 (continued)

GENERIC SSLs FOR RESIDENTIAL SCENARIO[a]

Compound	CAS No.	Ingestion-Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Ground Water	
					DAF=20 (mg/kg)	DAF=1 (mg/kg)
***Organics** (continued)*						
Vinyl acetate	108-05-4	78,000 [b,c]	980 [b]	---	170 [b]	8 [b]
Vinyl chloride (chloroethene)	75-01-4	0.4 [c,e,h]	0.6 [e,i]	---	0.01 [f,k,i]	0.0007 [f,i]
m-Xylene	108-38-3	160,000 [b,c]	--- [c]	---	210	10
o-Xylene	95-47-6	160,000 [b,c]	--- [c]	---	190	9
p-Xylene	106-42-3	160,000 [b,c]	--- [c]	---	200	10
Inorganics						
Antimony	7440-36-0	31 [b,c]	---	--- [c]	5	0.3
Arsenic	7440-38-2	0.4 [e]	---	770 [e]	29 [k]	1 [k]
Barium	7440-39-3	5,500 [b,c]	---	710,000 [b]	1,600 [k]	82 [k]
Beryllium	7440-41-7	160 [c,e]	---	1,400 [e]	63 [k]	3 [k]
Cadmium	7440-43-9	70 [b,j]	---	1,800 [e]	8 [k]	0.4 [k]
Chromium (total)	7440-47-3	230 [b,c]	---	280 [e]	38 [k]	2 [k]
Chromium (III)	16065-83-1	120,000 [b,c]	---	--- [c]	--- [g]	--- [g]
Chromium (VI)	18540-29-9	230 [b,c]	---	280 [e]	38 [k]	2 [k]
Cyanide (amenable)	57-12-5	1,600 [b,c]	---	--- [c]	40	2
Mercury	7439-97-6	23 [b,c,l]	10 [b,k]	---	2 [k]	0.1 [k]
Nickel	7440-02-0	1,600 [b,c]	---	14,000 [e]	130 [k]	7 [k]
Selenium	7782-49-2	390 [b,c]	---	--- [c]	5 [k]	0.3 [k]
Silver	7440-22-4	390 [b,c]	---	--- [c]	34 [b,k]	2 [b,k]
Thallium	7440-28-0	6 [b,c,m]	---	--- [c]	0.7 [k]	0.04 [k]
Vanadium	7440-62-2	550 [b,c]	---	--- [c]	6,000 [b]	300 [b]
Zinc	7440-66-6	23,000 [b,c]	---	--- [c]	12,000 [b,k]	620 [b,k]

DAF = Dilution Attenuation Factor

[a] Screening level based on human health criteria only

[b] Calculated values correspond to a noncancer hazard quotient of 1. For exposure to multiple non-carcinogens, EPA evaluates contaminants according to their critical effect. See section 2.3 for further discussion.

[c] Ingestion-Dermal pathway: no dermal absorption data available; calculated based on ingestion data only. Inhalation of volatiles pathway: no toxicity criteria available

[d] Soil Saturation Limit (Csat)

[e] Calculated values correspond to a cancer risk of 1 in 1,000,000. For multiple carcinogens, EPA believes values will accumulate to be within acceptable risk levels. See section 2.3 for further discussion.

[f] Level is at or below Contract Laboratory Program required quantification limit for Regular Analytical Services (RAS)

[g] Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration

[h] SSL is based on continuous exposure to vinyl chloride over a lifetime.

[i] SSL is based on continuous exposure to vinyl chloride during adulthood.

[j] SSL is based on dietary RfD for Cadmium

[k] SSL for pH of 6.8

[l] SSL is based on RfD for mercuric chloride (CAS No. 007847-94-7)

[m] SSL is based on RfD for thallium chloride (CAS No. 7791-12-0)

[^] Health benchmark values are based on NCEA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft* (ORD, August, 2001). The trichloroethylene draft risk assessment is still under review. As a result, the health benchmark values are subject to change.

Exhibit A-2

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: OUTDOOR WORKER RECEPTOR[a]

Compound					Migration to Ground Water	
Organics	CAS No.	Ingestion-Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	DAF=20 (mg/kg)	DAF=1 (mg/kg)
Acenaphthene	83-32-9	37,000[b]	---[c]	---	570[b]	29[b]
Acetone (2-Propanone)	67-64-1	110,000[b,c]	---[c]	---	16[b]	0.8[b]
Aldrin	309-00-2	0.2[c,e]	6[e]	---	0.5[e]	0.02[e]
Anthracene	120-12-7	180,000[b]	---[c]	---	12,000[b]	590[b]
Benz(a)anthracene	56-55-3	2[e]	---[c]	---	2[e]	0.08[e,f]
Benzene	71-43-2	58[c,e]	1[e]	---	0.03	0.002[f]
Benzo(b)fluoranthene	205-99-2	2[e]	---[c]	---	5[e]	0.2[e,f]
Benzo(k)fluoranthene	207-08-9	23[e]	---[c]	---	49[e]	2[e]
Benzoic acid	65-85-0	1,000,000[b,c]	---[c]	---	400[b,j]	20[b,j]
Benzo(a)pyrene	50-32-8	0.2[e]	---[c]	---	8	0.4
Bis(2-chloroethyl)ether	111-44-4	2[e]	0.4[e]	---	0.0004[e,f]	0.00002[e,f]
Bis(2-ethylhexyl)phthalate	117-81-7	140[e]	---[c]	---	3,600	180
Bromodichloromethane	75-27-4	51[c,e]	---[c]	---	0.6	0.03
Bromoform (tribromomethane)	75-25-2	400[c,e]	88[e]	---	0.8	0.04
Butanol	71-36-3	110,000[b,c]	---[c]	---	17[b]	0.9[b]
Butyl benzyl phthalate	85-68-7	140,000[b]	---[c]	---	930[d]	810[b]
Carbazole	86-74-8	96[e]	---[c]	---	0.6[e]	0.03[e,f]
Carbon disulfide	75-15-0	110,000[b,c]	720[d]	---	32[b]	2[b]
Carbon tetrachloride	56-23-5	24[c,e]	0.6[e]	---	0.07	0.003[f]
Chlordane	57-74-9	7[e]	120[e]	---	10	0.5
p-Chloroaniline	106-47-8	2,700[b]	---[c]	---	0.7[b]	0.03[b,f]
Chlorobenzene	108-90-7	23,000[b,c]	540[b]	---	1	0.07
Chlorodibromomethane	124-48-1	38[c,e]	---[c]	---	0.4	0.02
Chloroform	67-66-3	11,000[b,c]	---[c]	---	0.6	0.03
2-Chlorophenol	95-57-8	3,400[b]	---[c]	---	4[b,j]	0.2[b,f,j]
Chrysene	218-01-9	230[e]	---[c]	---	160[e]	8[e]
DDD	72-54-8	13[c,e]	---[c]	---	16[e]	0.8[e]
DDE	72-55-9	9[c,e]	---[c]	---	54[e]	3[e]
DDT	50-29-3	8[e]	---[g]	---	32[e]	2[e]
Dibenz(a,h)anthracene	53-70-3	0.2[e]	---[c]	---	2[e]	0.08[e,f]
Di-n-butyl phthalate	84-74-2	68,000[b]	---[c]	---	2,300[d]	270[b]
1,2-Dichlorobenzene	95-50-1	62,000[b]	600[d]	---	17	0.9
1,4-Dichlorobenzene	106-46-7	80[e]	---[g]	---	2	0.1[f]
3,3-Dichlorobenzidine	91-94-1	4[e]	---[c]	---	0.007[e,f]	0.0003[e,f]
1,1-Dichloroethane	75-34-3	110,000[b,c]	1,700[d]	---	23[b]	1[b]
1,2-Dichloroethane	107-06-2	35[c,e]	0.6[e]	---	0.02	0.001[f]
1,1-Dichloroethylene	75-35-4	57,000[b,c]	410[b]	---	0.06	0.003[f]
cis-1,2-Dichloroethylene	156-59-2	11,000[b,c]	---[c]	---	0.4	0.02
trans-1,2-Dichloroethylene	156-60-5	23,000[b,c]	---[c]	---	0.7	0.03
2,4-Dichlorophenol	120-83-2	2,100[b]	---[c]	---	1[b,j]	0.05[b,f,j]
2,4-Dichlorophenoxy-acetic acid	94-75-7	8,500[b]	---[c]	---	0.4[b,j]	0.02[b,j]
1,2-Dichloropropane	78-87-5	47[c,e]	21[b]	---	0.03	0.001[f]
1,3-Dichloropropene	542-75-6	32[c,e]	2[e]	---	0.004[e]	0.0002[e]

Exhibit A-2 (continued)

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: OUTDOOR WORKER RECEPTOR[a]

Compound	CAS No.	Ingestion-Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Ground Water	
***Organics* (continued)**					**DAF=20 (mg/kg)**	**DAF=1 (mg/kg)**
Dieldrin	60-57-1	0.2 [c,e]	2 [e]	---	0.004 [e]	0.0002 [e,f]
Diethylphthalate	84-66-2	550,000 [b]	--- [c]	---	470 [b]	23 [b]
2,4-Dimethylphenol	105-67-9	14,000 [b]	--- [c]	---	9 [b]	0.4 [b]
2,4-Dinitrophenol	51-28-5	1,400 [b]	--- [c]	---	0.2 [b,f,j]	0.008 [b,f,j]
2,4-Dinitrotoluene	121-14-2	3 [e]	--- [c]	---	0.0008 [e,f]	0.00004 [e,f]
2,6-Dinitrotoluene	606-20-2	3 [e]	--- [c]	---	0.0007 [e,f]	0.00003 [e,f]
Di-n-octyl phthalate	117-84-0	14,000 [b]	--- [c]	---	10,000 [d]	10,000 [d]
Endosulfan	115-29-7	6,800 [b,c]	--- [c]	---	18 [b]	0.9 [b]
Endrin	72-20-8	340 [b,c]	--- [c]	---	1	0.05
Ethylbenzene	100-41-4	110,000 [b,c]	400 [d]	---	13	0.7
Fluoranthene	206-44-0	24,000 [b]	--- [c]	---	4,300 [b]	210 [b]
Fluorene	86-73-7	24,000 [b]	--- [c]	---	560 [b]	28 [b]
Heptachlor	76-44-8	0.7 [c,e]	7 [e]	---	23	1
Heptachlor Epoxide	1024-57-3	0.3 [c,e]	8 [e]	---	0.7	0.03
Hexachlorobenzene	118-74-1	1 [e]	2 [e]	---	2	0.1 [f]
Hexachloro-1,3-butadiene	87-68-3	25 [e]	13 [e]	---	2	0.1 [f]
α-HCH (α-BHC)	319-84-6	0.5 [c,e]	1 [e]	---	0.0005 [e,f]	0.00003 [e,f]
β-HCH(β-BHC)	319-85-7	2 [c,e]	--- [g]	---	0.003 [e]	0.0001 [e,f]
γ-HCH(Lindane)	58-89-9	2 [e]	--- [c]	---	0.009	0.0005 [f]
Hexachlorocyclopentadiene	77-47-4	4,100 [b]	41 [b]	---	400	20
Hexachloroethane	67-72-1	140 [e]	92 [e]	---	0.5 [e]	0.02 [e,f]
Indeno(1,2,3-cd)pyrene	193-39-5	2 [e]	--- [c]	---	14 [e]	0.7 [e]
Isophorone	78-59-1	2,000 [e]	--- [c]	---	0.5 [e]	0.03 [e,f]
Methoxychlor	72-43-5	5,700 [b,c]	--- [c]	---	160	8
Methyl bromide	74-83-9	1,600 [b,c]	13 [b]	---	0.2 [b]	0.01 [b,f]
Methylene chloride	75-09-2	420 [c,e]	22 [e]	---	0.02 [e]	0.001 [e,f]
2-Methylphenol (o-cresol)	95-48-7	34,000 [b]	--- [c]	---	15 [b]	0.8 [b]
Naphthalene	91-20-3	12,000 [b]	240 [b]	---	84 [b]	4 [b]
Nitrobenzene	98-95-3	340 [b]	130 [b]	---	0.1 [b,f]	0.007 [b,f]
N-Nitrosodiphenylamine	86-30-6	390 [e]	--- [c]	---	1 [e]	0.06 [e,f]
N-Nitrosodi-n-propylamine	621-64-7	0.3 [e]	--- [c]	---	0.00005 [e,f]	0.000002 [e,f]
Pentachlorophenol	87-86-5	10 [e]	--- [c]	---	0.03 [f,j]	0.001 [f,j]
Phenol	108-95-2	210,000 [b]	--- [c]	---	100 [b]	5 [b]
Pyrene	129-00-0	18,000 [b]	--- [c]	---	4,200 [b]	210 [b]
Styrene	100-42-5	230,000 [b,c]	1,500 [d]	---	4	0.2
1,1,2,2-Tetrachloroethane	79-34-5	16 [c,e]	1 [e]	---	0.003 [e,f]	0.0002 [e,f]
Tetrachloroethylene	127-18-4	6 [c,e]	2 [e]	---	0.06	0.003 [f]
Toluene	108-88-3	230,000 [b,c]	650 [d]	---	12	0.6
Toxaphene	8001-35-2	3 [c,e]	150 [e]	---	31	2
1,2,4-Trichlorobenzene	120-82-1	6,800 [b]	3,200 [d]	---	5	0.3 [f]
1,1,1-Trichloroethane	71-55-6	--- [c]	1,200 [d]	---	2	0.1
1,1,2-Trichloroethane	79-00-5	56 [c,e]	2 [e]	---	0.02	0.0009 [f]
Trichloroethylene[^]	79-01-6	8 [c,e]	0.1 [e]	---	0.06	0.003 [f]
2,4,5-Trichlorophenol	95-95-4	68,000 [b]	--- [c]	---	270 [b,j]	14 [b,j]
2,4,6-Trichlorophenol	88-06-2	170 [e]	340 [e]	---	0.2 [e,f,j]	0.008 [e,f,j]

Exhibit A-2 (continued)

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: OUTDOOR WORKER RECEPTOR[a]

Compound					Migration to Ground Water	
***Organics* (continued)**	**CAS No.**	**Ingestion-Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**DAF=20 (mg/kg)**	**DAF=1 (mg/kg)**
Vinyl acetate	108-05-4	1,000,000 [b,c]	1,400 [b]	---	170 [b]	8 [b]
Vinyl chloride (chloroethene)	75-01-4	4 [c,e,h]	1 [e,h]	---	0.01 [f,h,j]	0.0007 [f,h]
m-Xylene	108-38-3	1,000,000 [b,c]	--- [c]	---	210	10
o-Xylene	95-47-6	1,000,000 [b,c]	--- [c]	---	190	9
p-Xylene	106-42-3	1,000,000 [b,c]	--- [c]	---	200	10
Inorganics						
Antimony	7440-36-0	450 [b,c]	---	--- [c]	5	0.3
Arsenic	7440-38-2	2 [e]	---	1,400 [e]	29 [j]	1 [j]
Barium	7440-39-3	79,000 [b,c]	---	1,000,000 [b]	1,600 [j]	82 [j]
Beryllium	7440-41-7	2,300 [c,e]	---	2,600 [e]	63 [j]	3 [j]
Cadmium	7440-43-9	900 [b,i]	---	3,400 [e]	8 [j]	0.4 [j]
Chromium (total)	7440-47-3	3,400 [b,c]	---	510 [e]	38 [j]	2 [j]
Chromium (III)	16065-83-1	1,000,000 [b,c]	---	--- [c]	--- [g]	--- [g]
Chromium (VI)	18540-29-9	3,400 [b,c]	---	510 [e]	38 [j]	2 [j]
Cyanide (amenable)	57-12-5	23,000 [b,c]	---	--- [c]	40	2
Mercury	7439-97-6	340 [b,c,k]	14 [b,k]	---	2 [j]	0.1 [j]
Nickel	7440-02-0	23,000 [b,c]	---	26,000 [e]	130 [j]	7 [j]
Selenium	7782-49-2	5,700 [b,c]	---	--- [c]	5 [j]	0.3 [j]
Silver	7440-22-4	5,700 [b,c]	---	--- [c]	34 [b,j]	2 [b,j]
Thallium	7440-28-0	91 [b,c,l]	---	--- [c]	0.7 [j]	0.04 [j]
Vanadium	7440-62-2	7,900 [b,c]	---	--- [c]	6,000 [b]	300 [b]
Zinc	7440-66-6	340,000 [b,c]	---	--- [c]	12,000 [b,j]	620 [b,j]

DAF = Dilution Attenuation Factor

[a] Screening level based on human health criteria only

[b] Calculated values correspond to a noncancer hazard quotient of 1. For exposure to multiple non-carcinogens, EPA evaluates contaminants according to their critical effect. See section 2.3 for further discussion.

[c] Ingestion-Dermal pathway: no dermal absorption data available; calculated based on ingestion data only. Inhalation of volatiles pathway: no toxicity criteria available

[d] Soil Saturation Limit (Csat)

[e] Calculated values correspond to a cancer risk of 1 in 1,000,000. For multiple carcinogens, EPA believes values will accumulate to be within acceptable risk levels. See section 2.3 for further discussion.

[f] Level is at or below Contract Laboratory Program required quantification limit for Regular Analytical Services (RAS)

[g] Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration

[h] SSL is based on continuous exposure to vinyl chloride during adulthood.

[i] SSL is based on dietary RfD for Cadmium

[j] SSL for pH of 6.8

[k] SSL is based on RfD for mercuric chloride (CAS No. 007847-94-7)

[l] SSL is based on RfD for thallium chloride (CAS No. 7791-12-0)

[^] Health benchmark values are based on NCEA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft* (ORD, August, 2001). The trichloroethylene draft risk assessment is still under review. As a result, the health benchmark values are subject to change.

Exhibit A-3

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: INDOOR WORKER RECEPTOR[a]

Compound	CAS No.	Ingestion-Dermal* (mg/kg)	Migration to Ground Water	
			DAF=20 (mg/kg)	DAF=1 (mg/kg)
Organics				
Acenaphthene	83-32-9	120,000[b]	570[b]	29[b]
Acetone (2-Propanone)	67-64-1	200,000[b]	16[b]	0.8[b]
Aldrin	309-00-2	0.3[e]	0.5[e]	0.02[e]
Anthracene	120-12-7	610,000[b]	12,000[b]	590[b]
Benz(a)anthracene	56-55-3	8[e]	2[e]	0.08[e,f]
Benzene	71-43-2	100[e]	0.03	0.002[f]
Benzo(b)fluoranthene	205-99-2	8[e]	5[e]	0.2[e,f]
Benzo(k)fluoranthene	207-08-9	78[e]	49[e]	2[e]
Benzoic acid	65-85-0	1,000,000[b]	400[b,j]	20[b,j]
Benzo(a)pyrene	50-32-8	0.8[e]	8	0.4
Bis(2-chloroethyl)ether	111-44-4	5[e]	0.0004[e,f]	0.00002[e,f]
Bis(2-ethylhexyl)phthalate	117-81-7	410[e]	3,600	180
Bromodichloromethane	75-27-4	92[e]	0.6	0.03
Bromoform (tribromomethane)	75-25-2	720[e]	0.8	0.04
Butanol	71-36-3	200,000[b]	17[b]	0.9[b]
Butyl benzyl phthalate	85-68-7	410,000[b]	930[d]	810[b]
Carbazole	86-74-8	290[e]	0.6[e]	0.03[e,f]
Carbon disulfide	75-15-0	200,000[b]	32[b]	2[b]
Carbon tetrachloride	56-23-5	44[e]	0.07	0.003[f]
Chlordane	57-74-9	16[e]	10	0.5
p-Chloroaniline	106-47-8	8,200[b]	0.7[b]	0.03[b,f]
Chlorobenzene	108-90-7	41,000[b]	1	0.07
Chlorodibromomethane	124-48-1	68[e]	0.4	0.02
Chloroform	67-66-3	20,000[b]	0.6	0.03
2-Chlorophenol	95-57-8	10,000[b]	4[b,j]	0.2[b,f,j]
Chrysene	218-01-9	780[e]	160[e]	8[e]
DDD	72-54-8	24[e]	16[e]	0.8[e]
DDE	72-55-9	17[e]	54[e]	3[e]
DDT	50-29-3	17[e]	32[e]	2[e]
Dibenz(a,h)anthracene	53-70-3	0.8[e]	2[e]	0.08[e,f]
Di-n-butyl phthalate	84-74-2	200,000[b]	2,300[d]	270[b]
1,2-Dichlorobenzene	95-50-1	180,000[b]	17	0.9
1,4-Dichlorobenzene	106-46-7	240[e]	2	0.1[f]
3,3-Dichlorobenzidine	91-94-1	13[e]	0.007[e,f]	0.0003[e,f]
1,1-Dichloroethane	75-34-3	200,000[b]	23[b]	1[b]
1,2-Dichloroethane	107-06-2	63[e]	0.02	0.001[f]
1,1-Dichloroethylene	75-35-4	100,000[b]	0.06	0.003[f]
cis-1,2-Dichloroethylene	156-59-2	20,000[b]	0.4	0.02
trans-1,2-Dichloroethylene	156-60-5	41,000[b]	0.7	0.03
2,4-Dichlorophenol	120-83-2	6,100[b]	1[b,j]	0.05[b,f,j]
2,4-Dichlorophenoxy-acetic acid	94-75-7	20,000[b]	0.4[b]	0.02[b,j]

Exhibit A-3 (continued)

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: INDOOR WORKER RECEPTOR[a]

Compound	CAS No.	Ingestion-Dermal* (mg/kg)	Migration to Ground Water	
Organics(continued)			DAF=20 (mg/kg)	DAF=1 (mg/kg)
1,2-Dichloropropane	78-87-5	84[e]	0.03	0.001[f]
1,3-Dichloropropene	542-75-6	57[e]	0.004[e]	0.0002[e]
Dieldrin	60-57-1	0.4[e]	0.004[e]	0.0002[e,f]
Diethylphthalate	84-66-2	1,000,000[b]	470[b]	23[b]
2,4-Dimethylphenol	105-67-9	41,000[b]	9[b]	0.4[b]
2,4-Dinitrophenol	51-28-5	4,100[b]	0.2[b,f,j]	0.008[b,f,j]
2,4-Dinitrotoluene	121-14-2	8[e]	0.0008[e,f]	0.00004[e,f]
2,6-Dinitrotoluene	606-20-2	8[e]	0.0007[e,f]	0.00003[e,f]
Di-n-octyl phthalate	117-84-0	41,000[b]	10,000[d]	10,000[d]
Endosulfan	115-29-7	12,000[b]	18[b]	0.9[b]
Endrin	72-20-8	610[b]	1	0.05
Ethylbenzene	100-41-4	200,000[b]	13	0.7
Fluoranthene	206-44-0	82,000[b]	4,300[b]	210[b]
Fluorene	86-73-7	82,000[b]	560[b]	28[b]
Heptachlor	76-44-8	1[e]	23	1
Heptachlor Epoxide	1024-57-3	0.6[e]	0.7	0.03
Hexachlorobenzene	118-74-1	4[e]	2	0.1[f]
Hexachloro-1,3-butadiene	87-68-3	73[e]	2	0.1[f]
"-HCH ("-BHC)	319-84-6	0.9[e]	0.0005[e,f]	0.00003[e,f]
$-HCH($-BHC)	319-85-7	3[e]	0.003[e]	0.0001[e,f]
(-HCH(Lindane)	58-89-9	4[e]	0.009	0.0005[f]
Hexachlorocyclopentadiene	77-47-4	12,000[b]	400	20
Hexachloroethane	67-72-1	410[e]	0.5[e]	0.02[e,f]
Indeno(1,2,3-cd)pyrene	193-39-5	8[e]	14[e]	0.7[e]
Isophorone	78-59-1	6,000[e]	0.5[e]	0.03[e,f]
Methoxychlor	72-43-5	10,000[b]	160	8
Methyl bromide	74-83-9	2,900[b]	0.2[b]	0.01[b,f]
Methylene chloride	75-09-2	760[e]	0.02[e]	0.001[e,f]
2-Methylphenol (o-cresol)	95-48-7	100,000[b]	15[b]	0.8[b]
Naphthalene	91-20-3	41,000[b]	84[b]	4[b]
Nitrobenzene	98-95-3	1,000[b]	0.1[b,f]	0.007[b,f]
N-Nitrosodiphenylamine	86-30-6	1,200[e]	1[e]	0.06[e,f]
N-Nitrosodi-n-propylamine	621-64-7	0.8[e]	0.00005[e,f]	0.000002[e,f]
Pentachlorophenol	87-86-5	48[e]	0.03[f,j]	0.001[f,j]
Phenol	108-95-2	610,000[b]	100[b]	5[b]
Pyrene	129-00-0	61,000[b]	4,200[b]	210[b]
Styrene	100-42-5	410,000[b]	4	0.2
1,1,2,2-Tetrachloroethane	79-34-5	29[e]	0.003[e,f]	0.0002[e,f]
Tetrachloroethylene	127-18-4	11[e]	0.06	0.003[f]
Toluene	108-88-3	410,000[b]	12	0.6
Toxaphene	8001-35-2	5[e]	31	2
1,2,4-Trichlorobenzene	120-82-1	20,000[b]	5	0.3[f]
1,1,1-Trichloroethane	71-55-6	---[c]	2	0.1
1,1,2-Trichloroethane	79-00-5	100[e]	0.02	0.0009[f]
Trichloroethylene^	79-01-6	14[e]	0.06	0.003[f]
2,4,5-Trichlorophenol	95-95-4	200,000[b]	270[b,j]	14[b,j]

Exhibit A-3 (continued)

GENERIC SSLs FOR COMMERCIAL/INDUSTRIAL SCENARIO: INDOOR WORKER RECEPTOR[a]

Compound			Migration to Ground Water	
Organics(continued)	**CAS No.**	**Ingestion-Dermal* (mg/kg)**	**DAF=20 (mg/kg)**	**DAF=1 (mg/kg)**
2,4,6-Trichlorophenol	88-06-2	520 [e]	0.2 [e,f,j]	0.008 [e,f,j]
Vinyl acetate	108-05-4	1,000,000 [b,c]	170 [b]	8 [b]
Vinyl chloride (chloroethene)	75-01-4	8 [e,h]	0.01 [f,h,j]	0.0007 [f,h]
m-Xylene	108-38-3	1,000,000 [b]	210	10
o-Xylene	95-47-6	1,000,000 [b]	190	9
p-Xylene	106-42-3	1,000,000 [b]	200	10
Inorganics				
Antimony	7440-36-0	820 [b]	5	0.3
Arsenic	7440-38-2	4 [e]	29 [j]	1 [j]
Barium	7440-39-3	140,000 [b]	1,600 [j]	82 [j]
Beryllium	7440-41-7	4,100 [b]	63 [j]	3 [j]
Cadmium	7440-43-9	2,000 [b,i]	8 [j]	0.4 [j]
Chromium (total)	7440-47-3	6,100 [b]	38 [j]	2 [j]
Chromium (III)	16065-83-1	1,000,000 [b]	--- [g]	--- [g]
Chromium (VI)	18540-29-9	6,100 [b]	38 [j]	2 [j]
Cyanide (amenable)	57-12-5	41,000 [b]	40	2
Mercury	7439-97-6	610 [b,k]	2 [j]	0.1 [j]
Nickel	7440-02-0	41,000 [b]	130 [j]	7 [j]
Selenium	7782-49-2	10,000 [b]	5 [j]	0.3 [j]
Silver	7440-22-4	10,000 [b]	34 [b,j]	2 [b,j]
Thallium	7440-28-0	160 [b,l]	0.7 [j]	0.04 [j]
Vanadium	7440-62-2	14,000 [b]	6,000 [b]	300 [b]
Zinc	7440-66-6	610,000 [b]	12,000 [b,j]	620 [b,j]

DAF = Dilution Attenuation Factor

* No dermal absorption data available for indoor worker receptor; calculated based on ingestion data only

[a] Screening level based on human health criteria only

[b] Calculated values correspond to a noncancer hazard quotient of 1

[c] Ingestion-Dermal pathway: no dermal absorption data available; calculated based on ingestion data only. Inhalation of volatiles pathway: no toxicity criteria available

[d] Soil Saturation Limit (Csat)

[e] Calculated values correspond to a cancer risk of 1 in 1,000,000

[f] Level is at or below Contract Laboratory Program required quantification limit for Regular Analytical Services (RAS)

[g] Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration

[h] SSL is based on continuous exposure to vinyl chloride during adulthood.

[i] SSL is based on dietary RfD for Cadmium

[j] SSL for pH of 6.8

[k] SSL is based on RfD for mercuric chloride (CAS No. 007847-94-7)

[l] SSL is based on RfD for thallium chloride (CAS No. 7791-12-0)

^ Health benchmark values are based on NCEA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft* (ORD, August, 2001). The trichloroethylene draft risk assessment is still under review. As a result, the health benchmark values are subject to change.

Exhibit A-4

GENERIC SSLs: DEFAULT VALUES FOR PARAMETERS DESCRIBING SITE CONDITIONS - INHALATION AND MIGRATION TO GROUND WATER PATHWAYS

	SSL Pathway		
Parameter	**Inhalation**	**Migration to Ground Water**	**Method**
Source Characteristics			
Continuous vegetative cover	!		50 percent
Roughness height	"		0.5 cm for open terrain; used to derive $U_{t,7}$
Source area (A)	!	"	0.5 acres (2,024m^2); used to derive L for GW
Source length (L)		!	45 m (assumes square source)
Source depth		"	Extends to water table (i.e., no attenuation in unsaturated zone)
Soil Characteristics			
Soil texture	"	"	Loam; defines soil characteristics/parameters
Dry soil bulk density (D_b)	!	!	1.5 kg/L
Soil porosity (n)	!	"	0.43
Vol. soil water content (θ_w)	!	!	0.15 (INH); 0.30 (GW; Indoor INH)*
Vol. soil air content (θ_a)	!	!	0.28 (INH); 0.13 (GW; Indoor INH)*
Soil organic carbon (f_{oc})	!	!	0.006 (0.6%, INH); 0.002 (0.2%, GW)
Soil pH	"	"	6.8; used to determine pH-specific K_d (metals) and K_{OC} (ionizable organics)
Mode soil aggregate size	"		0.5 mm; used to derive $U_{t,7}$
Threshold windspeed @ 7 m ($U_{t,7}$)	!		11.32 m/s
Meteorological Data			
Mean annual windspeed (U_m)	!		4.69 m/s (Minneapolis, MN)
Air dispersion factor (Q/C)	!		90th percentile conterminous U.S.
Volatilization Q/C	!		68.18; Los Angeles, CA; 0.5-acre source
Fugitive particulate Q/C	!		93.77; Minneapolis, MN; 0.5-acre source
Hydrogeologic Characteristics (DAF)			
Hydrogeologic setting		"	Generic (national); surficial aquifer
Dilution/attenuation factor (DAF)		!	20 or 1

! Indicates parameters used directly in the SSL equations.
" Indicates parameters/assumptions used to develop input parameters for SSL equations.
INH = Inhalation pathway.
GW = Migration to ground water pathway.
Indoor INH = Inhalation of volatiles in indoor air pathway.
* The inhalation of volatiles in indoor air pathway is evaluated using subsurface soil defaults for θ_w and θ_a. The model's default parameters assume contamination located directly beneath a basement floor that is two meters below the ground surface.

APPENDIX B

SSL EQUATIONS FOR RESIDENTIAL SCENARIO

This appendix provides equations for the simple site-specific approach to developing SSLs for the residential exposure scenario. These equations, along with the default values for exposure assumptions and other model parameters listed below them, were used to develop the generic residential SSLs presented in Appendix A, Exhibit A-1. Site-specific parameters are indicated in bold. Site managers can use site-specific values for these parameters when developing SSLs; the default values for these parameters should be used when site-specific data are not available.

These equations allow site managers to calculate simple site-specific SSLs for chronic exposures to contaminants via the combined routes of direct ingestion and dermal absorption, outdoor inhalation of volatiles, outdoor inhalation of fugitive dust, and ingestion of leachate contaminated ground water. With the exception of the combined equations for direct ingestion and dermal absorption (Equations B-1 and B-2), the equations in this appendix are identical to those presented in the 1996 *Soil Screening Guidance*, though users should note that the default values for the fugitive dust and volatiles dispersion factors have been updated since the original guidance was published. For information on the applicability and use of these equations, users should refer to Section 2.5 of the 1996 *SSG* for ingestion, inhalation, and ground water exposures, and Section 3.2 of *RAGS, Part E* for dermal exposures. The specific equations provided in this appendix are:

- **Equations B-1 through B-5.** Screening level equations for combined ingestion and dermal absorption exposures to carcinogenic and non-carcinogenic soil contaminants, including calculation of dermal toxicity values and the age-adjusted dermal factor.

- **Equations B-6 through B-8.** Screening level equations for inhalation of carcinogenic and non-carcinogenic contaminants in fugitive dust, including calculation of the Particulate Emission Factor (PEF).

- **Equations B-9 through B-12.** Screening level equations for inhalation of carcinogenic and non-carcinogenic volatile contaminants, including calculation of the Volatilization Factor (VF) and the chemical-specific soil saturation limits (C_{sat}).

- **Equations B-13 through B-17.** Screening level equations for ingestion of contaminants in ground water, including calculation of chemical-specific dilution attenuation factors, site-specific mixing-zone depth, and mass limit volatilization factors.

Equation B-1
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Carcinogenic Contaminants in Soil
- Residential Scenario

$$\begin{matrix}\text{Screening}\\ \text{Level}\\ (\text{mg/kg})\end{matrix} = \frac{TR \times AT \times 365\,\text{d/yr}}{(EF \times 10^{-6}\,\text{kg/mg})\,[(SF_o \times IF_{soil/adj}) + (SF_{ABS} \times SFS \times ABS_d \times EV)]}$$

Parameter/Definition (units)	**Default**
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (years)	70
EF/exposure frequency (days/year)	350
SF_{ABS}/dermally adjusted cancer slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific (Equation B-3)
SFS/age-adjusted dermal factor (mg-yr/kg-event)	**360** **(Equation B-5)**
ABS_d/dermal absorption fraction (unitless)	chemical-specific (Appendix C)
EV/event frequency (events/day)	1
SF_o/oral cancer slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific (Appendix C)
$IF_{soil/adj}$/age-adjusted soil ingestion factor (mg-yr/kg-d)	114[a]

[a] Calculated per *RAGS, Part B,* Equation 3.

Equation B-2
Screening Level Equation for Combined Ingestion and Dermal Absorption Exposure to Non-Carcinogenic Contaminants in Soil - Residential Scenario

$$\text{Screening Level (mg/kg)} = \frac{\text{THQ}\times\text{BW}\times\text{AT}\times 365\,\text{d/yr}}{(\text{EF}\times\text{ED}\times 10^{-6}\,\text{kg/mg})\left[\left(\frac{1}{\text{RfD}_o}\times\text{IR}\right)+\left(\frac{1}{\text{RfD}_{ABS}}\times\text{AF}\times\text{ABS}_d\times\text{EV}\times\text{SA}\right)\right]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	15
AT/averaging time (years)	6[a]
EF/exposure frequency (days/year)	350
ED/exposure duration (years)	6
RfD_o/oral reference dose (mg/kg-d)	chemical-specific (Appendix C)
IR/soil ingestion rate (mg/d)	200
RfD_{ABS}/dermally-adjusted reference dose (mg/kg-d)	chemical-specific (Equation B-4)
AF/skin-soil adherence factor (mg/cm^2-event)	**0.2**
ABS_d/dermal absorption factor (unitless)	chemical-specific (Appendix C)
EV/event frequency (events/day)	1
SA/skin surface area exposed-child (cm^2)	**2,800**

[a] For non-carcinogens, averaging time equals to exposure duration.

Equation B-3
Calculation of Dermal Carcinogenic Toxicity Values

$$SF_{ABS} \; ' \; \frac{SF_O}{ABS_{GI}}$$

Parameter/Definition (units)	Default
SF_{ABS}/dermally adjusted slope factor $(mg/kg\text{-}d)^{-1}$	chemical-specific
SF_O/oral slope factor $(mg/kg\text{-}d\,)^{-1}$	chemical-specific (Appendix C)
ABS_{GI}/gastro-intestinal absorption factor (unitless)	chemical-specific (Appendix C)

Equation B-4
Calculation of Dermal Non-Carcinogenic Toxicity Values

$$RfD_{ABS} \; ' \; RfD_O \times ABS_{GI}$$

Parameter/Definition (units)	Default
RfD_{ABS}/dermally adjusted reference dose (mg/kg-d)	chemical-specific
RfD_O/oral reference dose (mg/kg-d)	chemical-specific (Appendix C)
ABS_{GI}/gastro-intestinal absorption factor (unitless)	chemical-specific (Appendix C)

Equation B-5
Derivation of the Age-Adjusted Dermal Factor

$$SFS \; ' \; \left[\frac{SA_{1\&6} \times AF_{1\&6} \times ED_{1\&6}}{BW_{1\&6}}\right] \% \left[\frac{SA_{7\&31} \times AF_{7\&31} \times ED_{7\&31}}{BW_{7\&31}}\right]$$

Parameter/Definition (units)	Default
SFS/age-adjusted dermal factor (mg-yr/kg-event)	360
$SA_{1\text{-}6}$/skin surface area exposed-child (cm2)	**2,800**
$SA_{7\text{-}31}$/skin surface area exposed-adult (cm2)	**5,700**
$AF_{1\text{-}6}$/skin-soil adherence factor-child (mg/cm2 - event)	**0.2**
$AF_{7\text{-}31}$/skin-soil adherence factor-adult (mg/cm2 - event)	**0.07**
$ED_{1\text{-}6}$/exposure duration-child (years)	6
$ED_{7\text{-}31}$/exposure duration-adult (years)	24
$BW_{1\text{-}6}$/body weight-child (kg)	15
$BW_{7\text{-}31}$/body weight-adult (kg)	70

Equation B-6
Screening Level Equation for Inhalation of Carcinogenic Fugitive Dusts - Residential Scenario

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{(mg/kg)}\end{array} = \frac{TR \times AT \times 365\,\text{d/yr}}{URF \times 1{,}000\,\mu\text{g/mg} \times EF \times ED \times \frac{1}{PEF}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor ($\mu g/m^3$)$^{-1}$	chemical-specific (Appendix C)
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
PEF/particulate emission factor (m^3/kg)	**1.36×10^9 (Equation B-8)**

Equation B-7
Screening Level Equation for Inhalation of Non-carcinogenic Fugitive Dusts - Residential Scenario

$$\begin{array}{c}\text{Screening}\\ \text{Level}\\ \text{(mg/kg)}\end{array} = \frac{THQ \times AT \times 365\,\text{d/yr}}{EF \times ED \times [\frac{1}{RfC} \times \frac{1}{PEF}]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (yr)	30[a]
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
RfC/inhalation reference concentration (mg/m^3)	chemical-specific (Appendix C)
PEF/particulate emission factor (m^3/kg)	**1.36×10^9 (Equation B-8)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation B-8
Derivation of the Particulate Emission Factor - Residential Scenario

$$PEF = Q/C_{wind} \times \frac{3{,}600 s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)}$$

Parameter/Definition (units)	Default
PEF/particulate emission factor (m^3/kg)	1.36×10^9
Q/C_{wind}/inverse of the ratio of the geometric mean air concentration to the emission flux at center of a square source (g/m^2-s per kg/m^3)	**93.77**[a]
V/fraction of vegetative cover (unitless)	**0.5 (50%)**
U_m/mean annual windspeed (m/s)	**4.69**
U_t/equivalent threshold value of windspeed at 7m (m/s)	**11.32**
F(x)/function dependent on U_m/U_t derived using Cowherd et al. (1985) (unitless)	**0.194**

[a] Assumes as 0.5 acre source; for site-specific values, consult Appendix D.

Equation B-9
Screening Level Equation for Inhalation of Carcinogenic Volatile Contaminants in Soil - Residential Scenario

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365 d/yr}{URF \times 1{,}000 \mu g/mg \times EF \times ED \times \frac{1}{VF}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor ($(\mu g/m^3)^{-1}$)	chemical-specific (Appendix C)
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
VF/soil-to-air volatilization factor (m^3/kg)	**chemical-specific (Equation B-11)**

Equation B-10
Screening Level Equation for Inhalation of Non-carcinogenic Volatile Contaminants in Soil - Residential Scenario

$$\text{Screening Level (mg/kg)} = \frac{THQ \times AT \times 365\,d/yr}{EF \times ED \times [\frac{1}{RfC} \times \frac{1}{VF}]}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
AT/averaging time (yr) Outdoor Worker	30[a]
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
RfC/inhalation reference concentration (mg/m^3)	chemical-specific (Appendix C)
VF/soil-to-air volatilization factor (m^3/kg)	**chemical-specific (Equation B-11)**

[a] For non-carcinogens, averaging time equals exposure duration.

Equation B-11
Derivation of the Volatilization Factor
- Residential Scenario

$$VF = \frac{Q/C_{vol} \times (3.14 \times D_A \times T)^{1/2} \times 10^{-4} (m^2/cm^2)}{(2 \times \rho_b \times D_A)}$$

where:

$$D_A = \frac{[(\theta_a^{10/3} D_i H' + \theta_w^{10/3} D_w)\ /n^2]}{\rho_b K_d + \theta_w + \theta_a H'}$$

Parameter/Definition (units)	Default
VF/volatilization factor (m^3/kg)	—
D_A/apparent diffusivity (cm^2/s)	—
Q/C_{vol} /inverse of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)	**68.18[a]**
T/exposure interval (s)	9.5×10^8
ρ_b/dry soil bulk density (g/cm^3)	**1.5**
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n-\theta_w$
n/total soil porosity (L_{pore}/L_{soil})	$1-(\rho_b/\rho_s)$
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
ρ_s/soil particle density (g/cm^3)	2.65
D_i/diffusivity in air (cm^2/s)	chemical-specific[b]
H′/dimensionless Henry's law constant	chemical-specific[b]
D_w/diffusivity in water (cm^2/s)	chemical-specific[b]
K_d/soil-water partition coefficient (cm^3/g)	organics = $K_{oc} \times f_{oc}$ inorganics = see Appendix C[c]
K_{oc}/soil organic carbon partition coefficient (cm^3/g)	chemical-specific[b]
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**

[a] Assumes a 0.5 acre source; for site-specific values, consult Appendix D.

[b] See Appendix C.

[c] Assume a pH of 6.8 when selecting default K_d values for metals.

Equation B-12
Derivation of the Soil Saturation Limit

$$C_{sat} = \frac{S}{\rho_b}(K_d\rho_b + \theta_w + H'\theta_a)$$

Parameter/Definition (units)	Default
C_{sat}/soil saturation concentration (mg/kg)	--
S/solubility in water (mg/L-water)	chemical-specific[a]
ρ_b/dry soil bulk density (kg/L)	**1.5**
K_d/soil-water partition coefficient (L/kg)	organics = $K_{oc} \times f_{oc}$ inorganics = see Appendix C[b]
K_{oc}/organic carbon partition coefficient (L/kg)	chemical-specific[a]
f_{oc}/fraction organic carbon in soil (g/g)	**0.006 (0.6%)**
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.15**
H'/dimensionless Henry's law constant	chemical-specific[a]
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n - \theta_w$
n/total soil porosity (L_{pore}/L_{soil})	$1 - (\rho_b/\rho_s)$
ρ_s/soil particle density (kg/L)	2.65

[a] See Appendix C.

[b] Assume a pH of 6.8 when selecting default K_d values for metals.

Equation B-13
Soil Screening Level Partitioning Equation for Migration to Ground Water

$$\text{Screening Level in Soil (mg/kg)} = C_w \left[K_D + \frac{(\theta_w + \theta_a H')}{\rho_b} \right]$$

Parameter/Definition (units)	Default
C_w/target soil leachate concentration (mg/L)	(nonzero MCLG, MCL, or HBL)[a] × dilution factor
K_d/soil-water partition coefficient (L/kg)	organics = $K_{oc} \times f_{oc}$ inorganics = see Appendix C[b]
K_{oc}/soil organic carbon/water partition coefficient (L/kg)	chemical-specific[c]
f_{oc}/fraction organic carbon in soil (g/g)	**0.002 (0.2%)**
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.3**
θ_a/air-filled soil porosity (L_{air}/L_{soil})	$n - \theta_w$
ρ_b/dry soil bulk density (kg/L)	**1.5**
n/soil porosity (L_{pore}/L_{soil})	$1 - (\rho_b/\rho_s)$
ρ_s/soil particle density (kg/L)	2.65
H'/dimensionless Henry's law constant	chemical-specific[c] (assume to be zero for inorganic contaminants except mercury)

[a] Chemical-specific (see Appendix C).

[b] Assume a pH of 6.8 when selecting default K_d values for metals.

[c] See Appendix C.

Equation B-14
Derivation of Dilution Attenuation Factor

$$\text{Dilution Attenuation Factor (DAF)} = 1 + \frac{K \times i \times d}{I \times L}$$

Parameter/Definition (units)	Default
DAF/dilution attenuation factor (unitless)	20 or 1 (0.5-acre source)
K/aquifer hydraulic conductivity (m/yr)	Site-specific
i/hydraulic gradient (m/m)	Site-specific
I/infiltration rate (m/yr)	Site-specific
d/mixing zone depth (m)	Site-specific
L/source length parallel to ground water flow (m)	Site-specific

Equation B-15
Estimation of Mixing Zone Depth

$$d = (0.0112 L^{2})^{0.5} + d_a(1 - \exp[(-L \times I)/(K \times i \times d_a)])$$

Parameter/Definition (units)	Default
d/mixing zone depth (m)	Site-specific
L/source length parallel to ground water flow (m)	Site-specific
I/infiltration rate (m/yr)	Site-specific
K/aquifer hydraulic conductivity (m/yr)	Site-specific
i/hydraulic gradient (m/m)	Site-specific
d_a/aquifer thickness (m)	Site-specific

Equation B-16
Mass-Limit Volatilization Factor - Residential Scenario

$$\mathrm{VF} = \mathrm{Q/C_{vol}} \times \frac{[\mathrm{T} \times (3.15\times10^{7}\,\mathrm{s/yr})]}{(\rho_b \times d_s \times 10^{6}\,\mathrm{g/Mg})}$$

Parameter/Definition (units)	Default
d_s/average source depth (m)	**site-specific**
T/exposure interval (yr)	30
Q/C_{vol}/inverse of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)	**68.18[a]**
ρ_b/dry soil bulk density (kg/L or Mg/m^3)	**1.5**

[a] Assumes a 0.5 acre source; for site-specific values, consult Appendix D.

Equation B-17
Mass-Limit Soil Screening Level for Migration to Ground Water

$$\text{Screening Level in Soil (mg/kg)} = \frac{(C_w \times I \times ED)}{\rho_b \times d_s}$$

Parameter/Definition (units)	Default
C_w/target soil leachate concentration (mg/L)	(nonzero MCLG, MCL, or HBL)[a] × dilution factor
d_s/depth of source (m)	**site-specific**
I/infiltration rate (m/yr)	**0.18**
ED/exposure duration (yr)	70
ρ_b/dry soil bulk density (kg/L)	**1.5**

[a] Chemical-specific, see Appendix C.

APPENDIX C

Chemical Properties and Regulatory/Human Health Benchmarks for SSL Calculations

This appendix provides the chemical properties and regulatory and human health benchmarks necessary to calculate SSLs for 109 chemicals commonly found at NPL sites. It consists of the following exhibits:

- Exhibit C-1 provides chemical-specific organic carbon-water partition coefficients (K_{oc}), air and water diffusivities (D_a and D_w), water solubilities (S), and dimensionless Henry's law constants (H').

- Exhibit C-2 provides pH-specific K_{oc} values for 10 organic contaminants that ionize under natural pH conditions. Site-specific soil pH measurements (see EPA's 1996 *SSG*, Section 2.3.5) can be used to select appropriate K_{oc} values for these contaminants. Where site-specific soil pH values are not available, values corresponding to a pH of 6.8 should be used. Note that K_{oc} values presented in Exhibit C-1 for these contaminants are based on a default pH of 6.8).

- Exhibit C-3 provides the physical state (liquid or solid) for organic contaminants. This information is needed to apply and interpret soil saturation limit (C_{sat}) results when calculating SSLs for the inhalation of volatiles in outdoor air pathway.

- Exhibit C-4 provides pH-specific soil-water partition coefficients (K_d) for metals. Site-specific soil pH measurements (see 1996 *SSG*, Section 2.3.5) can be used to select appropriate K_d values for these metals. Where site-specific soil pH values are not available, values corresponding to a pH of 6.8 should be used.

- Exhibit C-5 provides chemical-specific regulatory and human health benchmarks for organic and inorganic contaminants. The chemical-specific Maximum Contaminant Level Goal (MCLG), Maximum Contaminant Level (MCL), Water Health Based Limit (HBL), Cancer Slope Factor (CSF), Unit Risk Factor (URF), Reference Dose (RfD), and Reference Concentration (RfC) values presented in this exhibit are used as inputs in the SSL equations in Sections 3, 4, and 5 of this document.

- Exhibit C-6 presents chemical-specific absorption percentages for dermal contact (ABS_d) for all contaminants for which this pathway is relevant. The values presented represent the average dermal absorption values across a range of soil types, loading rates, and chemical concentrations for these contaminants.

- Exhibit C-7 provides gastrointestinal absorption factors (ABS_{GI}) for contaminants of concern for the dermal pathway. These values are used for route-to-route extrapolation of toxicity values. Specifically, these factors are used to adjust the oral reference dose (RfD) and cancer slope factor (SF) for a contaminant, which is based on administered dose, to more accurately reflect the dermal dose, which is an absorbed dose. Where there is greater than 50 percent gastrointestinal absorption (e.g., ABS_{GI}>.5), no adjustment is made.

With the exception of values for air diffusivity (D_a), water diffusivity (D_w), and certain K_{oc} values, all of the chemical properties used to calculate SSLs are also reported in the Superfund Chemical Data Matrix (SCDM). Water and air diffusivities were obtained from EPA's CHEMDAT8 and WATER8 models. For more information on the derivation of K_{oc} values, or for a more detailed discussion of the chemical properties presented in Exhibits C-1 through C-4, please refer to the *Technical Background Document* for the 1996 *Soil Screening Guidance* (*SSG*).[1]

The sources for the regulatory and human health benchmarks include the list of National Primary Drinking Water Regulations (NPDWRs), maintained by EPA's Office of Ground Water and Drinking Water, and EPA's *Integrated Risk Information System* (IRIS).[2] The full list of sources for the regulatory and chronic human health benchmarks is presented at the end of Exhibit C-5. Chemical-specific dermal and gastro-intestinal absorption fractions for the dermal contact pathway were obtained from EPA's *RAGS, Part E, Supplemental Guidance for Dermal Risk Assessment* (U.S. EPA, 2001).

All of the sources of the values listed in Exhibits C-1 through C-5 are regularly updated by EPA. In addition, the information in Exhibits C-6 and C-7 was obtained from *RAGS, Part E*. Therefore, prior to calculating SSLs for a site, regulatory/health benchmarks and chemical properties should be checked against the most recent versions of the appropriate sources to ensure that they are up to date. These sources may also be useful for identifying properties and benchmarks for additional contaminants of concern not included in this appendix. Several of these sources are available on-line at the following EPA web sites:

IRIS:	http://www.epa.gov/iriswebp/iris/index.html
NPDWRs:	http://www.epa.gov/safewater/mcl.html
SCDM:	http://www.epa.gov/superfund/resources/scdm/index.htm
CHEMDAT8:	http://www.epa.gov/ttn/chief/index.html
WATER8:	http://www.epa.gov/ttn/chief/index.html

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[1] The K_{oc} value for 2,4-Dichlorophenoxyacetic acid was estimated using information from the *1996 Technical Background Document* and the *Chemical Database for HWIR99* (U.S. EPA, 1999) along with the Office of Solid Waste's Multimedia, Multipathway, and Multireceptor (3MRA) Assessment Model (U.S. EPA, 2001, Version 1.01).

[2] The National Primary Drinking Water Regulations can be found at www.epa.gov/safewater/mcl.html. Human health benchmarks are available through EPA's IRIS system which can be found at www.epa.gov/iris.

Exhibit C-1

CHEMICAL-SPECIFIC PROPERTIES USED IN SSL CALCULATIONS

CAS No.	Compound	K_{oc} (L/kg)	D_i (cm^2/s)	D_w (cm^2/s)	S (mg/L)	H' (dimensionless)
83-32-9	Acenaphthene	7.08E+03	4.21E-02	7.69E-06	4.24E+00	6.36E-03
67-64-1	Acetone	5.75E-01	1.24E-01	1.14E-05	1.00E+06	1.59E-03
309-00-2	Aldrin	2.45E+06	1.32E-02	4.86E-06	1.80E-01	6.97E-03
120-12-7	Anthracene	2.95E+04	3.24E-02	7.74E-06	4.34E-02	2.67E-03
56-55-3	Benz(*a*)anthracene	3.98E+05	5.10E-02	9.00E-06	9.40E-03	1.37E-04
71-43-2	Benzene	5.89E+01	8.80E-02	9.80E-06	1.75E+03	2.28E-01
205-99-2	Benzo(*b*)fluoranthene	1.23E+06	2.26E-02	5.56E-06	1.50E-03	4.55E-03
207-08-9	Benzo(*k*)fluoranthene	1.23E+06	2.26E-02	5.56E-06	8.00E-04	3.40E-05
65-85-0	Benzoic acid	5.76E-01	5.36E-02	7.97E-06	3.50E+03	6.31E-05
50-32-8	Benzo(*a*)pyrene	1.02E+06	4.30E-02	9.00E-06	1.62E-03	4.63E-05
111-44-4	Bis(2-chloroethyl)ether	1.55E+01	6.92E-02	7.53E-06	1.72E+04	7.38E-04
117-81-7	Bis(2-ethylhexyl)phthalate	1.51E+07	3.51E-02	3.66E-06	3.40E-01	4.18E-06
75-27-4	Bromodichloromethane	5.50E+01	2.98E-02	1.06E-05	6.74E+03	6.56E-02
75-25-2	Bromoform	8.71E+01	1.49E-02	1.03E-05	3.10E+03	2.19E-02
71-36-3	Butanol	6.92E+00	8.00E-02	9.30E-06	7.40E+04	3.61E-04
85-68-7	Butyl benzyl phthalate	5.75E+04	1.74E-02	4.83E-06	2.69E+00	5.17E-05
86-74-8	Carbazole	3.39E+03	3.90E-02	7.03E-06	7.48E+00	6.26E-07
75-15-0	Carbon disulfide	4.57E+01	1.04E-01	1.00E-05	1.19E+03	1.24E+00
56-23-5	Carbon tetrachloride	1.74E+02	7.80E-02	8.80E-06	7.93E+02	1.25E+00
57-74-9	Chlordane	1.20E+05	1.18E-02	4.37E-06	5.60E-02	1.99E-03
106-47-8	*p*-Chloroaniline	6.61E+01	4.83E-02	1.01E-05	5.30E+03	1.36E-05
108-90-7	Chlorobenzene	2.19E+02	7.30E-02	8.70E-06	4.72E+02	1.52E-01
124-48-1	Chlorodibromomethane	6.31E+01	1.96E-02	1.05E-05	2.60E+03	3.21E-02
67-66-3	Chloroform	3.98E+01	1.04E-01	1.00E-05	7.92E+03	1.50E-01
95-57-8	2-Chlorophenol	3.88E+02	5.01E-02	9.46E-06	2.20E+04	1.60E-02
218-01-9	Chrysene	3.98E+05	2.48E-02	6.21E-06	1.60E-03	3.88E-03
72-54-8	DDD	1.00E+06	1.69E-02	4.76E-06	9.00E-02	1.64E-04
72-55-9	DDE	4.47E+06	1.44E-02	5.87E-06	1.20E-01	8.61E-04
50-29-3	DDT	2.63E+06	1.37E-02	4.95E-06	2.50E-02	3.32E-04
53-70-3	Dibenz(*a*,*h*)anthracene	3.80E+06	2.02E-02	5.18E-06	2.49E-03	6.03E-07
84-74-2	Di-*n*-butyl phthalate	3.39E+04	4.38E-02	7.86E-06	1.12E+01	3.85E-08
95-50-1	1,2-Dichlorobenzene	6.17E+02	6.90E-02	7.90E-06	1.56E+02	7.79E-02
106-46-7	1,4-Dichlorobenzene	6.17E+02	6.90E-02	7.90E-06	7.38E+01	9.96E-02
91-94-1	3,3-Dichlorobenzidine	7.24E+02	1.94E-02	6.74E-06	3.11E+00	1.64E-07
75-34-3	1,1-Dichloroethane	3.16E+01	7.42E-02	1.05E-05	5.06E+03	2.30E-01
107-06-2	1,2-Dichloroethane	1.74E+01	1.04E-01	9.90E-06	8.52E+03	4.01E-02
75-35-4	1,1-Dichloroethylene	5.89E+01	9.00E-02	1.04E-05	2.25E+03	1.07E+00
156-59-2	*cis*-1,2-Dichloroethylene	3.55E+01	7.36E-02	1.13E-05	3.50E+03	1.67E-01
156-60-5	*trans*-1,2-Dichloroethylene	5.25E+01	7.07E-02	1.19E-05	6.30E+03	3.85E-01
120-83-2	2,4-Dichlorophenol	1.47E+02	3.46E-02	8.77E-06	4.50E+03	1.30E-04
94-75-7	2,4-Dichlorophenoxyacetic acid	2.62E+01	2.31E-02	7.31E-06	6.80E+02	4.10E-07
78-87-5	1,2-Dichloropropane	4.37E+01	7.82E-02	8.73E-06	2.80E+03	1.15E-01
542-75-6	1,3-Dichloropropene	4.57E+01	6.26E-02	1.00E-05	2.80E+03	7.26E-01
60-57-1	Dieldrin	2.14E+04	1.25E-02	4.74E-06	1.95E-01	6.19E-04
84-66-2	Diethylphthalate	2.88E+02	2.56E-02	6.35E-06	1.08E+03	1.85E-05
105-67-9	2,4-Dimethylphenol	2.09E+02	5.84E-02	8.69E-06	7.87E+03	8.20E-05
51-28-5	2,4-Dinitrophenol	1.02E-02	2.73E-02	9.06E-06	2.79E+03	1.82E-05
121-14-2	2,4-Dinitrotoluene	9.55E+01	2.03E-01	7.06E-06	2.70E+02	3.80E-06
117-84-0	Di-*n*-octyl phthalate	8.32E+07	1.51E-02	3.58E-06	2.00E-02	2.74E-03

Exhibit-C-1 (continued)

CHEMICAL-SPECIFIC PROPERTIES USED IN SSL CALCULATIONS

CAS No.	Compound	K_{OC} (L/kg)	D_i (cm^2/s)	D_w (cm^2/s)	S (mg/L)	H^I (dimensionless)
115-29-7	Endosulfan	2.14E+03	1.15E-02	4.55E-06	5.10E-01	4.59E-04
72-20-8	Endrin	1.23E+04	1.25E-02	4.74E-06	2.50E-01	3.08E-04
100-41-4	Ethylbenzene	3.63E+02	7.50E-02	7.80E-06	1.69E+02	3.23E-01
206-44-0	Fluoranthene	1.07E+05	3.02E-02	6.35E-06	2.06E-01	6.60E-04
86-73-7	Fluorene	1.38E+04	3.63E-02	7.88E-06	1.98E+00	2.61E-03
76-44-8	Heptachlor	1.41E+06	1.12E-02	5.69E-06	1.80E-01	4.47E-02
1024-57-3	Heptachlor epoxide	8.32E+04	1.32E-02	4.23E-06	2.00E-01	3.90E-04
118-74-1	Hexachlorobenzene	5.50E+04	5.42E-02	5.91E-06	6.20E+00	5.41E-02
87-68-3	Hexachloro-1,3-butadiene	5.37E+04	5.61E-02	6.16E-06	3.23E+00	3.34E-01
319-84-6	"-HCH ("-BHC)	1.23E+03	1.42E-02	7.34E-06	2.00E+00	4.35E-04
319-85-7	$-HCH ($-BHC)	1.26E+03	1.42E-02	7.34E-06	2.40E-01	3.05E-05
58-89-9	(-HCH (Lindane)	1.07E+03	1.42E-02	7.34E-06	6.80E+00	5.74E-04
77-47-4	Hexachlorocyclopentadiene	2.00E+05	1.61E-02	7.21E-06	1.80E+00	1.11E+00
67-72-1	Hexachloroethane	1.78E+03	2.50E-03	6.80E-06	5.00E+01	1.59E-01
193-39-5	Indeno(1,2,3-*cd*)pyrene	3.47E+06	1.90E-02	5.66E-06	2.20E-05	6.56E-05
78-59-1	Isophorone	4.68E+01	6.23E-02	6.76E-06	1.20E+04	2.72E-04
7439-97-6	Mercury	---	3.07E-02	6.30E-06	---	4.67E-01
72-43-5	Methoxychlor	9.77E+04	1.56E-02	4.46E-06	4.50E-02	6.48E-04
74-83-9	Methyl bromide	1.05E+01	7.28E-02	1.21E-05	1.52E+04	2.56E-01
75-09-2	Methylene chloride	1.17E+01	1.01E-01	1.17E-05	1.30E+04	8.98E-02
95-48-7	2-Methylphenol	9.12E+01	7.40E-02	8.30E-06	2.60E+04	4.92E-05
91-20-3	Naphthalene	2.00E+03	5.90E-02	7.50E-06	3.10E+01	1.98E-02
98-95-3	Nitrobenzene	6.46E+01	7.60E-02	8.60E-06	2.09E+03	9.84E-04
86-30-6	*N*-Nitrosodiphenylamine	1.29E+03	3.12E-02	6.35E-06	3.51E+01	2.05E-04
621-64-7	*N*-Nitrosodi-*n*-propylamine	2.40E+01	5.45E-02	8.17E-06	9.89E+03	9.23E-05
87-86-5	Pentachlorophenol	5.92E+02	5.60E-02	6.10E-06	1.95E+03	1.00E-06
108-95-2	Phenol	2.88E+01	8.20E-02	9.10E-06	8.28E+04	1.63E-05
129-00-0	Pyrene	1.05E+05	2.72E-02	7.24E-06	1.35E-01	4.51E-04
100-42-5	Styrene	7.76E+02	7.10E-02	8.00E-06	3.10E+02	1.13E-01
79-34-5	1,1,2,2-Tetrachloroethane	9.33E+01	7.10E-02	7.90E-06	2.97E+03	1.41E-02
127-18-4	Tetrachloroethylene	1.55E+02	7.20E-02	8.20E-06	2.00E+02	7.54E-01
108-88-3	Toluene	1.82E+02	8.70E-02	8.60E-06	5.26E+02	2.72E-01
8001-35-2	Toxaphene	2.57E+05	1.16E-02	4.34E-06	7.40E-01	2.46E-04
120-82-1	1,2,4-Trichlorobenzene	1.78E+03	3.00E-02	8.23E-06	3.00E+02	5.82E-02
71-55-6	1,1,1-Trichloroethane	1.10E+02	7.80E-02	8.80E-06	1.33E+03	7.05E-01
79-00-5	1,1,2-Trichloroethane	5.01E+01	7.80E-02	8.80E-06	4.42E+03	3.74E-02
79-01-6	Trichloroethylene	1.66E+02	7.90E-02	9.10E-06	1.10E+03	4.22E-01
95-95-4	2,4,5-Trichlorophenol	1.60E+03	2.91E-02	7.03E-06	1.20E+03	1.78E-04
88-06-2	2,4,6-Trichlorophenol	3.81E+02	3.18E-02	6.25E-06	8.00E+02	3.19E-04
108-05-4	Vinyl acetate	5.25E+00	8.50E-02	9.20E-06	2.00E+04	2.10E-02
75-01-4	Vinyl chloride	1.86E+01	1.06E-01	1.23E-05	2.76E+03	1.11E+00
108-38-3	*m*-Xylene	4.07E+02	7.00E-02	7.80E-06	1.61E+02	3.01E-01
95-47-6	*o*-Xylene	3.63E+02	8.70E-02	1.00E-05	1.78E+02	2.13E-01
106-42-3	*p*-Xylene	3.89E+02	7.69E-02	8.44E-06	1.85E+02	3.14E-01

K_{OC} = Organic carbon partition coefficient.
D_i = Diffusivity in air (25°C).
D_w = Diffusivity in water (25°C).
S = Solubility in water (20-25°C).
H^I = Dimensionless Henry's Law Constant (HLC [atm-m^3/mol] * 41) (25°C).

Exhibit C-2

K_{OC} VALUES FOR IONIZING ORGANICS AS A FUNCTION OF pH

pH	Benzoic Acid	2-Chloro-phenol	2,4-Dichloro-phenoxy-acetic acid	2,4-Dichloro-phenol	2,4-Dinitro-phenol	Penta-chloro-phenol	2,3,4,5-Tetrachloro-phenol	2,4,6-Tetrachloro-phenol	2,4,5-Trichloro-phenol	2,4,6-Trichloro-phenol
4.9	5.54E+00	3.98E+02	6.53E+01	1.59E+02	2.94E-02	9.05E+03	1.73E+04	4.45E+03	2.37E+03	1.04E+03
5.0	4.64E+00	3.98E+02	5.72E+01	1.59E+02	2.55E-02	7.96E+03	1.72E+04	4.15E+03	2.36E+03	1.03E+03
5.1	3.88E+00	3.98E+02	5.08E+01	1.59E+02	2.23E-02	6.93E+03	1.70E+04	3.83E+03	2.36E+03	1.02E+03
5.2	3.25E+00	3.98E+02	4.57E+01	1.59E+02	1.98E-02	5.97E+03	1.67E+04	3.49E+03	2.35E+03	1.01E+03
5.3	2.72E+00	3.98E+02	4.16E+01	1.59E+02	1.78E-02	5.10E+03	1.65E+04	3.14E+03	2.34E+03	9.99E+02
5.4	2.29E+00	3.98E+02	3.83E+01	1.58E+02	1.62E-02	4.32E+03	1.61E+04	2.79E+03	2.33E+03	9.82E+02
5.5	1.94E+00	3.97E+02	3.57E+01	1.58E+02	1.50E-02	3.65E+03	1.57E+04	2.45E+03	2.32E+03	9.62E+02
5.6	1.65E+00	3.97E+02	3.37E+01	1.58E+02	1.40E-02	3.07E+03	1.52E+04	2.13E+03	2.31E+03	9.38E+02
5.7	1.42E+00	3.97E+02	3.20E+01	1.58E+02	1.32E-02	2.58E+03	1.47E+04	1.83E+03	2.29E+03	9.10E+02
5.8	1.24E+00	3.97E+02	3.07E+01	1.58E+02	1.25E-02	2.18E+03	1.40E+04	1.56E+03	2.27E+03	8.77E+02
5.9	1.09E+00	3.97E+02	2.97E+01	1.57E+02	1.20E-02	1.84E+03	1.32E+04	1.32E+03	2.24E+03	8.39E+02
6.0	9.69E-01	3.96E+02	2.89E+01	1.57E+02	1.16E-02	1.56E+03	1.24E+04	1.11E+03	2.21E+03	7.96E+02
6.1	8.75E-01	3.96E+02	2.82E+01	1.57E+02	1.13E-02	1.33E+03	1.15E+04	9.27E+02	2.17E+03	7.48E+02
6.2	7.99E-01	3.96E+02	2.77E+01	1.56E+02	1.10E-02	1.15E+03	1.05E+04	7.75E+02	2.12E+03	6.97E+02
6.3	7.36E-01	3.95E+02	2.73E+01	1.55E+02	1.08E-02	9.98E+02	9.51E+03	6.47E+02	2.06E+03	6.44E+02
6.4	6.89E-01	3.94E+02	2.69E+01	1.54E+02	1.06E-02	8.77E+02	8.48E+03	5.42E+02	1.99E+03	5.89E+02
6.5	6.51E-01	3.93E+02	2.67E+01	1.53E+02	1.05E-02	7.81E+02	7.47E+03	4.55E+02	1.91E+03	5.33E+02
6.6	6.20E-01	3.92E+02	2.65E+01	1.52E+02	1.04E-02	7.03E+02	6.49E+03	3.84E+02	1.82E+03	4.80E+02
6.7	5.95E-01	3.90E+02	2.63E+01	1.50E+02	1.03E-02	6.40E+02	5.58E+03	3.27E+02	1.71E+03	4.29E+02
6.8	5.76E-01	3.88E+02	2.62E+01	1.47E+02	1.02E-02	5.92E+02	4.74E+03	2.80E+02	1.60E+03	3.81E+02
6.9	5.60E-01	3.86E+02	2.61E+01	1.45E+02	1.02E-02	5.52E+02	3.99E+03	2.42E+02	1.47E+03	3.38E+02
7.0	5.47E-01	3.83E+02	2.60E+01	1.41E+02	1.02E-02	5.21E+02	3.33E+03	2.13E+02	1.34E+03	3.00E+02
7.1	5.38E-01	3.79E+02	2.59E+01	1.38E+02	1.02E-02	4.96E+02	2.76E+03	1.88E+02	1.21E+03	2.67E+02
7.2	5.32E-01	3.75E+02	2.59E+01	1.33E+02	1.01E-02	4.76E+02	2.28E+03	1.69E+02	1.07E+03	2.39E+02
7.3	5.25E-01	3.69E+02	2.58E+01	1.28E+02	1.01E-02	4.61E+02	1.87E+03	1.53E+02	9.43E+02	2.15E+02
7.4	5.19E-01	3.62E+02	2.58E+01	1.21E+02	1.01E-02	4.47E+02	1.53E+03	1.41E+02	8.19E+02	1.95E+02
7.5	5.16E-01	3.54E+02	2.58E+01	1.14E+02	1.01E-02	4.37E+02	1.25E+03	1.31E+02	7.03E+02	1.78E+02
7.6	5.13E-01	3.44E+02	2.57E+01	1.07E+02	1.01E-02	4.29E+02	1.02E+03	1.23E+02	5.99E+02	1.64E+02
7.7	5.09E-01	3.33E+02	2.57E+01	9.84E+01	1.00E-02	4.23E+02	8.31E+02	1.17E+02	5.07E+02	1.53E+02
7.8	5.06E-01	3.19E+02	2.57E+01	8.97E+01	1.00E-02	4.18E+02	6.79E+02	1.13E+02	4.26E+02	1.44E+02
7.9	5.06E-01	3.04E+02	2.57E+01	8.07E+01	1.00E-02	4.14E+02	5.56E+02	1.08E+02	3.57E+02	1.37E+02
8.0	5.06E-01	2.86E+02	2.57E+01	7.17E+01	1.00E-02	4.10E+02	4.58E+02	1.05E+02	2.98E+02	1.31E+02

Exhibit C-3
PHYSICAL STATE OF ORGANIC CHEMICALS AT TYPICAL SOIL TEMPERATURES

Compounds Present in Liquid Phase			Compounds Present in Solid Phase		
CAS No.	**Chemical**	**Melting Point (°C)**	**CAS No.**	**Chemical**	**Melting Point (°C)**
67-64-1	Acetone	-94.8	83-32-9	Acenaphthene	93.4
71-43-2	Benzene	5.5	309-00-2	Aldrin	104
117-81-7	Bis(2-ethylhexyl)phthalate	-55	120-12-7	Anthracene	215
111-44-4	Bis(2-chloroethyl)ether	-51.9	56-55-3	Benz(*a*)anthracene	84
75-27-4	Bromodichloromethane	-57	50-32-8	Benzo(*b*)pyrene	176.5
75-25-2	Bromoform	8	205-99-2	Benzo(*b*)fluoranthene	168
71-36-3	Butanol	-89.8	207-08-9	Benzo(*k*)fluoranthene	217
85-68-7	Butyl benzyl phthalate	-35	65-85-0	Benzoic acid	122.4
75-15-0	Carbon disulfide	-115	86-74-8	Carbazole	246.2
56-23-5	Carbon tetrachloride	-23	57-74-9	Chlordane	106
108-90-7	Chlorobenzene	-45.2	106-47-8	*p*-Chloroaniline	72.5
124-48-1	Chlorodibromomethane	-20	218-01-9	Chrysene	258.2
67-66-3	Chloroform	-63.6	72-54-8	DDD	109.5
95-57-8	2-Chlorophenol	9.8	72-55-9	DDE	89
84-74-2	Di-*n*-butyl phthalate	-35	50-29-3	DDT	108.5
95-50-1	1,2-Dichlorobenzene	-16.7	53-70-3	Dibenzo(*a*,*h*)anthracene	269.5
75-34-3	1,1-Dichloroethane	-96.9	106-46-7	1,4-Dichlorobenzene	52.7
107-06-2	1,2-Dichloroethane	-35.5	91-94-1	3,3-Dichlorobenzidine	132.5
75-35-4	1,1Dichloroethylene	-122.5	120-83-2	2,4-Dichlorophenol	45
156-59-2	*cis*-1,2-Dichloroethylene	-80	94-75-7	2,4-Dichlorophenoxyacetic acid	140.5
156-60-5	*trans*-1,2-Dichloroethylene	-49.8	60-57-1	Dieldrin	175.5
78-87-5	1,2-Dichloropropane	-70	105-67-9	2,4-Dimethylphenol	24.5
542-75-6	1,3-Dichloropropene	N/A	51-28-5	2,4-Dinitrophenol	115-116
84-66-2	Diethylphthalate	-40.5	121-14-2	2,4-Dinitrotoluene	71
117-84-0	Di-*n*-octyl phthalate	-30	606-20-2	2,6-Dinitrotoluene	66
100-41-4	Ethylbenzene	-94.9	72-20-8	Endrin	200
87-68-3	Hexachloro-1,3-butadiene	-21	115-29-7	Endosulfan	106
77-47-4	Hexachlorocyclopentadiene	-9	206-44-0	Fluoranthene	107.8
78-59-1	Isophorone	-8.1	86-73-7	Fluorene	114.8
74-83-9	Methyl bromide	-93.7	76-44-8	Heptachlor	95.5
75-09-2	Methylene chloride	-95.1	1024-57-3	Heptachlor epoxide	160
98-95-3	Nitrobenzene	5.7	118-74-1	Hexachlorobenzene	231.8
100-42-5	Styrene	-31	319-84-6	α-HCH (α-BHC)	160
79-34-5	1,1,2,2-Tetrachloroethane	-43.8	319-85-7	β-HCH (β-BHC)	315
127-18-4	Tetrachloroethylene	-22.3	58-89-9	γ-HCH (Lindane)	112.5
108-88-3	Toluene	-94.9	67-72-1	Hexachloroethane	187
120-82-1	1,2,4-Trichlorobenzene	17	193-39-5	Indeno(1,2,3-*cd*)pyrene	161.5
71-55-6	1,1,1-Trichloroethane	-30.4	72-43-5	Methoxychlor	87
79-00-5	1,1,2-Trichloroethane	-36.6	95-48-7	2-Methylphenol	29.8
79-01-6	Trichloroethylene	-84.7	621-64-7	*N*-Nitrosodi-*n*-propylamine	N/A
108-05-4	Vinyl acetate	-93.2	86-30-6	*N*-Nitrosodiphenylamine	66.5
75-01-4	Vinyl chloride	-153.7	91-20-3	Naphthalene	80.2
108-38-3	*m*-Xylene	-47.8	87-86-5	Pentachlorophenol	174
95-47-6	*o*-Xylene	-25.2	108-95-2	Phenol	40.9
106-42-3	*p*-Xylene	13.2	129-00-0	Pyrene	151.2
			8001-35-2	Toxaphene	65-90
			95-95-4	2,4,5-Trichlorophenol	69
			88-06-2	2,4,6-Trichlorophenol	69

Exhibit C-4

METAL K_d VALUES (L/kg) AS A FUNCTION OF pH[a]

pH	Arsenic	Barium	Beryllium	Cadmium	Chromium (+III)	Chromium (+VI)	Mercury	Nickel	Silver	Selenium	Thallium	Zinc
4.9	2.5E+01	1.1E+01	2.3E+01	1.5E+01	1.2E+03	3.1E+01	4.0E-02	1.6E+01	1.0E-01	1.8E+01	4.4E+01	1.6E+01
5.0	2.5E+01	1.2E+01	2.6E+01	1.7E+01	1.9E+03	3.1E+01	6.0E-02	1.8E+01	1.3E-01	1.7E+01	4.5E+01	1.8E+01
5.1	2.5E+01	1.4E+01	2.8E+01	1.9E+01	3.0E+03	3.0E+01	9.0E-02	2.0E+01	1.6E-01	1.6E+01	4.6E+01	1.9E+01
5.2	2.6E+01	1.5E+01	3.1E+01	2.1E+01	4.9E+03	2.9E+01	1.4E-01	2.2E+01	2.1E-01	1.5E+01	4.7E+01	2.1E+01
5.3	2.6E+01	1.7E+01	3.5E+01	2.3E+01	8.1E+03	2.8E+01	2.0E-01	2.4E+01	2.6E-01	1.4E+01	4.8E+01	2.3E+01
5.4	2.6E+01	1.9E+01	3.8E+01	2.5E+01	1.3E+04	2.7E+01	3.0E-01	2.6E+01	3.3E-01	1.3E+01	5.0E+01	2.5E+01
5.5	2.6E+01	2.1E+01	4.2E+01	2.7E+01	2.1E+04	2.7E+01	4.6E-01	2.8E+01	4.2E-01	1.2E+01	5.1E+01	2.6E+01
5.6	2.6E+01	2.2E+01	4.7E+01	2.9E+01	3.5E+04	2.6E+01	6.9E-01	3.0E+01	5.3E-01	1.1E+01	5.2E+01	2.8E+01
5.7	2.7E+01	2.4E+01	5.3E+01	3.1E+01	5.5E+04	2.5E+01	1.0E+00	3.2E+01	6.7E-01	1.1E+01	5.4E+01	3.0E+01
5.8	2.7E+01	2.6E+01	6.0E+01	3.3E+01	8.7E+04	2.5E+01	1.6E+00	3.4E+01	8.4E-01	9.8E+00	5.5E+01	3.2E+01
5.9	2.7E+01	2.8E+01	6.9E+01	3.5E+01	1.3E+05	2.4E+01	2.3E+00	3.6E+01	1.1E+00	9.2E+00	5.6E+01	3.4E+01
6.0	2.7E+01	3.0E+01	8.2E+01	3.7E+01	2.0E+05	2.3E+01	3.5E+00	3.8E+01	1.3E+00	8.6E+00	5.8E+01	3.6E+01
6.1	2.7E+01	3.1E+01	9.9E+01	4.0E+01	3.0E+05	2.3E+01	5.1E+00	4.0E+01	1.7E+00	8.0E+00	5.9E+01	3.9E+01
6.2	2.8E+01	3.3E+01	1.2E+02	4.2E+01	4.2E+05	2.2E+01	7.5E+00	4.2E+01	2.1E+00	7.5E+00	6.1E+01	4.2E+01
6.3	2.8E+01	3.5E+01	1.6E+02	4.4E+01	5.8E+05	2.2E+01	1.1E+01	4.5E+01	2.7E+00	7.0E+00	6.2E+01	4.4E+01
6.4	2.8E+01	3.6E+01	2.1E+02	4.8E+01	7.7E+05	2.1E+01	1.6E+01	4.7E+01	3.4E+00	6.5E+00	6.4E+01	4.7E+01
6.5	2.8E+01	3.7E+01	2.8E+02	5.2E+01	9.9E+05	2.0E+01	2.2E+01	5.0E+01	4.2E+00	6.1E+00	6.6E+01	5.1E+01
6.6	2.8E+01	3.9E+01	3.9E+02	5.7E+01	1.2E+06	2.0E+01	3.0E+01	5.4E+01	5.3E+00	5.7E+00	6.7E+01	5.4E+01
6.7	2.9E+01	4.0E+01	5.5E+02	6.4E+01	1.5E+06	1.9E+01	4.0E+01	5.8E+01	6.6E+00	5.3E+00	6.9E+01	5.8E+01
6.8	2.9E+01	4.1E+01	7.9E+02	7.5E+01	1.8E+06	1.9E+01	5.2E+01	6.5E+01	8.3E+00	5.0E+00	7.1E+01	6.2E+01
6.9	2.9E+01	4.2E+01	1.1E+03	9.1E+01	2.1E+06	1.8E+01	6.6E+01	7.4E+01	1.0E+01	4.7E+00	7.3E+01	6.8E+01
7.0	2.9E+01	4.2E+01	1.7E+03	1.1E+02	2.5E+06	1.8E+01	8.2E+01	8.8E+01	1.3E+01	4.3E+00	7.4E+01	7.5E+01
7.1	2.9E+01	4.3E+01	2.5E+03	1.5E+02	2.8E+06	1.7E+01	9.9E+01	1.1E+02	1.6E+01	4.1E+00	7.6E+01	8.3E+01
7.2	3.0E+01	4.4E+01	3.8E+03	2.0E+02	3.1E+06	1.7E+01	1.2E+02	1.4E+02	2.0E+01	3.8E+00	7.8E+01	9.5E+01
7.3	3.0E+01	4.4E+01	5.7E+03	2.8E+02	3.4E+06	1.6E+01	1.3E+02	1.8E+02	2.5E+01	3.5E+00	8.0E+01	1.1E+02
7.4	3.0E+01	4.5E+01	8.6E+03	4.0E+02	3.7E+06	1.6E+01	1.5E+02	2.5E+02	3.1E+01	3.3E+00	8.2E+01	1.3E+02
7.5	3.0E+01	4.6E+01	1.3E+04	5.9E+02	3.9E+06	1.6E+01	1.6E+02	3.5E+02	3.9E+01	3.1E+00	8.5E+01	1.6E+02
7.6	3.1E+01	4.6E+01	2.0E+04	8.7E+02	4.1E+06	1.5E+01	1.7E+02	4.9E+02	4.8E+01	2.9E+00	8.7E+01	1.9E+02
7.7	3.1E+01	4.7E+01	3.0E+04	1.3E+03	4.2E+06	1.5E+01	1.8E+02	7.0E+02	5.9E+01	2.7E+00	8.9E+01	2.4E+02
7.8	3.1E+01	4.9E+01	4.6E+04	1.9E+03	4.3E+06	1.4E+01	1.9E+02	9.9E+02	7.3E+01	2.5E+00	9.1E+01	3.1E+02
7.9	3.1E+01	5.0E+01	6.9E+04	2.9E+03	4.3E+06	1.4E+01	1.9E+02	1.4E+03	8.9E+01	2.4E+00	9.4E+01	4.0E+02
8.0	3.1E+01	5.2E+01	1.0E+05	4.3E+03	4.3E+06	1.4E+01	2.0E+02	1.9E+03	1.1E+02	2.2E+00	9.6E+01	5.3E+02

[a] Non pH-dependent inorganic K_d values for antimony, cyanide, and vanadium are 45, 9.9, and 1,000 (L/kg), respectively.

Exhibit C-5

REGULATORY AND HUMAN HEALTH BENCHMARKS USED TO DEVELOP SSLs

		Maximum Contaminant Level Goal (mg/L)		Maximum Contaminant Level (mg/L)		Water Health Based Limit (mg/L)		Cancer Slope Factor $(mg/kg\text{-}d)^{-1}$			Unit Risk Factor $(\mu g/m^3)^{-1}$			Reference Dose (mg/kg-d)		Reference Concentration (mg/m^3)	
CAS No.	Compound	MCLG (PCMLG)	Ref^a	MCL (PMCL)	Ref^a	HBL^b	Basis^a	Carc. Class^c	SF$_o$	Ref^a	Carc. Class^c	URF	Ref^a	RfD	Ref^a	RfC	Ref^a
83-32-9	Acenaphthene					2E+00	RfD							6.0E-02	1		
67-64-1	Acetone (2-Propanone)					4E+00	RfD	D			D			1.0E-01	1		
309-00-2	Aldrin					5E-06	SF$_O$	B2	1.7E+01	1	B2	4.9E-03	1	3.0E-05	1		
120-12-7	Anthracene					1E+01	RfD	D			D			3.0E-01	1		
7440-36-0	Antimony	6E-03	3	6E-03	3									4.0E-04	1		
7440-38-2	Arsenic			5E-02	3			A	1.5E+00	1	A	4.3E-03	1	3.0E-04	1		
7440-39-3	Barium	2E+00	3	2E+00	3									7.0E-02	1	5.0E-04	2b
56-55-3	Benz(*a*)anthracene					1E-04	SF$_O$	B2	7.3E-01	4	B2						
71-43-2	Benzene			5E-03	3			A	5.5E-02	1	A	7.8E-06	1				
205-99-2	Benzo(*b*)fluoranthene					1E-04	SF$_O$	B2	7.3E-01	4	B2						
207-08-9	Benzo(*k*)fluoranthene					1E-03	SF$_O$	B2	7.3E-02	4	B2						
65-85-0	Benzoic acid					1E+02	RfD							4.0E+00	1		
50-32-8	Benzo(*a*)pyrene			2E-04	3			B2	7.3E+00	1	B2						
7440-41-7	Beryllium	4E-03	3	4E-03	3						B1	2.4E-03	1	2.0E-03	1	2.0E-05	1
111-44-4	Bis(2-chloroethyl)ether					8E-05	SF$_O$	B2	1.1E+00	1	B2	3.3E-04	1				
117-81-7	Bis(2-ethylhexyl)phthalate			6E-03	3			B2	1.4E-02	1	B2			2.0E-02	1		
75-27-4	Bromodichloromethane			1E-01*	3			B2	6.2E-02	1	B2			2.0E-02	1		
75-25-2	Bromoform (tribromomethane)			1E-01*	3			B2	7.9E-03	1	B2	1.1E-06	1	2.0E-02	1		
71-36-3	Butanol					4E+00	RfD	D			D			1.0E-01	1		
85-68-7	Butyl benzyl phthalate					7E+00	RfD	C			C			2.0E-01	1		
7440-43-9	Cadmium	5E-03	3	5E-03	3						B1	1.8E-03	1	1.0E-03†	1		
86-74-8	Carbazole					4E-03	SF$_O$	B2	2.0E-02	2a							
75-15-0	Carbon disulfide					4E+00	RfD							1.0E-01	1	7.0E-01	1
56-23-5	Carbon tetrachloride			5E-03	3			B2	1.3E-01	1	B2	1.5E-05	1	7.0E-04	1		
57-74-9	Chlordane			2E-03	3			B2	3.5E-01	1	B2	1.0E-04	1	5.0E-04	1	7.0E-04	1
106-47-8	*p*-Chloroaniline					1E-01	RfD							4.0E-03	1		
108-90-7	Chlorobenzene	1E-01	3	1E-01	3			D			D			2.0E-02	1	6.0E-02	5
124-48-1	Chlorodibromomethane	6E-02	3	1E-01*	3			C	8.4E-02	1	C			2.0E-02	1		
67-66-3	Chloroform			1E-01*	3			B2			B2			1.0E-02	1		

* Proposed MCL = 0.08 mg/L, *Drinking Water Regulations and Health Advisories,* U.S. EPA (1995).

† Cadmium RfD is based on dietary exposure.

Exhibit C-5 (Continued)

REGULATORY AND HUMAN HEALTH BENCHMARKS USED TO DEVELOP SSLs

CAS No.	Compound	Maximum Contaminant Level Goal (mg/L)		Maximum Contaminant Level (mg/L)		Water Health Based Limit (mg/L)		Cancer Slope Factor (mg/kg-d)$^{-1}$			Unit Risk Factor (µg/m^3)$^{-1}$			Reference Dose (mg/kg-d)		Reference Concentration (mg/m^3)	
		MCLG (PCMLG)	Ref[a]	MCL (PMCL)	Ref[a]	HBL[b]	Basis[a]	Carc. Class[c]	SF_o	Ref[a]	Carc. Class[c]	URF	Ref[a]	RfD	Ref[a]	RfC	Ref[a]
95-57-8	2-Chlorophenol					2E-01	RfD							5.0E-03	1		
7440-47-3	Chromium	1E-01	3	1E-01	3			A			A	1.2E-02	1	3.0E-03	1		
16065-83-1	Chromium (III)					4E+01	RfD							1.5E+00	1		
18540-29-9	Chromium (VI)			1E-01*	3			A			A	1.2E-02	1	3.0E-03	1	1.0E-04[‡]	1
218-01-9	Chrysene					1E-02	SF_O	B2	7.3E-03	4							
57-12-5	Cyanide (amenable)	2E-01	3	2E-01	3			D			D			2.0E-02	1		
72-54-8	DDD					4E-04	SF_O	B2	2.4E-01	1	B2						
72-55-9	DDE					3E-04	SF_O	B2	3.4E-01	1	B2						
50-29-3	DDT					3E-04	SF_O	B2	3.4E-01	1	B2	9.7E-05	1	5.0E-04	1		
53-70-3	Dibenz(*a*,*h*)anthracene					1E-05	SF_O	B2	7.3E+00	4	B2						
84-74-2	Di-*n*-butyl phthalate					4E+00	RfD	D			D			1.0E-01	1		
95-50-1	1,2-Dichlorobenzene	6E-01	3	6E-01	3			D			D			9.0E-02	1	2.0E-01	2b
106-46-7	1,4-Dichlorobenzene	7E-02	3	7E-02	3			C	2.4E-02	2a	C					8.0E-01	1
91-94-1	3,3-Dichlorobenzidine					2E-04	SF_O	B2	4.5E-01	1	B2						
75-34-3	1,1-Dichloroethane					4E+00	RfD	C			C			1.0E-01	2a	5.0E-01	2b
107-06-2	1,2-Dichloroethane			5E-03	3			B2	9.1E-02	1	B2	2.6E-05	1				
75-35-4	1,1-Dichloroethylene	7E-03	3	7E-03	3			C			C			5.0E-02	1	2.0E-01	1
156-59-2	*cis*-1,2-Dichloroethylene	7E-02	3	7E-02	3			D			D			1.0E-02	5		
156-60-5	*trans*-1,2-Dichloroethylene	1E-01	3	1E-01	3									2.0E-02	1		
120-83-2	2,4-Dichlorophenol					1E-01	RfD							3.0E-03	1		
94-75-7	2,4-Dichlorophenoxyacetic acid	7E-02	3	7E-02	3									1.0E-02	1		
78-87-5	1,2-Dichloropropane			5E-03	3			B2	6.8E-02	2a	B2					4.0E-03	1
542-75-6	1,3-Dichloropropene					5E-04	SF_O	B2	1.0E-01	1	B2	4.0E-06	1	3.0E-02	1	2.0E-02	1
60-57-1	Dieldrin					5E-06	SF_O	B2	1.6E+01	1	B2	4.6E-03	1	5.0E-05	1		
84-66-2	Diethylphthalate					3E+01	RfD	D			D			8.0E-01	1		
105-67-9	2,4-Dimethylphenol					7E-01	RfD							2.0E-02	1		
51-28-5	2,4-Dinitrophenol					4E-02	RfD							2.0E-03	1		
121-14-2	2,4-Dinitrotoluene[†]					1E-04	SF_O	B2	6.8E-01	1				2.0E-03	1		
606-20-2	2,6-Dinitrotoluene[†]					1E-04	SF_O	B2	6.8E-01	1				1.0E-03	2a		
117-84-0	Di-*n*-octyl phthalate					7E-01	RfD							2.0E-02	2a		

* MCL for total chromium is based on Cr (VI) toxicity.

[†] Cancer Slope Factor is for 2,4-, 2,6-Dinitrotoluene mixture.

[‡] RfC for Chromium (VI) is based on exposure to Cr (VI) particulates.

Exhibit C-5 (Continued)

REGULATORY AND HUMAN HEALTH BENCHMARKS USED TO DEVELOP SSLs

		Maximum Contaminant Level Goal (mg/L)		Maximum Contaminant Level (mg/L)		Water Health Based Limit (mg/L)		Cancer Slope Factor (mg/kg-d)$^{-1}$			Unit Risk Factor (µg/m^3)$^{-1}$			Reference Dose (mg/kg-d)		Reference Concentration (mg/m^3)	
CAS No.	**Compound**	**MCLG (PCMLG)**	**Ref^a**	**MCL (PMCL)**	**Ref^a**	**HBL^b**	**Basis^a**	**Carc. Class^c**	**SF$_o$**	**Ref^a**	**Carc. Class^c**	**URF**	**Ref^a**	**RfD**	**Ref^a**	**RfC**	**Ref^a**
115-29-7	Endosulfan					2E-01	RfD							6.0E-03	1		
72-20-8	Endrin	2E-03	3	2E-03	3			D			D			3.0E-04	1		
100-41-4	Ethylbenzene	7E-01	3	7E-01	3			D			D			1.0E-01	1	1.0E+00	1
206-44-0	Fluoranthene					1E+00	RfD	D			D			4.0E-02	1		
86-73-7	Fluorene					1E+00	RfD	D						4.0E-02	1		
76-44-8	Heptachlor			4E-04	3			B2	4.5E+00	1	B2	1.3E-03	1	5.0E-04	1		
1024-57-3	Heptachlor Epoxide			2E-04	3			B2	9.1E+00	1	B2	2.6E-03	1	1.3E-05	1		
118-74-1	Hexachlorobenzene			1E-03	3			B2	1.6E+00	1	B2	4.6E-04	1	8.0E-04	1		
87-68-3	Hexachloro-1,3-butadiene	1E-03	3			1E-03	SF$_O$	C	7.8E-02	1	C	2.2E-05	1	2.0E-04	2a		
319-84-6	"-HCH ("-BHC)					1E-05	SF$_O$	B2	6.3E+00	1	B2	1.8E-03	1				
319-85-7	$-HCH ($-BHC)					5E-05	SF$_O$	C	1.8E+00	1	C	5.3E-04	1				
58-89-9	(-HCH (Lindane)	2E-04	3	2E-04	3			B2	1.3E+00	2a	C			3.0E-04	1		
77-47-4	Hexachlorocyclopentadiene	5E-02	3	5E-02	3			D			D			6.0E-03	1	2.0E-04	1
67-72-1	Hexachloroethane					6E-03	SF$_O$	C	1.4E-02	1	C	4.0E-06	1	1.0E-03	1		
193-39-5	Indeno(1,2,3-*cd*)pyrene					1E-04	SF$_O$	B2	7.3E-01	4	B2						
78-59-1	Isophorone					9E-02	SF$_O$	C	9.5E-04	1	C			2.0E-01	1		
7439-97-6	Mercury	2E-03	3	2E-03	3			D			D			3.0E-04*	2a	3.0E-04	1
72-43-5	Methoxychlor	4E-02	3	4E-02	3			D			D			5.0E-03	1		
74-83-9	Methyl bromide					5E-02	RfD	D			D			1.4E-03	1	5.0E-03	1
75-09-2	Methylene chloride			5E-03	3			B2	7.5E-03	1	B2	4.7E-07	1	6.0E-02	1	3.0E+00	2a
95-48-7	2-Methylphenol (*o*-cresol)					2E+00	RfD	C			C			5.0E-02	1		
91-20-3	Naphthalene					1E+00	RfD	C			C			2.0E-02	1	3.0E-03	1
7440-02-0	Nickel					1E-01	HA**	A			A	2.4E-04	1	2.0E-02	1		
98-95-3	Nitrobenzene					2E-02	RfD	D			D			5.0E-04	1	2.0E-03	2b
86-30-6	*N*-Nitrosodiphenylamine					2E-02	SF$_O$	B2	4.9E-03	1	B2						
621-64-7	*N*-Nitrosodi-*n*-propylamine					1E-05	SF$_O$	B2	7.0E+00	1	B2						
87-86-5	Pentachlorophenol			1E-03	3			B2	1.2E-01	1	B2			3.0E-02	1		
108-95-2	Phenol					2E+01	RfD	D			D			3.0E-01	1		
129-00-0	Pyrene					1E+00	RfD	D			D			3.0E-02	1		
7782-49-2	Selenium	5E-02	3	5E-02	3			D			D			5.0E-03	1		
7440-22-4	Silver						RfD	D			D			5.0E-03	1		

* RfD is for mercuric chloride (CAS No. 007847-94-7).

** Health advisory for nickel (MCL is currently remanded); EPA Office of Science and Technology, 7/10/95.

Exhibit C-5 (Continued)

REGULATORY AND HUMAN HEALTH BENCHMARKS USED TO DEVELOP SSLs

CAS No.	Compound	Maximum Contaminant Level Goal (mg/L)		Maximum Contaminant Level (mg/L)		Water Health Based Limit (mg/L)		Cancer Slope Factor $(mg/kg\text{-}d)^{-1}$			Unit Risk Factor $(\mu g/m^3)^{-1}$			Reference Dose (mg/kg-d)		Reference Concentration (mg/m^3)	
		MCLG (PCMLG)	Ref[a]	MCL (PMCL)	Ref[a]	HBL[b]	Basis[a]	Carc. Class[c]	SF_o	Ref[a]	Carc. Class[c]	URF	Ref[a]	RfD	Ref[a]	RfC	Ref[a]
100-42-5	Styrene	1E-01	3	1E-01	3									2.0E-01	1	1.0E+00	1
79-34-5	1,1,2,2-Tetrachloroethane					4E-04	SF_O	C	2.0E-01	1	C	5.8E-05	1				
127-18-4	Tetrachloroethylene			5E-03	3				5.4E-01	6		5.9E-06	6	1.0E-02	1		
7440-28-0	Thallium	5E-04	3	2E-03	3									8.0E-05	1		
108-88-3	Toluene	1E+00	3	1E+00	3			D			D			2.0E-01	1	4.0E-01	1
8001-35-2	Toxaphene			3E-03	3			B2	1.1E+00	1	B2	3.2E-04	1				
120-82-1	1,2,4-Trichlorobenzene	7E-02	3	7E-02	3			D			D			1.0E-02	1	2.0E-01	2a
71-55-6	1,1,1-Trichloroethane	2E-01	3	2E-01	3			D			D					2.2E+00	5
79-00-5	1,1,2-Trichloroethane	3E-03	3	5E-03	3			C	5.7E-02	1	C	1.6E-05	1	4.0E-03	1		
79-01-6	Trichloroethylene^	zero	3	5E-03	3				4.0E-01*	5		1.1E-04**	5	3.0E-04	5	4.0E-02	5
95-95-4	2,4,5-Trichlorophenol					4E+00	RfD							1.0E-01	1		
88-06-2	2,4,6-Trichlorophenol					8E-03	SF_O	B2	1.1E-02	1	B2	3.1E-06	1				
7440-62-2	Vanadium					3E-01	RfD							7.0E-03	2a		
108-05-4	Vinyl acetate					4E+01	RfD							1.0E+00	2a	2.0E-01	1
75-01-4	Vinyl chloride[d] (chloroethene)			2E-03	3			A	7.2E-01 (Adult) 1.5E+00 (Lifetime)	1 1	A	4.4E-06 (Adult) 8.8E-06 (Lifetime)	1 1	3.0E-03	1	1.0E-01	1
108-38-3	*m*-Xylene[e]	1E+01	3	1E+01	3			D			D			2.0E+00	2a		
95-47-6	*o*-Xylene[e]	1E+01	3	1E+01	3			D			D			2.0E+00	2a		
106-42-3	*p*-Xylene[e]	1E+01	3	1E+01	3			D			D			2.0E+00	1		
7440-66-6	Zinc					1E+01	RfD	D			D			3.0E-01	1		

^ Health benchmark values are based on NCEA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft* (ORD, August, 2001). The trichloroethylene draft risk assessment is still under review. As a result, the health benchmark values are subject to change.

* The cancer slope factor is the upper end of the range given in the risk assessment. This conservative value is appropriate given that the SSL is used for screening purposes.

** The unit risk factor is extrapolated from an upper bound cancer slope factor of $4x10^{-1}$ per mg/kg-d. This extrapolation is supported by evidence of similar carcinogenic effects via both inhalation and ingestion pathways.

[a] References:

1 = IRIS, U.S. EPA (2002c)
2a = HEAST, U.S. EPA (1997c)
2b = HEAST values from alternative tables, U.S. EPA (1997c)
3 = National Primary Drinking Water Standards, U.S. EPA (2002d)
4 = Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons, Office of Health and Environmental Assessment, U.S. EPA (1993)
5 = National Center for Environmental Assessment (NCEA), personal communication (2002)
6 = California EPA, Toxicity Criteria Database, www.oehha.ca.gov/risk/chemicaldb (2002)
Note:OHEA is now part of the National Center for Environmental Assessment (NCEA).

[b] Health Based Limits calculated for 30-year exposure duration, 10^6 cancer risk or hazard quotient=1. Assumes an ingestion rate of 2 L / day. RfD = 2 mg/kg-day

[c] Carcinogen Class based on overall weight of evidence for human carcinogenicity:
Group A: human carcinogen
Group B: probable human carcinogen
B1: limited evidence from epidemiologic studies
B2: "sufficient" evidence from animal studies and "inadequate" evidence or "no data" from epidemiologic studies
Group C: possible human carcinogen
Group D: not classifiable as to human carcinogenicity
Group E: evidence of non-carcinogenicity for humans

[d] Both adult and lifetime cancer slope factors and unit risk factors are listed for vinyl chloride. The lifetime exposure pathway is used to calculate the SSL in the direct contact exposure pathway (ingestion-dermal) for the residential scenario. The adult value is appropriate for the other residential pathways & the commercial/industrial pathways.

[e] Values listed are those for total xylenes: [CAS No. 1330-20-7] MCLG/MCL = 10 mg/L

Exhibit C-6

DERMAL ABSORPTION FRACTION FROM SOIL

Compound	Dermal Absorption Fraction (ABS_d)[a]	Reference
Arsenic	0.03	Wester, *et al.* (1993a)
Cadmium	0.001	Wester, *et al.* (1992a) U.S. EPA (1992a)
Chlordane	0.04	Wester, *et al.* (1992b)
DDT	0.03	Wester, *et al.* (1990)
2,4-Dichlorophenoxyacetic acid	0.05	Wester, *et al.* (1996)
Lindane	0.04	Duff & Kissel (1996)
PAHs	0.13	Wester, *et al.* (1990)
Pentachlorophenol	0.25	Wester, *et al.* (1993c)
Generic default *for screening*		
Semivolatile organic compounds	0.1	

[a] The values presented are mean values from empirical data.

Source: *RAGS Part E*, U.S. EPA, 2001.

Exhibit C-7

GASTROINTESTINAL ABSORPTION EFFICIENCIES AND ADJUSTMENT OF DERMAL TOXICITY FACTORS

CAS Number	Compound	Percent Absorbed*	ABS_{GI}
Organics			
57-74-9	Chlordane	80%	1
50-29-3	DDT	70-90%	1
94-75-7	2,4-Dichlorophenoxyacetic acid	>90%	1
87-86-5	Pentachlorophenol	76-100%	1
N/A	Polycyclic aromatic hydrocarbons (PAHs)	58-89%	1
N/A	All other organic compounds	generally >50%	1
Inorganics			
7440-38-2	Arsenic	95%	1
7440-43-9	Cadmium	2.5-5%	0.025

* *RAGS Part E*, U.S. EPA, 2001.

APPENDIX D

DISPERSION FACTOR CALCULATIONS

When developing SSLs for the outdoor inhalation of fugitive dusts and volatiles using the simple site-specific approach, site managers may want to calculate air dispersion factors (Q/C) that reflect the site location/climate and site size. This appendix provides information regarding the calculation of such "site-specific" dispersion factors (Q/C), which can be used in lieu of default values provided in this document.

These Q/C values should be used in conjunction with the Particulate Emission Factor (PEF) and Volatization Factor (VF) equations provided for outdoor workers under the commercial/industrial scenario (Section 4.2.3) and for off-site residents under the construction scenario in (Section 5.3.2).

The soil screening process presented in this guidance includes three receptor- and pathway-specific Q/C values for which site managers can calculate site-specific values using the information presented in this appendix. These include:

- **Q/C_{wind}:** The dispersion factor for fugitive dusts emitted from soils; used to derive commercial/industrial SSLs for the outdoor worker/landscaper receptor.

- **Q/C_{vol}:** The dispersion factor for volatiles emitted from soils; used to derive commercial/industrial SSLs for the outdoor worker/landscaper receptor.

- **Q/C_{off}:** The dispersion factor for fugitive dusts emitted from soils; used to derive construction SSLs for the off-site resident receptor.

The equations for calculating these dispersion factors all take the general form of Equation D-1. The specific instructions for calculating each of these receptor-specific dispersion factors are presented below. Site managers should use the map shown in Exhibit D-1 to identify their climate zone and refer to the relevant lookup table (Exhibits D-2 through D-4) to identify the appropriate values for the constants A, B, and C. To evaluate the dispersion factor, the ISC3 dispersion model was used to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. These data were used to generate the best-fit curve equation for predicting air concentration as a function of site size. CURVEFIT was used to determine the best fit equation and the resulting default values for constants A, B, and C.[1] This program performs a least squares curve fit on X (site size), Y (concentration data). Curves are fitted and Equation coefficients, Correlation Coefficient, and Best Fit parameters are computed. It was determined that a log normal distribution had the highest correlation coefficient when comparing site size to the concentration data. For additional information regarding the derivation of the dispersion modeling conducted, please refer to Appendix E of this document or to Section 2.4.3 in the *Technical Background Document* of the 1996 *Soil Screening Guidance*.

Equation D-1

GENERAL FORM FOR CALCULATING RECEPTOR- AND PATHWAY-SPECIFIC DISPERSION FACTORS (Q/C)

$$Q / C = A \times \exp\left[\frac{\left(\ln A_{site} - B\right)^2}{C}\right]$$

Parameter/Definition (Units)

Q/C: Inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source or at the boundary of the source* (g/m^2-s per kg/m^2)

A, B, C: Constants based on air dispersion modeling for specific climate zones

A_{site}: Areal extent of the site or contamination (acres)**

* Q/C_{wind} and Q/C_{vol} are calculated for concentrations at the center of the source. Only Q/C_{off} is calculated for the concentration at the site boundary in the direction of the prevailing wind.
** Site size can range from 0.5 to 500 acres.

---

[1] CURVEFIT Version 2.11 A July 29, 1988 by Thomas S. Cox.

Q/C_{wind} (Outdoor Worker - Fugitive Dusts)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 16.2302
B = 18.7762
C = 216.1080

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{wind} of 93.77.

Exhibit D-2 presents values for the constants for use in the calculation of site-specific values of Q/C_{wind}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{wind}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{wind} can then be used with Equation 4-5 in Chapter 4 of this guidance to calculate an appropriate PEF value. This is used in calculating SSLs for the inhalation of fugitive dusts pathway using Equations 4-3 and 4-4.

Q/C_{vol}(Outdoor Worker - Volatiles)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 11.9110
B = 18.4385
C = 209.7845

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{vol} of 68.18.

Exhibit D-3 presents values for the constants for use in the calculation of site-specific values of Q/C_{vol}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{vol}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{vol} can then be used with Equation 4-8 from Chapter 4 of this guidance to calculate an appropriate VF value. This is used in calculating SSLs for the inhalation of volatiles pathway using Equations 4-6 and 4-7.

Q/C_{off} (Offsite Residents - Fugitive Dusts)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 11.6831
B = 23.4910
C = 287.9969

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{off} of 89.03.

Exhibit D-4 presents values for the constants for use in the calculation of site-specific values of Q/C_{off}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{off}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{off} can then be used with Equation 5-9 in Chapter 5 of the guidance to calculate an appropriate PEF value. This is used in calculating SSLs for the inhalation of fugitive dusts pathway using Equations 5-7 and 5-8.

Exhibit D-1

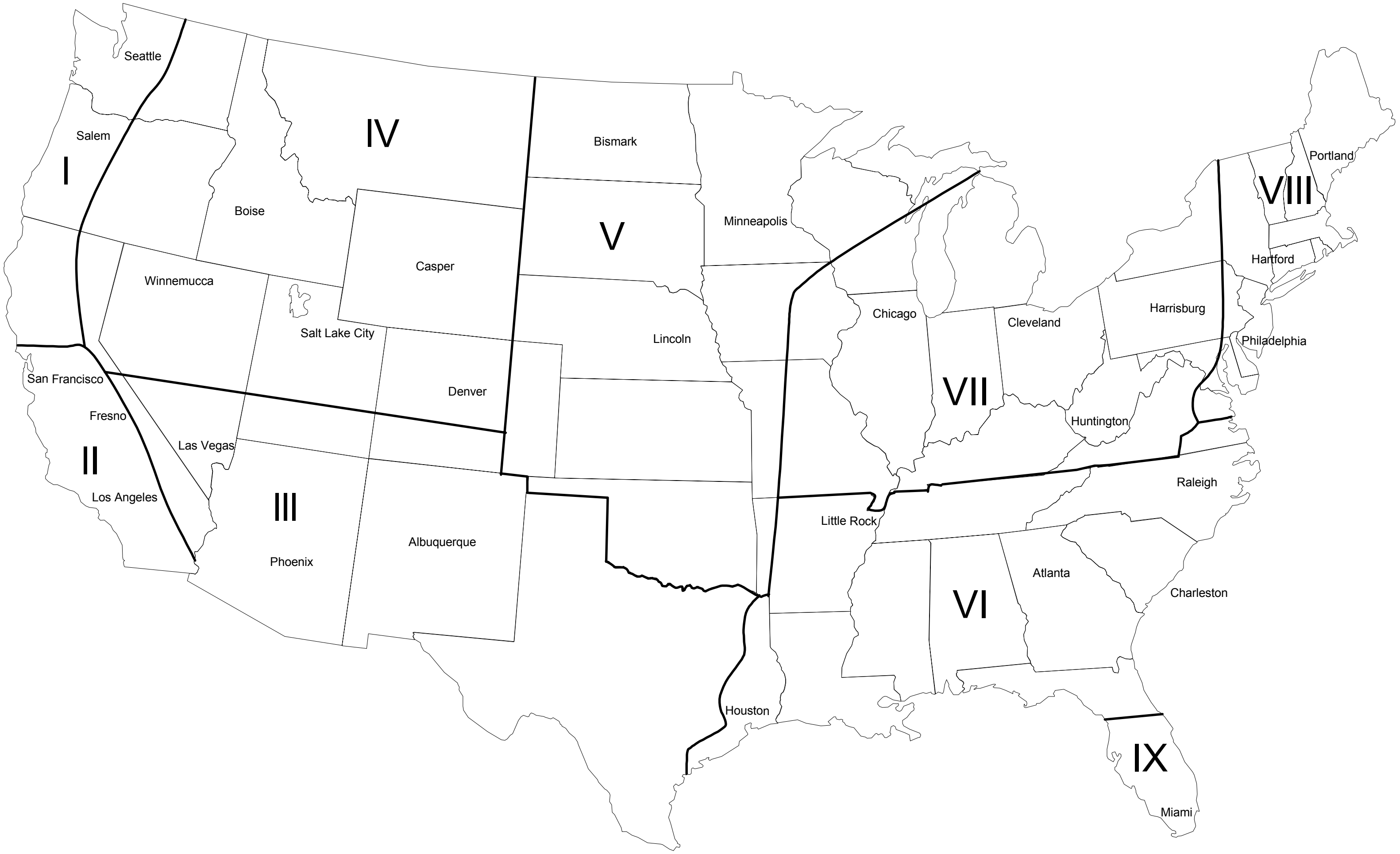
Seattle
Salem
I
Boise
IV
Bismark
V
Minneapolis
Portland
VIII
Hartford
Casper
Winnemucca
Salt Lake City
Lincoln
Chicago
Cleveland
Harrisburg
Philadelphia
San Francisco
Denver
VII
Huntington
Fresno
Las Vegas
II
Los Angeles
III
Raleigh
Little Rock
Albuquerque
Phoenix
Atlanta
Charleston
VI
Houston
IX
Miami

Exhibit D-2

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C$_{\text{wind}}$

$$Q / C_{wind} = A \times \exp\left[\frac{\left(\ln\ A_{site} - B\right)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Zone 2			
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Zone 3			
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Zone 4			
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	7.1414	31.1794	382.6078
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Zone 5			
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Zone 6			
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Zone 7			
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Zone 8			
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Zone 9			
Miami, FL	12.1960	19.0645	215.3923

Exhibit D-3

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C$_{vol}$

$$Q / C_{vol} = A \times \exp\left[\frac{\left(\ln\ A_{site} - B\right)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Zone 2			
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Zone 3			
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Zone 4			
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Zone 5			
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Zone 6			
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Zone 7			
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Zone 8			
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Zone 9			
Miami, FL	12.1960	19.0645	215.3923

Exhibit D-4

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C$_{off}$

$$Q / C_{off} = A \times \exp\left[\frac{(\ln A_{site} - B)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	14.5609	21.9974	265.3198
Seattle, WA	18.5578	21.5469	269.0431
Zone 2			
Fresno, CA	11.5554	22.2571	268.0331
Los Angeles, CA	15.7133	21.8997	269.8244
San Francisco, CA	13.1994	23.6414	283.5307
Zone 3			
Albuquerque, NM	17.8252	22.8701	274.1261
Las Vegas, NV	12.1784	24.5606	296.4571
Phoenix, AZ	11.6831	23.5910	287.9969
Zone 4			
Boise, ID	12.2294	23.8156	286.4807
Casper, WY	18.4275	22.9015	280.6949
Denver, CO	12.0770	22.5621	272.5685
Salt Lake City, UT	11.3006	25.8655	321.3924
Winnemucca, NV	16.5157	21.2894	252.8634
Zone 5			
Bismarck, ND	18.8928	22.2274	268.2849
Lincoln, NE	17.6897	22.7826	273.2907
Minneapolis, MN	20.2352	22.3129	271.1316
Zone 6			
Atlanta, GA	15.8125	23.7527	288.6108
Charleston, SC	19.2904	21.9679	265.0506
Houston, TX	18.9273	20.1609	242.9736
Little Rock, AR	15.4094	21.7198	261.8926
Raleigh, NC	15.4081	21.8656	261.3267
Zone 7			
Chicago, IL	20.1837	21.6367	264.0685
Cleveland, OH	13.4283	24.5328	302.1738
Harrisburg, PA	17.2968	22.2917	272.9800
Huntington, WV	12.1521	21.1970	252.6964
Zone 8			
Hartford, CT	15.3353	21.6690	261.7432
Philadelphia, PA	16.4927	22.2187	268.3139
Portland, ME	13.2438	23.2754	277.8473
Zone 9			
Miami, FL	17.7682	21.3218	253.6436

APPENDIX E

DETAILED SITE-SPECIFIC APPROACHES FOR DEVELOPING INHALATION SSLs

This appendix presents suggested methods of calculating SSLs for inhalation pathways using a detailed site-specific approach. The detailed site-specific approach is the most rigorous of the three approaches to SSL development and requires the largest amount of site-specific data. EPA generally recommends that site managers use the simple site-specific approach, which represents a reasonable balance between cost and site-specificity. This method is the focus of the soil screening guidance documents. However, the detailed site-specific approach allows a site manager to model more complex site conditions and employ less conservative assumptions than those used in the simple site-specific approach. For example, a detailed approach could be used to model volatilization of contaminants from either surface and subsurface (i.e., buried) soils, while the simple site-specific modeling conservatively assumes all contamination is located at the soil surface. If such modeling would produce SSLs more appropriate for site conditions and thus result in a substantial savings in cleanup costs, the detailed site-specific approach would be a reasonable choice for developing SSLs, despite the added cost and effort.

This appendix focuses on development of SSLs for the inhalation pathways (i.e., inhalation of outdoor volatiles and fugitive dust) because exposure modeling for these pathways can be complex and more detailed approaches that incorporate additional site-specific information may be useful in soil screening evaluations. Detailed modeling of the migration to ground water pathway can also be complex and useful in the soil screening process. Information on detailed site-specific approaches to this pathway are discussed in the *Technical Background Document* to EPA's 1996 *Soil Screening Guidance*.

The remainder of this appendix consists of two parts. The first presents a detailed site-specific approach for developing inhalation SSLs under the commercial/industrial or non-residential exposure scenario. The second section discusses a detailed site-specific approach for developing inhalation SSLs under the construction exposure scenario.

INHALATION SSLs FOR THE NON-RESIDENTIAL EXPOSURE SCENARIO

This section presents methods appropriate for the detailed site-specific approach to developing SSLs for the inhalation of volatiles and fugitive dust in outdoor air pathways. In describing these methods, it focuses on their application to the commercial/industrial exposure scenario; however, these methods could be applied to residential or other non-residential scenarios as well.

Detailed Site-Specific Approach to Developing Outdoor Inhalation of Volatiles SSLs for the Outdoor Worker/Landscaper

The key difference between a detailed and a simple site-specific approach to developing SSLs for the inhalation of volatiles in the outdoor air pathway is the use of a more rigorous model. The Exposure Model for Soil Organic Fate and Transport (EMSOFT), can be used to estimate the average emissions of volatiles from soil. This model, which is largely based on the work of Jury et al. (1983, 1990), estimates volatile emissions from both surface and subsurface soil contamination. It provides a one-dimensional analytical solution to mass transfer from soil to outdoor air. The major advantages of using EMSOFT rather than the infinite source model and mass balance approaches used in the simple site-specific SSL approach described in Section 4.3.2 of this guidance are that EMSOFT:

- Handles both surface and subsurface sources of emissions.
- Accounts for a finite source of emissions.
- Accounts for subsurface water convection (e.g., leaching).
- Accounts for a soil-to-air boundary layer which impedes emissions of contaminants with relatively low Henry's law constants.
- Provides time-averaged emissions over the exposure duration.

The EMSOFT model is available at no charge from the U.S. EPA National Center for Environmental Assessment (NCEA) web site at: http://www.epa.gov/ncea/emsoft.htm.

If the site is comprised of areas with both surface and subsurface soil contamination, the EMSOFT model can be used to calculate the unit emission flux for each area independently. The unit emission flux is calculated based on an initial soil concentration of 1 mg/kg or 1×10^{-6} g/g. This is subsequently used to reverse-calculate the SSL for inhalation of volatiles.

When using the EMSOFT model for calculating SSLs, set the model options as follows:

A. Calculation Options

- Check the box for "Time-Averaged Flux."

B. Calculation Control

- Set "Time Period for Averaging and Printing Flux and Soil Concentration Results" equal to the exposure duration in units of days.

- Set "Depth (D1)..." equal to any value > 0 but < the depth to the bottom of soil contamination.

- Set "Depth (D2)..." equal to the same value as "Depth (D1)."

C. Chemical Data

- Set the value of the "Half Life" equal to 1,000,000 days; this will eliminate calculation of transformation processes such as biodegradation.

- Set the value of the "Number of Layers" equal to 1.

D. Soil Properties

- Set the value of each soil property equal to an appropriate long-term average value. EMSOFT assumes homogeneous soil properties from the soil surface to an infinite depth; therefore, the selection of the soil properties values will have a significant effect on calculated emissions.

E. Physical Constants

- Set the value of the "Porewater Flux" to the appropriate long-term average value for the site. For worst-case conditions, set the value equal to zero.

- Set the value of the "Boundary Layer Thickness" to the appropriate value or to the default value of 0.5 cm.

F. Layer Properties

- Set the value of the "Cover Thickness" to the appropriate site-specific value. For surface contamination, set this value equal to zero. The "cover" should consist only of clean uncontaminated soil.

- Set the value of the "Layer Thickness" equal to the appropriate site-specific value. If the depth to the bottom of soil contamination is unknown, estimate the thickness of the contaminated layer as the depth from the soil surface to the top of the water table minus the depth from the soil surface to the top of soil contamination. If an infinitely thick layer of soil contamination is preferred, set the value of the "Layer Thickness" equal to a very large value (e.g., 1,000,000 cm).

- Set the value of the "Contaminant Concentration" equal to 1.0 mg/kg.

Equation E-1 along with the appropriate EMSOFT model results for areas of surface and subsurface soil contamination, are used to calculate the SSLs for outdoor inhalation of volatiles.

Equation E-1

$$VF = Q/C_{vol} \times \frac{1}{< J_T^{\ s} >} \times 0.1\ \mathrm{mg\text{-}m^2/g\text{-}cm^2} \times 86{,}400\ \mathrm{s/day} \times 10^{-6}\ \mathrm{g/g}$$

where: VF = Volatilization factor (m^3/kg)

Q/C_{vol} = Inverse of the ratio of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)

$< J_T^s >$ = Total EMSOFT time-averaged unit emission flux; sum of results for both surface and subsurface soils (g/m^2-s).

The dispersion factor (Q/C_{vol}) used in Equation E-1 was evaluated using the Industrial Source Complex (ISC3) dispersion model to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 national sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. The ISC3 model run was set up using the regulatory default options. Other selected options are identified in Exhibit E-1. These data were then used to generate a best-fit curve equation for predicting air concentration as a function of site size. Equation E-2 represents the best-fit curve equation for calculating the dispersion factor for emissions of volatiles. The default *A*, *B*, and *C* constants in Equation E-2 represent the 90th percentile of the 29 national sites with regard to dispersion. This equation is used to calculate the long-term dispersion factor for on-site exposure to volatile emissions from soils.

Equation E-2

$$Q/C_{vol} = A \times \exp\left[\frac{(\ln A_c - B)^2}{C}\right]$$

where: Q/C_{vol} = Inverse of the ratio of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)

A = Constant; default = 11.9 110

B = Constant; default = 18.4385

C = Constant: default = 209.7845

A_c = Areal extent of site soil contamination (acres).

Exhibit E-1
OPTIONS SELECTED IN THE ISCST3 MODELING

Option description
Regulatory default option. Emission Flux was set to 1 g/m^2-sec. Discrete receptor locations were established for site boundaries and out to at least 1000 meters. Terrain elevations were not considered. Rural Mode. Default wind profile exponent values. Default vertical potential temperature gradient values. The downwind distance plume rise option was used. Buoyancy-induced dispersion was used. The wind system measurement height was set to ten meters. No down wash considerations for area/line sources. Program control parameters, receptors, and source input data were output with the results. Concentrations during calm wind speed hours set to zero. Averaging times were set to annual.

Exhibit E-2 shows the values of the *A*, *B*, and *C* constants for Equation E-2 for each of the 29 national sites. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

Exhibit E-2

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C$_{vol}$

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	14.9421	17.9869	205.1782
Atlanta, GA	14.8349	17.9259	204.1516
Bismarck, ND	15.0235	18.2526	207.3387
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Charleston, SC	13.7674	18.0441	204.8689
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Denver, CO	11.3612	19.3324	221.2167
Fresno, CA	10.2152	19.2654	220.0604
Harrisburg, PA	15.5169	18.4248	211.7679
Hartford, CT	12.5907	18.8368	215.4377
Houston, TX	13.6482	18.1754	206.7273
Huntington, WV	9.9253	18.6636	211.8862
Las Vegas, NV	13.3093	19.8387	230.1652
Lincoln, NE	14.1901	18.5634	210.5281
Little Rock, AR	12.4964	18.4476	210.2128
Los Angeles, CA	11.9110	18.4385	209.7845
Miami, FL	12.1960	19.0645	215.3923
Minneapolis, MN	16.2302	18.7762	216.1080
Philadelphia, PA	14.0111	19.6154	225.3397
Phoenix, AZ	10.2871	18.7124	212.2704
Portland, ME	10.4660	20.9077	238.0318
Raleigh, NC	12.3675	18.6337	212.7284
Salem, OR	12.3783	18.9683	218.2086
Salt Lake City, UT	13.2559	19.2978	221.3379
San Francisco, CA	13.8139	20.1624	234.2869
Seattle, WA	14.2253	18.8366	218.1845
Winnemucca, NV	12.8784	17.9804	204.1028

Once the Q/C and VF factors have been calculated, SSLs for inhalation exposure to volatile contaminants in outdoor air by the outdoor worker can be calculated using Equations 4-6, 4-7, and 4-9 in Chapter 4 of this guidance document. Equations 4-6 and 4-7 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively. Equation 4-9 calculates C_{sat}, which serves as a ceiling for SSLs calculated using a VF model. If the SSL calculated using Equation 4-6 or 4-7 exceeds C_{sat} and the contaminant is liquid at soil temperatures (see Appendix C, Exhibit C-3), the SSL is set at C_{sat}. The SSL calculated using these equations represents the screening level for both surface and subsurface soils.

Detailed Site-Specific Approach to Developing Fugitive Dust Inhalation SSLs for Outdoor Workers

The simple site-specific fugitive dust equations (Equations 4-3 and 4-4 in this guidance document) are also used to calculate fugitive dust SSLs for the outdoor worker for carcinogenic and non-carcinogenic contaminants, respectively, under the detailed site-specific approach. The particulate emission factor (*PEF*) represents an estimate of the relationship between the concentration of contaminant in soil to the concentration of contaminant in air (as a consequence of particle suspension). The *PEF* is calculated using either the "unlimited reservoir" model from Cowherd et al. (1985) or the "emission factor" model from EPA's Compilation of Air Pollution Factors (1985), as appropriate for site-specific conditions. The "unlimited reservoir" model is the same model used in the simple site-specific approach and calculates emissions based on an unlimited reservoir of erodible particles. This assumes that the surface material consists of dry finely divided soils. The "emission factor" model assumes a "limited reservoir" of erodible particles that are completely suspended in air after a single soil disturbance; subsequent emissions are a function of the number of disturbances per year. The user is advised to review the appropriate sections of Cowherd et al. (1985) for a discussion of when to use these different models. Both models can be used to calculate the PM_{10} emission flux due to wind erosion. When using the "unlimited reservoir" model as given in Cowherd et al. (1985), the wind erosion emission flux of PM_{10} (given as E_{10}) is calculated in units of mg/m^2-h and must be converted to units of g/m^2-s. When using the EPA model, the "emission factor" or flux is calculated in units of g/m^2-yr and must be converted to units of g/m^2-s. The *PEF* is then calculated using Equation E-3.

Equation E-3

$$PEF = Q/C_{wind} \times \frac{1}{J_w}$$

where:

PEF = Particulate emission factor (m^3/kg)

Q/C_{wind} = Inverse of the ratio of the geometric mean air concentration to the emission flux at the center of a square source (g/m^2-s per kg/m^3)

J_w = PM_{10} emission flux (g/m^2-s).

For a detailed site-specific analysis, the air dispersion factor Q/C_{wind} is not based on an assumed exposure area of 0.5 acres. The exposure area for commercial/industrial land use may range in size from less than one acre to hundreds of acres. For this reason, the value of Q/C_{wind} is calculated as a function of site size.

To evaluate the dispersion factor for wind erosion, the ISC3 dispersion model was used to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. These data were used to generate a best-fit curve equation for predicting air concentration as a function of site size. Equation E-4 represents the best-fit curve equation for calculating the dispersion factor for wind erosion. The default *A*, *B*, and *C* constants in Equation E-4 represent the 90th percentile of the 29 national sites with regard to emissions and dispersion in that both are a function of meteorology. Equation E-4 is used to calculate the long-term dispersion factor for on-site exposure to emissions from wind erosion.

Equation E-4

$$Q/C_{wind} = A \times \exp\left[\frac{(\ln A_S - B)^2}{C}\right]$$

where: Q/C_{wind} = Inverse of the geometric mean air concentration to the emission flux at the center of a square source (g/m^2-s per kg/m^3)
A = Constant; default = 16.2302
B = Constant; default = 18.7762
C = Constant; default = 216.1080
A_S = Areal extent of site surface contamination (acres).

Exhibit E-3 shows the values of the *A*, *B*, and *C* constants for Equation E-4 for each of the 29 national sites. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

Exhibit E-3

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C_{wind}

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	14.9421	17.9869	205.1782
Atlanta, GA	14.8349	17.9259	204.1516
Bismarck, ND	15.0235	18.2526	207.3387
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	7.1414	31.1794	382.6078
Charleston, SC	13.7674	18.0441	204.8689
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Denver, CO	11.3612	19.3324	221.2167
Fresno, CA	10.2152	19.2654	220.0604
Harrisburg, PA	15.5169	18.4248	211.7679
Hartford, CT	12.5907	18.8368	215.4377
Houston, TX	13.6482	18.1754	206.7273
Huntington, WV	9.9253	18.6636	211.8862
Las Vegas, NV	13.3093	19.8387	230.1652
Lincoln, NE	14.1901	18.5634	210.5281
Little Rock, AR	12.4964	18.4476	210.2128
Los Angeles, CA	11.9110	18.4385	209.7845
Miami, FL	12.1960	19.0645	215.3923
Minneapolis, MN	16.2302	18.7762	216.1080
Philadelphia, PA	14.0111	19.6154	225.3397
Phoenix, AZ	10.2871	18.7124	212.2704
Portland, ME	10.4660	20.9077	238.0318
Raleigh, NC	12.3675	18.6337	212.7284
Salem, OR	12.3783	18.9683	218.2086
Salt Lake City, UT	13.2559	19.2978	221.3379
San Francisco, CA	13.8139	20.1624	234.2869
Seattle, WA	14.2253	18.8366	218.1845
Winnemucca, NV	12.8784	17.9804	204.1028

INHALATION SSLs FOR THE CONSTRUCTION EXPOSURE SCENARIO

This section presents methods appropriate for the detailed site-specific approach to developing construction-specific SSLs for the inhalation of volatiles and fugitive dust in outdoor air pathways. These SSLs reflect the increased inhalation exposures likely to result due to construction activities such as excavation and vehicle traffic on temporary, unpaved roads. This section first describes methods for evaluating the short-term inhalation exposures experienced by a construction worker and then presents methods for evaluating increased inhalation exposures to off-site residents living at the site boundary.

Detailed Site-Specific Approach to Developing Subchronic Inhalation SSLs for Construction Workers

For the construction worker exposure scenario, the primary assumption is that a commercial/industrial building or group of buildings will be constructed at the site. Additional assumptions are that the building or group of buildings will be constructed within the area of residual soil contamination and that the total time of construction is less than one year. As discussed in the guidance document, the short exposure duration of the construction worker constitutes a subchronic exposure that should be evaluated using subchronic toxicity values (denoted here and in the guidance document as HBL_{sc}). See Section 5.3.1 of the guidance document for suggestions on how to determine appropriate HBL_{sc} values.

The dynamic processes inherent in construction activities are likely to increase emissions of both volatiles and particulate matter from affected soils. Modeling studies have shown that high emissions of volatiles can occur from both excavation of contaminated soils and from undisturbed surface soil contamination. In the case of particulate matter, traffic on contaminated unpaved roads typically accounts for the majority of emissions, with wind erosion, excavation soil dumping, dozing, grading, and tilling operations contributing lesser emissions. The following approach can be used to estimate SSLs for construction activities based on subchronic inhalation exposures of the construction worker.

Volatile Emissions from Subsurface Soil Contamination

Because of the relatively short exposure duration of the construction worker, the emission model used to estimate volatile emissions from undisturbed subsurface soils should take into consideration the time that has elapsed since the time of initial soil contamination. If an estimate of the elapsed time can be made with significant certainty, this value may be used as the starting point for estimating time-averaged emissions during construction. Typically, however, this time period cannot be estimated with a high degree of certainty. In such cases, it is assumed that sufficient time has elapsed such that the volatile emissions at the soil surface have reached near steady-state conditions. The time required for the volatile emissions from subsurface soil contamination to reach near steady-state conditions is estimated by Equations E-5 and E-6 (API, 1998).

Equation E-5

$$\tau_{ss} \cong \frac{R_v \theta_a d^2}{D_A}$$

where: τ_{ss} = Time required to reach near steady-state (s)
R_v = Vapor-phase retardation factor (unitless)
θ_a = Soil air-filled porosity (cm^3/cm^3)
d = Depth to top of soil contamination (cm)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document.

Equation E-6

$$R_v = 1 + \frac{\theta_w}{\theta_a H'} + \frac{\rho_b K_d}{\theta_a H'}$$

where: R_v = Vapor-phase retardation factor (unitless)
θ_w = Soil water-filled porosity (cm^3/cm^3)
θ_a = Soil air-filled porosity (cm^3/cm^3)
H' = Henry's law constant (unitless)
ρ_b = Soil dry bulk density (g/cm^3)
K_d = Soil-water partition coefficient (cm^3/g).

Equation E-7 (from Jury et al., 1990) is used to calculate the unit emission flux at the soil surface. The "unit" emission flux assumes an initial soil contaminant concentration of 1 mg/kg or 10^{-6} g/g-soil. This equation should be run for a minimum of 100 time-steps, starting at time = τ_{ss} (or, if available, the actual elapsed time since initial soil contamination) and extending to the end of the duration of construction *(T)* in units of seconds.

Equation E-7

$$J_{sub} = \rho_b \left(\frac{\mathrm{D}_A}{\pi\tau} \right)^{1/2} \left[\exp\left(-\frac{d^2}{4\mathrm{D_A t}} \right) - \exp\left(-\frac{(d+\mathrm{W})^2}{4\mathrm{D_A t}} \right) \right] \times 10^4 \,\mathrm{cm^2/m^2}$$

where:

J_{sub} = Unit emission flux from subsurface soils at each time-step (g/m^2-s)

ρ_b = Soil dry bulk density (g/cm^3)

D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document

t = Elapsed time at the end of each time-step (s)

d = Depth to top of soil contamination (cm)

W = Thickness of subsurface contaminated soil (cm).

If the depth to the bottom of soil contamination is unknown, the value of the thickness of contaminated soil (W) is calculated as the depth to the top of the water table minus the depth to the top of soil contamination (d). In addition, the 100 time-steps using Equation E-7 are of equal intervals. These calculations can be performed easily using a PC-based spreadsheet program. Please note that the EMSOFT model cannot presently be used for these calculations because the averaging time period always begins at time = 0 and cannot be changed to time = τ_{ss} or any other value. For a relatively short exposure duration such as for construction, beginning the time period at t = 0 will underpredict the time-averaged unit emission flux in some cases.

From these data, Equation E-8 is used to estimate the cumulative unit mass emitted from undisturbed subsurface soil contamination using a trapezoidal approximation of the integral.[1] To ensure that the total unit mass of each subsurface contaminant emitted does not exceed the total unit initial mass in soil, a mass-balance is performed using Equations E-8 and E-9.

If the cumulative unit mass emitted from subsurface soils (M_{sub}) exceeds the total unit initial mass of subsurface contamination (M^T_{sub}), Equation E-7 may be rerun with a smaller time-step interval and a greater number of time-steps until the unit mass emitted is less than the total unit initial mass. As a more conservative alternative, the value of M_{sub} may be set equal to the value of M^T_{sub}.

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[1] For a more complete description of the tapezoidal approximation and example calculations, see *Calculus and Analytic Geometry*, pages 178-180 (Thomas, 1968).

Equation E-8

$$M_{sub} = \left[\frac{h}{2}\left(J_0 + 2J_1 + 2J_2 + ... + 2J_{n-1} + J_n\right)\right] \times A_{sub}$$

where: M_{sub} = Cumulative unit mass emitted from undisturbed subsurface soils (g)

h = Constant time-step interval (s), $h = \mathrm{T}/100$

T = Total time of construction (s)

J_0 = Unit emission flux at time = 0 (g/m^2-s), set time zero = τ_{ss} or = the actual elapsed time since initial soil contamination

$J_{1,2...n}$ = Unit emission flux at time-step J_1 and each succeeding time-step where n = 100 (g/m^2-s)

A_{sub} = Areal extent of site with undisturbed subsurface soil contamination (m^2).

NOTE: In Microsoft® Excel, the formula for M_{sub} can be written as:
= (((*T*/100)/2)*(J_0 + 2*SUM(J_1:J_{n-1}) + J_n))*A_{sub}

Equation E-9

$$M^T{}_{sub} = \rho_b \times A_{sub} \times W \times 10^{-2} \text{ m/cm} \times 10^6 \text{ cm}^3/\text{m}^3$$

where: $M^T{}_{sub}$ = Total unit initial mass of subsurface contamination, (g)

ρ_b = Soil dry bulk density (g/cm^3)

A_{sub} = Areal extent of site with undisturbed subsurface soil contamination (m^2)

W = Thickness of subsurface contaminated soil (cm).

Volatile Emissions from Surface Soil Contamination and from Excavation

Volatile emissions from both surface soil contamination and from excavation of areas with subsurface contamination are calculated assuming that contamination begins at the soil surface. The cumulative unit mass emitted from areas of the site where surface contamination is found and from site areas where subsurface contamination is expected to be excavated are added to the cumulative unit mass emitted from subsurface soil contamination. The unit mass emitted from all three of these areas of the site are then totaled and divided by the product of the total area of contamination and the total duration of construction. In this manner, the emissions from all three site areas are averaged over the total areal extent of contamination and over the duration of construction which is also the exposure duration.

Equation E-10 (from Jury et al., 1990) is used to calculate the unit emission flux from surface soil contamination. As with Equation E-7, the unit emission flux assumes an initial soil contaminant concentration of 1 mg/kg or 10^{-6} g/g-soil. This equation should be run for a minimum of 100 time-steps, starting at time = τ_{ss} (or, if available, the actual elapsed time since initial soil contamination) and extending to the end of the duration of construction (T) in units of seconds. If the time to reach near steady-state is used, the value of τ_{ss} for surface soil contamination should be set equal to that of subsurface soil contamination as calculated by Equations E-5 and E-6. If subsurface soil contamination is not present at the site, a best estimate should be made of the time since surface soil contamination last occurred and this value substituted for the value of τ_{ss}.

Equation E-10

$$J_{surf} = \rho_b \left(\frac{D_A}{\pi t} \right)^{1/2} \left[1 - \exp\left(-\frac{L^2}{4 D_A t} \right) \right] x 10^4 \text{ cm}^2/\text{m}^2$$

where:

J_{surf} = Unit emission flux from surface soils at each time-step (g/m^2-s)
ρ_b = Soil dry bulk density (g/cm^3)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document
t = Elapsed time at the end of each time-step (s)
L = Depth to the bottom of soil contamination (cm).

From these data, Equation E-11 is used to estimate the cumulative unit mass emitted from undisturbed surface soil contamination using a trapezoidal approximation of the integral. To ensure that the total unit mass of each surface contaminant emitted does not exceed the total unit initial mass in soil, a mass-balance is performed using Equations E-11 and E-12.

Equation E-11

$$M_{surf} = \left[\frac{h}{2}\left(J_0 + 2J_1 + 2J_2 + ... + 2J_{n-1} + J_n\right)\right] \times A_{surf}$$

where:
M_{surf} = Cumulative unit mass emitted from undisturbed surface soils (g)
h = Constant time-step interval (s), $h = T/100$
T = Total time of construction (s)
J_0 = Unit emission flux at time = 0 (g/m^2-s), set time zero = τ_{ss} or = the actual elapsed time since initial soil contamination
$J_{1,2...n}$ = Unit emission flux at time-step J_1 and each succeeding time-step where n = 100 (g/m^2-s)
A_{surf} = Areal extent of site with undisturbed surface soil contamination (m^2).

Equation E-12

$$M^T{}_{surf} = \rho_b \times A_{surf} \times L \times 10^{-2} \text{ m/cm} \times 10^6 \text{ cm}^3/\text{m}^3$$

where:
$M^T{}_{surf}$ = Total unit initial mass of surface contamination (g)
ρ_b = Soil dry bulk density (g/cm^3)
A_{surf} = Areal extent of site with undisturbed surface soil contamination (m^2)
L = Depth to the bottom of soil contamination (cm).

If the cumulative unit mass emitted from surface soils (M_{surf}) exceeds the total unit initial mass of surface contamination ($M^T{}_{surf}$), Equation E-10 may be rerun with a smaller time-step interval and a greater number of time-steps until the unit mass emitted is less than the total unit initial mass. As a more conservative alternative, the value of M_{surf} may be set equal to the value of $M^T{}_{surf}$.

Equation E-13 (from Jury et al., 1984) is used to calculate the cumulative unit mass emitted from the areal extent of excavation.

Equation E-13

$$M_{excvav} = \frac{2\rho_b D_A T_E}{(\pi D_A T_E)^{1/2}} x 10^4 \text{ cm}^2/\text{m}^2 x\ A_{excav}$$

where: M_{excav} = Cumulative unit mass emitted from excavation (g)
ρ_b = Soil dry bulk density (g/cm^3)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document
T_E = Duration of excavation (s); T_E ends when the excavation is covered by an impermeable material
A_{excav} = Areal extent of excavation (m^2).

Equation E-13 operates under the assumption of an infinitely deep emission source. This should not be problematic, however, for the relatively short duration of excavation. Equation E-13 differs from Equations E-7 and E-10 in that excavation is assumed to expose subsurface soil contamination to the atmosphere at time = 0. That is to say that excavation is assumed to instantaneously uncover the subsurface contamination. The duration of the excavation event ends when the areal extent of excavation is covered by an impermeable material (e.g., a concrete slab).

The total time-averaged unit emission flux from undisturbed subsurface soils, undisturbed surface soils, and from excavation is calculated using Equation E-14.

Equation E-14

$$< J_T > = \frac{\left(M_{sub} + M_{surf} + M_{excav}\right)}{A_c \times T}$$

where: $< J_T >$ = Total time-averaged unit emission flux (g/m^2-s)
M_{sub} = Cumulative unit mass emitted from undisturbed subsurface soils (g)
M_{surf} = Cumulative unit mass emitted from undisturbed surface soils (g)
M_{excav} = Cumulative unit mass emitted from excavation (g)
A_c = Areal extent of site soil contamination (m^2)
T = Duration of construction (s).

Calculation of the Soil-to-Air Volatilization Factor for the Construction Scenario

Because the exposure duration during construction is typically less than one year (i.e., subchronic), the dispersion factor must also reflect the same time period. The on-site subchronic dispersion factor for a ground-level area emission source, Q/C_{sa}, was derived by employing the EPA SCREEN3 dispersion model to predict the maximum 1-h. average on-site unit concentration for a ground-level area source of emissions. Identical dispersion modeling was performed for square site sizes ranging 0.5 to 500 acres. A best curve was then fit to the paired data of maximum concentration and site size to predict the value of Q/C_{sa} This resulted in Equation E-15 for calculating the subchronic on-site dispersion factor for area sources.

Equation E-15

$$Q/C_{sa} = A \times \exp\left[\frac{(\ln A_c - B)^2}{C}\right]$$

where: Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the volatilization flux at the center of a square emission source (g/m^2-s per kg/m^3)
A = Constant; default = 2.4538
B = Constant; default = 17.5660
C = Constant; default = 189.0426
A_c = Areal extent of site soil contamination (acres).

The value of Q/C_{sa} must be corrected for the averaging time represented by the duration of construction. To accomplish this, a best curve was fit to the EPA correction factors for converting 1-h. average concentrations to 3-h., 8-h., and 24-h. averages (U.S. EPA, 1992). In addition, a fourth data point was included representing the correction factor for converting the SCREEN3 1-h. average concentration to an annual average concentration. The median concentration was computed as the geometric mean of all 29 national sites as determined using the ISC3 dispersion model. This resulted in Equation E-16 for estimating the dispersion correction factor for averaging times less than one year.

Equation E-16

$$F_D = 0.1852 + \frac{5.3537}{t_c} + \frac{-9.6318}{t_c^{\;2}}$$

where:
F_D = Dispersion correction factor (unitless)
t_c = Duration of construction (hr), $t_c = T$ in units of hours.

The subchronic soil-to-air volatilization factor for the exposure of the construction worker is calculated by Equation E-17.

Equation E-17

$$VF_{sc} = Q/C_{sa} \times \frac{1}{F_D} \times \frac{1}{< J_T >}$$

where:
VF_{sc} = Subchronic soil-to-air volatilization factor (m^3/kg)
Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the volatilization flux at the center of a square emission source (g/m^2-s per kg/m^3), Eq. E-15
F_D = Dispersion correction factor (unitless), Eq. E-16
$< J_T >$ = Total time-averaged unit emission flux, Eq. E-14.

Once these values have been calculated, the SSL for subchronic on-site inhalation exposure to volatile emissions during construction can be calculated using Equations 5-12, 5-13, and 5-16 in Chapter 5 of this guidance document. Equations 5-12 and 5-13 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively, and Equation 5-16 calculates C_{sat}, which is an upper bound on SSLs calculated using the VF model. If the SSL calculated using Equation 5-12 and 5-13 exceed C_{sat} and the contaminant is liquid at soil temperatures (see Appendix C, Exhibit C-3), the SSL is set at C_{sat}. The value of the SSL calculated by these equations represents the soil screening level for all three areas of soil contamination, i.e., surface soils, subsurface soils, and areas of excavation.

Fugitive Dust Emissions During Construction

The construction worker is assumed to be exposed to contaminants in the form of particulate matter with an aerodynamic particle diameter of less than 10 microns (PM_{10}). Fugitive dust emissions are generated by construction vehicle traffic on temporary unpaved roads. In addition, fugitive dust emissions are generated by other construction activities such as excavation, soil dumping, dozing, grading, and tilling operations as well as from wind erosion of soil surfaces. Reasonable maximum exposure (RME) of the construction worker to unpaved road emissions occurs in proximity to the road(s). RME for wind erosion emissions and emissions from other construction activities are assumed to occur at the center of the emission source. The ambient air dispersion of emissions, therefore, is different for these two classes of emission sources. For this reason, the subchronic exposure SSL for unpaved road traffic and the subchronic exposure SSL for other construction activities (including wind erosion) are calculated separately.

The following fugitive dust emission equations represent approximations of actual emissions at a specific site. Sensitive emission model parameters include the soil silt content and moisture content. Silt is defined as soil particles smaller than 75 micrometers (Fm) in diameter and can be measured as that proportion of soil passing a 200-mesh screen, using the American Society for Testing and Materials (ASTM) Method C-136. Soil moisture content is defined on a percent gravimetric basis [(g-water/g-soil) x 100] and should be approximated as the mean value for the duration of the construction project. In general, soil silt and moisture content are the most sensitive model parameters for which default values have been assigned, however, site-specific values will produce more accurate modeling results. Other emission model parameters have not been assigned default values and are typically defined on a site-specific basis. These parameters include the total distance traveled by construction site vehicles, mean vehicle weight, average vehicle speed, and the area of soil disturbance.

Fugitive Dust Emissions from Unpaved Road Traffic

The subchronic particulate emission factor for unpaved road traffic (PEF_{sc}) is calculated using Equation E-18 (EPA, 19895). Equation E-18 differs from Equation 5-5 in Chapter 5 of this document in that it contains the unabridged equation for PM_{10} emissions from traffic on unpaved roads. Equation E-18 therefore allows the user to enter a site-specific value for each variable.

Equation E-18

$$PEF_{sc} \text{ ' } Q/C_{sr} \times \frac{1}{F_D} \times \frac{T \times A_R}{\frac{2.6 \times (s/12)^{0.8} (W/3)^{0.4}}{(M_{dry}/0.2)^{0.3}} \times \left[\frac{(365 \& p)}{365} \right] \times 281.9 \times \Sigma VKT}$$

where: PEF_{sc} = Subchronic particulate emission factor for unpaved road traffic (m^3/kg)

Q/C_{sr} = Inverse of the ratio of the 1-h. geometric mean air concentration to the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3), Eq. E-19

F_D = Dispersion correction factor (unitless), Eq. E-16

T = Total time over which construction occurs (s)

A_R = Surface area of contaminated road segment (m^2), $A_R = L_R$ x W_R x 0.092903 m^2/ft^2

s = Road surface silt content (%), default = 8.5 %

W = Mean vehicle weight (tons)

M_{dry} = Road surface material moisture content under dry, uncontrolled conditions (%), default = 0.2 %

p = Number of days per year with at least 0.01 inches of precipitation (Exhibit E-1)

' VKT = Sum of fleet vehicle kilometers traveled during the exposure duration (km)

L_R = Length of road segment (ft) L_R = square root of site surface contamination configured as a square

W_R = Width of road segment (ft), default = 20 ft.

Equation E-18 operates under the assumption of a road surface silt content of 8.5 percent as the mean value for "construction sites – scraper routes" (see Table 13.2.2-1 of EPA, 1985). In addition, the surface material moisture content under dry conditions is assumed to be 0.2 percent as the default value (see Section 13.2.2 of EPA, 1985).

The number of days with at least 0.01 inches of rainfall can be estimated using Exhibit E-4. Mean vehicle weight *(W)* can be estimated by assuming the numbers and weights of different types of vehicles. For example, assume that the daily unpaved road traffic consists of 20 two-ton cars and 10 twenty-ton trucks. The mean vehicle weight would then be:

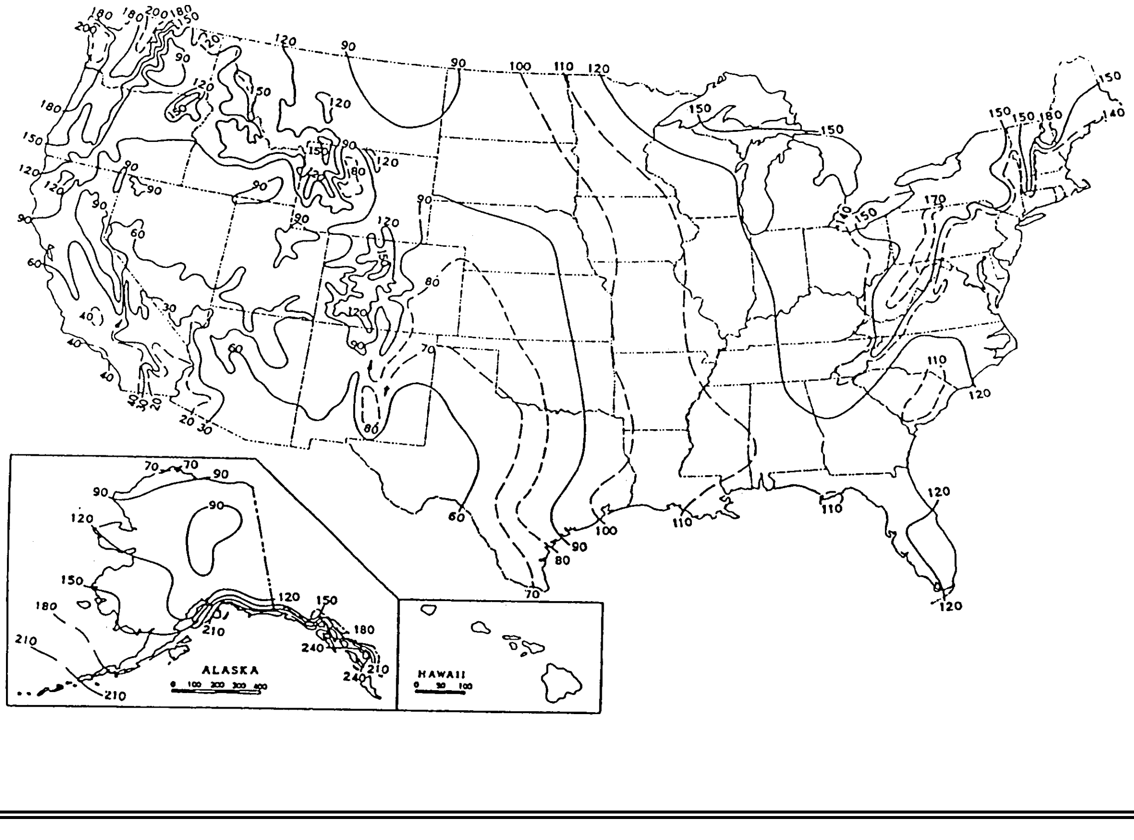
W = [(20 cars x 2 tons/car) + (10 trucks x 20 tons/truck)]/30 vehicles = 8 tons

The sum of the fleet vehicle kilometers traveled during construction *(ΣVKT)* can be estimated based on the size of the area of surface soil contamination, the configuration of the unpaved road, and the amount of vehicle traffic on the road. For example, if the area of surface soil contamination is 0.5 acres (or 2,024 m^2), and one assumes that this area is configured as a square with the unpaved road segment dividing the square evenly, the road length would be equal to the square root of 2,024 m^2 (45 m or 0.045 km). Assuming that each vehicle travels the length of the road once per day, 5 days per week for a total of 6 months, the total fleet vehicle kilometers traveled would be:

$$\Sigma VKT = 30 \text{ vehicles x } 0.045 \text{ km/day x } (52 \text{ wks/yr} \div 2) \text{ x } 5 \text{ days/wk} = 175.5 \text{ km.}$$

Exhibit E-4

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF ANNUAL PRECIPITATION



The subchronic dispersion factor for on-site exposure to unpaved road traffic, Q/C_{sr}, was derived by using the ISC3 dispersion model with a meteorological data set that mimics that of the SCREEN3 dispersion model. A straight road segment was situated such that the road bisected the site configured as a square. A series of square sites ranging in size from 0.5 to 500 acres with their associated road segments were modeled. A series of receptors were placed along each road segment and the road emissions were set equal to 1 g/m^2-s. The final on-site 1-h. average unit concentration was calculated as the mean of these receptors.

The subchronic dispersion factor for on-site exposure to unpaved road traffic is calculated using Equation E-19.

Equation E-19

$$Q/C_{sr} = A \times \exp\left[\frac{(\ln A_S - B)^2}{C}\right]$$

where:

Q/C_{sr} = Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3)

A = Constant; default = 12.9351

B = Constant; default = 5.7383

C = Constant; default = 71.7711

A_S = Areal extent of site surface contamination (acres).

Once these values have been calculated, the SSL for subchronic on-site inhalation exposure to particulate matter emissions from unpaved road traffic during construction can be calculated using Equations 5-7 and 5-8 in Chapter 5 of this guidance document. Equations 5-7 and 5-8 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively.

Fugitive Dust Emissions from Other Construction Activities

Other than emissions from unpaved road traffic, the construction worker may also be exposed to particulate matter emissions from wind erosion, excavation soil dumping, dozing, grading, and tilling or similar operations. These operations may occur separately or concurrently and the duration of each operation may be different. For these reasons, the total unit mass emitted from each operation is calculated separately and the sum is normalized over the entire area of contamination and over the entire time during which construction activities take place.

Equation E-20 is used to calculate the unit mass emitted from wind erosion of contaminated soil surfaces (from Cowherd et al., 1985).

Equation E-20

$$M_{wind} = 0.036 \times (1-V) \times \left(\frac{U_m}{U_t} \right)^3 \times F(x) \times A_{surf} \times ED \times 8{,}760\, hr/yr$$

where: M_{wind} = Unit mass emitted from wind erosion (g)

V = Fraction of vegetative cover (unitless), default = 0

U_m = Mean windspeed during construction (m/s), default = 4.69 m/s (EPA, 1996)

U_t = Equivalent threshold value of windspeed at 7 m (m/s), default = 11.32 m/s (EPA, 1996)

$F(x)$ = Function dependent on U_m/U_t derived from Cowherd et al. (1985) (unitless), default = 0.194 (EPA, 1996)

A_{surf} = Areal extent of site with surface soil contamination (m^2)

ED = Exposure duration (yr).

The unit mass emitted from the dumping of excavated soils can be calculated using Equation E-21 (from EPA, 1985).

Equation E-21

$$M_{excav} = 0.35 \times 0.0016 \times \frac{\left(\frac{U_m}{2.2} \right)^{1.3}}{\left(\frac{M}{2} \right)^{1.4}} \times \rho_{soil} \times A_{excav} \times d_{excav} \times N_A \times 10^3\, g/kg$$

where: M_{excav} = Unit mass emitted from excavation soil dumping (g)

0.35 = PM_{10} particle size multiplier (unitless) (EPA, 1985)

U_m = Mean windspeed during construction (m/s), default = 4.69 m/s (EPA, 1996)

M = Gravimetric soil moisture content (%), default = 12 %, EPA (1985) Table 13.2.4-1, mean value for municipal landfill cover

ρ_{soil} = In situ soil density (includes water) (Mg/m^3), default = 1.68 Mg/m^3

A_{excav} = Areal extent of excavation (m^2)

d_{excav} = Average depth of excavation (m)

N_A = Number of times soil is dumped (unitless), default = 2.

Equation E-22 (from EPA, 1985) is used to calculate the unit mass emitted from dozing operations.

Equation E-22

$$M_{doz} \;'\; 0.75 \times \frac{0.45(s)^{1.5}}{(M)^{1.4}} \times \frac{\Sigma VKT}{S} \times 10^3\, g/kg$$

where: M_{doz} = Unit mass emitted from dozing operations (g)

0.75 = PM$_{10}$ scaling factor (unitless)

s = Soil silt content (%), default = 6.9 %, EPA (1985) Table 11.9-3, mean value for overburden

M = Gravimetric soil moisture content (%), default = 7.9 %, EPA (1985) Table 11.9-3, mean value for overburden

$'VKT$ = Sum of dozing kilometers traveled (km)

S = Average dozing speed (kph), default = 11.4 kph, EPA (1985) Table 11.9-3, mean value for graders.

The unit mass emitted from grading operations is calculated by Equation E-23 (from EPA, 1985).

Equation E-23

$$M_{grade} \;'\; 0.60 \times 0.0056(S)^{2.0} \times \Sigma VKT \times 10^3\, g/kg$$

where: M_{grade} = Unit mass emitted from grading operations (g)

0.60 = PM$_{10}$ scaling factor (unitless)

S = Average grading speed (kph), default = 11.4 kph, EPA (1985) Table 11.9-3 mean value for graders

$'VKT$ = Sum of grading kilometers traveled (km).

Finally, Equation E-24 (from EPA, 1992a) is used to calculate the unit mass emitted from tilling or similar operations.

Equation E-24

$$M_{till} = 1.1(s)^{0.6} \times A_{till} \times 4{,}047 m^2/acre \times 10^{-4} ha/m^2 \times 10^3 g/kg \times N_A$$

where:

M_{till} = Unit mass emitted from tilling or similar operations (g)

s = Soil silt content (%), default = 18 % EPA (1992a) Section 2.6.1.1

A_{till} = Areal extent of tilling (acres)

N_A = Number of times soil is tilled (unitless), default = 2.

The total time-averaged unit emission flux from wind erosion, excavation soil dumping, dozing, grading, and tilling operations is calculated by Equation E-25.

Equation E-25

$$\langle J'_T \rangle = \frac{M_{wind} + M_{excav} + M_{doz} + M_{grade} + M_{till}}{A_c \times T}$$

where:

$\langle J'_T \rangle$ = Total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads (g/m^2-s)

M_{wind} = Unit mass emitted from wind erosion (g)

M_{excav} = Unit mass emitted from excavation soil dumping (g)

M_{doz} = Unit mass emitted from dozing operations (g)

M_{grade} = Unit mass emitted from grading operations (g)

M_{till} = Unit mass emitted from tilling operations (g)

A_c = Areal extent of site soil contamination (m^2)

T = Duration of construction (s).

The subchronic particulate emission factor for the construction worker due to construction activities other than unpaved road traffic is calculated by Equation E-26.

Equation E-26

$$PEF'_{sc} = Q/C_{sa} \times \frac{1}{F_D} \times \frac{1}{<J'_T>}$$

where: PEF'_{sc} = Subchronic particulate emission factor for construction activities other than traffic on unpaved roads (m^3/kg)

Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux at the center of the square emission source
(g/m^2-s per kg/m^3), Eq. E-15

F_D = Dispersion correction factor (unitless), Eq. E-16

$<J'_T>$ = Total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads (g/m^2-s), Eq. E-25.

Once these values have been calculated, the construction worker subchronic exposure SSLs for particulate matter emissions due to traffic on unpaved roads and due to other construction activities are calculated separately using Equations 5-3 and 5-4 in Chapter 5 this guidance document. Equations 5-3 and 5-4 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively. With values of the SSL for unpaved road traffic and the SSL for other construction activities, the lowest of the two SSLs should be used.

Particulate Matter Case Example

The following represents a theoretical case example illustrating the use of the previously cited equations for determining the SSL for unpaved road traffic and the SSL for other construction activities. The case example site consists of a 5-acre square area contaminated with hexavalent chromium (chromium VI). Contamination occurs in both surface and subsurface soils. Construction activities are anticipated to include unpaved road traffic, excavation soil dumping, dozing, grading, and tilling. In addition, wind erosion of the construction site is expected. Actual soil excavation will encompass one acre of soil to a depth of one meter. Likewise, one acre will be tilled twice for landscaping purposes. Dozing and grading operations are expected to cover the entire 5 acres.

SSL for Unpaved Road Traffic

From Equation E-18, the width of the road segment (W_R) is assumed to be 20 ft. The length of the road segment (L_R) is calculated as the square root of the area of the 5-acre site configured as a square:

$$L_R = (5 \text{ acres x } 43{,}560 \text{ ft}^2/\text{acre})^{0.5} = 467 \text{ ft.}$$

Therefore, the area of the road segment (A_R) is the product of the width and length of the road segment and a conversion factor of 0.092903 m^2/ft^2:

$$A_R = 20 \text{ ft x } 467 \text{ ft x } 0.092903 \text{ m}^2/\text{ft}^2 = 867 \text{ m}^2.$$

The total time period over which traffic will occur is estimated to be 6 months. Therefore, the value of T is calculated by:

$$T = (52 \text{ wks/yr} \div 2) \text{ x } 5 \text{ days/wk x } 8 \text{ hrs/day x } 3{,}600 \text{ s/hr} = 3{,}744{,}000 \text{ s.}$$

From Exhibit E-1, the value of the number of days with at least 0.01 inches of precipitation (p) is determined to be 70 days. Assuming that 30 vehicles per day travel the entire length of the road segment, the sum of the fleet vehicle kilometers traveled during the exposure duration $(' VKT)$ is calculated by:

$$' VKT = 30 \text{ vehicles x } 467 \text{ ft/day x } (52 \text{ wks/yr} \div 2) \text{ x } 5 \text{ days/wk} \div 3{,}281 \text{ ft/km} = 555 \text{ km.}$$

For a square 5-acre site, the value of Q/C_{sr} is calculated to be 16.40 $\text{g/m}^2\text{-s per kg/m}^3$ from Equation E-19. Assuming that the overall duration of construction is 6 months or 4,380 hours (t_c), the value of the dispersion correction factor (F_D) is calculated to be 0.186 from Equation E-16. Finally, the values of the road surface silt content (s) and the dry road surface moisture content (M_{dry}) in Equation E-18 are set equal to the default values of 8.5 % and 0.2 %, respectively. The value of the mean vehicle weight (W) in Equation E-18 is assumed to be 8 tons.

From these data, the value of the subchronic particulate emission factor for unpaved road traffic (PEF_{sc}) is calculated by Equation E-18:

$$PEF_{sc} \; ' \; 16.40 \times \frac{1}{0.186} \times \frac{3{,}744{,}000 \times 867}{\frac{2.6 \times (8.5/12)^{0.8} (8/3)^{0.4}}{(0.2/0.2)^{0.3}} \times [(365\&70)/365] \times 281.9 \times 555}$$

$$PEF_{sc} \; ' \; 7.74 \times 10^5 \; m^3/kg.$$

With a value of the PEF_{sc} for chromium VI (a carcinogenic contaminant), the construction worker subchronic exposure soil screening level for unpaved road traffic is calculated by Equation 5-3:

$$SSL_{sc} = \frac{TR \times AT \times 365\, days/yr}{URF \times 1{,}000\, \mu g/mg \times EF \times ED \times (1/PEF_{sc})}$$

$$SSL_{sc} = \frac{10^{-6} \times 70 \times 365}{(1.2 \times 10^{-2}) \times 1{,}000 \times 130 \times 1 \times (1/7.74 \times 10^{5})}$$

$$SSL_{sc} = 13\ \ mg/kg.$$

SSL for Wind Erosion and Other Construction Activities

The particulate emission factor for wind erosion and for construction activities other than unpaved road traffic *(PEF'_{sc})* is calculated using Equations E-20 through E-26. In each of these equations, the default values are used for each variable assigned a default value. In Equation E-20, the value of the areal extent of the site with surface soil contamination *(A_{surf})* is assigned a value of 5 acres or 20,235 m^2. In Equation E-21, the value of the areal extent of excavation *(A_{excav})* is set equal to 1 acre or 4,047 m^2, and the value of the average depth of excavation *(d_{excav})* is set equal to 1 meter. In Equation E-24, the value of the areal extent of tilling *(A_{till})* is also set equal to 1 acre or 4,047 m^2. The values of the sum of dozing and grading kilometers traveled in Equations E-22 and E-23 *(ΣVKT)* are each calculated assuming that the entire 5 acres are dozed and graded three times over the duration of construction. Assuming that the dozing and grading blades each have a length of 8 ft (2.44 m) and that one dozing or grading pass across the length of the site is equal to the square root of the site area (142 m), the value of ΣVKT is calculated by:

$$\Sigma VKT = ((142m/2.44m) \times 142m \times 3)/1{,}000\, m/km$$

$$\Sigma VKT = 24.79\, km.$$

From Equation E-15, the value of the dispersion factor *(Q/C_{sa})* for a square 5-acre site is calculated to be 9.44 g/m^2-s per kg/m^3. The value of the dispersion correction factor *(F_D)* is calculated from Equation E-16 as 0.186 based on a value for the duration of construction *(t_c)* equal to 6 months or 4,380 hours.

The total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads *($<J_T'>$)* is calculated by Equation E-25:

$$<J_T'> = \frac{(8.80 \times 10^4 g) + (1.66 \times 10^3 g) + (7.37 \times 10^2 g) + (1.08 \times 10^4 g) + (5.04 \times 10^3 g)}{20{,}235\, m^2 \times 3{,}744{,}000\, s}$$

$$<J_T'> = 1.40 \times 10^{-6}\, g/m\text{-}s.$$

From these data, the value of the subchronic particulate emission factor for construction activities other than unpaved road traffic (PEF'_{sc}) is calculated by Equation E-26:

$$PEF'_{sc} = 9.44 \times \frac{1}{0.186} \times \frac{1}{1.40 \times 10^{-6}}$$

$$PEF'_{sc} = 3.61 \times 10^{7}\, m^{3}/kg.$$

With a value of the PEF'_{sc} for chromium VI, the construction worker subchronic exposure SSL for construction activities other than unpaved road traffic is calculated by Equation 5-3:

$$SSL_{sc} = \frac{TR \times AT \times 365\, days/yr}{URF \times 1{,}000\, \mu g/mg \times EF \times ED \times (1/PEF'_{sc})}$$

$$SSL_{sc} = \frac{10^{-6} \times 70 \times 365}{(1.2 \times 10^{-2}) \times 1{,}000 \times 130 \times 1 \times (1/3.61 \times 10^{7})}$$

$$SSL_{sc} = 590\, mg/kg.$$

Because the SSL for unpaved road traffic (13 mg/kg) is less than the SSL for construction activities other than unpaved road traffic (590 mg/kg), the final value of the SSL_{sc} is set equal to the value for unpaved road traffic.

Inhalation SSLs for the Off-site Resident[2]

The off-site resident receptor refers to a receptor who does not live on the site. The major assumption is that the relevant exposure point is located at the site boundary. Dispersion modeling has shown that an exposure point at the site boundary will always experience the highest off-site air concentration from the ground-level nonbuoyant type of site emission sources considered for this analysis. This receptor will experience volatile and particulate matter emissions from the site both during construction and after construction is completed. In some cases, the magnitude of the emissions during construction may exceed that of post-construction even though the post-construction exposure duration is considerably longer.

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[2] The approach described in this section can also be applied to other off-site receptors, such as an off-site commercial/industrial worker.

Volatile Emissions

Simple site-specific inhalation SSLs due to volatile emissions that are calculated for the on-site outdoor worker are considered to be protective of the off-site resident for two primary reasons. First, the volatile emission model used in the simple site-specific analyses for off-site receptors operates under the assumption that soil contamination begins at the soil surface. This assumption equates to worst-case conditions in terms of the magnitude of emissions. Second, dispersion modeling has shown that for a square area emission source the on-site air concentration will always be higher than the off-site air concentration. Preliminary emission and dispersion modeling has shown that considering the greater exposure frequency and longer exposure duration of the off-site residential receptor, the resulting SSLs are typically lower than those of the on-site outdoor worker by less than 30 percent. However, one must consider the relative uncertainty in these analyses. The uncertainty is a function of several variables. First, the actual geometry of a site may not closely resemble a square. Second, the emission model assumes that volatiles are emitted uniformly across the entire areal extent of the site, whereas emissions from actual sites may be heterogeneous with respect to both strength and location. Finally, the dispersion factor for the off-site receptor assumes that it is located at the emission source boundary as an upper bound estimate; in reality, this may or may not be the case. For these reasons, the difference in the on-site outdoor worker and off-site residential SSLs is considered to be negligible.

Particulate Matter Emissions

The off-site resident is exposed to particulate matter emissions both during site construction and after construction is complete. During site construction, this receptor is assumed to be exposed to particulate matter emissions from unpaved road traffic, excavation soil dumping, dozing, grading, and tilling operations as well as emissions from wind erosion. After construction, the receptor is assumed to be exposed only to fugitive dust emissions from wind erosion. Although the construction exposure duration is considerably shorter than the post-construction exposure duration, the magnitude of emissions during construction may be higher than that due to wind erosion alone. For this reason, the total unit mass emitted from all construction activities and the total unit mass emitted from wind erosion are summed and normalized over the entire site area and over the total exposure duration of the off-site resident receptor.

The unit masses of each contaminant emitted during construction from wind erosion, excavation soil dumping, dozing, grading, and tilling operations are calculated using Equations E-20 through E-24. The post-construction unit mass emitted due to wind erosion (M^{pc}_{wind}) is calculated using Equation E-20. In this case, the value of the exposure duration *(ED)* in Equation E-20 must be changed to reflect a long-term exposure (i.e., 30 years for residential or 25 years for commercial/industrial exposure). In addition, the default value of the fraction of vegetative cover *(V)* in Equation E-20 is changed from 0 to 0.5 for post-construction exposure. The unit mass emitted from traffic on unpaved roads (M_{road}) is calculated by Equation E-27.

Equation E-27

$$M_{road} = \frac{2.6 \times (s/12)^{0.8}\,(W/3)^{0.4}}{(M_{dry}/0.2)^{0.3}} \times [(365 - p)/365] \times 281.9 \times \Sigma VKT$$

where each variable has been defined previously in Equation E-18.

The total time-averaged unit emission flux for the off-site receptor is calculated by Equation E-28.

Equation E-28

$$<J_T^{off}> = \frac{(M_{road} + M_{wind} + M_{excav} + M_{doz} + M_{grade} + M_{till} + M_{wind}^{pc})}{A_{site} \times ED \times 3.1536E+07\, s/yr}$$

where: $<J_T^{off}>$ = Total time-averaged PM_{10} unit emission flux for the off-site receptor (g/m^2-s)
M_{road} = Unit mass emitted from unpaved roads (g)
M_{wind} = Unit mass emitted from wind erosion (g)
M_{excav} = Unit mass emitted from excavation soil dumping (g)
M_{doz} = Unit mass emitted from dozing operations (g)
M_{grade} = Unit mass emitted from grading operations (g)
M_{till} = Unit mass emitted from tilling operations (g)
$M^{pc}{}_{wind}$ = Post-construction unit mass emitted from wind erosion (g)
A_{site} = Areal extent of site (m^2)
ED = Exposure duration (yr).

Equation E-28 combines the unit mass emitted from construction activities and from wind erosion and normalizes these emissions across the entire site area and the exposure duration of the off-site receptor. Because the emission source geometry at an actual site is unknown, spreading the total emissions across the entire site facilitates calculation of the dispersion factor such that the receptor is located at the point of maximum annual average concentration at the site boundary. This concentration represents the maximum concentration at the point of public access.

The particulate emission factor for the exposure of the off-site receptor is calculated by Equation E-29.

Equation E-29

$$PEF_{off} = Q/C_{off} \times \frac{1}{<J_T^{off}>}$$

where: PEF_{off} = Particulate emission factor for the off-site receptor (m^3/kg)

Q/C_{off} = Inverse of the ratio of the geometric mean air concentration at the emission flux at the site boundary (g/m^2-s per kg/m^3), Eq. E-30

$<J_T^{off}>$ = Total time-averaged PM_{10} unit emission flux for the off-site receptor (g/m^2-s), Eq. E-28.

The dispersion factor for the off-site resident, Q/C_{off}, was derived by using EPA's ISC3 dispersion model to predict the maximum annual average unit concentration at the boundary of a series of square ground-level area emissions sources. Site sizes ranged from 0.5 to 500 acres. A best curve was fit to the paired data of maximum concentration and site size to predict the value of $(Q/C)_{off}$. This resulted in Equation E-30 for calculating the dispersion factor.

The dispersion factor for the off-site resident, Q/C_{off}, is therefore calculated using Equation E-30.

Equation E-30

$$Q/C_{off} = A \times \exp\left[\frac{(\ln A_{site} - B)^2}{C}\right]$$

where: Q/C_{off} = Inverse of the ratio of the geometric mean air concentration at the emission flux at the site boundary (g/m^2-s per kg/m^3)

A = Constant; default = 11.6831

B = Constant; default = 23.4910

C = Constant; default = 287.9969

A_{site} = Areal extent of the site (acres).

Exhibit E-5 shows the values of the *A, B,* and *C* constants used in Equation E-30 for each of the 29 meteorological stations used in the dispersion modeling analysis. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

With a calculated value of the off-site receptor particulate emission factor (PEF_{off}), the inhalation soil screening level is calculated using Equations 5-3 and 5-4 in Chapter 5 of the supplemental soil screening guidance document, as appropriate.

Exhibit E-5

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C$_{off}$

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	17.8252	22.8701	274.1261
Atlanta, GA	15.8125	23.7527	288.6108
Bismarck, ND	18.8928	22.2274	268.2849
Boise, ID	12.2294	23.8156	286.4807
Casper, WY	18.4275	22.9015	280.6949
Charleston, SC	19.2904	21.9679	265.0506
Chicago, IL	20.1837	21.6367	264.0685
Cleveland, OH	13.4283	24.5328	302.1738
Denver, CO	12.0770	22.5621	272.5685
Fresno, CA	11.5554	22.2571	268.0331
Harrisburg, PA	17.2968	22.2917	272.9800
Hartford, CT	15.3353	21.6690	261.7432
Houston, TX	18.9273	20.1609	242.9736
Huntington, WV	12.1521	21.1970	252.6964
Las Vegas, NV	12.1784	24.5606	296.4751
Lincoln, NE	17.6897	22.7826	273.2907
Little Rock, AR	15.4094	21.7198	261.8926
Los Angeles, CA	15.7133	21.8997	269.8244
Miami, FL	17.7682	21.3218	253.6436
Minneapolis, MN	20.2352	22.3129	271.1316
Philadelphia, PA	16.4927	22.2187	268.3139
Phoenix, AZ	11.6831	23.4910	287.9969
Portland, ME	13.2438	23.2754	277.8473
Raleigh, NC	15.4081	21.8656	261.3267
Salem, OR	14.5609	21.9974	265.3198
Salt Lake City, UT	11.3006	25.8655	321.3924
San Francisco, CA	13.1994	23.6414	283.5307
Seattle, WA	18.5578	21.5469	269.0431
Winnemucca, NV	16.5157	21.2894	252.8634

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