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In reply, please refer to:
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TO: Interested Parties 2005-292-RB

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DATE: June 1, 2005

SUBJECT: May 2005 Update to Environmental Action Levels ("EALs") Technical Document

The Hazard Evaluation and Emergency Response (HEER) office has prepared a technical document entitled *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (Interim Final - May 2005). Previous drafts of the document (December 2003, January 2005) were revised to reflect comments provided by the general public and agency staff. Environmental Action Levels ("EALs") presented in the May 2005 document replace and take precedence over action levels presented in the 1995 HDOH document *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater* (December, 1995; revised June, 1996). The EALs also replace action levels presented in the HEER office *Technical Guidance Manual* (based on the 1995/1996 document noted above). The May 2005 EALs are currently intended for use at sites overseen by the HEER office. Use of the updated EALs in "site-specific" risk assessments at Leaking Underground Storage Tank sites overseen by the Office of Solid and Hazardous Waste is also being reviewed. Contact that office for more information.

The EAL document is intended to help expedite the identification of potential environmental concerns at sites with contaminated soil and groundwater and expedite the cleanup and redevelopment of these properties. As an alternative to preparing a detailed, baseline environmental risk assessment, soil, groundwater and other data collected at a site can be directly compared to the EALs presented in the document and the need for additional actions determined. This approach has been shown to be especially effective and efficient at sites with limited or relatively straightforward types of contamination, where the preparation of a more formal risk assessment may not be warranted or feasible due to time and cost constraints. HEER office staff overseeing work at a specific site should be contacted prior to use of this document in order to ensure that the document is applicable to the site and that the user has the most up-to-date version available.

The EAL document is not intended to establish policy or regulation. Use of the document and associated EALs is entirely optional on the part of the party responsible for the investigation and cleanup of a contaminated site. Reference to the updated EALs will generally not be needed at

sites where final cleanup levels have already been reviewed and approved by the HEER office, including sites that have already been closed. For sites where investigation is currently underway, referral to the updated EALs is strongly recommended.

The EAL document will be revised and updated on a regular basis. Comments and suggestions from the general public are welcome at any time. Updates will be posted to this website and notification sent to persons on the EAL mailing list. Workshops to present and discuss the EALs will also be held periodically. To provide comments or be included on the mailing list for updates and workshop announcements, please contact:

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Screening For Environmental Concerns At Sites With Contaminated Soil and Groundwater

Volume 1: Summary Tier 1 Lookup Tables

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DISCLAIMER

This document, *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (Interim Final, May 2005), is a technical report prepared by staff of the Hawai'i Department of Health, Environmental Management Division. It is intended to serve as an update to the 1996 HDOH document entitled *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater*. This document is not intended to establish policy or regulation. The Environmental Action Levels presented in this document and the accompanying text are specifically not intended to serve as: 1) a stand-alone decision making tool, 2) guidance for the preparation of baseline ("Tier 3") environmental assessments, 3) a rule to determine if a waste is hazardous under the state or federal regulations, or 4) a rule to determine when the release of hazardous substances must be reported to the overseeing regulatory agency.

This document will be periodically updated as needed. Please send comments, edits, etc. in writing to the above contacts. Staff overseeing work at a specific site should be contacted prior to use of this document in order to ensure that the document is applicable to the site and that the user has the most up-to-date version available. This document is not copyrighted. Copies may be freely made and distributed. It is cautioned, however, that reference to the action levels presented in this document without adequate review of the accompanying narrative could result in misinterpretation and misuse of the information.

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Executive Summary

This document presents Environmental Action Levels (EALs) for contaminants commonly found in soil and groundwater at sites where releases of hazardous substances have occurred (refer to Section 128D-1 of the Hawai'i Revised Statutes for a definition of "Hazardous Substances"). The EALs are intended to serve as an update and supplement to the Hawai'i Department of Health (HIDOH) document *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater* (June 1996). The change in terminology from "Risk-Based Action Levels" to "Environmental Action Levels" is intended to better convey the broad scope of the document and clarify that some action levels are not "risk-based" in a strict toxicological definition of this term. Use of the EALs is recommended not mandatory. The document may especially be beneficial for use at sites with limited impacts, however, where preparation of a detailed environmental assessment may not be warranted or feasible due to time and cost constraints.

The EALs are considered to be conservative. Under most circumstances, and within the limitations described, the presence of a chemical in soil, soil gas or groundwater at concentrations below the corresponding EAL can be assumed to not pose a significant, long-term (chronic) threat to human health and the environment. Additional evaluation will generally be necessary at sites where a chemical is present at concentrations above the corresponding EAL. Active remediation may or may not be required, however, depending on site-specific conditions and considerations.

The EALs were developed to help address the following environmental goals:

Surface Water and Groundwater:

- Protection of drinking water resources;
- Protection of aquatic habitats (discharges to surface water);
- Protection against vapor intrusion into buildings;
- Protection against gross contamination conditions;

Soil:

- Protection of human health (direct-exposure);
- Protection against vapor intrusion into buildings;
- Protection against leaching and subsequent impacts to groundwater;
- Protection of terrestrial (nonhuman) habitats; and
- Protection against gross contamination conditions.

Primary EALs for soil and groundwater are summarized in two lookup tables. Each table reflects a specific designation of groundwater utility and location with respect to the nearest body of surface water. A detailed review of environmental concerns addressed by the action levels is provided in Appendix 1. Groundwater action levels specific to drinking water concerns and aquatic habitat protection are provided in separate tables for

use on a site-specific basis. Additional soil action levels are presented for areas of high rainfall (>200cm/year).

As described in the 1996 HIDOH document, the action levels are intended to be used in a "tiered" approach. Under "Tier 1", sample data are directly compared to EALs selected for the site and decisions are made regarding the need for additional site investigation, remedial action or a more detailed risk assessment. In a "Tier 2" risk assessment, a selected component(s) of the Tier 1 EAL is modified with respect to site-specific considerations. An example may be the adjustment of a screening level for direct exposure with respect to an approved, alternative target risk level. Site data are then compared to the revised screening level as well as the remaining, unmodified components of the Tier 1 EAL. This provides an intermediate but still relatively rapid and cost-effective option for preparing more site-specific risk assessments. Risk assessment models and assumptions that depart significantly from those used to develop the Tier 1 EALs are described in a more traditional, "Tier 3" risk assessment. The Tier 1 methodology can, however, still provide a common platform to initiate a Tier 3 risk assessment and help ensure that all potentially significant environmental concerns are considered.

It is important to understand that the assessment and cleanup of contaminated sites must address **all** potential environmental concerns, not simply concerns directly related to human health. For example, cleanup of soil contaminated with highly toxic, relatively immobile substances will most often be driven by human-health (direct-exposure) concerns (e.g., PCBs). Cleanup of soil contaminated with relatively mobile, noncarcinogenic, volatile substances will, however, most often be driven by leaching and groundwater protection concerns (e.g., xylenes). Cleanup of soil contaminated with metals or pesticides that are more toxic to flora and fauna than to humans may be driven by ecotoxicity concerns (e.g., copper and endrin). Under a Tier 2 assessment, cleanup of soil contaminated with highly odiferous substances that do not threaten drinking water supplies or surface water bodies may be driven by nuisance concerns (e.g., petroleum fuels). Cleanup of soil contaminated with substances that are relatively immobile and nontoxic to humans and do not threaten ecological receptors may be driven by simple gross contamination concerns (e.g., chromium III). Refer to Tables A-1 through B-2 in Appendix 1 for a more detailed review of these examples.

The Tier 1 EALs presented in the lookup tables are NOT regulatory "cleanup standards". This document is intended to serve as a supplement to cleanup standards currently presented in the Hawai'i Administrative Rules, Title 11, Chapter 281 (Underground Storage Tanks). Use of the EALs and this document in general is intended to be optional on the part of the regulated facility and subject to the approval of the project manager in the Department of Health. The presence of a chemical at concentrations in excess of an EAL does not necessarily indicate that adverse impacts to human health or the environment are occurring; this simply indicates that a potential for adverse risk may exist and that additional evaluation is warranted. EALs presented for

chemicals that are known to be highly biodegradable in the environment may in particular be overly conservative for use as final cleanup levels (e.g., many petroleum-related compounds). Use of the EALs as cleanup levels should be evaluated in view of the overall site investigation results and the cost/benefit of performing a more site-specific risk assessment.

Reliance on only the Tier 1 EALs to identify potential environmental concerns may not be appropriate for some sites. Examples include sites that require a detailed discussion of potential risks to human health, sites where physical conditions differ drastically from those assumed in development of the EALs (e.g., mine sites, landfills, etc., with excessively high or low pH) and sites where impacts pose heightened threats to sensitive ecological habitats. Potential impacts to sediment are also not addressed. The need for a detailed ecological risk assessment should be evaluated on a site-by-site basis for areas where significant concerns may exist.

The EALs should NOT be used to determine when impacts at a site should be reported to a regulatory agency. All releases of hazardous substances to the environment should be reported to the HDOH in accordance with governing regulations. The lookup tables will be updated on a regular basis, as needed, in order to reflect changes in the referenced sources as well as lessons gained from site investigations and field observations.

1

Introduction

1.1 Purpose

Preparation of detailed environmental risk assessments for sites impacted by releases of hazardous substances can be a time consuming and costly effort that requires expertise in a multiple of disciplines, including toxicology, geology, ecology, chemistry, physics and engineering, among others. For small-business owners and property owners with limited financial resources, preparation of such risk assessments can be time and cost-prohibitive.

As a means to partially address this problem, this document presents a series of conservative Environmental Action Levels (EALs) for soil, groundwater and soil gas that can be directly compared to environmental data collected at a site. Correlative action levels for surface water are also provided. Action levels for over 100 commonly detected contaminants are given in a series of "lookup" tables. The tables are arranged in a format that allows the user to take into account site-specific factors that help define environmental concerns at a given property.

Within noted limits, risks to human health and the environment can be considered to be insignificant at sites where concentrations of chemicals of concern do not exceed the respective EALs. The presence of chemicals at concentrations above the EALs does not necessarily indicate that a significant risk exists at the site. It does, however, generally indicate that additional investigation and evaluation of potential environmental concerns is warranted.

The introductory text of this document is kept intentionally brief with a focus on the use of the EALs rather than technical details about their derivation. Technical background data regarding the EALs are provided in the appendices of Volume 2.

1.2 Tiered Approach to Environmental Risk Assessments

This document presents a three-tiered approach to environmental risk assessment. Under "Tier 1", sample data are directly compared to EALs selected for the site and decisions are made regarding the need for additional site investigation, remedial action or a more

detailed risk assessment. A detailed understanding of the derivation of the action levels is not required for use at this level.

Under "Tier 2", selected components of the models used to develop the Tier 1 EALs are modified with respect to site-specific data or considerations. Examples include adjustment of the assumed depth to impacted groundwater in the Tier 1 indoor-air impact model or use of an approved, alternative target risk level for direct-exposure concerns. Site data are then compared to the revised screening level as well as the remaining, unmodified components of the Tier 1 EALs. This provides an intermediate but still relatively rapid and cost-effective option for preparing more site-specific risk assessments.

Under Tier 3, the user employs alternative models and modeling assumptions to develop site-specific screening or final cleanup levels or quantitatively evaluate the actual risk posed to human and/or ecological receptors by the impacted media. Consideration of the methodologies and potential environmental concerns discussed in this document is still encouraged, however. This will help increase the comprehensiveness and consistency of Tier 3 risk assessments as well as expedite their preparation and review.

1.3 Comparison To Existing Action Levels

Soil and groundwater action levels previously prepared by HDOH are presented in the document *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater* (June 1996). In addition, Region IX of the U.S. Environmental Protection Agency (USEPA 2004) prepares and routinely updates risk-based "Preliminary Remediation Goals (PRGs)" for soil, water and air. The lookup tables presented in this document represent a compilation and expansion of this work. Differences and similarities between the 1996 HDOH action levels and the USEPA PRGs are summarized below. A brief discussion of OSHA "PELs" is also provided.

1.3.1 1996 HDOH Action Levels

1.3.1.1 Updates to Environmental Concerns

A comparison of soil and groundwater action levels presented in the earlier HDOH RBCA document (HDOH 1996) to those presented in this document is provided in Appendix 9. Responses to comments provided on a December 2003 draft of this document are provided in Appendix 10. Soil and groundwater action levels presented in the June 1996 HDOH document addressed the following environmental concerns:

Groundwater Quality:

- Protection of human health
 - Current or potential drinking water resource;

- Protection of aquatic habitats (discharges to surface water);

Soil Quality:

- Protection of human health
 - Direct/indirect exposure to impacted soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);
- Protection of groundwater quality (leaching of chemicals from soil);
- Maximum levels (theoretical saturation limits for liquid chemicals).

This document presents a comparable set of action levels for the above concerns. In addition, soil action levels are presented for potential gross contamination concerns (odors, general resource degradation, etc.), terrestrial ecological concerns (e.g., phytotoxicity) and potential emissions of vapors from contaminated soil to indoor air. Additional groundwater action levels are presented for potential gross contamination concerns and the potential emission of vapors from contaminated groundwater to indoor air. This is discussed in detail in Chapter 2 and in Appendix 1.

1.3.1.2 Changes to Site Categories

Under the 1996 RBCA program, release sites are categorized into two groundwater utility scenarios – “Drinking Water Source Threatened” and “Drinking Water Source NOT Threatened” (Figure 1). Groundwater utility is determined based on the location of the site with respect to the Underground Injection Control Line and the state *Aquifer Identification and Classification* technical reports prepared by the University of Hawai‘i. This procedure is summarized in a policy update dated September 19, 1995. Sites were further categorized based on annual rainfall (≤ 200 cm/year and >200 cm/year).

These categories are retained for use in this document but two additional categories are added – “Release Site ≤ 150 m From a Surface Water Body” and “Release Site >150 m From a Surface Water Body” (Figure 2). This is intended to enhance screening and monitoring of contaminated groundwater in close proximity to surface water bodies. Groundwater quality goals vary within each category, depending on the driving environmental concern for each specific contaminant. This is discussed in more detail below as well as in Chapter 2 and Appendix 1.

1.3.1.3 Updates to Groundwater Action Levels

Drinking water goals incorporated into the 1996 HDOH RBCA document focused on toxicity to humans (e.g., Primary Maximum Contaminant Levels or MCLs). For many chemicals that are not carcinogens, however, drinking water goals based on taste and odor concerns (e.g., Secondary MCLs) are lower than goals based on toxicity. For example, the USEPA Primary MCL for xylenes is 10,000 ug/L. The USEPA Secondary MCL for xylenes is significantly lower, however, at 20 ug/L (see Table D-2 in Appendix 1). In this update, taste and odor goals are used as drinking water action levels if lower than goals based on toxicity. This does not necessarily require that groundwater that is a

potential source of drinking water be aggressively cleaned up to the taste and odor goal, only that more scrutiny is warranted if the groundwater is within the near-term capture zone of a currently operating water supply well (see Chapter 3).

Groundwater action levels presented in the 1996 RBCA document also incorporated surface water goals for the protection of aquatic habitats. Most groundwater outside of geologically diked areas of the islands ultimately migrates to and discharges into streams, bays or other ocean. As stated above, one environmental goal is to ensure that groundwater with concentrations of contaminants that exceed chronic surface water goals does not discharge into a sensitive aquatic habitat. In the 1996 RBCA document, groundwater goals intended to address this concern were based on promulgated surface water standards. In retrospect, however, many of these standards are based on acute rather than chronic impacts to aquatic habitats. For example, the HDOH freshwater surface standard for benzene is 1,800 ug/L, based on potential acute toxicity (see Table D-3c in Appendix 1). The current USEPA chronic goal for benzene is, in contrast, only 46 ug/L (see Table D-3d in Appendix 1). In addition, no promulgated surface water standards were available for some chemicals (e.g., xylenes).

In this update, chronic surface water goals for all chemicals listed in the lookup tables are compiled. For release sites and contaminated groundwater situated within 150 meters (approximately 500 feet) of a surface water bodies, the chronic goals, rather than acute goals, are incorporated into the lookup tables. Acute goals are retained for use in distal areas located more than 150m from a surface water body. This again does not necessarily imply that all groundwater situated within 150m of a surface water body must be aggressively remediated to chronic surface water goals, only that additional evaluation is warranted to ensure that environmental goals appropriate to that site are met. This is discussed further in Chapter 2 and 3 as well as Appendix 1.

1.3.1.4 Updates to Soil Action Levels

Soil direct-exposure action levels presented in the 1996 HDOH document were developed using a model that allowed the actual thickness of the contaminated soil to be preset. This is an important variable in evaluating the maximum duration and magnitude of the emission of volatile chemicals from soil to outdoor air over time. A two-meter thickness of contaminated soil was assumed and considered to be adequately conservative for the majority of sites.

Direct-exposure action levels for soil presented in this document are based on an updated, “infinite source” model currently used by USEPA Region IX to develop the Preliminary Remediation Goals (PRGs). This model assumes an infinite thickness of contaminated soil. Action levels developed by this model are consequently up to an order of magnitude lower (more stringent) than those based on “finite source” models. Adjustment of direct-exposure action levels for soil to reflect the site-specific thickness of contaminated soil is

a relatively simple process and can be done using a spreadsheet currently available from HDOH (updated “DETIER2” spreadsheet, available from HDOH).

The soil action levels for the protection of groundwater presented in the 1996 HDOH document were developed based on detailed computer models, using the SESOIL leaching application. The models in general assumed 200cm of annual rainfall (approximately 75cm of infiltrating surface water), a very permeable soil type that allowed leachate to quickly reach groundwater and a depth to groundwater of one meter.

Preparing and running detailed SESOIL models is a time consuming process. As an alternative, the leaching based soil action levels presented in this document are based on a simplified SESOIL algorithm based on similar site conditions (refer to Appendix 1). Use of the model only requires input of the target groundwater goal (e.g., the drinking water MCL) and two easily obtained constants for the chemical (Henry’s Law constant and sorption coefficient or “koc”). This allows more rapid calculation of soil action levels for groundwater protection concerns. Action levels produced by the simplified algorithm are reasonable comparable to those produced by the full SESOIL model in the 1996 HDOH document (e.g., compare action levels in Appendix F of the 1996 HDOH document to Table E-1 in Appendix 1). Alternative action levels presented in Appendix F of the 1996 document for varying depth to groundwater can still be used on a site-by-site basis, as can action levels for higher rainfall areas.

1.3.1.5 Soil and Groundwater Gross Contamination “Ceiling Levels”

“Ceiling Levels” or action levels for potential gross contamination concerns (odors, sheens, general resource degradation, etc.) are also incorporated into the updated lookup tables. Ceiling levels for individual contaminants are listed in the Table F series (soil) and G series (groundwater) of Appendix 1. The use of ceiling levels primarily affects final action levels for contaminants that have relatively low toxicity to humans and in some cases are highly odiferous. Examples include chromium III, petroleum contaminants and phenols (refer to Tables A-1 through B-2 and D-1a and D-1b in Appendix 1). As noted in Tables A and B of this volume, ceiling levels for Total Petroleum Hydrocarbons could drive cleanup of soil exposed or potentially exposed at the ground surface in both residential and commercial/industrial areas. For residential sites with private yards, gross contamination concerns should generally be addressed for soil situated within three meters (ten feet) of the ground surface. For other sites, gross contamination concerns should be addressed by a minimum one-meter (three feet) cap of clean soil or by isolating the soil under pavement or a building foundation. The need to address gross contamination concerns should ultimately be decided on a case-by-case basis.

1.3.2 USEPA Region IX PRGs

The U.S. Environmental Protection Agency (USEPA) Region IX "Preliminary Remediation Goals" or "PRGs" are included in this document as soil action levels for direct-exposure concerns (USEPA 2004). Expansion of the USEPA PRGs in the lookup tables presented in this document includes:

- Addition of soil and groundwater action levels for indoor-air impact concerns;
- Addition of groundwater action levels for the protection of aquatic habitats/surface water quality;
- Use of a more rigorous leaching model to develop soil action levels for protection of groundwater quality;
- Addition of soil action levels for urban area, ecological concerns;
- Addition of soil and groundwater "ceiling levels" to address gross contamination and general resource degradation concerns; and
- Addition of soil and groundwater action levels for Total Petroleum Hydrocarbons (TPH);
- Addition of direct-exposure action levels for construction and trench workers' exposure to subsurface soils (see Appendix 1).

Use of the USEPA Region IX PRGs is discussed further in Section 3.2 of Appendix 1. Slight differences in the PRGs and direct-exposure action levels presented in this document are generally due to minor differences in physiochemical constants and toxicity factors that were not fully presented in the PRG document (e.g., k_{oc} of 10 cm³/gram presented in PRG table for specific chemical but actual value used in models was 10.3 cm³/gram). A copy of the PRG background document is provided in Appendix 2.

1.3.3 OSHA Standards Permissible Exposure Levels

The National Institute for Occupational Safety and Health (NIOSH) is the Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury, including exposure to hazardous substances in air (NIOSH 2003). NIOSH develops and periodically revises Recommended Exposure Limits (RELs) for hazardous substances in the workplace. The RELs are used to promulgate Permissible Exposure Levels (PELs) under the Occupational Safety and Health Act (OSHA).

OSHA Permissible Exposure Levels (PELs) for indoor air are intended for use in controlled, industrial work areas where generally healthy employees are aware of potential health hazards associated with the chemicals they are using and are trained to take proper precautions and minimize exposure (NIOSH 2003). The PELs are in part based on epidemiological studies at workplaces. OSHA PELs are **not** appropriate for use at commercial/industrial sites where the chemical is not currently being used. This is due in part to the fact that the PELs do not consider potential exposure of sensitive populations (e.g., pregnant mothers) or workers with existing medical conditions. This

includes sites affected by the migration of offsite releases (e.g., via emissions from a moving plume of contaminated groundwater). Indoor-air protection goals for these sites should be based on long-term (chronic) health risk to workers. Such risk-based goals levels are typically much more stringent than OSHA PELs.

For example, the current OSHA PEL for trichloroethylene (TCE) is 678,000 ug/m³ (100 ppmv, NIOSH 2003). Comparable risk-based action levels for uncontrolled, commercial/industrial settings included in this document fall between 0.036 ug/m³ and 51 ug/m³ (carcinogenic effects vs noncarcinogenic effects, respectively; refer to Table C in this volume and Table C-3 in Appendix 1). The PEL is applicable to work areas where TCE is being used and the employees have been properly trained to minimize exposure. The risk-based goals are applicable to all other areas.

1.4 Chemicals Not Listed In Lookup Tables

The lookup tables in this document list 100-plus chemicals most commonly found at sites with impacted soil or groundwater, a significant increase over the approximately 26 chemicals listed in the 1996 document. Inclusion of EALs for additional chemicals is a relatively straightforward process, provided that adequate supporting data are available. To obtain EALs for chemicals not listed in the lookup tables, the interested party should contact the HDOH staff noted at the beginning of this document. Development of EALs will be carried out in the same manner as done for the listed chemicals. As an alternative, EALs may be developed by qualified persons and submitted to the overseeing regulatory agency for review (refer to Section 3.0).

1.5 Limitations

The Tier 1 EALs presented in the lookup tables are recommended for use in screening level risk assessments. The EALs are NOT required, regulatory "cleanup standards," however. This document is intended to serve as a supplement to cleanup standards currently presented in the Hawai'i Administrative Rules, Title 11, Chapter 281 (Underground Storage Tanks). Use of the EALs as actual cleanup levels should be evaluated in view of the overall site investigation results and the cost/benefit of performing a more detailed environmental risk assessment. The EALs are intended to be conservative for use at the vast majority of impacted sites in developed areas. As discussed in Chapter 3, however, use of the Environmental Action Levels may not be appropriate for final assessment of all sites. Examples include:

- Sites that have a high public profile and warrant a detailed, fully documented environmental risk assessment;

- Sites with high rainfall (>200cm/year) and subsequent high surface water infiltration rates (i.e., infiltration >720mm or 28 inches per year, refer to additional soil action levels in Table 2-1 in Chapter 2),
- Sites where inorganic chemicals (e.g., metals) are potentially mobile in leachate due to soil or groundwater conditions different than those assumed in development of the lookup tables (e.g., low pH at landfill sites);
- Areas where impacts pose heightened threats to terrestrial ecological habitats (e.g., parklands, nature reserves, etc.); and
- Sites where more than three known or suspected carcinogens or more than five chemicals with similar noncarcinogenic health effects have been identified.
- Sites affected by tides, rivers, streams, etc. where there is a potential for erosion and concentration of contaminants in aquatic habitats.

Examples of other site characteristics that may warrant a more detailed environmental risk assessment are discussed in Chapter 3 (refer also to discussion of action levels in Appendix 1). In such cases, the information provided in this document may still be useful for identification of potential environmental concerns and development of strategies for preparation of a more site-specific risk assessment.

EALs for chemicals that are known to be highly biodegradable in the environment may in particular be overly conservative for use as final cleanup levels. For example, final soil EALs for Total Petroleum Hydrocarbon (TPH) and many noncarcinogenic, petroleum-related compounds (e.g., xylenes) are driven by the protection of groundwater quality. If long-term monitoring demonstrates that actual impacts to groundwater do not exceed action levels then soil action levels for leaching concerns can be omitted from consideration in a Tier 2 assessment.

Soil EALs do not consider potential water- or wind-related erosion and deposition of contaminants in a sensitive ecological habitat. This may especially be of concern for metals and pesticides that are only moderately toxic to humans but highly toxic to aquatic and terrestrial biota (e.g., copper).

It is conceivable that soil, groundwater and soil gas action levels for the emission of chlorinated, volatile organic compounds to indoor air concerns may not be adequately conservative in some cases. This is most likely to occur at sites where the vapor permeability of vadose-zone soils is exceptionally high (e.g., highly fractured bedrock, gravels, etc.) and/or where building designs, ventilation systems and local environmental conditions otherwise lead to higher-than-expected vapor flow rates through foundations (e.g., depressurization of buildings due to wind effects or use of heating and air conditioning (HVAC) systems). As discussed in Appendix 1, conservative target risks are used in part to address these uncertainties.

2

Tier 1 Lookup Tables

2.1 Organization of Lookup Tables

Environmental Action Levels (EALs) are presented in two separate lookup tables and reflect four default site scenarios, based on groundwater utility and proximity to a surface water body (Figure 2). The first table presents soil and groundwater action levels for sites that directly overlie a current or potential source of drinking water (Table A). Two sets of action levels are provided, one for sites within 150m (500 feet) of a surface water body and one for sites located more than 150m (500 feet) from a surface water body. A second table presents a similar set of action levels for sites that do *not* directly overlie a current or potential source of drinking water (Table B).

The EALs in each table are intended to collectively address the environmental concerns noted below. For the purpose of this document, "soil" refers to any un lithified material in the vadose zone that is situated above the capillary fringe of the shallowest saturated unit.

Groundwater Quality:

- Protection of human health
 - Current or potential drinking water resource;
 - Emission of subsurface vapors to building interiors;
- Protection of aquatic habitats (discharges to surface water);
- Protection against gross contamination conditions (odors, sheens, general resource degradation, etc.).

Soil Quality:

- Protection of human health
 - Direct/indirect exposure to impacted soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);
 - Emission of subsurface vapors to building interiors;
- Protection of groundwater quality (leaching of chemicals from soil);
- Protection of terrestrial (nonhuman) habitats;
- Protection against gross contamination conditions (odors, sheens, general resource degradation, etc.).

Shallow Soil Gas:

- Protection of human health
 - Emission of subsurface vapors to building interiors.

A summary of environmental concerns considered in the EALs is depicted schematically in Figure 3. This is correlative to a “conceptual site model” that may be prepared for a detailed environmental risk assessment. For the purpose of the Tier 1 lookup tables, soils are assumed to be exposed or potentially exposed in a “residential” or sensitive land-use setting. This includes sites to be used for residences, hospitals, day-care centers and other sensitive purposes. Soil and groundwater EALs listed under this category incorporate conservative assumptions regarding long-term, frequent exposure of children and adults to impacted soils in a residential setting (see Section 3.2 in Appendices 1 and Appendix 2).

For each chemical listed in the lookup tables, action levels were selected to address each applicable environmental concern under the specified combination of site characteristics. The lowest of the individual action levels for each concern was selected for inclusion in the summary Tier EAL tables presented in Volume 1 of this document. This ensures that the EALs presented in these tables are protective of all potential environmental concerns and provides a tool for rapid screening of site data. The degree to which any given concern will “drive” environmental risk at a site depends on the actual potential for exposure and the toxicity and mobility of the chemical. Where EALs are exceeded, the detailed tables provided in Appendix 1 can be used to identify the specific environmental concerns that may be present at the site.

An example of the selection of summary, Tier 1 EALs for benzene is presented in Figure 4 (refer also to Tables A-1 (soil) and D-1a (groundwater) in Appendix 1). In this example, groundwater immediately underlying the site is a source of drinking water. The site is to be used for residential purposes and is located within 150m of a surface water body. The final groundwater action level for benzene is driven by drinking water toxicity concerns (lowest GAL = 5.0 ug/L). The individual action levels can also be used to identify specific, potential environmental concerns at a site. Benzene in groundwater at a concentration of 50 ug/L, for example, would pose drinking water toxicity concerns (action level 5.0 ug/L) but not vapor intrusion concerns (action level 1,600 ug/L) and only marginal concerns regarding the discharge of contaminated groundwater into a body of surface water (action level 46 ug/L). The benzene would probably not produce taste or odor concerns in drinking water by at this level (action level 170 ug/L).

As noted in Figure 4, leaching and potential impacts to groundwater quality drive environmental concerns for benzene in soil under the assumed site scenario (lowest SAL = 0.22 mg/kg). Benzene in soil at a concentration of 1.0 mg/kg would pose marginal direct-exposure concerns (action level 0.64 mg/kg) and vapor intrusion concerns (action level 0.53 mg/kg). Odors from the soil would not pose nuisance concerns (action level 500 mg/kg) and the soil would not be particularly toxic to urban area flora or fauna (action level 25 mg/kg). In the absence of cleanup, soil gas sampling would be

recommended to further evaluate vapor intrusion concerns. The correlative soil gas action level for residences is 250 ug/m³. If this action level was exceeded, indoor air sampling may be required (indoor air action level 0.25 ug/m³). Ambient levels of benzene in outdoor air from auto exhaust (up to 5 ug/m³ in some mainland areas) may hinder full evaluation of vapor intrusion concerns at sites with only moderate levels of contamination, however. A more detailed discussion of the action levels provided in Appendix 1.

2.2 Use of Lookup Tables

2.2.1 Steps To Use Of Tables

A step-by-step use of the lookup tables is summarized below and discussed in more detail in the following sections. A flow chart that summarizes the steps is provided in Figure 5. An outline and discussion of information that should be included in a Tier 1 environmental risk assessment is provided in Section 2.9.

Step 1: EAL Updates and Applicability

Check with the overseeing regulatory agency to determine if the EALs can be applied to the subject site. Ensure that the most up-to-date version of this document is being used.

Step 2: Identify All Chemicals of Potential Concern

An environmental risk assessment must be based on the results of a thorough site investigation, where all chemicals of potential concern have been identified. A summary of the site investigation results should be included in the risk assessment in order for it to be reviewed as a "stand alone" document. A general outline of site investigation information that should be included in a Tier 1 risk assessment is provided in Section 2.9.

Step 3: Select Lookup Table(s)

Determine the beneficial use of impacted or threatened groundwater beneath the site and the distance to the nearest surfaced water body from the downgradient edge of the release site (refer to Figure 2). In general, all groundwater inland of the Underground Injection Control (UIC) lines should initially be treated as a current or potential source of drinking water (see Section 2.3, Appendix 8 and discussion in 1996 HDOH RBCA document). Reference can be made to the Water Resources Research Center *Aquifer Identification and Classification* reports, however, to evaluate the utility of the groundwater on a more site-specific basis. This information is then used to select soil and groundwater action levels in Table A (potential source of drinking water) or Table B (not a potential source of drinking water).

Step 4: Select Soil and/or Groundwater EALs

Select appropriate soil EALs from the appropriate lookup table. EALs for groundwater are provided in the adjacent column of each table and are not dependent on land use or

depth to impacted soil. Replace EALs with naturally occurring, background concentrations of chemicals of concern (e.g., arsenic) or laboratory method reporting levels if higher (see Section 2.6). For areas of high rainfall (>200cm/year), additional soil action levels for elevated leaching concerns should also be considered (refer to Table 2-1 in Chapter 2).

Step 5: Determine Extent of Impacted Soil and/or Groundwater

Using the selected EALs, determine the extent of impacted soil or groundwater and areas of potential environmental concern at the site and offsite, as required. (Soil data should be reported on a dry-weight basis. While this is not likely to affect final cleanup decisions, it is more in line with assumptions used to develop direct-exposure action levels for human health concerns. See also Appendix 1, Section 6.2.) If a groundwater plume originating from an inland release site is suspected to have migrated to within 150m of a surface water body, then additional downgradient investigation may be necessary, using more conservative action levels for this zone.

Step 6: Evaluate The Need For Additional Investigation or Corrective Actions; Submit Appropriate Reports

Based on a comparison of available site data to the EALs, evaluate the need for additional action at the site (e.g. additional site investigation, remedial action, preparation of a more site-specific risk assessment, etc.). For sites where sample data are limited, it will be most appropriate to compare the maximum-detected concentrations of chemicals of concern to the EALs to initially evaluate potential environmental concerns.

For sites where an adequate number of data points are available, the use of statistical methods to estimate more site-specific exposure point concentrations and evaluate environmental risks may be appropriate. The exposure point concentration is generally selected as the lesser of the maximum-detected concentration and the 95% upper confidence interval of the arithmetic mean of sample data. Guidance for the estimation of exposure point concentrations, use of “non-detect” data, and other issues is provided in the California EPA documents *Preliminary Endangerment Assessment Guidance Manual* (CalEPA 1994b) and *Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (CalEPA 1996a), among other sources. As discussed in these documents, sample data collected outside of impacted areas should generally not be included in estimation of exposure point concentrations. **For residential land use scenarios, sample data should not be averaged over areas greater than the size of a typical backyard (e.g., 100m²/1,000 ft², CalEPA 1996a).**

This evaluation should be summarized in the Tier 1 Environmental Risk Assessment report and workplans for additional corrective actions as needed (see Section 2.9). Decisions for or against additional actions should always be made in conjunction with guidance from the Department of Health. Adjustment of Tier 1 action levels under more site-specific, Tier 2 or Tier 3 assessments is discussed in Chapter 3.

2.2.2 TPH And Related Compounds

2.2.2.1 Target Indicator Compounds

Impacts to soil and water from petroleum mixtures are evaluated in terms of both Total Petroleum Hydrocarbon (TPH) and target "indicator chemicals" for the given petroleum mixture. Indicator chemicals typically recommended for petroleum mixtures include (after CalEPA 1996a):

Monocyclic Aromatic Compounds (primarily gasolines and middle distillates):

- benzene
- ethylbenzene
- toluene
- xylene

Fuel additives (primarily gasolines):

- MTBE
- other oxygenates as necessary

Polycyclic Aromatic Compounds (primarily middle distillates and residual fuels):

- acenaphthene
- acenaphthylene
- anthracene
- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(g,h,i)perylene
- benzo(a)pyrene
- benzo(k)fluoranthene
- chrysene
- dibenzo(a,h)anthracene
- fluoranthene
- fluorene
- indeno(1,2,3)pyrene
- methylnaphthalene (1- and 2-)
- naphthalene
- phenanthrene
- pyrene

The TPH EALs should be used in conjunction with EALs for these chemicals. (Note that the reported concentration of TPH should exclude concentrations of target indicator compounds that will be assessed separately. For example, BTEX should not be included in the reported concentration of TPH for a gasoline release.) As discussed in Appendix 1, the "middle distillates" category of TPH includes diesel fuel kerosene, stoddard solvent, home heating fuel, jet fuel and similar petroleum mixtures. "Residual fuels" includes heavy petroleum products such as No. 6 fuel oil ("Bunker C"), lubricating oils, "waste oils" and asphalts. Soil and groundwater impacted by releases of waste oil may also require testing for heavy metals and chemicals such as chlorinated solvents and PCBs.

Action levels for these chemicals are included in the lookup tables. A more detailed discussion of action levels for petroleum and petroleum-related compounds is provided in Appendix 1.

2.2.2.2 TPH in Isolated Soils

Two screening levels for each category of TPH are presented in the lookup tables. The first screening level is presumed to be protective of direct exposure to contaminated soils as well as potential nuisance concerns (odors, etc.). These concerns will typically drive the cleanup of petroleum-contaminated soils under an unrestricted (e.g., residential) future land use. These action levels (or approved, alternative levels) should be adhered to where feasible.

For soils that are not likely to be exposed at the surface in the future, however, less stringent action levels based on leaching and gross contamination concerns may be appropriate. These alternative soil action levels for TPH are presented in parentheses in the lookup tables and reflect action levels used in the 1996 HDOH RBCA document. For properties where unrestricted land use is desired, the alternative action levels can be applied to vadose-zone soils situated greater than three meters (ten feet) from the ground surface (excluding potential smear zones in the capillary fringe of shallow groundwater). For commercial/industrial properties, the alternative action levels can be applied to soils situated at least one meter below the ground surface, provided that adequate measures are taken to ensure that the soils are properly managed if exposed during future subsurface activities (e.g., trenching, redevelopment, etc.). Note that this may place restrictions on future use of the property, however (refer also to Section 2.7).

Use of the alternative soil action levels must also ensure that future leaching of TPH from soil will not adversely impact drinking water resources or sensitive aquatic habitats. This is discussed in the following section.

2.2.2.3 Elevated Threat To Drinking Water and Surface Water

The leaching based TPH action levels for soil included in the lookup tables are based on an assumption that most petroleum-contaminated sites are not situated adjacent to a sensitive aquatic habitat or directly in contact with shallow groundwater that is used as a source of drinking water (refer to Appendix 1, Section 5.3). It is also assumed that petroleum in plumes of contaminated groundwater is highly biodegradable and not likely to migrate a significant distance from the original release area. This typifies the majority of petroleum release sites in Hawai'i. To address these issues, leaching based action levels of 2,000 mg/kg for TPH as gasolines and 5,000 mg/kg for TPH as middle distillates and residual fuels presented in the 1996 HDOH RBCA document were retained for use in this document.

More conservative action levels for leaching of TPH from soil may be appropriate for sites within close proximity to a producing water supply well or a sensitive aquatic habitat. Action levels derived using the same model as used for other chemicals are provided in Table E-1 of Appendix 1 and summarized in the table below.

Alternative TPH Soil Leaching Action Levels		
	Elevated Threat To Drinking Water (mg/kg)	Elevated Threat To Aquatic Habitats (mg/kg)
TPH (gasolines)	100	400
TPH (middle distillates)	100	500
TPH (residual fuels)	1,000	5,000

Refer to Appendix 1, Table E-1.

The need to apply the more stringent action levels should be evaluated on a site-by-site basis. If the soil is in contact or immediately above groundwater that is within the capture zone of a producing well then use of the alternative screening levels (or approved equivalents) should be considered. Similarly, if the soil is within the immediate vicinity of a sensitive aquatic habitat then the alternative action levels noted above should likewise be considered.

2.2.3 Areas of High Rainfall (>200cm/year)

Soil screening presented in Tables A and B are based on an assumption that annual rainfall at the site is less than 200cm (approximately 80 inches). This was used to develop soil action levels for leaching concerns and protection of groundwater quality. For sites located in areas of significantly higher rainfall, more stringent soil screening levels for leaching concerns are appropriate. This is especially important for sites contaminated with chlorinated solvents or other highly mobile compounds that are not significantly biodegradable.

Additional screening levels for common contaminants in soil that are highly leachable are provided in Table 2-1. These screening levels were taken from the 1996 HODOH RBCA document and adjusted to reflect updated groundwater action levels. For sites where the annual rainfall exceeds 200cm/year, these screening levels should be used in conjunction with soil screening levels in Tables A and B. Additional guidance on the development of more site-specific soil action levels for leaching concerns is provided in Chapter 3 and Appendices 1 and 5.

2.3 Groundwater Utility

Groundwater utility is determined based on the location of the site with respect to the Underground Injection Control (UIC) Line and the state *Aquifer Identification and*

Classification technical reports prepared by the University of Hawai'i. This procedure is summarized in a policy update dated September 19, 1995 (see Appendix 8). In general, groundwater situated mauka (inland) of the UIC line is considered a potential source of drinking water, provided it is present in a suitably productive geologic formation. Groundwater situated makai (oceanward) of the UIC line is generally considered to not be a potential source of drinking water, due to high salinity, low permeability and production and/or historic contamination.

In general, soil and groundwater action levels are more stringent for sites that threaten a potential source of drinking water (e.g., compare Tables A and B). This is particularly true for chemicals that are highly mobile in the subsurface and easily leached from impacted soil. For chemicals that are especially toxic to aquatic life (e.g., several long-chain hydrocarbons, pesticides and heavy metals), however, action levels for sites that threaten drinking water resources may be driven by surface water/aquatic habitat protection concerns. This is discussed in more detail in the following section.

2.4 Threat To Surface Water Habitats

For the purposes of the Tier 1 lookup tables, it is assumed that impacted or potentially impacted groundwater at all sites could at some time migrate offsite and discharge into a body of surface water. This could occur due to the natural, downgradient migration of groundwater or to human activities such as dewatering of construction sites. To address this concern, groundwater action levels for both drinking water sources (Table A) and non-drinking water sources (Table B) include consideration of surface water goals (see Chapter 2 of Appendix 1).

For sites located more than 150m from a surface water body, acute surface water goals were considered in development of groundwater action levels. This follows the approach used in the 1996 RBCA document (refer to Section 1.3.1). Based on studies of petroleum-contaminated groundwater, natural degradation processes significantly reduced the likelihood that these types of plumes will extend more than one- or two-hundred meters from the original release area. An argument could be made that plumes located more than a few hundred meters will never naturally migrate to a surface water body and therefore this concern does not need to be addressed. Screening and monitoring of these plumes with respect to acute surface water goals will, however, assist in avoiding the unanticipated migration and discharge of a plume into shoreline areas or unmonitored extraction and discharge of the plume during construction or utility maintenance related activities. This is especially important for contaminants that do not readily biodegrade, such as chlorinated solvents and MTBE. Additional characterization and monitoring of groundwater impacted with these contaminants may be needed if it is suspected that the plumes could move to within 150m of a surface water body at levels above chronic surface water goals.

Ideally, concentrations of contaminants in groundwater should meet chronic surface water goals at the point that the groundwater discharges into a sensitive aquatic habitat. For sites located within 150m of a surface water body, more stringent chronic goals were therefore considered in development of groundwater screening levels (zones A-2 and B-2 in Figure 2). This is likely to be overly conservative for many sites but is appropriate under a Tier 1 assessment. If long-term monitoring of groundwater (e.g., two-plus years) adequately demonstrates that a plume is not likely to discharge into a surface water body above chronic goals even though it is within 150m of the body, then the use of acute surface water goals as final cleanup and closure levels may be appropriate (similar to the 1996 RBCA document). This is discussed in more detail in Chapter 3 under Tier 2 environmental risk assessments.

The groundwater action levels for potential impacts to aquatic habitats do not consider dilution of groundwater upon discharge to a body of surface water. Benthic flora and fauna communities situated below or at the groundwater/surface water interface are assumed to be exposed to the full concentration of chemicals in impacted groundwater. Use of a generic "dilution factor" to adjust the surface water protection action levels with respect to dilution of groundwater upon discharge to surface water was therefore not considered. Consideration of dilution/attenuation factor and alternative groundwater action levels for the protection of surface water quality may, however, be appropriate on a limited basis.

The soil and groundwater action levels presented in the lookup tables do not directly address the protection of sediment quality. Site-specific concerns could include the accumulation and magnification of concentrations of highly sorptive chemicals in sediment over time due to long-term discharges of impacted groundwater. This may be especially true for groundwater impacted with highly sorptive (lipophilic) chemicals, including heavy petroleum products.

Potential erosion and runoff of surface soils from impacted sites may also need to be considered, particularly at sites impacted with metals and pesticides that are situated near a sensitive body of surface water. The need for a more detailed, ecological risk assessment of impacts to sediment should be evaluated on a site-by-site basis and discussed with the Department of Health.

2.5 Screening For Vapor Intrusion Concerns

Volatile chemicals can be emitted from contaminated soil or groundwater and intrude overlying buildings, impacting the quality of indoor air. Heating and air conditioning (HVAC) systems, basements, and strong winds can exacerbate this problem by reducing the internal air pressure and creating a "vacuum effect" that enhances the advective flow of vapors out of the underlying soil and into the building. Additional information on subsurface vapor intrusion into buildings is provided in the USEPA document *User's*

Guide For The Johnson and Ettinger (1991) Model For Subsurface Vapor Intrusion Into Buildings (USEPA 2000; refer also to Appendix 1).

The direct collection and analysis of indoor air samples would seem to be an easy way to evaluate this concern. Identification of the source of impacts is complicated, however, by the presence of the same chemicals in many household goods (aerosol sprays, dry-cleaned clothing, cleaners, etc.). In addition, plumes of groundwater impacted with volatile chemicals are known to extend over significant areas and comprehensive testing of every structure over the plume is not practical.

As an alternative, the comparison of site groundwater, soil gas and soil data to conservative action levels for indoor air concerns is recommended. Action levels incorporated into this document are based on scientific models for vapor intrusion into buildings as well as a growing body of data from actual field investigations. A detailed discussion of the action levels is presented in Appendix 1. The following three-step, sequential approach is recommended for initial evaluation of potential indoor-air impact concerns at sites where shallow groundwater has been impacted by volatile chemicals:

- 1) Compare groundwater data to appropriate action levels for indoor air concerns (see Table C-1a of Appendix 1).
- 2) For areas over the plume where groundwater action levels for indoor-air concerns are approached or exceeded (e.g., >99 ug/L PCE), collect shallow soil gas samples under (preferred) or adjacent to buildings and compare results to soil-gas action levels for this concern (see Table C).
- 3) At sites where soil-gas action levels for indoor-air concerns are approached or exceeded (e.g., >320 ug/m³ PCE), collect indoor-air samples and compare results to indoor-air action levels and known or anticipated background levels in indoor air (e.g., 0.32 ug/m³ PCE, see Table C).

For sites where the vapor permeability of shallow soils has not been evaluated, action levels for groundwater overlain by highly permeable vadose-zone soils should be used. Imported fill material or disturbed native soils should be considered to be highly permeable unless site-specific data indicates otherwise.

Unless inhibited by very high water tables or other obstacles, soil gas samples should be collected immediately beneath the foundations of existing buildings (e.g., “subslab” or in crawl spaces) or one to one-and-a-half meters (three to five feet) below ground surface in open areas where buildings may be constructed in the future. Soil gas samples collected in open areas from depths of less than one meter are considered unreliable due to the increased potential to draw in ambient, surface air. If site-specific modeling of vapor flow rates or indoor-air impacts is to be carried out, the collection of additional

geotechnical data at the time soil gas samples are collected should be considered (soil grain-size analysis, moisture content, vapor permeability, etc.).

Soil action levels for potential indoor-air concerns are incorporated into the summary tables of this volume and presented separately in Table C-1b of Appendix 1. At sites where minor releases of volatile chemicals have occurred (e.g., restricted spills around underground tank fill ports), direct comparison of soil action levels to site data is generally acceptable. If action levels are exceeded, a similar approach to that outlined above for impacted groundwater is recommended. The restricted size of soil samples and the difficulty in predicting vapor-phase concentrations of chemicals from soil data limits the use of this data as a stand-alone tool for evaluating indoor-air concerns. **At sites where significant releases of volatile chemicals have occurred, active soil gas samples should be collected and used to evaluate vapor intrusion concerns.** Recent advances in passive soil gas sampling methods reportedly allow quantification of the data collected (i.e., in terms of VOC concentration rather than qualitative data). If adequately supported by active soil gas data collected on the site (preferred) or data from other, similar sites, then the use of passive data may also be appropriate.

Guidance on the collection of indoor air and active soil gas samples is provided in the following documents, among other sources:

- *Indoor Air Sampling And Evaluation Guide* (2002): Massachusetts Department of Environmental Protection, Office of Research and Standards, WSC Policy #02-430; <http://www.state.ma.us/dep/bwsc/finalpol.htm>;
- *Soil Gas Advisory* (January 2003): Department of Toxic Substances Control and Los Angeles Regional Water Quality Control Board; http://www.dtsc.ca.gov/PolicyAndProcedures/SiteCleanup/SMBR_ADV_activesoilgasinvst.pdf.

Additional information on the intrusion of subsurface vapors into buildings will be incorporated into this document as available. Individuals are encouraged to provide comments and suggestions to the contacts listed in the front of this document at anytime.

2.6 Substitution of Laboratory Reporting Limits and Ambient Background Concentrations for EALs

In cases where an EAL for a specific chemical is less than the laboratory method reporting limit for that chemical (as agreed upon by the Department of Health), it is generally acceptable to consider the method reporting limit in place of the screening level. Potential examples include the action levels for dioxin and some pesticides in soil and groundwater and action levels for carcinogenic volatile chemicals in indoor-air.

Background concentrations of metals in soils should be used as soil and groundwater action levels in cases where they exceed risk-based action levels for human health and environmental concerns presented in this document. This is particularly an issue for arsenic, chromium and even lead in some soils in Hawai'i. Based on studies conducted on soils in Hawai'i, background concentrations of total chromium in soils can range from a few parts per million to several thousand parts per million (Nakamura and Sherman, 1958, Feldman, 1979, and DPED, 1985, as referenced in Daugherty 1990). Due to this variability, site-specific background data should be used to determine if a release of chromium has occurred at a site where the direct-exposure action level for total chromium has been exceeded. If so, analysis of soil samples for chromium III and chromium VI should be used to determine appropriate remedial measures.

Similar compilations of data for background concentration of arsenic in soil were not available at the time that this document was being prepared. Based on a preliminary review of data available in site investigation reports submitted to HDOH, background concentrations of arsenic in soils range from less than 1.0 mg/kg to greater than 20 mg/kg, with typical concentrations in the range of 5 to 15 mg/kg. This is well above the health-based, direct-exposure goals for arsenic in soil of 0.39 mg/kg for residential exposure and 1.6 mg/kg for commercial/industrial exposure (Appendix 1, Tables I-1 and I-2). Based professional judgment and for provisional use in this document, a maximum background concentration of arsenic in soil correlative to the noncancer USEPA IX PRG of 22 mg/kg was used as a final action level (refer to Appendix 1, Tables A-1 through B-2). Unless a release of arsenic is known to have occurred at a site, further investigation of soil with concentrations of arsenic below this level will generally not be necessary. Additional review of background arsenic in soil should be carried out at sites where the default value is exceeded. Appropriate remedial actions for sites where releases of arsenic have been confirmed should be discussed with HDOH on a site-by-site basis.

2.7 Implied Land-Use Restrictions Under Tiers 2 and 3

Adherence to Tier 1 (or equivalent) action levels is intended to permit unrestricted use of the property, including redevelopment for residential housing and other sensitive purposes. Allowing the use of less stringent, Tier 2 or Tier 3 cleanup levels for properties that will not be used for sensitive purposes in the future can save considerably in investigation and remediation costs, however (e.g., commercial/industrial areas). For example, the action level for polychlorinated biphenyls (PCBs) in soils is 1.1 mg/kg in residential areas but up to 11 mg/kg for commercial/industrial areas (Appendix 1, Tables I-1 and I-2). Even higher levels of PCBs could potentially be allowed to remain in place onsite provided that adequate controls to mitigate potential exposure are put into effect (e.g., permanent cap, protection of groundwater, etc.).

The use of cleanup levels less stringent than those appropriate for unrestricted land use will place restrictions on future use of the property, however. For example, if commercial/industrial cleanup levels are used for remediation of contaminated soils then

the property should not be used for residential or other sensitive purposes without additional evaluation. If heavily contaminated soils are left in place under a building or other “permanent” cap, then steps to ensure that the cap is maintained and that disturbed soils are properly managed in the future should be clearly described in a site-specific risk management plan. In some cases, and especially for highly persistent contaminants (e.g., PCBs, metals, chlorinated solvents and other nonpetroleum-based contaminants), this will require that a formal covenant to the deed be recorded and maintained on file as part of the public record for the property.

Land-use restrictions inherent in the development of Tier 2 or Tier 3 cleanup levels should be kept as minimal as possible. **The effort required to remediate a site to unrestricted land use should always be evaluated, even if the property will be used for commercial/industrial purposes for the foreseeable future.** This will allow the property owner and overseeing regulatory agency to understand the advantages and disadvantages of remediating the site to less stringent land use criteria and help optimize future use of the property. If the soils in fact meet Tier 1 EALs for unrestricted land use after final cleanup then this should be clearly stated in the site closure report. Recognizing this point may prove important should the site unexpectedly become desirable for other, more sensitive uses. **Assumptions that impacted soil at a property will remain isolated at shallow depths under pavement, buildings or some other type of "cap" should likewise be avoided if at all possible.** A foresighted approach in the use of Tier 1 EALs or alternative, site-specific cleanup levels will allow more flexibility in future use of a site, help avoid unexpected complications during site redevelopment and minimize the liability of future land owners.

2.8 Cumulative Risks at Sites With Multiple Chemicals of Concern

Risks posed by direct exposure to multiple chemicals with similar health effects are considered to be additive or "cumulative." For example, the total risk of cancer posed by the presence of two carcinogenic chemicals in soil is the sum of the risk posed by each individual chemical. The same is true for chemicals that cause noncarcinogenic health effects. A summary of example target health effects for the chemicals listed in the lookup tables is provided in Appendix 1 (Table J).

Use of EALs for single chemicals is limited to the extent that the action levels remain protective of human health should other chemicals with similar health effects also be present. Soil EALs are considered to be adequate for use at sites where no more than three carcinogenic chemicals are present and the total risk posed by residual concentrations of chemicals with similar noncarcinogenic ("systemic") health effects does not exceed a target Hazard Index of 1.0. This is based on a combination of conservative exposure assumptions and target risk factors in direct-exposure models. Site-specific adjustment of action levels for human health concerns may need to be carried out where these conditions are not met. Refer to Appendix 1, Section 1.3, for additional discussion

of this subject and in the documentation for USEPA Region IX Preliminary Remediation Goals provided in Appendix 2.

2.9 Framework For a Tier 1 Environmental Risk Assessment

Tier 1 environmental risk assessments should serve as "stand alone" documents that provide a good summary of environment impacts at a site and assess the threats posed to human health and the environment by these impacts. The risk assessment can be prepared as a component of a site investigation or remedial action report or as a separate document. Information on each of the topics listed below should be addressed in a report that presents the risk assessment (after MADEP 1995). Together, this information is intended to provide a basic "conceptual model" of site conditions. The level of detail required for each topic will vary depending on site-specific considerations.

1. Summarize Past, Current and Anticipated Future Site Activities and Uses:

- Describe past and current site uses and activities;
- Describe foreseeable future site uses and activities. **(Always include a comparison of site data to EALs for residential land use to evaluate need for formal covenants to the deed; see Section 2.7).**

2. Summary of Site Investigation:

- Identify all types of impacted media;
- Identify all sources of chemical releases;
- Identify all chemicals of concern;
- Identify magnitude and extent of impacts that exceed EALs to extent feasible and applicable (include maps of site with isoconcentration contours for soil and groundwater);
- Identify nearby groundwater extraction wells, bodies of surface water and other potentially sensitive ecological habitats;
- Ensure data are representative of site conditions.

3. Summarize Appropriateness of Use of Tier 1 Lookup Tables and EALs (see Section 1.5):

- Do Tier 1 EALs exist for all chemicals of concern?
- Does the site have a high public profile and warrant a fully documented, detailed environmental risk assessment?
- Do soil and groundwater conditions at the site differ significantly from those assumed in development of the lookup tables (e.g., low pH at landfill sites)?
- Do impacts pose a heightened threat to sensitive ecological habitats (e.g., presence of endangered or protected species)?
- Have more than three carcinogens or five chemicals with similar noncarcinogenic health effects been identified (see Section 2.8)?

- Other issues as applicable to the site.

4. Groundwater Categorization (see Sections 2.3):

- State the default utility use of impacted or potentially impacted groundwater beneath the site as determined by proximity to the UIC line and Aquifer Identification and Classification reports for that area; discuss the actual, likely beneficial use of groundwater based on measured or assumed quality of the groundwater and the hydrogeologic nature of the soil or bedrock containing the groundwater.

5. Exposure Point Concentrations (see Section 2.2, Step 6):

- Identify maximum concentrations of chemicals present in impacted media.
- Describe how alternative exposure point concentrations were determined (e.g., 95% UCLs), if proposed, and provide supporting data. **For residential land use scenarios, sample data should typically not be averaged over an area greater than 100m² (1,000 ft², presumed minimal size of an open backyard).**
- Discuss the need to evaluate groundwater data with respect to surface water standards for potential bioaccumulation of chemicals in aquatic organisms, based on the size of the plume, the proximity of the plume to a body of surface water and the potential for minimal dilution of groundwater upon discharge to surface water (see Section 2.4).
- Discuss how background concentrations of chemicals were determined, if considered for use in the risk assessment (see Section 2.6).

6. Selection of Tier 1 EALs and Comparison to Site Data (see Section 2.2)

- Summarize how Tier 1 EALs were selected with respect to the information provided above and additional assumptions as applicable.
- Compare site data to the selected summary Tier 1 EALs (presented in Volume 1) and discuss general results.
- If desired or recommended, compare site data to detailed EALs for individual environmental concerns (presented in Volume 2, Appendix 1) and discuss specific, potential environmental concerns present at site.

7. Conclusions:

- Describe the extent of soil and groundwater impacts above Tier 1 EALs, using maps and cross sections as necessary.
- Discuss if a condition of potential risk to human health and the environment exists at the site.
- Discuss if a more site-specific risk assessment is warranted at the site.
- Present a summary of recommended future actions proposed to address environmental concerns at the site.
- Discuss the need to impose land-use restrictions and institutional controls at the site based on the results of the Tier 1 assessment (see Section 2.7; e.g., requirements for caps, etc.; need for covenant to deed to restrict land use to commercial/industrial purposes only, etc).

The above list is not intended to be exhaustive or representative of an exact outline required for all Tier 1 risk assessments. Requirements for completion of an adequate site investigation and Tier 1 environmental risk assessment should be discussed with the overseeing regulatory agency.

Table 2-1. Additional Soil Action Levels for Areas of High Rainfall (>200 cm/year).

	Soil Leaching Action Levels			
	Drinking Water IS Threatened		Drinking Water NOT Threatened	
	A-1 (Surface Water Within 150m)	A-2 (Surface Water NOT Within 150m)	B-1 (Surface Water Within 150m)	B-2 (Surface Water NOT Within 150m)
CONTAMINANT	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
BENZENE	2.0E-03	2.0E-03	1.8E-02	6.8E-01
ETHYLBENZENE	2.8E-02	2.8E-02	2.7E-01	2.8E-01
TOLUENE	1.0E-01	1.0E-01	3.4E-01	1.0E+00
XYLENES	2.0E-03	2.0E-03	1.0E-02	2.0E-01
CARBON TETRACHLORIDE	2.4E-02	2.4E-02	4.7E-02	1.3E-01
CHLOROBENZENE	1.3E-02	2.5E-02	1.3E-02	8.0E-02
CHLOROFORM	6.3E-02	6.3E-02	3.9E-01	1.5E+00
METHYLENE CHLORIDE	2.4E-03	2.4E-03	1.2E+00	2.9E+00
TETRACHLOROETHYLENE	4.0E-02	4.0E-02	8.7E-01	8.7E-01
TRICHLOROETHANE, 1,1,1-	1.0E-02	3.3E-02	1.0E-02	1.0E+00
TRICHLOROETHYLENE	7.1E-03	7.1E-03	1.4E-01	1.4E-01

Notes:
Reference: Table E-2 in Appendix 1. Based on greater potential for groundwater impacts due to increased leaching of contaminants from soil.
Soil leaching action levels only generated for common, mobile contaminants modeled in 1996 HIDOH RBCA document.

3

Tier 2 and 3 Environmental Risk Assessments

3.1 Conditions Warranting More Detailed Risk Assessments

Use of the Tier 1 Environmental Action Levels is optional and independent environmental risk assessments may be undertaken for any site. In some cases, site conditions may negate the full use of the Tier 1 EALs and require preparation of a Tier 2 or Tier 3 risk assessment. Examples of site conditions that may warrant a more site-specific assessment of environmental concerns include (see also Section 1.5):

- Sites with groundwater contaminated above chronic surface water goals within 150m of a surface water body but unlikely to migrate to and discharge into that body at those concentrations.
- Sites with groundwater contaminated above taste and odor goals that is technically a source of drinking water but is not likely to impact an existing water supply well or a well that could be located in the area in the near future.
- Sites where alternative target risk levels or chemical-specific toxicity factors and fate and transport constants may be acceptable to the regulatory agency (see Appendix 1, Sections 1.3 and 3.2);
- Sites where the thickness of vadose-zone soils impacted by volatile organic compounds is greater than three meters (soil action levels for potential vapor intrusion concerns may not be adequately conservative; see Appendix 1, Section 3.3);
- Sites where action levels for soil are driven by potential leaching concerns and groundwater data are available for evaluating actual groundwater impacts (main mass of impacted soil should be in contact with groundwater; see Appendix 1, Section 3.4);
- Sites where inorganic chemicals (e.g., metals) cannot be assumed to be immobile in soil (potential threat to groundwater quality; see Appendix 1, Section 3.4);

- Sites with soils impacted by pesticides, where final action levels are driven by leaching concerns and potential impacts to aquatic habitats but the site is not located near a body of surface water (e.g., dieldrin, endrin, endosulfan, etc.);
- Sites where the depth to groundwater is greater than ten meters below the base of impacted soil (soil action levels for leaching concerns may be excessively conservative; see Appendix 1, Section 3.4, and Appendix F in 1996 HDOH RBCA document);
- Sites where protected terrestrial habitats or other ecologically sensitive areas are threatened (soil EALs may not be adequately conservative; see Appendix 1, Section 3.5);
- Sites where engineered controls will be implemented to eliminate or reduce specific exposure pathways (avoid when feasible; see Section 2.7);
- Sites where the future erosion of shallow soils could lead to significant transport and concentration of contaminated sediments in sensitive ecological habitats; and
- Sites where field observations or site conditions otherwise indicate that the EALs may not be adequately conservative or may be excessively conservative.

The need for a detailed ecological risk assessment should be evaluated on a site-by-site basis for areas where these concerns may be present (see Section 3.3.5). Evaluation of landfills and sites impacted by highly acidic or basic wastes may in particular require the preparation of a detailed, site-specific assessment of groundwater and surface water impact concerns due to the possible elevated mobility of metals and other chemicals or the emission of potentially explosive vapors (e.g., methane). Soil leaching models incorporated into the Tier 1 EALs assume typical, ambient physio-chemical conditions in soil and groundwater (e.g., soil pH 5.0 to 9.0) and the relatively immobility of heavy metals and organic chemicals with very high sorption factors (e.g., PCBs, PAHs, etc.). This assumption may not hold true at sites where physiochemical conditions could lead to substantial mobility of these compounds. More rigorous field and laboratory studies may be required to adequately assess risks to human health and the environment in these cases.

Site-specific soil leaching action levels can be developed using SESOIL or an alternative model or approach. Steps used to develop the SESOIL-based action levels in the 1996 HDOH RBCA document and considerations for site-specific action levels are provided in Appendix 5.

Final surface water and groundwater action levels for several pesticides that are highly toxic to aquatic organisms are very stringent (e.g., dieldrin, endrin, endosulfan, etc.; refer to Tables A and B in this volume and Table D series in Appendix 1). Correlative soil action levels for leaching concerns are likewise very low and potentially below widespread, ambient levels of these pesticides in soil (refer to Table A and B series in Appendix 1). The pesticides in question are only moderately mobile in the environment,

however, and the groundwater action levels and leaching based soil action levels are likely to be excessively conservative for sites not located beside or near a body of surface water. The need to apply the action levels to soil and groundwater data should be evaluated on a site-by-site basis. Less conservative action based only on human-toxicity, direct-exposure concerns may be appropriate at many sites.

Site-specific risk assessments are grouped under the loosely defined terms "Tier 2" and "Tier 3". The nature of these risk assessments is briefly discussed below.

3.2 Tier 2 Environmental Risk Assessments

3.2.1 Purpose

This process is intended to be a screening level risk assessment. There are limitations to the data gathered and collated for the environmental action levels presented under Tier 1. For example, the ecological action levels presented in the lookup tables are summarized to include sometimes very conservative data without identifying the receptor species and the endpoint and the original citation is not provided. While these limitations are inherent when compiling data of this sort, even with their limitations, the effort is considered worthwhile and even necessary. Further refinement of the environmental assessment must be pursued with the collection of site-specific data or further testing to show that the site-specific exposure and/or toxicity is a more realistic estimate of the overall risk. Tier 2 (and subsequently Tier 3) efforts are directed at confirming the estimates to move the screening risk assessment closer to a more realistic evaluation of risk by using more relevant site-specific data.

Tier 2 environmental risk assessments are intended to be relatively easy and cost-effective to prepare. Preparation of Tier 2 risk assessments will require a thorough understanding of the Tier 1 EALs being re-evaluated, however. Under Tier 2, specific Tier 1 action levels are adjusted or deleted to more closely reflect site conditions or alternative risk assumptions. Replacing only targeted components of the Tier 1 EALs reduces the need to prepare and justify an independent, detailed risk assessment when Tier 1 EALs cannot or should not be fully applied. This greatly reduces the time and cost incurred by both the regulated business and the overseeing regulatory agency in finalizing the risk assessment.

For example, the Tier 1 screening level for leaching concerns may not need to be considered at sites where groundwater monitoring data indicate that leaching impacts from soil to groundwater are minimal or not posing an adverse risk. A common modification under Tier 2 may also include the adjustment of target risk level for carcinogens in soils at commercial/industrial sites from 10^{-6} to a cumulative risk of 10^{-5} or a cumulative hazard index of 1.0 (and likely preparation of a covenant to the deed that formally restricts land use). This could increase the direct-exposure action levels for

carcinogens by a factor of up to ten. In these examples, all other components of the Tier 1 EALs are retained for use in the risk assessment. The modifications to Tier 1 assumptions are described and justified in the text of the report and the revised set of action levels are presented.

3.2.2 Example Tier 2 Modifications of Tier 1 EALs

A more detailed list of potential Tier 2 modifications to Tier 1 action levels is presented below (refer also to Appendix 1). These examples are not intended to reflect the full range of modifications possible:

Groundwater Action Levels

Drinking Water:

- Use of toxicity-based drinking water goals only (even if higher than taste and odor goals, e.g., xylenes) for cleanup and closure of groundwater that is classified as a drinking water source but is unlikely to be used as such in the foreseeable future.
- Exclusion of drinking water impact concerns based on natural groundwater quality or geologic characteristics of groundwater containing unit (e.g., brackish groundwater in coastal areas);

Indoor Air Impacts:

- Use of site-specific data for model input parameters (depth to groundwater, soil properties, building characteristics, target risk or hazard index, etc.);
- Use of soil gas and/or indoor air data to more directly evaluate potential impacts;
- Use of alternative chemical toxicity factors or target risk levels;

Surface Water Impacts:

- Use of acute surface water goals for final cleanup and closure of contaminated groundwater that is within 150m of a surface water body but, based on long-term monitoring and the nature of the contaminant, is unlikely to discharge into the surface water body at concentrations above chronic surface water goals;
- Exclusive use of freshwater or saltwater action levels;
- Consideration of alternative surface water action levels;

- Consideration of groundwater monitoring data and observed plume migration over time;
- Consideration of site-specific dilution effects during potential discharge of groundwater to surface water (generally not recommended except in highly developed and disturbed water front properties);

Gross Contamination:

- Use of alternative ceiling levels and/or site-specific observations and considerations regarding gross contamination concerns;

General:

- Consideration of method reporting limits or natural background concentrations of a chemical in place of the EAL.

Adjustment of Tier 1 groundwater action levels for drinking water and surface water protection is likely to be common on a site-by-site basis. Tier 1 actions levels in Table A incorporate the lowest of toxicity-based goals and goals for taste and odor concerns for groundwater that is a source of drinking water. Taste and odor goals for noncarcinogens are typically lower or more stringent than toxicity-based goals. For example, the toxicity-based drinking water goal for ethylbenzene is 700 ug/L but the goal for taste and odors is 30 ug/L. Both toxicity-based goals and taste and odors goals should be met in groundwater that is within 500m of active drinking water supply well screened in same aquifer or otherwise likely to be drawn into a supply well in the near future. **For sites that do not directly threaten an active water supply well, groundwater should be remediated to meet toxicity-based drinking water goals at a minimum before closure (refer to Table D-2 in Appendix 1).** This will allow more flexibility for cleanup of groundwater impacted by noncarcinogenic chemicals and is similar to guidance in the 1996 HODOH RBCA document. This should be supported and discussed under a Tier 2 risk assessment.

For groundwater that is within 150m of a surface water body, Tier 1 action levels incorporate stringent chronic surface water goals. This is intended to address potential long-term impacts to sensitive aquatic habitats. Chronic surface water goals can be significantly lower than acute goals and can strongly affect the magnitude of remediation required and the timing of case closure. For example, the chronic, freshwater goal for benzene is 46 ug/L but the acute goal is 1,800 ug/L. **Use of chronic surface water goals as groundwater action levels may be overly conservative for sites adjacent to low quality surface water habitats (e.g., drainage canals) or sites where long-term monitoring has demonstrated that the plume is stable or receding and not likely to discharge into a sensitive aquatic habitat. For these sites, groundwater action levels that incorporate acute rather than chronic surface water goals may be more**

appropriate (refer to action levels for sites >150m from a surface water body in Tables A and B). This is similar to guidance in the 1996 HODOH RBCA document. This should be supported and discussed under a Tier 2 assessment.

Soil Action Levels

Direct Exposure:

- Use of alternative action levels for direct-exposure concerns based on commercial/industrial land use rather than residential land use, as assumed in the Tier 1 EALs (e.g., refer to Table I-2 in Appendix 1, see also Section 2.7);
- Use of alternative action levels for soil that is isolated at depth (e.g., >3m below ground surface) or under a permanent cap and not likely to be exposed at the ground surface in the foreseeable future (e.g., refer to Table I-3 in Appendix 1, see also Section 2.7);
- Use of alternative chemical toxicity factors;
- Use of alternative target risk levels;

Indoor Air Impacts:

- Use of soil gas and/or indoor air data to more directly evaluate potential impacts;
- Use of alternative chemical toxicity factors or target risk levels.

Groundwater Protection (leaching effects):

- Consideration of alternative, target groundwater levels;
- Use of groundwater monitoring data to evaluate leaching impacts and groundwater quality concerns (most appropriate where main mass of chemical is in contact with groundwater);
- Use of laboratory leaching test to evaluate potential groundwater impacts (see Section 3.3.3).

Ecological Impact Concerns:

- Use of alternative action levels based on site studies or published data;
- Elimination of use of ecotoxicity action levels in highly developed areas where no significant open spaces are anticipated (e.g., lead).

Gross Contamination:

- Use of alternative ceiling levels and/or site-specific observations and considerations for gross contamination concerns (e.g., for soils isolated at depth, refer to Table F-3 in Appendix 1).

General:

- Consideration of method reporting limits or natural background concentrations of a chemical in place of the EAL.

In each of these examples, an alternative screening level is generated for the specified environmental concern and re-compared to site data. Models and assumptions used to generate each of the Tier 1 action levels are discussed in detail in Appendix 1. The format of the Tier 2 Environmental Risk Assessment Report should be similar to that outlined for Tier 1 reports. Adjustments to Tier 1 action levels should be clearly described and justified within the report and additional information included as necessary.

A depth of three meters (approximately 10 feet) is typically used to delineate between “shallow” soils that could at some point be exposed at the ground surface and “deep” soils that are only likely to be temporarily exposed during construction and utility maintenance work (CalEPA 1996a). The potential for deeper soils to be brought to the surface in the future should be evaluated on a site-by-site basis based on planned redevelopment or maintenance activities. Direct-exposure SALs used in the Tier 1 lookup tables may be overly conservative for use as cleanup levels for deep soils or soils that are to be permanently capped under clean fill, pavement or a building. Direct exposure action levels developed for construction and utility worker scenarios may be more appropriate for these scenarios (e.g., refer to Table I-3 in Appendix 1), although this could place significant restrictions on future use of the land. Other potential environmental concerns such as leaching and vapor emissions to indoor air must also be addressed.

Use of a less conservative commercial/industrial land-use scenario may be appropriate for sites where cleanup to residential land use is not practical. Under this scenario, a target excess cancer risk of 10^{-5} is generally acceptable, provided that cumulative risk after closure does not exceed 10^{-5} or in limited cases 10^{-4} . Commercial/industrial action levels for carcinogens in Appendix 1 are based on a target excess cancer risk of 10^{-6} (see action levels for vapor intrusion concerns in Table C series and action levels for direct-exposure concerns in Table I-2). These action levels can be adjusted to a target 10^{-5} risk by simply multiplying the levels by a factor of ten. The lowest of the adjusted action levels for carcinogenic effects and action levels for noncarcinogenic effects are then used to screen site data. This type of approach must be presented and approved in a site-specific environmental risk assessment.

Cleanup and closure under a commercial/industrial land-use scenario places implicit land-use restrictions on the affected property. While this may be considered acceptable for properties currently zoned for such purposes, the need for such restrictions in the

future should be seriously weighed against the cost-benefit of remediating the property to meet the sometimes more conservative but less restrictive EALs for unrestricted land use. Implications for land-use restriction are discussed in more detail in Section 2.7.

3.3 Tier 3 Environmental Risk Assessments

3.3.1 Purpose

Under Tier 3, alternative models and assumptions are used and fully justified to develop a detailed, comprehensive environmental risk assessment. Portions of the Tier 1 models may still be retained for some components of the risk assessment. A detailed review of the preparation of Tier 3 environmental risk assessments is beyond the scope of this document. A few potentially useful methods and some general cautions are highlighted below. Example references for the preparation of Tier 3 risk assessments are provided at the end of this section.

3.3.2 Mass-Balanced Soil Volatilization Factor Model

A good example of a useful, alternative model for evaluating soil direct-exposure concerns is the mass-balanced volatilization factor model provided in the USEPA document *Soil Screening Guidance* (USEPA 1996). This model was used in earlier versions of the USEPA Preliminary Remedial Goals (PRGs) document (pre-1995). The current PRG model, and the model reflected in the soil direct-exposure action levels presented in this document, assumes an infinite thickness of contaminated soil at a site. For highly volatile chemicals such as vinyl chloride and even benzene, this is excessively conservative and would require the presence of tens of meters impacted soil over a large area to be justifiable. The mass-balanced model allows for the input of the actual thickness of impacted soil at a site and can result in substantially less stringent, and more realistic, screening or cleanup levels for direct-exposure concerns. Note, however, that groundwater protection concerns (i.e., soil leaching) or potential indoor-air impacts often drive screening level environmental concerns at sites impacted with highly mobile, volatile chemicals. This concern and others, as appropriate, should be evaluated in conjunction with direct-exposure concerns.

Easy-to-use spreadsheets that incorporate the mass-balanced direct-exposure model are available for downloading from the Hawaii Department of Health website (HIDOH 1996, DETIER2 spreadsheet developed by editor of this document). Care should be taken to ensure that default toxicity factors presented in these and other spreadsheets are up-to-date and consistent with those used in this document (see Appendix 1, Table H).

3.3.3 Laboratory-Based Soil Leaching Tests

Laboratory-based soil leaching tests offer an alternative to the use of conservative, model-derived soil action levels for groundwater protection concerns (refer to Section 3.4 in Appendix 1). These tests may be especially useful for evaluating soils impacted by inorganic chemicals (e.g., metals and salts) and relatively nonsorptive and nonvolatile organic chemicals. Action levels for leaching of metals from soil are specifically excluded from this document. Where releases of metal compounds to soil are identified, groundwater monitoring (if appropriate) and/or laboratory-based leaching tests should be carried out to fully evaluate potential leaching impacts (refer to Section 3.4 of Appendix 1).

The USEPA Synthetic Precipitation Leaching Procedure (SPLP) is one example of laboratory-based soil leaching tests (USEPA 1994). The SPLP test differs from the more commonly referenced Toxicity Characteristic Leaching Procedure (TCLP) for hazardous waste in that it is specifically designed to evaluate the mobility of organic and inorganic compounds in soils. The results of a TCLP test are compared to regulatory levels for disposal of materials in landfills and this is then used to determine the type of landfill most appropriate for disposal of the soil (e.g., lining, leachate collection system requirements, etc.).

The SPLP test was **not** specifically developed to evaluate leaching of chemicals from soil outside of a controlled, landfill environment but can be used to do so with some caveats. From a groundwater protection standpoint, one goal is to predict the dissolved-phase concentration of a chemical in the pore space of a saturated soil sample (i.e. the leachate) through either models or laboratory tests. The SPLP test does **not** directly provide this information. Using the SPLP test method, 100 grams of soil are added to two liters of reagent water, the sample is mixed for a specified period of time, and an extract of the reagent water is analyzed for targeted chemicals. The volume of reagent water added to the sample significantly exceeds the volume of the sample pore space. This leads to significant dilution of the potential "leachate" had the volume of added reagent water only been equal to the volume of the sample pore space.

For example, the pore volume of a 100-gram sample of soil with 35% effective porosity is approximately 20 cm³ (assumes bulk density of 1.8, total volume 57 cm³). Adding two liters, or 2,000 cm³, of water to the sample therefore introduces a laboratory-based, leachate "dilution factor" of approximately 100 to the SPLP test results (volume reagent divided by volume sample pore space). Concentrations of chemicals reported under the SPLP test could therefore be up to 100 times less than the dissolved-phase concentration of the chemical in a saturated sample.

The inherent dilution effect of the SPLP test method is only significant for chemicals that are highly mobile and not significantly volatile (or biodegradable). From a fate and transport perspective, the dilution factor inherent in the SPLP test could be considered to

reflect the decrease in chemical concentrations due to resorption, volatilization and dilution as the leachate migrates downward and mixes with groundwater. Based on comparisons of soil leaching models that take these fate and transport considerations into account (e.g., SESOIL, see Appendix 1) and those that don't (e.g., USEPA 1996), the dilution factor inherent in the SPLP test method appears to be adequately conservative for chemicals that are at least moderately sorptive (i.e., sorption coefficient of at least 100 cm³/g) or highly volatile (i.e., Henry's Constant of at least 0.001 atm-m³/mole.). **For moderately sorptive and/or volatile chemicals, the results of the SPLP test can be directly compared to target groundwater goals.** This includes most of the organic chemicals listed in the EAL lookup tables (refer to Table H in Appendix 1).

Chemicals listed in the EAL document that are not adequately sorptive or volatile to justify unmodified use of the SPLP test method include all inorganic compounds (e.g., metals and perchlorate) as well as acetone, 2,4 dinitrophenol and methyl ethyl ketone (very low sorption coefficients). Other organic chemicals that fail this test but only moderately include bis(2-chloroethyl)ether, bis(2-chloroisopropyl)ether, chloraniline, 1,2 dibromoethane, 2,4 dimethylphenol, 2,4 dinitrotoluene, MTBE, phenol, 1,1,1,2-tetrachloroethane and 1,1,2,2-tetrachloroethane. **For these and other relatively nonsorptive and nonvolatile chemicals not listed in the EAL tables, the results of the SPLP test should be multiplied by a factor of 100 (or a sample-specific factor) to negate the method-related dilution effect.** The sample results can then be adjusted with respect to chemical-specific and site-specific Dilution/Attenuation Factors (DAFs) that take into account volatilization, resorption, degradation and other factors anticipated to reduce the concentrations of chemicals in leachate as the leachate migrates downward and ultimately mixes with groundwater.

Relatively simple DAFs that only address mixing of leachate with groundwater can be calculated using equations provided in the USEPA *Soil Screening Guidance* (USEPA 1996), among other sources. For Hawai'i, simple leachate/groundwater mixing DAFs for shallow aquifers would typically fall in the range of 5 for silty soils to 20 for sandy soils (e.g., assuming 2m thick shallow aquifer, 30% effective porosity, infiltration rate of 8.0 cm/year (3 inches/year or approximately 15% of total, average rainfall), and hydraulic conductivities of 2m/day and 15m/day, respectively). DAFs could be much higher for areas with fast moving groundwater and/or little infiltration of precipitation and lower in areas with slow moving groundwater and/or greater infiltration of precipitation. Potentially less conservative DAFs that also address resorption, volatilization and other factors can be calculated using more rigorous models such as SESOIL (see Appendix 1).

3.3.4 Tier 3 Environmental Risk Assessments for Parklands

For initial cleanup efforts at sites to be used as parks or wildlife refuges, it is strongly recommended that such areas be remediated to meet unrestricted land use (i.e., assumed residential exposure, target Excess Cancer Risk of one-in-a-million; target Hazard Index of 1.0 and address potential ecological concerns). From a strictly toxicological

standpoint, a typical recreational-use exposure scenario may suggest that substantially higher concentrations of contaminants could be left in place at the site and not pose a threat to human health. Public parks are typically frequented by children, young mothers, elderly people and other groups of people with potentially elevated sensitivities to environmental contaminants, however. In addition, cleanup levels based on recreational land-use scenarios are oftentimes higher (less stringent) than levels that would be allowed for commercial/industrial properties. This intuitively goes against the concept of developing a park as "refuge" for humans and wildlife. Assumption of a limited exposure frequency and duration (e.g., 100 days per year for ten years) also puts an inherent restriction on the number of days and years that an individual can visit the park without exceeding potential health hazards. Long-term, future uses of such properties are also difficult to predict.

In some cases, remediation of proposed parklands to unrestricted land-use standards may not be technically or economically feasible. This should be evaluated on a site-specific basis and receive approval from the overseeing regulatory agency. In such cases, the appropriateness of allowing unrestricted access to the area should be carefully evaluated. This could include the need to impose access restrictions on the property (i.e., based on the exposure assumptions used in the risk assessment) and/or cap impacted soils with a minimal amount of clean fill. It may also be prudent to post signs at the property entrance that warn of potential health hazards (see Section 2.7).

3.3.5 Tier 3 Reference Documents

Potentially useful reference documents for preparation of Tier 3 environmental risk assessments include the following:

Human Health Risk Assessment:

- *Superfund Exposure Assessment Manual* (USEPA 1988)
- *Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A)* (USEPA 1989a);
- *Soil Screening Guidance: Technical Background Document* (USEPA 1996);
- *CalTOX, A Multimedia Total Exposure Model For Hazardous-Waste Sites* (CalEPA 1994a);
- *Preliminary Endangerment Assessment Guidance Manual* (CalEPA 1994b);
- *Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (CalEPA 1996a);
- *Exposure Factors Handbook* (USEPA 1997a);

- *Standard Provisional Guide for Risk-Based Corrective Action* (ASTM 1995); and
- *Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces* (Johnson et. al, 1998).

Ecological Risk Assessment:

- *Risk Assessment Guidance for Superfund: Volume II Environmental Evaluation Manual* (USEPA 1989b);
- *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (USEPA 1997b), and
- *Guidance for Ecological Risk Assessments at Hazardous Waste Sites and Permitted Facilities* (CalEPA 1996a,b).

The above list of references is not intended to be comprehensive. Additional risk assessment guidance should be referred to as needed.

4

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FIGURES

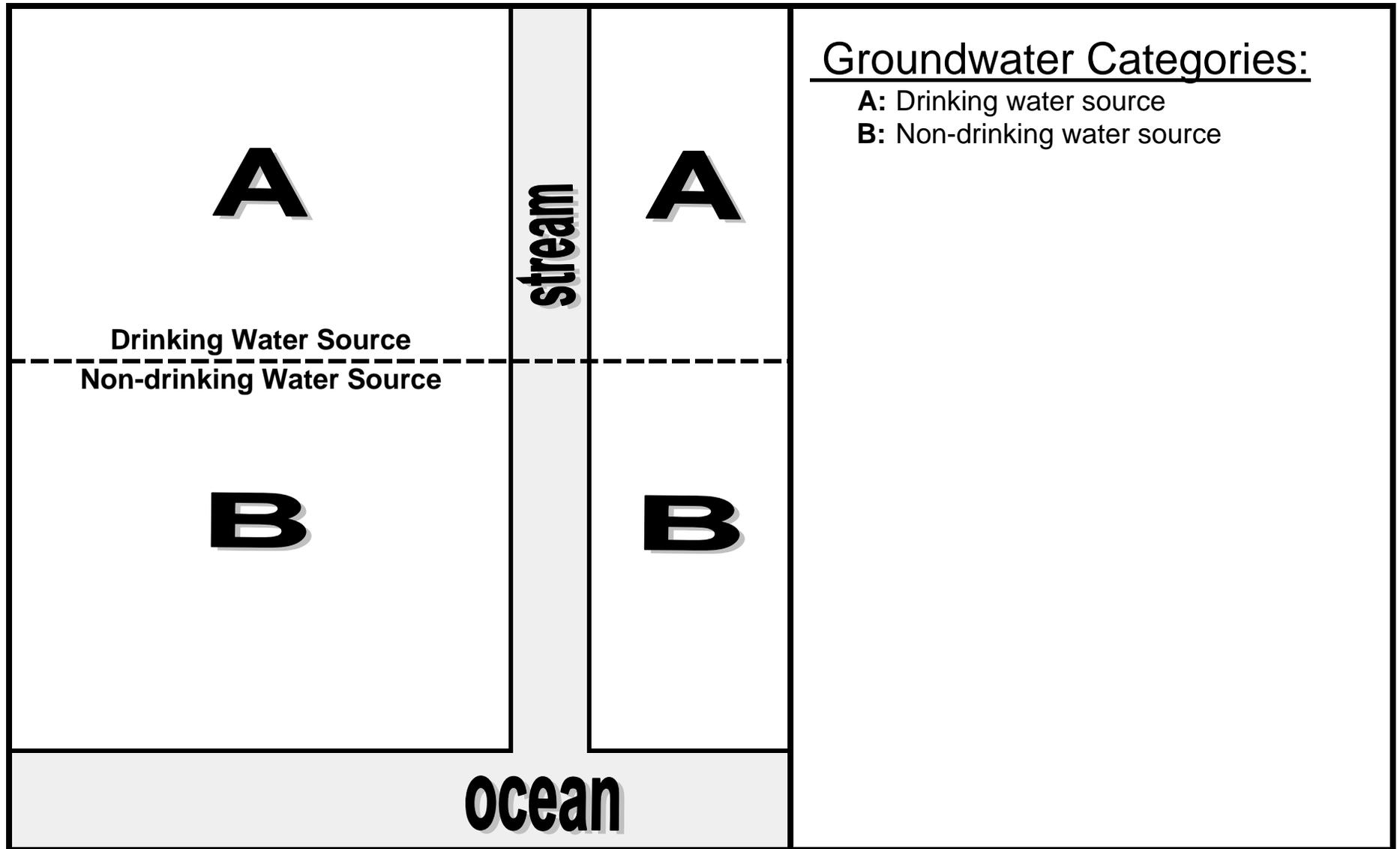


Figure 1. Groundwater zones used in 1996 RBCA lookup tables.

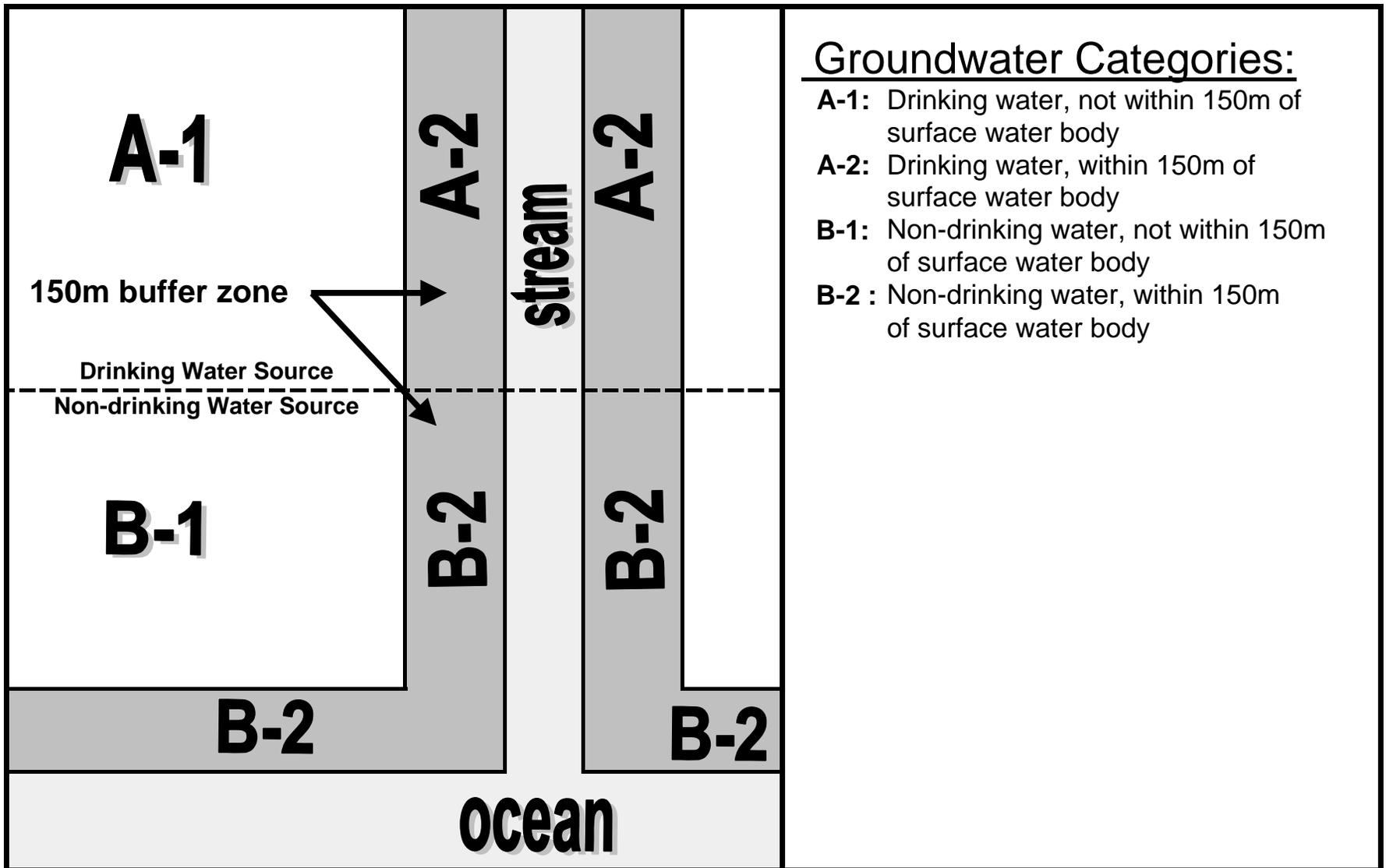


Figure 2. Groundwater zones used in 2005 RBCA lookup tables.

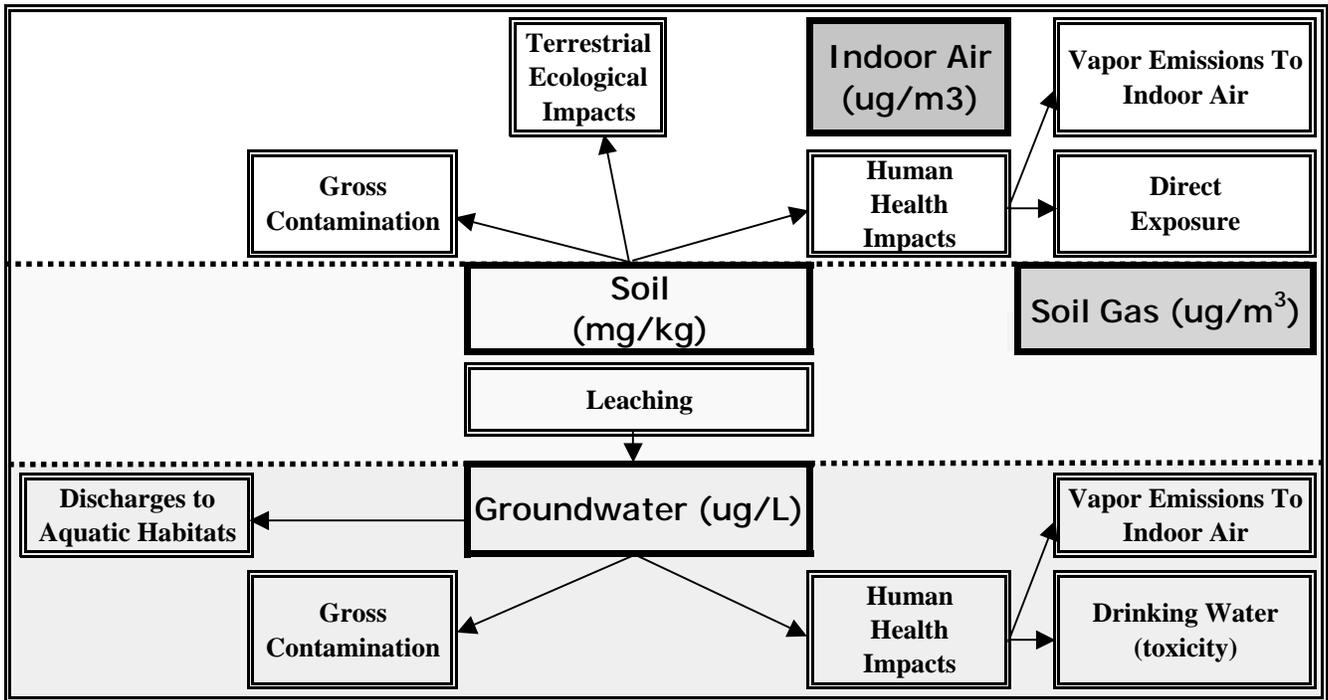


Figure 3. Summary of human health and environmental concerns considered in screening levels. Gross contamination concerns include free product, odors, tastes (drinking water) and general resource degradation. This figure is intended for Tier 1 and Tier 2 assessments only. Evaluation of environmental concerns not shown requires site-specific assessment.

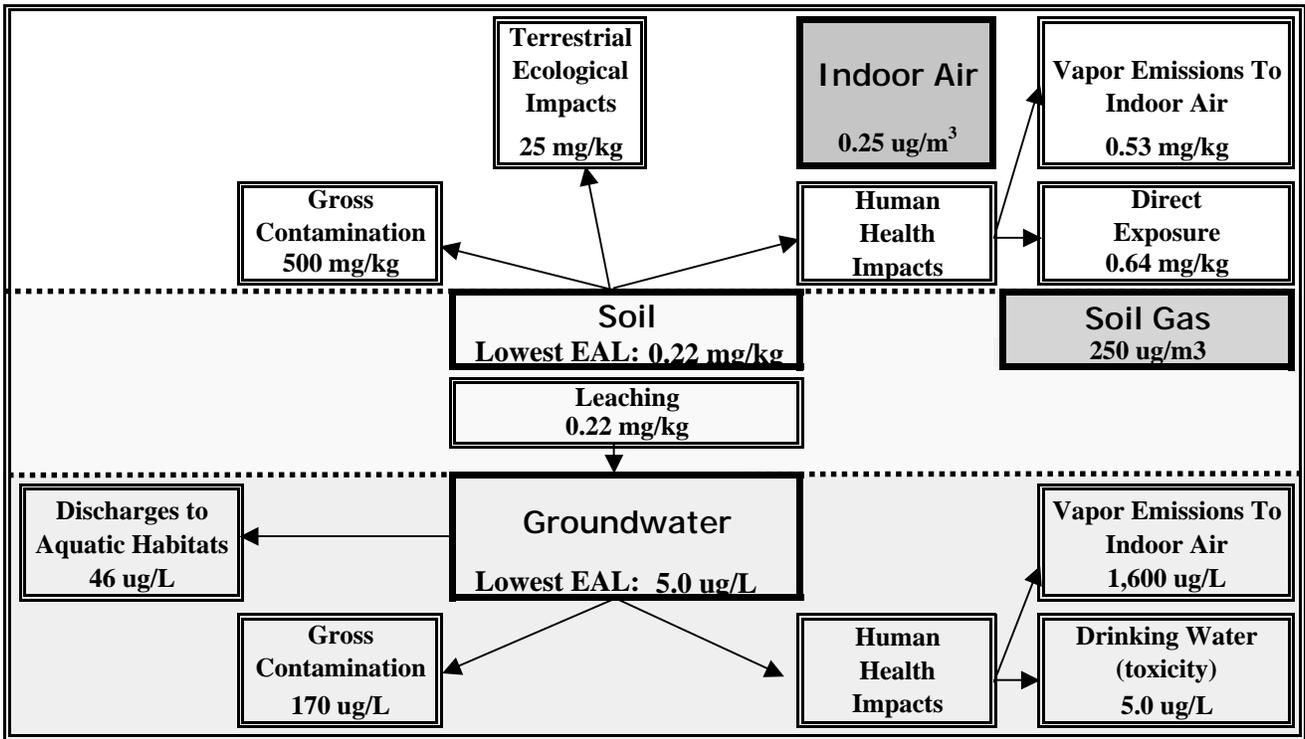


Figure 4. Summary of individual screening levels used to select final, Tier 1 soil and groundwater EALs for benzene in Volume 1, Table A. Refer Appendix 1, Table A-1 (soil), Table C-3 (indoor air and soil gas) and Table D-1a (groundwater).

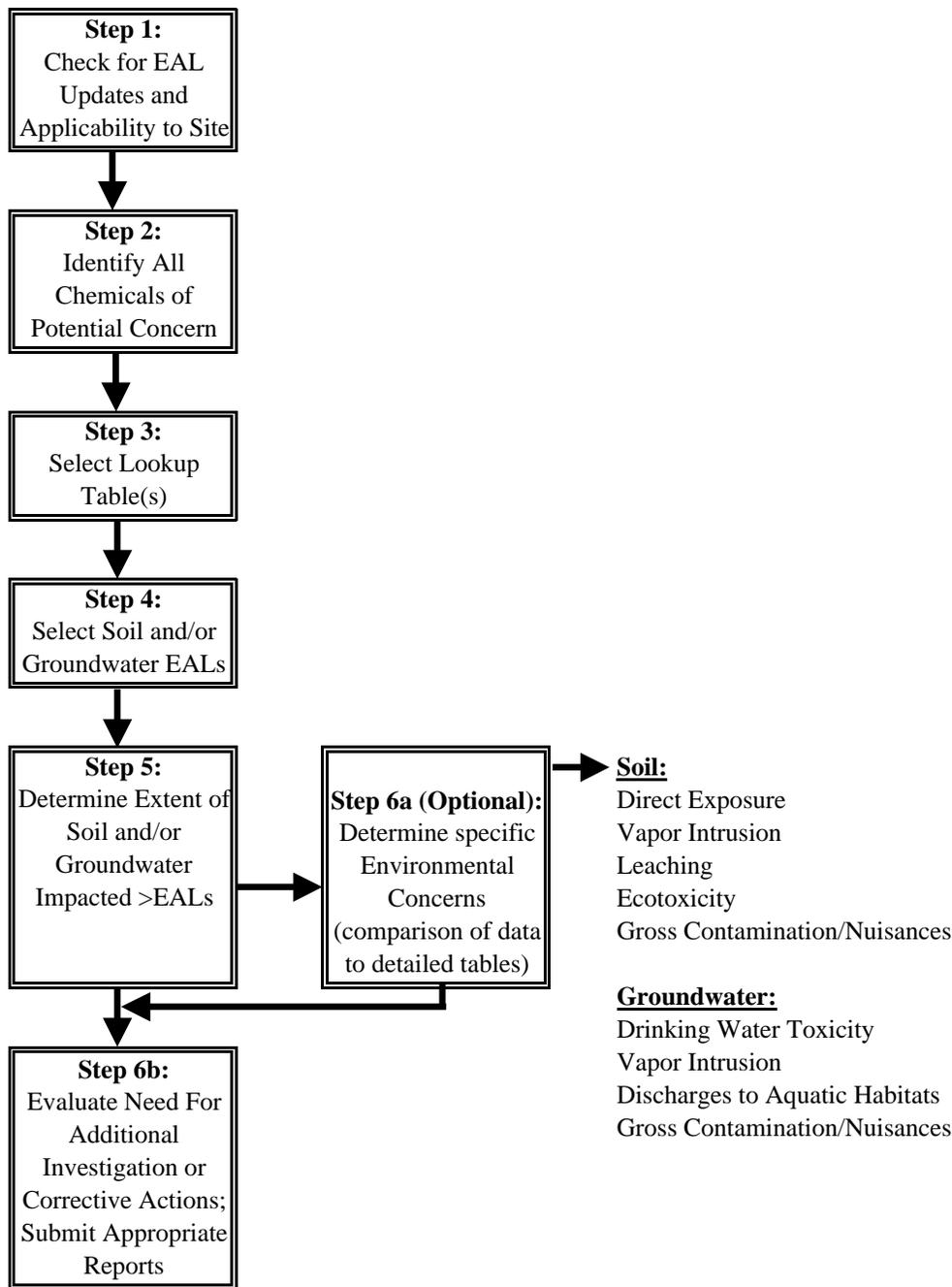


Figure 5. Summary of steps for use of lookup tables following initial investigation of site. Identification and assessment of specific environmental concerns required for sites not cleaned up to Tier 1 action levels.

TABLES

**TABLE A: GROUNDWATER IS A CURRENT OR
POTENTIAL SOURCE OF DRINKING WATER**

**TABLE A. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
ACENAPHTHENE	1.6E+01	2.0E+01	1.6E+01	2.0E+01
ACENAPHTHYLENE	1.0E+02	2.4E+02	1.3E+01	3.0E+01
ACETONE	5.0E-01	1.5E+03	5.0E-01	1.5E+03
ALDRIN	2.9E-02	4.0E-03	2.9E-02	4.0E-03
ANTHRACENE	2.8E+00	7.3E-01	2.8E+00	7.3E-01
ANTIMONY	2.0E+01	6.0E+00	2.0E+01	6.0E+00
ARSENIC	2.2E+01	1.0E+01	2.2E+01	1.0E+01
BARIUM	7.5E+02	2.0E+03	7.5E+02	2.0E+03
BENZENE	2.2E-01	5.0E+00	2.2E-01	5.0E+00
BENZO(a)ANTHRACENE	6.2E+00	2.7E-02	6.2E+00	2.7E-02
BENZO(a)PYRENE	6.2E-01	1.4E-02	6.2E-01	1.4E-02
BENZO(b)FLUORANTHENE	6.2E+00	9.2E-02	6.2E+00	9.2E-02
BENZO(g,h,i)PERYLENE	2.7E+01	1.0E-01	2.7E+01	1.0E-01
BENZO(k)FLUORANTHENE	3.7E+01	4.0E-01	3.7E+01	4.0E-01
BERYLLIUM	4.0E+00	4.0E+00	4.0E+00	2.7E+00
BIPHENYL, 1,1-	6.5E-01	5.0E-01	6.5E-01	5.0E-01
BIS(2-CHLOROETHYL)ETHER	1.2E-04	9.5E-03	1.2E-04	9.5E-03
BIS(2-CHLOROISOPROPYL)ETHER	3.0E-03	2.7E-01	3.0E-03	2.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	6.0E+00	3.5E+01	6.0E+00
BORON	1.6E+00	1.6E+00	1.6E+00	1.6E+00
BROMODICHLOROMETHANE	3.4E-03	1.8E-01	3.4E-03	1.8E-01
BROMOFORM	2.2E+00	1.0E+02	2.2E+00	1.0E+02
BROMOMETHANE	3.4E-01	8.5E+00	3.4E-01	8.5E+00
CADMIUM	1.2E+01	3.0E+00	1.2E+01	3.0E+00
CARBON TETRACHLORIDE	2.7E-02	5.0E+00	2.7E-02	5.0E+00
CHLORDANE	1.6E+00	9.0E-02	1.6E+00	4.0E-03
CHLOROANILINE, p-	5.3E-02	5.0E+00	5.3E-02	5.0E+00
CHLOROBENZENE	3.0E+00	5.0E+01	1.5E+00	2.5E+01
CHLOROETHANE	2.7E-01	3.9E+00	2.7E-01	3.9E+00
CHLOROFORM	1.8E-02	6.2E+01	1.8E-02	6.2E+01
CHLOROMETHANE	1.6E+01	1.6E+02	1.6E+01	1.6E+02
CHLOROPHENOL, 2-	1.2E-02	1.8E-01	1.2E-02	1.8E-01
CHROMIUM (Total)	2.1E+02	7.4E+01	2.1E+02	7.4E+01
CHROMIUM III	7.5E+02	5.7E+02	7.5E+02	7.4E+01
CHROMIUM VI	8.0E+00	1.6E+01	8.0E+00	1.1E+01
CHRYSENE	2.8E+01	3.5E-01	2.8E+01	3.5E-01
COBALT	4.0E+01	3.0E+00	4.0E+01	3.0E+00
COPPER	2.3E+02	2.9E+00	2.3E+02	2.9E+00
CYANIDE (Free)	1.0E+02	1.0E+00	1.0E+02	1.0E+00

**TABLE A. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
DIBENZO(a,h)ANTHTRACENE	6.2E-01	9.2E-03	6.2E-01	9.2E-03
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	4.0E-02	9.0E-04	4.0E-02
DIBROMOCHLOROMETHANE	1.1E-02	1.3E-01	1.1E-02	1.3E-01
DIBROMOETHANE, 1,2-	5.2E-05	5.6E-03	5.2E-05	5.6E-03
DICHLOROBENZENE, 1,2-	1.1E+00	1.0E+01	1.1E+00	1.0E+01
DICHLOROBENZENE, 1,3-	2.1E+01	1.8E+02	7.4E+00	6.5E+01
DICHLOROBENZENE, 1,4-	6.5E-02	5.0E+00	6.5E-02	5.0E+00
DICHLOROBENZAZINE, 3,3-	4.0E-02	1.5E-01	4.0E-02	1.5E-01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	2.8E-01	2.4E+00	1.0E-03
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	2.8E-01	2.4E+00	1.0E-03
DICHLORODIPHENYL TRICHLOROETHANE (DDT)	1.7E+00	1.3E-02	1.7E+00	1.0E-03
DICHLOROETHANE, 1,1-	1.9E+00	4.7E+01	1.9E+00	4.7E+01
DICHLOROETHANE, 1,2-	1.1E-03	1.2E-01	1.1E-03	1.2E-01
DICHLOROETHYLENE, 1,1-	1.2E+00	7.0E+00	1.2E+00	7.0E+00
DICHLOROETHYLENE, Cis 1,2-	2.2E+00	7.0E+01	2.2E+00	7.0E+01
DICHLOROETHYLENE, Trans 1,2-	6.7E+00	1.0E+02	6.7E+00	1.0E+02
DICHLOROPHENOL, 2,4-	3.0E-01	3.0E-01	3.0E-01	3.0E-01
DICHLOROPROPANE, 1,2-	2.1E-02	5.0E+00	2.1E-02	5.0E+00
DICHLOROPROPENE, 1,3-	4.6E-02	4.0E-01	4.6E-02	4.0E-01
DIELDRIN	5.2E-03	4.2E-03	2.3E-03	1.9E-03
DIETHYLPHTHALATE	2.2E+01	9.4E+02	3.5E-02	1.5E+00
DIMETHYLPHENOL, 2,4-	1.8E+00	2.7E+02	7.3E-01	1.1E+02
DIMETHYLPHTHALATE	2.2E+01	9.4E+02	3.5E-02	1.5E+00
DINITROPHENOL, 2,4-	2.1E-01	7.3E+01	2.1E-01	7.3E+01
DINITROTOLUENE, 2,4-	2.5E-01	3.4E+01	2.5E-01	3.4E+01
DIOXANE, 1,4-	3.7E-03	6.1E+00	3.7E-03	6.1E+00
DIOXIN (2,3,7,8-TCDD)	3.9E-06	3.0E-05	3.9E-06	5.0E-06
ENDOSULFAN	1.8E-02	3.4E-02	4.6E-03	8.7E-03
ENDRIN	1.0E-02	3.7E-02	6.5E-04	2.3E-03
ETHYLBENZENE	3.3E+00	3.0E+01	3.3E+00	3.0E+01
FLUORANTHENE	4.0E+01	4.0E+01	4.0E+01	8.0E+00
FLUORENE	1.6E+02	2.4E+02	8.9E+00	3.9E+00
HEPTACHLOR	1.1E-01	5.3E-02	1.3E-02	3.6E-03
HEPTACHLOR EPOXIDE	5.3E-02	5.3E-02	1.4E-02	3.6E-03
HEXACHLOROBENZENE	3.0E-01	1.0E+00	3.0E-01	1.0E+00
HEXACHLOROBUTADIENE	4.3E+00	8.6E-01	4.3E+00	8.6E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	9.8E-02	1.6E-01	4.9E-02	8.0E-02
HEXACHLOROETHANE	1.6E+01	4.8E+00	1.6E+01	4.8E+00
INDENO(1,2,3-cd)PYRENE	6.2E+00	9.2E-02	6.2E+00	9.2E-02

**TABLE A. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
LEAD ³	2.0E+02 (4.0E+02)	1.5E+01	2.0E+02 (4.0E+02)	5.6E+00
MERCURY	1.0E+01	2.0E+00	1.0E+01	2.5E-02
METHOXYCHLOR	1.9E+01	3.0E-02	1.9E+01	3.0E-02
METHYL ETHYL KETONE	6.4E+00	7.0E+03	6.4E+00	7.0E+03
METHYL ISOBUTYL KETONE	3.9E+00	1.7E+02	3.9E+00	1.7E+02
METHYL MERCURY	6.1E+00	3.0E-03	6.1E+00	3.0E-03
METHYL TERT BUTYL ETHER	2.3E-02	5.0E+00	2.3E-02	5.0E+00
METHYLENE CHLORIDE	6.7E-02	4.3E+00	6.7E-02	4.3E+00
METHYLNAPHTHALENE (total 1- & 2-)	1.2E+00	1.0E+01	2.5E-01	2.1E+00
MOLYBDENUM	4.0E+01	1.8E+02	4.0E+01	1.8E+02
NAPHTHALENE	1.2E+00	6.2E+00	1.2E+00	6.2E+00
NICKEL	1.5E+02	5.0E+00	1.5E+02	5.0E+00
PENTACHLOROPHENOL	3.0E+00	1.0E+00	3.0E+00	1.0E+00
PERCHLORATE	7.0E-03	3.7E+00	7.0E-03	3.7E+00
PHENANTHRENE	1.8E+01	7.7E+00	1.1E+01	4.6E+00
PHENOL	7.6E-02	5.0E+00	7.6E-02	5.0E+00
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	5.0E-01	1.1E+00	1.4E-02
PYRENE	8.5E+01	2.0E+00	8.5E+01	2.0E+00
SELENIUM	1.0E+01	2.0E+01	1.0E+01	5.0E+00
SILVER	2.0E+01	1.0E+00	2.0E+01	1.0E+00
STYRENE	1.5E+00	1.0E+01	1.5E+00	1.0E+01
tert-BUTYL ALCOHOL	2.3E-02	3.7E+00	2.3E-02	3.7E+00
TETRACHLOROETHANE, 1,1,1,2-	7.6E-03	4.3E-01	7.6E-03	4.3E-01
TETRACHLOROETHANE, 1,1,2,2-	9.9E-04	5.6E-02	9.9E-04	5.6E-02
TETRACHLOROETHYLENE	6.9E-02	5.0E+00	6.9E-02	5.0E+00
THALLIUM	5.2E+00	2.0E+00	5.2E+00	2.0E+00
TOLUENE	2.9E+00	4.0E+01	2.9E+00	4.0E+01
TOXAPHENE	4.0E-01	2.1E-01	4.2E-04	2.0E-04
TPH (gasolines)	1.0E+02 (2.0E+03)	1.0E+02	1.0E+02 (2.0E+03)	1.0E+02
TPH (middle distillates)	5.0E+02 (5.0E+03)	1.0E+02	5.0E+02 (5.0E+03)	1.0E+02
TPH (residual fuels)	5.0E+02 (5.0E+03)	1.0E+02	5.0E+02 (5.0E+03)	1.0E+02
TRICHLOROETHANE, 1,2,4-	1.6E+00	7.0E+01	1.6E+00	2.5E+01
TRICHLOROETHANE, 1,1,1-	2.5E+01	2.0E+02	7.8E+00	6.2E+01
TRICHLOROETHANE, 1,1,2-	2.6E-02	5.0E+00	2.6E-02	5.0E+00
TRICHLOROETHYLENE	3.6E-02	5.0E+00	3.6E-02	5.0E+00
TRICHLOROPHENOL, 2,4,5-	1.6E+00	1.0E+02	1.8E-01	1.1E+01
TRICHLOROPHENOL, 2,4,6-	1.2E+00	3.7E+00	1.2E+00	3.7E+00
VANADIUM	7.8E+01	1.9E+01	7.8E+01	1.9E+01
VINYL CHLORIDE	3.9E-02	2.0E+00	3.9E-02	2.0E+00

**TABLE A. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	'Soil (mg/kg)	'Groundwater (ug/L)	'Soil (mg/kg)	'Groundwater (ug/L)
XYLENES	2.3E+00	2.0E+01	2.3E+00	2.0E+01
ZINC	6.0E+02	2.2E+01	6.0E+02	2.2E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0	not applicable	2.0	not applicable
Sodium Adsorption Ratio	5.0	not applicable	5.0	not applicable

Notes:

1. Assumes current or future residential land use, generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.)
2. Assumes potential impacts to drinking water source and discharge of groundwater into a freshwater, marine or estuary surface water system.
3. Lead: First action level is based on ecotoxicity. Action level in parentheses is based on direct exposure to humans. Ecotoxicity action level generally not applicable to highly developed urban sites where no significant open spaces are anticipated.

Source of Soil Action Levels: Refer to Appendix 1, Tables A-1 and A-2.

Source of Groundwater Action Levels: Appendix 1, Table D-1a (≤150m to Surface Water Body) and Table D-1b (>150m to Surface Water Body).
Soil data should be reported on dry-weight basis (see Appendix 1, Section 6.2).

Soil Action Levels intended to address direct-exposure, vapor intrusion, groundwater protection (leaching), ecologic (urban areas) and nuisance concerns. Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil. See also Section 2.5 and Table C.

Groundwater Action Levels intended to address surface water impacts, vapor intrusion and nuisance concerns. Use in conjunction with soil gas action levels to evaluate potential impacts to indoor-air if groundwater action levels for this concern approached or exceeded (refer to Table C-1a in Appendix 1). See also Section 2.5 and Table C.

Groundwater action levels should be compared to dissolved phase chemical concentrations unless otherwise instructed by HDOH.

GALs >150m to Surface Water Body: Groundwater screened with respect to acute surface water goals (See Table D-1b).

GALs ≤150m to Surface Water Body: Groundwater screened with respect to chronic surface water goals (see Table D-1a).

TPH -Total Petroleum Hydrocarbons: TPH Action Levels must be used in conjunction with Action Levels for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Section 2.2 in text. TPH Soil Action Levels: First Action Level based on potential nuisance concerns. Second Action Level based on potential leaching concerns. Action Levels for nuisance concerns recommended for soils exposed or potentially exposed at the ground surface (minimum three meters below ground surface for residential sites with private yards and three feet below ground surface for other land use scenarios). **More stringent TPH soil action levels for leaching concerns may be required at sites with elevated threats to drinking water resources or aquatic habitats. Refer to Section 2.2.2.3 in text.**

**TABLE B: GROUNDWATER IS NOT A CURRENT OR
POTENTIAL SOURCE OF DRINKING WATER**

**TABLE B. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS NOT Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
ACENAPHTHENE	1.3E+02	2.0E+02	1.9E+01	2.3E+01
ACENAPHTHYLENE	1.3E+02	3.0E+02	1.3E+01	3.0E+01
ACETONE	5.0E-01	1.5E+03	5.0E-01	1.5E+03
ALDRIN	2.9E-02	1.3E+00	2.9E-02	1.3E-01
ANTHRACENE	2.8E+00	7.3E-01	2.8E+00	7.3E-01
ANTIMONY	2.0E+01	1.5E+03	2.0E+01	3.0E+01
ARSENIC	2.2E+01	6.9E+01	2.2E+01	3.6E+01
BARIUM	7.5E+02	2.0E+03	7.5E+02	2.0E+03
BENZENE	5.3E-01	1.6E+03	5.3E-01	4.6E+01
BENZO(a)ANTHRACENE	6.2E+00	2.7E-02	6.2E+00	2.7E-02
BENZO(a)PYRENE	6.2E-01	1.4E-02	6.2E-01	1.4E-02
BENZO(b)FLUORANTHENE	6.2E+00	9.2E-02	6.2E+00	9.2E-02
BENZO(g,h,i)PERYLENE	2.7E+01	1.0E-01	2.7E+01	1.0E-01
BENZO(k)FLUORANTHENE	3.7E+01	4.0E-01	3.7E+01	4.0E-01
BERYLLIUM	4.0E+00	4.3E+01	4.0E+00	2.7E+00
BIPHENYL, 1,1-	6.5E+00	5.0E+00	6.5E+00	5.0E+00
BIS(2-CHLOROETHYL)ETHER	6.7E-03	1.0E+02	6.7E-03	6.1E+01
BIS(2-CHLOROISOPROPYL)ETHER	2.9E+00	3.2E+03	6.6E-01	6.1E+01
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	3.2E+01	3.5E+01	3.2E+01
BORON	1.6E+00	1.6E+00	1.6E+00	1.6E+00
BROMODICHLOROMETHANE	2.3E-02	2.7E+02	2.3E-02	2.7E+02
BROMOFORM	6.1E+01	5.1E+03	6.1E+01	3.2E+03
BROMOMETHANE	8.6E-01	2.3E+03	8.6E-01	1.6E+02
CADMIUM	1.2E+01	3.0E+00	1.2E+01	3.0E+00
CARBON TETRACHLORIDE	2.7E-02	2.1E+01	2.7E-02	9.8E+00
CHLORDANE	1.6E+00	9.0E-02	1.6E+00	4.0E-03
CHLOROANILINE, p-	5.3E-02	5.0E+00	5.3E-02	5.0E+00
CHLOROBENZENE	9.5E+00	1.6E+02	1.5E+00	2.5E+01
CHLOROETHANE	2.7E-01	3.9E+00	2.7E-01	3.9E+00
CHLOROFORM	1.8E-02	6.2E+01	1.8E-02	6.2E+01
CHLOROMETHANE	1.6E+01	9.5E+03	1.6E+01	3.2E+03
CHLOROPHENOL, 2-	1.2E-01	1.8E+00	1.2E-01	1.8E+00
CHROMIUM (Total)	2.1E+02	7.4E+01	2.1E+02	7.4E+01
CHROMIUM III	7.5E+02	5.7E+02	7.5E+02	7.4E+01
CHROMIUM VI	8.0E+00	1.6E+01	8.0E+00	1.1E+01
CHRYSENE	2.3E+01	3.5E-01	2.3E+01	3.5E-01
COBALT	4.0E+01	3.0E+00	4.0E+01	3.0E+00
COPPER	2.3E+02	2.9E+00	2.3E+02	2.9E+00
CYANIDE (Free)	1.0E+02	1.0E+00	1.0E+02	1.0E+00

**TABLE B. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS NOT Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
DIBENZO(a,h)ANTHTRACENE	6.2E-01	2.5E-01	6.2E-01	2.5E-01
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	4.0E-02	9.0E-04	4.0E-02
DIBROMOCHLOROMETHANE	1.7E-02	1.6E+02	1.7E-02	1.6E+02
DIBROMOETHANE, 1,2-	7.2E-04	1.6E+01	7.2E-04	1.6E+01
DICHLOROBENZENE, 1,2-	1.1E+01	1.0E+02	1.6E+00	1.4E+01
DICHLOROBENZENE, 1,3-	3.0E+01	3.7E+02	7.4E+00	6.5E+01
DICHLOROBENZENE, 1,4-	6.5E-02	1.1E+02	6.5E-02	1.5E+01
DICHLOROBENZIDINE, 3,3'-	1.1E+00	2.5E+02	1.1E+00	2.5E+02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	6.0E-01	2.4E+00	1.0E-03
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	1.4E+01	2.4E+00	1.0E-03
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	1.3E-02	1.7E+00	1.0E-03
DICHLOROETHANE, 1,1-	1.9E+00	4.7E+01	1.9E+00	4.7E+01
DICHLOROETHANE, 1,2-	1.6E-02	1.3E+02	1.6E-02	1.3E+02
DICHLOROETHYLENE, 1,1-	3.5E+01	3.9E+03	4.3E+00	2.5E+01
DICHLOROETHYLENE, Cis 1,2-	6.2E+00	1.2E+04	6.2E+00	5.9E+02
DICHLOROETHYLENE, Trans 1,2-	1.2E+01	2.6E+03	1.2E+01	5.9E+02
DICHLOROPHENOL, 2,4-	3.0E+00	3.0E+00	3.0E+00	3.0E+00
DICHLOROPROPANE, 1,2-	2.1E-02	1.0E+02	2.1E-02	1.0E+02
DICHLOROPROPENE, 1,3-	1.0E-01	1.6E+02	1.0E-01	1.2E+02
DIELDRIN	3.0E-02	7.1E-01	2.3E-03	1.9E-03
DIETHYLPHTHALATE	2.2E+01	9.4E+02	3.5E-02	1.5E+00
DIMETHYLPHENOL, 2,4-	1.8E+00	2.7E+02	7.3E-01	1.1E+02
DIMETHYLPHTHALATE	2.2E+01	9.4E+02	3.5E-02	1.5E+00
DINITROPHENOL, 2,4-	6.5E-01	2.3E+02	2.1E-01	7.5E+01
DINITROTOLUENE, 2,4-	1.5E+00	2.0E+02	8.6E-01	1.2E+02
DIOXANE, 1,4-	3.0E+01	5.0E+04	3.0E+01	5.0E+04
DIOXIN (2,3,7,8-TCDD)	3.9E-06	3.0E-03	3.9E-06	5.0E-06
ENDOSULFAN	1.8E-02	3.4E-02	4.6E-03	8.7E-03
ENDRIN	1.0E-02	3.7E-02	6.5E-04	2.3E-03
ETHYLBENZENE	3.3E+01	3.0E+02	3.2E+01	2.9E+02
FLUORANTHENE	4.0E+01	4.0E+01	4.0E+01	8.0E+00
FLUORENE	1.6E+02	3.0E+02	8.9E+00	3.9E+00
HEPTACHLOR	1.1E-01	5.3E-02	1.3E-02	3.6E-03
HEPTACHLOR EPOXIDE	5.3E-02	5.3E-02	1.4E-02	3.6E-03
HEXACHLOROBENZENE	3.0E-01	6.0E+00	3.0E-01	3.7E+00
HEXACHLOROBUTADIENE	6.2E+00	1.1E+01	6.2E+00	4.7E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	9.8E-02	1.6E-01	4.9E-02	8.0E-02
HEXACHLOROETHANE	3.5E+01	1.0E+02	3.5E+01	1.2E+01
INDENO(1,2,3-cd)PYRENE	6.2E+00	9.2E-02	6.2E+00	9.2E-02

**TABLE B. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS NOT Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
LEAD ³	2.0E+02 (4.0E+02)	2.9E+01	2.0E+02 (4.0E+02)	5.6E+00
MERCURY	1.0E+01	2.1E+00	1.0E+01	2.5E-02
METHOXYCHLOR	1.9E+01	3.0E-02	1.9E+01	3.0E-02
METHYL ETHYL KETONE	1.3E+01	1.4E+04	1.3E+01	1.4E+04
METHYL ISOBUTYL KETONE	3.9E+00	1.7E+02	3.9E+00	1.7E+02
METHYL MERCURY	6.1E+00	3.0E-03	6.1E+00	3.0E-03
METHYL TERT BUTYL ETHER	1.6E+00	1.8E+03	1.6E+00	1.8E+03
METHYLENE CHLORIDE	9.0E-01	4.2E+03	9.0E-01	2.2E+03
METHYLNAPHTHALENE (total 1- & 2-)	1.2E+01	1.0E+02	2.5E-01	2.1E+00
MOLYBDENUM	4.0E+01	2.4E+02	4.0E+01	2.4E+02
NAPHTHALENE	1.8E+01	2.1E+02	4.8E+00	2.4E+01
NICKEL	1.5E+02	5.0E+00	1.5E+02	5.0E+00
PENTACHLOROPHENOL	3.0E+00	1.3E+01	3.0E+00	7.9E+00
PERCHLORATE	1.2E+00	6.0E+02	1.2E+00	6.0E+02
PHENANTHRENE	1.8E+01	7.7E+00	1.1E+01	4.6E+00
PHENOL	4.0E+01	3.4E+03	1.9E+01	1.3E+03
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	2.0E+00	1.1E+00	1.4E-02
PYRENE	8.5E+01	2.0E+00	8.5E+01	2.0E+00
SELENIUM	1.0E+01	2.0E+01	1.0E+01	5.0E+00
SILVER	2.0E+01	1.0E+00	2.0E+01	1.0E+00
STYRENE	1.5E+01	1.0E+02	1.5E+01	1.0E+02
tert-BUTYL ALCOHOL	7.0E+01	5.0E+04	7.0E+01	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	3.1E+00	3.1E+03	3.1E+00	3.1E+02
TETRACHLOROETHANE, 1,1,2,2-	7.2E-03	1.5E+02	7.2E-03	1.5E+02
TETRACHLOROETHYLENE	6.9E-02	9.9E+01	6.9E-02	9.9E+01
THALLIUM	5.2E+00	4.7E+02	5.2E+00	2.0E+01
TOLUENE	2.9E+01	4.0E+02	9.3E+00	1.3E+02
TOXAPHENE	4.0E-01	2.1E-01	4.2E-04	2.0E-04
TPH (gasolines)	1.0E+02 (2.0E+03)	5.0E+03	1.0E+02 (2.0E+03)	5.0E+02
TPH (middle distillates)	5.0E+02 (5.0E+03)	2.5E+03	5.0E+02 (5.0E+03)	6.4E+02
TPH (residual fuels)	5.0E+02 (5.0E+03)	2.5E+03	5.0E+02 (5.0E+03)	6.4E+02
TRICHLOROBENZENE, 1,2,4-	1.6E+00	1.6E+02	1.6E+00	2.5E+01
TRICHLOROETHANE, 1,1,1-	3.9E+02	6.0E+03	7.8E+00	6.2E+01
TRICHLOROETHANE, 1,1,2-	2.6E-02	2.8E+02	2.6E-02	2.8E+02
TRICHLOROETHYLENE	3.6E-02	7.4E+01	3.6E-02	7.4E+01
TRICHLOROPHENOL, 2,4,5-	1.6E+00	1.0E+02	1.8E-01	1.1E+01
TRICHLOROPHENOL, 2,4,6-	6.1E+00	4.9E+02	6.1E+00	4.9E+02
VANADIUM	7.8E+01	1.9E+01	7.8E+01	1.9E+01
VINYL CHLORIDE	3.9E-02	2.2E+01	3.9E-02	2.2E+01

**TABLE B. ENVIRONMENTAL ACTION LEVELS (EALs)
Groundwater IS NOT Current or Potential Source of Drinking Water**

CONTAMINANT	>150m to Surface Water Body		≤150m to Surface Water Body	
	Soil (mg/kg)	Groundwater (ug/L)	Soil (mg/kg)	Groundwater (ug/L)
XYLENES	1.8E+02	2.0E+03	1.1E+01	1.0E+02
ZINC	6.0E+02	2.2E+01	6.0E+02	2.2E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0	not applicable	2.0	not applicable
Sodium Adsorption Ratio	5.0	not applicable	5.0	not applicable

Notes:

1. Assumes current or future residential land use, generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.)
2. Assumes potential discharge of groundwater into a freshwater, marine or estuary surface water system.
3. Lead: First action level is based on ecotoxicity. Action level in parentheses is based on direct exposure to humans. Ecotoxicity action level generally not applicable to highly developed urban sites where no significant open spaces are anticipated.

Source of Soil Action Levels: Refer to Appendix 1, Tables B-1 and B-2.

Source of Groundwater Action Levels: Appendix 1, Table D-1c (≤150m to Surface Water Body) and Table D-1d (>150m to Surface Water Body). Soil data should be reported on dry-weight basis (see Appendix 1, Section 6.2).

Soil Action Levels intended to address direct-exposure, vapor intrusion, groundwater protection (leaching), ecologic (urban areas) and nuisance concerns. Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil. See also Section 2.5 and Table C.

Groundwater Action Levels intended to be address surface water impacts, vapor intrusion and nuisance concerns. Use in conjunction with soil gas action levels to evaluate potential impacts to indoor-air if groundwater action levels for this concern approached or exceeded (refer to Table C-1a in Appendix 1). See also Section 2.5 and Table C.

Groundwater action levels should be compared to dissolved phase chemical concentrations unless otherwise instructed by HDOH.

GALs >150m to Surface Water Body: Groundwater screened with respect to acute surface water goals (See Table D-1d).

GALs ≤150m to Surface Water Body: Groundwater screened with respect to chronic surface water goals (see Table D-1c).

TPH - Total Petroleum Hydrocarbons: TPH Action Levels must be used in conjunction with Action Levels for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Section 2.2 in text. TPH Soil Action Levels: First Action Level based on potential nuisance concerns. Second Action Level based on potential leaching concerns. Action Levels for nuisance concerns recommended for soils exposed or potentially exposed at the ground surface (minimum three meters below ground surface for residential sites with private yards and three feet below ground surface for other land use scenarios). **More stringent TPH soil action levels for leaching concerns may be required at sites with elevated threats to drinking water resources or aquatic habitats. Refer to Section 2.2.3 in text.**

TABLE C: INDOOR AIR AND SOIL GAS

**TABLE C. ENVIRONMENTAL ACTION LEVELS (EALs)
Indoor Air and Soil Gas**

CONTAMINANT	INDOOR AIR ACTION LEVELS		² SHALLOW SOIL GAS ACTION LEVELS	
	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)
ACENAPHTHENE	2.2E+02	3.1E+02	2.2E+05	6.1E+05
ACENAPHTHYLENE	1.5E+02	2.0E+02	1.5E+05	4.1E+05
ACETONE	3.3E+03	4.6E+03	3.3E+06	9.2E+06
ALDRIN	-	-	-	-
ANTHRACENE	1.1E+03	1.5E+03	1.1E+06	3.1E+06
ANTIMONY	-	-	-	-
ARSENIC	-	-	-	-
BARIUM	-	-	-	-
BENZENE	2.5E-01	5.3E-01	2.5E+02	1.1E+03
BENZO(a)ANTHRACENE	-	-	-	-
BENZO(a)PYRENE	-	-	-	-
BENZO(b)FLUORANTHENE	-	-	-	-
BENZO(g,h,i)PERYLENE	-	-	-	-
BENZO(k)FLUORANTHENE	-	-	-	-
BERYLLIUM	-	-	-	-
BIPHENYL, 1,1-	1.8E+02	2.6E+02	1.8E+05	5.1E+05
BIS(2-CHLOROETHYL)ETHER	5.6E-03	1.2E-02	5.6E+00	2.4E+01
BIS(2-CHLOROISOPROPYL)ETHER	1.9E-01	4.1E-01	1.9E+02	8.2E+02
BIS(2-ETHYLHEXYL)PHTHALATE	-	-	-	-
BORON	-	-	-	-
BROMODICHLOROMETHANE	1.1E-01	2.3E-01	1.1E+02	4.6E+02
BROMOFORM	-	-	-	-
BROMOMETHANE	5.1E+00	7.2E+00	5.1E+03	1.4E+04
CADMIUM	-	-	-	-
CARBON TETRACHLORIDE	1.3E-01	2.7E-01	1.3E+02	5.4E+02
CHLORDANE	-	-	-	-
CHLOROANILINE, p-	-	-	-	-
CHLOROBENZENE	6.2E+01	8.7E+01	6.2E+04	1.7E+05
CHLOROETHANE	2.3E+00	4.9E+00	2.3E+03	9.9E+03
CHLOROFORM	8.3E-02	1.8E-01	8.3E+01	3.5E+02
CHLOROMETHANE	9.5E+01	1.3E+02	9.5E+04	2.7E+05
CHLOROPHENOL, 2-	1.8E+01	2.6E+01	1.8E+04	5.1E+04
CHROMIUM (Total)	-	-	-	-
CHROMIUM III	-	-	-	-
CHROMIUM VI	-	-	-	-
CHRYSENE	-	-	-	-
COBALT	-	-	-	-
COPPER	-	-	-	-
CYANIDE (Free)	-	-	-	-
DIBENZO(a,h)ANTHTRACENE	-	-	-	-
DIBROMO-3-CHLOROPROPANE, 1,2-	2.1E-01	2.9E-01	2.1E+02	5.8E+02
DIBROMOCHLOROMETHANE	8.0E-02	1.7E-01	8.0E+01	3.4E+02
DIBROMOETHANE, 1,2-	3.4E-03	7.2E-03	3.4E+00	1.4E+01

**TABLE C. ENVIRONMENTAL ACTION LEVELS (EALs)
Indoor Air and Soil Gas**

CONTAMINANT	INDOOR AIR ACTION LEVELS		² SHALLOW SOIL GAS ACTION LEVELS	
	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)
DICHLOROENZENE, 1,2-	2.1E+02	2.9E+02	2.1E+05	5.8E+05
DICHLOROENZENE, 1,3-	1.1E+02	1.5E+02	1.1E+05	3.1E+05
DICHLOROENZENE, 1,4-	3.1E-01	6.5E-01	3.1E+02	1.3E+03
DICHLOROBENZIDINE, 3,3-	-	-	-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	-	-	-	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	-	-	-	-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	-	-	-	-
DICHLOROETHANE, 1,1-	5.1E+02	7.2E+02	5.1E+05	1.4E+06
DICHLOROETHANE, 1,2-	7.4E-02	1.6E-01	7.4E+01	3.1E+02
DICHLOROETHYLENE, 1,1-	2.1E+02	2.9E+02	2.1E+05	5.8E+05
DICHLOROETHYLENE, Cis 1,2-	3.7E+01	5.1E+01	3.7E+04	1.0E+05
DICHLOROETHYLENE, Trans 1,2-	7.3E+01	1.0E+02	7.3E+04	2.0E+05
DICHLOROPHENOL, 2,4-	-	-	-	-
DICHLOROPROPANE, 1,2-	9.9E-02	2.1E-01	9.9E+01	4.2E+02
DICHLOROPROPENE, 1,3-	4.8E-01	1.0E+00	4.8E+02	2.0E+03
DIELDRIN	-	-	-	-
DIETHYLPHTHALATE	-	-	-	-
DIMETHYLPHENOL, 2,4-	-	-	-	-
DIMETHYLPHTHALATE	-	-	-	-
DINITROPHENOL, 2,4-	-	-	-	-
DINITROTOLUENE, 2,4-	-	-	-	-
DIOXANE, 1,4-	-	-	-	-
DIOXIN (2,3,7,8-TCDD)	-	-	-	-
ENDOSULFAN	-	-	-	-
ENDRIN	-	-	-	-
ETHYLBENZENE	1.1E+03	1.5E+03	1.1E+06	3.0E+06
FLUORANTHENE	-	-	-	-
FLUORENE	1.5E+02	2.0E+02	1.5E+05	4.1E+05
HEPTACHLOR	-	-	-	-
HEPTACHLOR EPOXIDE	-	-	-	-
HEXACHLOROENZENE	-	-	-	-
HEXACHLOROBUTADIENE	-	-	-	-
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	-	-	-	-
HEXACHLOROETHANE	-	-	-	-
INDENO(1,2,3-cd)PYRENE	-	-	-	-
LEAD	-	-	-	-
MERCURY	-	-	-	-
METHOXYCHLOR	-	-	-	-
METHYL ETHYL KETONE	5.1E+03	7.2E+03	5.1E+06	1.4E+07
METHYL ISOBUTYL KETONE	3.1E+03	4.4E+03	3.1E+06	8.8E+06
METHYL MERCURY	-	-	-	-
METHYL TERT BUTYL ETHER	7.4E+00	1.6E+01	7.4E+03	3.1E+04
METHYLENE CHLORIDE	4.2E+00	8.9E+00	4.2E+03	1.8E+04

**TABLE C. ENVIRONMENTAL ACTION LEVELS (EALs)
Indoor Air and Soil Gas**

CONTAMINANT	INDOOR AIR ACTION LEVELS		² SHALLOW SOIL GAS ACTION LEVELS	
	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)	¹ Residential Land Use (ug/m ³)	Commercial/ Industrial Land Use Only (ug/m ³)
METHYLNAPHTHALENE (total 1- & 2-)	1.5E+02	2.0E+02	1.5E+05	4.1E+05
MOLYBDENUM	-	-	-	-
NAPHTHALENE	3.1E+00	4.4E+00	3.1E+03	8.8E+03
NICKEL	-	-	-	-
PENTACHLOROPHENOL	-	-	-	-
PERCHLORATE	-	-	-	-
PHENANTHRENE	1.5E+02	2.0E+02	1.5E+05	4.1E+05
PHENOL	-	-	-	-
POLYCHLORINATED BIPHENYLS (PCBs)	-	-	-	-
PYRENE	1.1E+02	1.5E+02	1.1E+05	3.1E+05
SELENIUM	-	-	-	-
SILVER	-	-	-	-
STYRENE	1.1E+03	1.5E+03	1.1E+06	3.0E+06
tert-BUTYL ALCOHOL	2.2E+00	4.8E+00	2.2E+03	9.5E+03
TETRACHLOROETHANE, 1,1,1,2-	2.6E-01	5.5E-01	2.6E+02	1.1E+03
TETRACHLOROETHANE, 1,1,2,2-	3.4E-02	7.2E-02	3.4E+01	1.4E+02
TETRACHLOROETHYLENE	3.2E-01	6.8E-01	3.2E+02	1.4E+03
THALLIUM	-	-	-	-
TOLUENE	4.0E+02	5.6E+02	4.0E+05	1.1E+06
TOXAPHENE	-	-	-	-
TPH (gasolines)	5.1E+01	7.2E+01	5.1E+04	1.4E+05
TPH (middle distillates)	5.1E+01	7.2E+01	5.1E+04	1.4E+05
TPH (residual fuels)	-	-	-	-
TRICHLOROBENZENE, 1,2,4-	3.7E+00	5.1E+00	3.7E+03	1.0E+04
TRICHLOROETHANE, 1,1,1-	2.3E+03	3.2E+03	2.3E+06	6.4E+06
TRICHLOROETHANE, 1,1,2-	1.2E-01	2.6E-01	1.2E+02	5.1E+02
TRICHLOROETHYLENE	1.7E-01	3.6E-01	1.7E+02	7.2E+02
TRICHLOROPHENOL, 2,4,5-	3.7E+02	5.1E+02	3.7E+05	1.0E+06
TRICHLOROPHENOL, 2,4,6-	-	-	-	-
VANADIUM	-	-	-	-
VINYL CHLORIDE (nonresidential exposure)	4.2E-01	8.9E-01	4.2E+02	1.8E+03
VINYL CHLORIDE (residential exposure)	9.3E-02	4.6E-01	9.3E+01	9.2E+02
XYLENES	1.1E+02	1.5E+02	1.1E+05	3.0E+05
ZINC	-	-	-	-

**TABLE C. ENVIRONMENTAL ACTION LEVELS (EALs)
Indoor Air and Soil Gas**

CONTAMINANT	INDOOR AIR ACTION LEVELS		² SHALLOW SOIL GAS ACTION LEVELS	
	¹ Residential Land Use (ug/m ³)	Commercial/Industrial Land Use Only (ug/m ³)	¹ Residential Land Use (ug/m ³)	Commercial/Industrial Land Use Only (ug/m ³)
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	not applicable	not applicable	not applicable	not applicable
Sodium Adsorption Ratio	not applicable	not applicable	not applicable	not applicable
<p>Notes:</p> <p>1. Category "Residential Land Use" generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.)</p> <p>2. Soil Gas: Action levels based on soil gas data collected less than 1.5 meters (five feet) below a building foundation or the ground surface. Intended for evaluation of potential indoor-air impacts.</p> <p>Source of Action Levels: Refer to Tables C-2 and C-3 in Appendix 1.</p> <p>Indoor air action level may differ slightly from USEPA Region IX PRGs due to differences in USEPA Vapor Intrusion model (USEPA 2003) and USEPA PRG model (USEPA 2004).</p> <p>TPH -Total Petroleum Hydrocarbons. TPH EALs must be used in conjunction with EALs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 5.</p>				

TABLE D: SUMMARY OF DRINKING WATER GOALS

TABLE D. SUMMARY OF DRINKING WATER GOALS

CONTAMINANT	Action Level (ug/L)	Basis	¹ Toxicity (ug/L)	² Taste & Odors (ug/L)
ACENAPHTHENE	2.0E+01	Taste & Odors	3.7E+02	2.0E+01
ACENAPHTHYLENE	2.4E+02	Toxicity	2.4E+02	2.0E+03
ACETONE	5.5E+03	Toxicity	5.5E+03	2.0E+04
ALDRIN	4.0E-03	Toxicity	4.0E-03	8.5E+00
ANTHRACENE	2.2E+01	Taste & Odors	1.8E+03	2.2E+01
ANTIMONY	6.0E+00	Toxicity	6.0E+00	5.0E+04
ARSENIC	1.0E+01	Toxicity	1.0E+01	5.0E+04
BARIUM	2.0E+03	Toxicity	2.0E+03	5.0E+04
BENZENE	5.0E+00	Toxicity	5.0E+00	1.7E+02
BENZO(a)ANTHRACENE	9.2E-02	Toxicity	9.2E-02	5.0E+00
BENZO(a)PYRENE	2.0E-01	Toxicity	2.0E-01	1.9E+00
BENZO(b)FLUORANTHENE	9.2E-02	Toxicity	9.2E-02	7.0E+00
BENZO(g,h,i)PERYLENE	1.3E-01	Taste & Odors	1.5E+03	1.3E-01
BENZO(k)FLUORANTHENE	4.0E-01	Taste & Odors	9.2E-01	4.0E-01
BERYLLIUM	4.0E+00	Toxicity	4.0E+00	5.0E+04
BIPHENYL, 1,1-	5.0E-01	Taste & Odors	3.0E+02	5.0E-01
BIS(2-CHLOROETHYL)ETHER	9.5E-03	Toxicity	9.5E-03	3.6E+02
BIS(2-CHLOROISOPROPYL)ETHER	2.7E-01	Toxicity	2.7E-01	3.2E+02
BIS(2-ETHYLHEXYL)PHTHALATE	6.0E+00	Toxicity	6.0E+00	6.5E+02
BORON	7.3E+03	Toxicity	7.3E+03	5.0E+04
BROMODICHLOROMETHANE	1.8E-01	Toxicity	1.8E-01	5.0E+04
BROMOFORM	1.0E+02	Toxicity	1.0E+02	5.1E+02
BROMOMETHANE	8.5E+00	Toxicity	8.5E+00	5.0E+04
CADMIUM	5.0E+00	Toxicity	5.0E+00	5.0E+04
CARBON TETRACHLORIDE	5.0E+00	Toxicity	5.0E+00	5.2E+02
CHLORDANE	2.0E+00	Toxicity	2.0E+00	2.5E+00
CHLOROANILINE, p-	1.5E+02	Toxicity	1.5E+02	5.0E+04
CHLOROBENZENE	5.0E+01	Taste & Odors	1.0E+02	5.0E+01
CHLOROETHANE	3.9E+00	Toxicity	3.9E+00	1.6E+01
CHLOROFORM	1.0E+02	Toxicity	1.0E+02	2.4E+03
CHLOROMETHANE	1.6E+02	Toxicity	1.6E+02	5.0E+04
CHLOROPHENOL, 2-	1.8E-01	Taste & Odors	3.0E+01	1.8E-01
CHROMIUM (Total)	1.0E+02	Toxicity	1.0E+02	5.0E+04
CHROMIUM III	5.0E+04	Taste & Odors	5.5E+04	5.0E+04
CHROMIUM VI	1.1E+02	Toxicity	1.1E+02	5.0E+04
CHRYSENE	8.0E-01	Taste & Odors	9.2E+00	8.0E-01
COBALT	7.3E+02	Toxicity	7.3E+02	5.0E+04
COPPER	1.0E+03	Taste & Odors	1.3E+03	1.0E+03
CYANIDE (Free)	1.7E+02	Taste & Odors	2.0E+02	1.7E+02
DIBENZO(a,h)ANTHRACENE	9.2E-03	Toxicity	9.2E-03	2.5E-01
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	Toxicity	4.0E-02	1.0E+01
DIBROMOCHLOROMETHANE	1.3E-01	Toxicity	1.3E-01	5.0E+04
DIBROMOETHANE, 1,2-	5.6E-03	Toxicity	5.6E-03	5.0E+04
DICHLOROBENZENE, 1,2-	1.0E+01	Taste & Odors	6.0E+02	1.0E+01
DICHLOROBENZENE, 1,3-	1.8E+02	Toxicity	1.8E+02	5.0E+04
DICHLOROBENZENE, 1,4-	5.0E+00	Taste & Odors	7.5E+01	5.0E+00
DICHLOROBENZIDINE, 3,3-	1.5E-01	Toxicity	1.5E-01	1.6E+03
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.8E-01	Toxicity	2.8E-01	8.0E+01
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.8E-01	Toxicity	2.8E-01	2.0E+01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.0E-01	Toxicity	2.0E-01	1.5E+00
DICHLOROETHANE, 1,1-	8.0E+02	Toxicity	8.0E+02	5.0E+04
DICHLOROETHANE, 1,2-	1.2E-01	Toxicity	1.2E-01	7.0E+03

TABLE D. SUMMARY OF DRINKING WATER GOALS

CONTAMINANT	Action Level (ug/L)	Basis	¹ Toxicity (ug/L)	² Taste & Odors (ug/L)
DICHLOROETHYLENE, 1,1-	7.0E+00	Toxicity	7.0E+00	1.5E+03
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	Toxicity	7.0E+01	5.0E+04
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	Toxicity	1.0E+02	2.6E+02
DICHLOROPHENOL, 2,4-	3.0E-01	Taste & Odors	1.1E+02	3.0E-01
DICHLOROPROPANE, 1,2-	5.0E+00	Toxicity	5.0E+00	1.0E+01
DICHLOROPROPENE, 1,3-	4.0E-01	Toxicity	4.0E-01	5.0E+04
DIELDRIN	4.2E-03	Toxicity	4.2E-03	4.1E+01
DIETHYLPHthalate	2.9E+04	Toxicity	2.9E+04	5.0E+04
DIMETHYLPHENOL, 2,4-	4.0E+02	Taste & Odors	7.3E+02	4.0E+02
DIMETHYLPHthalate	5.0E+04	Taste & Odors	3.7E+05	5.0E+04
DINITROPHENOL, 2,4-	7.3E+01	Toxicity	7.3E+01	5.0E+04
DINITROToluene, 2,4-	3.4E+01	Toxicity	3.4E+01	5.0E+04
DIOXANE, 1,4-	6.1E+00	Toxicity	6.1E+00	5.0E+04
DIOXIN (2,3,7,8-TCDD)	3.0E-05	Toxicity	3.0E-05	7.0E+03
ENDOSULFAN	7.5E+01	Taste & Odors	2.2E+02	7.5E+01
ENDRIN	2.0E+00	Toxicity	2.0E+00	4.1E+01
ETHYLBENZENE	3.0E+01	Taste & Odors	7.0E+02	3.0E+01
FLUORANTHENE	1.3E+02	Taste & Odors	1.5E+03	1.3E+02
FLUORENE	2.4E+02	Toxicity	2.4E+02	9.5E+02
HEPTACHLOR	4.0E-01	Toxicity	4.0E-01	2.0E+01
HEPTACHLOR EPOXIDE	2.0E-01	Toxicity	2.0E-01	1.8E+02
HEXACHLOROBENZENE	1.0E+00	Toxicity	1.0E+00	5.5E+01
HEXACHLOROBUTADIENE	8.6E-01	Toxicity	8.6E-01	6.0E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.0E-01	Toxicity	2.0E-01	3.5E+03
HEXACHLOROETHANE	4.8E+00	Toxicity	4.8E+00	1.0E+01
INDENO(1,2,3-cd)PYRENE	9.2E-02	Toxicity	9.2E-02	2.7E-01
LEAD	1.5E+01	Toxicity	1.5E+01	5.0E+04
MERCURY	2.0E+00	Toxicity	2.0E+00	5.0E+04
METHOXYCHLOR	2.0E+01	Taste & Odors	4.0E+01	2.0E+01
METHYL ETHYL KETONE	7.0E+03	Toxicity	7.0E+03	8.4E+03
METHYL ISOBUTYL KETONE	1.3E+03	Taste & Odors	2.0E+03	1.3E+03
METHYL MERCURY	3.7E+00	Toxicity	3.7E+00	5.0E+04
METHYL TERT BUTYL ETHER	5.0E+00	Taste & Odors	1.1E+01	5.0E+00
METHYLENE CHLORIDE	4.3E+00	Toxicity	4.3E+00	9.1E+03
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+01	Taste & Odors	2.4E+02	1.0E+01
MOLYBDENUM	1.8E+02	Toxicity	1.8E+02	5.0E+04
NAPHTHALENE	6.2E+00	Toxicity	6.2E+00	2.1E+01
NICKEL	1.0E+02	Toxicity	1.0E+02	5.0E+04
PENTACHLOROPHENOL	1.0E+00	Toxicity	1.0E+00	3.0E+01
PERCHLORATE	3.7E+00	Toxicity	3.7E+00	5.0E+04
PHENANTHRENE	2.4E+02	Toxicity	2.4E+02	4.1E+02
PHENOL	5.0E+00	Taste & Odors	1.1E+04	5.0E+00
POLYCHLORINATED BIPHENYLS (PCBs)	5.0E-01	Toxicity	5.0E-01	1.6E+01
PYRENE	6.8E+01	Taste & Odors	1.8E+02	6.8E+01
SELENIUM	5.0E+01	Toxicity	5.0E+01	5.0E+04
SILVER	1.0E+02	Taste & Odors	1.8E+02	1.0E+02
STYRENE	1.0E+01	Taste & Odors	1.0E+02	1.0E+01
tert-BUTYL ALCOHOL	3.7E+00	Toxicity	3.7E+00	5.0E+04
TETRACHLOROETHANE, 1,1,1,2-	4.3E-01	Toxicity	4.3E-01	5.0E+04
TETRACHLOROETHANE, 1,1,2,2-	5.6E-02	Toxicity	5.6E-02	5.0E+02
TETRACHLOROETHYLENE	5.0E+00	Toxicity	5.0E+00	1.7E+02
THALLIUM	2.0E+00	Toxicity	2.0E+00	5.0E+04

TABLE D. SUMMARY OF DRINKING WATER GOALS

CONTAMINANT	Action Level (ug/L)	Basis	¹Toxicity (ug/L)	²Taste & Odors (ug/L)
TOLUENE	4.0E+01	Taste & Odors	1.0E+03	4.0E+01
TOXAPHENE	3.0E+00	Toxicity	3.0E+00	1.4E+02
TPH (gasolines)	1.0E+02	Toxicity	1.0E+02	1.0E+02
TPH (middle distillates)	1.0E+02	Toxicity	1.0E+02	1.0E+02
TPH (residual fuels)	1.0E+02	Taste & Odors	1.0E+03	1.0E+02
TRICHLOROBENZENE, 1,2,4-	7.0E+01	Toxicity	7.0E+01	3.0E+03
TRICHLOROETHANE, 1,1,1-	2.0E+02	Toxicity	2.0E+02	9.7E+02
TRICHLOROETHANE, 1,1,2-	5.0E+00	Toxicity	5.0E+00	5.0E+04
TRICHLOROETHYLENE	5.0E+00	Toxicity	5.0E+00	3.1E+02
TRICHLOROPHENOL, 2,4,5-	2.0E+02	Taste & Odors	6.1E+02	2.0E+02
TRICHLOROPHENOL, 2,4,6-	3.7E+00	Toxicity	3.7E+00	1.0E+02
VANADIUM	3.7E+01	Toxicity	3.7E+01	5.0E+04
VINYL CHLORIDE	2.0E+00	Toxicity	2.0E+00	3.4E+03
XYLENES	2.0E+01	Taste & Odors	1.0E+04	2.0E+01
ZINC	5.0E+03	Taste & Odors	1.1E+04	5.0E+03
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	-	-	not applicable	not applicable
Sodium Adsorption Ratio	-	-	not applicable	not applicable

Notes:

1. Drinking water goal based on toxicity to humans (e.g., Primary MCL). Refer to Appendix 1, Table D-2.
2. Drinking water goal based on taste and odor concerns (e.g., Secondary MCL). Refer to Appendix 1, Table G-1.

Toxicity-based goals should be met at a minimum in areas where groundwater is within 500m of active water supply well in same aquifer.

Screening For Environmental Concerns At Sites With Contaminated Soil and Groundwater

Volume 2: Background Documentation For The Development of Tier 1 Environmental Screening Levels

Appendix 1

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DISCLAIMER

This document, *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (Interim Final, May 2005), is a technical report prepared by staff of the Hawai'i Department of Health, Environmental Management Division. It is intended to serve as a update to the 1996 HIDOH document entitled *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater*. This document is not intended to establish policy or regulation. The Environmental Action Levels presented in this document and the accompanying text are specifically not intended to serve as: 1) a stand-alone decision making tool, 2) guidance for the preparation of baseline ("Tier 3") environmental assessments, 3) a rule to determine if a waste is hazardous under the state or federal regulations, or 4) a rule to determine when the release of hazardous chemicals must be reported to the overseeing regulatory agency.

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VOLUME 2: BACKGROUND DOCUMENTATION FOR THE DEVELOPMENT OF TIER 1 SOIL AND GROUNDWATER SCREENING LEVELS

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- 2 SUMMARY OF HUMAN HEALTH RISK-BASED EQUATIONS AND DEFAULT INPUT PARAMETER VALUES; USEPA REGION IX PRG DOCUMENT (OCTOBER 2004, TEXT ONLY)
- 3 RELEVANT PORTIONS OF *USER'S GUIDE FOR THE JOHNSON AND ETTINGER (1991) MODEL FOR SUBSURFACE VAPOR INTRUSION INTO BUILDINGS; SENSITIVITY ANALYSIS OF JOHNSON AND ETTINGER (1991) MODEL*
- 4 EXAMPLE PRINTOUTS OF INDOOR AIR IMPACT MODELS
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- 10 COMMENTS AND RESPONSES ON DECEMBER 2003 DRAFT EAL DOCUMENT

GLOSSARY OF TERMS

AWQC: Aquatic Water Quality Criteria
CCC: Criterion for Continuous Concentration
CCM: Criterion for Maximum Concentration
EPA: Environmental Protection Agency
ESL: Environmental Screening Level
FVC: Final Chronic Value
HIDOH: Hawai'i Department of Health
HH: Human Health-consumption of aquatic organisms
LOEL: Lowest-Observed-Effects Level
MADEP: Massachusetts Department of Environmental Protection
MCL: Maximum Concentration Level
MOEE: Ontario Ministry of Environment and Energy
MTBE: Methyl tert-Butyl Ethylene
PCE: Tetrachloroethylene
PRG: Preliminary Remediation Goals
RBSL: Risk-Based Screening Level
RWQCB: Regional Water Quality Control Board
TPH: Total Petroleum Hydrocarbons
USEPA: U.S. Environmental Protection Agency
USDOE: U.S. Department of Energy

APPENDIX 1

DEVELOPMENT OF TIER 1 LOOKUP TABLES

APPENDIX 1

DEVELOPMENT OF TIER 1 LOOKUP TABLES

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1

Development of Tier 1 Lookup Tables

1.1 Introduction

This document is modeled after similar documents published by the Ontario Ministry of Environment and Energy (MOEE 1996), the Massachusetts Department of Environmental Protection (MADEP 1994) and the Netherlands (Vetger 1993). Action levels for the following environmental concerns are presented (Figure 1):

Groundwater:

- Protection of human health
 - Current or potential drinking water resource;
 - Emission of subsurface vapors to building interiors;
- Protection of aquatic habitats (discharges to surface water);
- Protection against nuisance concerns (odors, etc.) and general resource degradation.

Soil:

- Protection of human health
 - Direct/indirect exposure with impacted soil (ingestion, dermal absorption, inhalation of vapors and dust in outdoor air);
 - Emission of subsurface vapors to building interiors;
- Protection of groundwater quality (leaching of chemicals from soil);
- Protection of terrestrial (nonhuman) habitats;
- Protection against nuisance concerns (odors, etc.) and general resource degradation.

Shallow Soil Gas:

- Protection of human health
 - Emission of subsurface vapors to building interiors.

For use in this document, the term "soil" refers to any unconsolidated material found in the subsurface, including actual soil, saprolite, sediment, fill material, etc. Action levels are organized with respect to groundwater utility and threat to surface water bodies:

¹ GROUNDWATER UTILITY	² LOCATION OF NEAREST SURFACE WATER BODY	
	>150m From Release Site	≤ 150m From Release site
Current or Potential Source of Drinking Water	Soil: Table A-1 Groundwater: Table D-1b	Soil: Table A-2 Groundwater: Table D-1a
NOT a Current or Potential Source of Drinking Water	Soil: Table B-1 Groundwater: Table D-1d	Soil: Table B-2 Groundwater: Table D-1c

1. Based on location of site with respect to UIC line and Aquifer Identification and Classification technical reports (see Appendix 8).

2. Location of downgradient edge of release site from nearest surface water body. Use of groundwater action levels for sites <150m from a surface water body may be necessary if plume is suspected to have moved into this area.

The Table A and B series summarize individual action levels compiled for soil overlying groundwater for the environmental concerns noted above. The Table C series in this appendix summarizes soil, groundwater and soil gas action levels compiled specifically for vapor intrusion and indoor-air impact concerns. Action levels for groundwater and surface water are summarized in the Table D series. Tables E through I provide supporting action levels and other information for the earlier tables.

A detailed discussion of action levels compiled for surface water and groundwater is provided in Chapter 2. A discussion of action levels compiled for soil is provided in Chapter 3. Chapter 4 discusses action levels compiled for indoor air and related action levels for shallow soil gas. Action levels developed for Total Petroleum Hydrocarbon (TPH) are discussed in Chapter 5. Other issues pertinent to the lookup tables are discussed in Chapter 6.

1.2 Example Selection of Tier 1 EALs for Benzene

Figure 2 illustrates the selection of final Tier 1 soil and groundwater EALs for the chemical benzene. The example assumes impacts to shallow, potentially exposed soils (e.g., ≤3 meters below ground surface) and a residential land-use scenario. Groundwater immediately underlying the site is assumed to be a potential source of drinking water. A surface water body is assumed to be located within 150m of the release site. This scenario places the site under Table A-2 of the Tier 1 lookup tables for soil and Table D-1a for groundwater (refer to Section 1.1).

The final, Tier 1 EAL for benzene in soil is selected as 0.22 mg/kg. This represents the lowest of the individual action levels for direct exposure (0.64 mg/kg), vapor emissions

to indoor air (0.53 mg/kg), terrestrial biota impacts (25 mg/kg), groundwater protection (leaching, 0.22 mg/kg) and the nuisance-based ceiling level (500 mg/kg).

The process for selection of a Tier 1 EAL for benzene in groundwater is similar (refer to Figure 2). Under the assumed site scenario, the final, Tier 1 GAL is 5.0 ug/L. This represents the lowest of individual action levels for drinking water toxicity (5.0 ug/L), vapor emissions to indoor air (1,600 ug/L), discharge to surface water (46 ug/L) and the nuisance-based ceiling level (170 ug/L, in this case the secondary drinking water MCL). Note that two action levels are presented in the lookup tables for vapor intrusion concerns (Table C-1b), one for high-permeability vadose-zone soils (1,600 ug/L) and one for low-permeability soils (5,600 ug/L). Only the screening level for sites with high-permeability vadose-zone soils is carried through for inclusion in the summary lookup tables, however (refer to Table D-1 series). The action levels for low-permeability soils are provided for reference only, to give an idea of the range of concentrations that may begin to pose vapor intrusion concerns at any given site. It is recommended that the action levels for high-permeability vadose-zone soils be used at all sites in the absence of soil gas data.

Action levels for indoor air (0.25 ug/m³) and shallow soil gas (250 ug/m³) are also presented (refer to Figure 2 and Chapter 4). These screening levels are independent of the source of the contamination.

The process described above was carried out for each of the 100+ chemicals included in the Tier 1 lookup tables under each combination of groundwater utility and location of the site with respect to surface water bodies. The results are summarized in Tables A through D of this appendix. As can be seen from a review of these tables, the selection of final, Tier 1 EALs for highly mobile or highly toxic chemicals is typically driven by groundwater protection or indoor-air impact concerns (e.g., see selection process for benzene or vinyl chloride EALs in Table A-1). Final EALs for chemicals that are relatively immobile in soils but highly toxic are typically driven by direct-exposure concerns (e.g., see selection process for PCBs in Table A-1). In contrast, selection of EALs for heavy metals that are relatively non-toxic to humans is typically driven by ecological concerns or ceiling levels for general resource degradation (e.g., see selection process for copper EAL in Table A-1). For chemicals that have particularly strong odors, selection of EALs may be driven in part by nuisance concerns or "ceiling levels" (e.g., see Total Petroleum Hydrocarbons in Table A-1). The consideration of ceiling levels could form a basis for final cleanup standards in the selection of EALs for relatively immobile chemicals in isolated, deep soils (see Section 3.6).

1.3 Cumulative Risk

Additive risk due to the potential presence of multiple chemicals with similar target health effects is addressed under Tier 1 through use of conservative exposure assumptions (exposure frequency and duration, ingestion and inhalation rates, etc.) and target risk levels. Exposure assumptions used to develop direct-exposure and indoor-air

action levels are primarily based on parameter values presented in USEPA risk assessment guidance for Superfund sites (refer to USEPA 2004). Alternative, and in some cases less conservative, exposure assumptions are presented in the USEPA technical document *Exposure Factors Handbook* (USEPA 1997), among other examples. For example, recommended inhalation rates for residents are 11.3 m³/day for women and 15.2 m³/day for men, in comparison to the value of 20 m³/day used to develop the direct-exposure action levels presented in this appendix (see Appendix 2). The average time (50th percentile) spent at one residence is also stated to be 9.0 years, in contrast to the more conservative exposure duration used of 30 years. The average occupational tenure is similarly stated to be 6.6 years, in contrast to the occupational exposure duration used of 25 years. While the more conservative exposure assumptions are still generally recommended for use in site-specific risk assessments, the variance in the assumptions helps to demonstrate the overall conservative nature of the models referenced in this document.

For most carcinogens, the human health action levels presented are based on a target excess cancer risk of 10⁻⁶. Exceptions to this approach are discussed in Section 3.2. This represents the upper end (most stringent) of the potentially acceptable range of 10⁻⁴ to 10⁻⁶ recommended by the USEPA (USEPA 1989a,b). As stated in the National Contingency Plan, however, "The 10⁻⁶ level shall be used as the point of departure for determining remediation goals..." (USEPA 1994). Remediation or risk management is rarely warranted at sites where the estimated cancer risk does not exceed 10⁻⁶. Remediation or risk management is almost always warranted at sites where the estimated cancer risk exceeds 10⁻⁴. For sites where the estimated risk is between 10⁻⁴ and 10⁻⁶, the need for active remediation or risk management is evaluated on a site-specific basis (i.e., risks within this range are "potentially acceptable", depending on site-specific considerations).

The use of alternative exposure assumptions in a more "detailed" risk assessment could result in an increase of direct-exposure action levels by a factor of three or more while still meeting a target excess cancer risk of 10⁻⁶. Based on above discussion and the conservative nature of the human exposure models in general, the direct-exposure action levels presented in this appendix and the soil EALs in general are considered to be adequate for use at sites where up to three carcinogenic chemicals of concern have been identified. Additional evaluation may be required for sites where more than three carcinogens are identified.

A cumulative, target Hazard Index of 1.0 is typically used in human health risk assessments for evaluation of noncarcinogenic risks. The USEPA Preliminary Remediation Goals (PRGs) for soil were developed based on a chemical-specific, target Hazard Quotient of 1.0. This was retained for use in this document. A target Hazard Quotient of 1.0 for individual chemicals is considered adequate provided that final residual levels of chemicals with similar systemic health effects do not exceed a total Hazard Index of 1.0. This may need to be more closely evaluated at sites where multiple chemicals with similar systemic effects are present (refer to discussion in USEPA PRG

document provided in Appendix 2). For reference, a compilation of chronic health effects for the chemicals listed in the EALs is provided in Table J of this appendix.

The direct-exposure action levels not consider potential synergistic effects (e.g., 1+1=3). Methods to quantitatively assess such effects have not been developed, however. Conservative target risk goals (e.g., target excess cancer risk of 10^{-6}) and exposure parameters are instead used to indirectly address this issue.

2

Groundwater Action Levels

2.1 Introduction

Action levels for groundwater are summarized in the "D" series of tables at the end of this appendix. A discuss of individual concerns considered in the action levels is provided in this Chapter and summarized below. For the purpose of developing Tier 1 action levels, it is assumed that all groundwater could at some point in time potentially discharge to a body of surface water. Discharge could occur through natural processes (e.g., natural discharge of groundwater to a stream, river, lake, wetland, bay, etc. via springs) or through human activities (e.g., pumping and discharge of groundwater at remediation or construction dewatering projects).

A summary of environmental concerns incorporated into groundwater action levels for different site scenarios is provided in Table 2-1. The final groundwater action level for sites that threaten drinking water resources reflects the lowest of a chemicals screening level for drinking water toxicity, aquatic habitat protection (discharges to surface water), indoor-air impacts (volatile chemicals only) and a "ceiling level" for tastes & odors or other nuisance concerns (Tables D-1a and D-1b). The final groundwater EAL for sites that do not threaten drinking water resources (Tables D-1c and D-1d) reflects the lowest of a chemicals screening level for the same set of environmental concerns with the exception of the drinking water component and use of less stringent ceiling level.

As discussed below, groundwater action levels for potential discharges to aquatic habitats consider chronic surface water quality goals for sites within 150m of a surface water body and acute goals for sites >150m from a surface water body. Although not used for groundwater action levels, HDOH standards for the potential bioaccumulation of contaminants in aquatic organisms and subsequent consumption of the organisms by humans must be used to evaluate actual impacts to a body of surface water. A summary of these standards is provided in Table D-3f for reference.

2.2 Action Levels for Drinking Water Toxicity

A summary of drinking water standards and guidelines used in this document is provided in Table D-2. Action levels for drinking water intended to address human toxicity were generally selected based on the following order of preference:

- USPEPA Primary Maximum Contaminant Level (MCL);
- Risk-based goal based on USEPA Region IX tap water model.

USPEPA Primary MCLs are available for approximately half of the chemicals listed in the lookup tables. Although numerous factors are taken into account in development of primary MCLs (toxicity, detection limits, attainability, etc.), these standards are primarily intended to address toxicity to humans in drinking water supplies and are used for this purpose in this document.

For chemicals where Primary MCLs have not been promulgated, a model presented in the USEPA Region IX *Preliminary Remediation Goals* document (USEPA 2004) was used to calculate alternative drinking water goals (Table D-4). For volatile chemicals, the tapwater goals take into account uptake via inhalation of vapors during showering and other activities in addition to toxicity via normal ingestion of drinking water. Goals for nonvolatile chemicals are based on ingestion only. Equations for the USEPA Region IX tapwater goals are included in Appendix 2. Risk-based goals for noncarcinogenic effects take precedence over goals for carcinogenic effects if lower.

Drinking water goals intended to address taste and odor concerns (e.g., Secondary MCLs) take precedence if lower than toxicity-based goals. For example, the USEPA Primary MCL for xylenes is 10,000 ug/L. The USEPA Secondary MCL for xylenes is only 20 ug/L, however. The latter value should be (and is) used as the groundwater action level for drinking water concerns. This is discussed under ceiling levels for groundwater (see Section 2.5).

2.3 Action Levels for Aquatic Habitat Protection

2.3.1 Basis of Action Levels

Groundwater action levels for the protection of aquatic habitats are based on the goal that concentrations of contaminants in groundwater should meet chronic surface water goals at the point that the groundwater discharges into a body of surface water. Dilution of contaminated groundwater as it mixes with surface water is not considered under a Tier 1 assessment. In accordance with this approach, chronic surface water goals are incorporated into groundwater screening levels for sites (or groundwater plumes) located within 150m of a surface water body. For more inland sites, acute surface water goals are

referred to. As a default under Tier 1, the lowest of freshwater versus saltwater goals are used. The prioritization and selection of these goals is described below.

2.3.2 Surface Water Aquatic Habitat Goals

A summary of aquatic habitat goals considered for use in this document is provided in Tables D-3a and D-3b. Separate goals were compiled for freshwater and saltwater habitats. The goals should be compared to dissolved phase chemical concentrations unless otherwise instructed by HDOH. Final goals were selected based on the following order of preference and availability:

- Hawai'i Chronic Surface Water Standard
- USEPA CCC;
- Lowest of USEPA Ecotox AWQC and FVC Threshold Value (or Tier II value if no AWQC or FVC) or 50% USEPA Chronic LOEL;
- USDOE Chronic PRG;
- 50% MOEE Chronic AWQC or LOEL;
- 10% Hawai'i Acute Surface Water Standard
- 10% USEPA CMC (or 10% Acute LOEL if no CMC);
- 10% MOEE Acute AWQC or LOEL;
- Other aquatic water quality criteria (e.g., 10% LC0, 5% LC 50);
- Toxicity-based drinking water goal.

abbreviations:

AWQC: Aquatic Water Quality Criteria

CCC: Criterion for Continuous Concentration

CCM: Criterion for Maximum Concentration

EPA: Environmental Protection Agency

FVC: Final Chronic Value

LC50: Lethal Concentration (50th percentile)

MOEE: Ontario Ministry of Environment and Energy

PRG: Preliminary Remediation Goals

USEPA: U.S. Environmental Protection Agency

USDOE: U.S. Department of Energy (chronic values only)

For chemicals where chronic, No Adverse Effect Level goals or the equivalent were not available, alternative goals were selected and modified as noted (refer also to Table D-3a). Modification factors in general followed recommendations and methods provided in the USEPA Great Lakes water quality initiative guidance (USEPA 1995). Goals

provided in each reference are generally based on dissolved-phase concentrations of the chemicals in water.

Chronic surface water goals were compiled for all of the chemicals listed in the lookup tables (Table D-3a). Acute goals were available for approximately 75% of the chemicals listed (Table D-3b). Chronic goals were substituted as acute goals when the latter were not available. Freshwater goals were similarly substituted for saltwater ("marine") goals if the latter were not available and vice versa. Exceptions to the prioritization scheme include the use of chemical-specific USDOE PRGs in place of USEPA chronic LOELs when the LOEL was developed for a general group of compounds rather than a specific chemical (e.g., halomethanes).

Chronic and acute surface water standards specific to Hawai'i are presented in the Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria (April 2000). The primary source of USEPA aquatic habitat goals was the California EPA document *A Compilation of Water Quality Goals* (RWQCBCV 2000). Other sources referenced to include: USEPA's *Water Quality Criteria Summary Concentrations* (USEPA 1996b), USEPA's *Ecotox Thresholds* (USEPA 1996c), USEPA's *National Recommended Water Quality Criteria* (USEPA 2002), U.S. Department of Energy's *Preliminary Remediation Goals for Ecological Endpoints* (USDOE 1997), and Ontario MOEE's *Rational For The Development and Application of Generic Soil, Groundwater and Sediment Criteria* (MOEE 1996).

Surface water standards for potential bioaccumulation of chemicals in aquatic organisms and subsequent human consumption of these organisms are presented in Table D-3f. Both Hawai'i and Federal standards are given.

2.3.3 Groundwater Action Levels for Aquatic Habitat Impacts

For the purposes of this document, it is assumed that groundwater could discharge into an estuary environment (tidally influenced portions of creeks, rivers, streams, etc.). Tier 1 goals for aquatic habitat protection are therefore based on the lowest of the goals for saltwater versus freshwater environments. For settings where this is not appropriate, target surface water goals and correlative groundwater goals can be adjusted on a site-specific basis under a Tier 2 or Tier 3 assessment.

Dilution of groundwater upon discharge to surface water was not considered in the selection of groundwater action levels for aquatic habitat protection. Benthic organisms were assumed to be exposed to the full concentration of chemicals in impacted groundwater prior to mixing of the groundwater with surface water. Potential dilution of groundwater upon discharge to surface water or in groundwater "mixing zones" adjacent to shorelines areas was therefore not appropriate for development of conservative action levels. Adjustment of the final groundwater action levels with respect to potential

dilution may, however, be appropriate on a site-specific basis (e.g., no significant benthic habitat present, see Volume 1, Section 3.0).

The USEPA Ecotox goal for barium (3.9 ug/L) was not considered as a screening level for groundwater due to low confidence in the goal and comparison to reported natural background concentrations of this metal in groundwater (up to >100 ug/L). Background concentrations of boron, copper, lead, mercury, selenium, thallium and zinc among other metals may also exceed groundwater action levels presented in the lookup tables. This issue should be evaluated on a site-by-site basis where necessary.

Surface water standards for potential bioaccumulation of chemicals in aquatic organisms and subsequent human consumption of these organisms were not considered in the selection of groundwater action levels for potential aquatic habitat impacts. Use of these standards would be excessively conservative at the large number of relatively small sites overseen by HDOH. Consideration of the standards may be appropriate for sites where the discharge of large plumes of impacted groundwater threatens long-term impacts to important aquatic habitats. This should be evaluated on a site-by-site basis.

2.4 Groundwater Action Levels for Vapor Intrusion Concerns

2.4.1 Vapor Intrusion Model Parameters

Groundwater action levels intended to address the intrusion of vapors into buildings and subsequent impact on indoor-air quality are summarized in Table C-1a and included in Tables D-1a through D-1d. Correlative soil gas action levels and indoor air action levels are presented in Tables C-2 and C-3, respectively, and discussed in Chapter 4.

The action levels were generated using a computer spreadsheet model published by the U.S. Environmental Protection Agency (available online, USEPA 2003a). The spreadsheet is based on a model presented in the document *Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors Into Buildings* (Johnson and Ettinger, 1991). The model considers both diffusive and convective flow of subsurface vapors into buildings. Summary text from the guidance document accompanying the spreadsheet is provided in Appendix 3, as is a sensitivity evaluation of the Johnson and Ettinger model. Example printouts of the model as used to calculate action levels for this document are included in Appendix 4. Input parameter values used in the models are noted in the examples (front pages). Default parameters values presented in the spreadsheet technical document were generally selected for use.

Assumptions used in the USEPA Region IX PRGs for residential and commercial/industrial exposure scenarios were retained for use in the vapor intrusion models (see Appendix 2). Action levels for all chemicals except TCE were calculated using a target risk of 1×10^{-6} for chemicals with carcinogenic health effects and a target

Hazard Quotient of 1.0 for chemicals with noncarcinogenic health effects. As discussed in Section 3.2, a target risk of 10^{-5} was used for TCE. For consistency purposes, default physio-chemical constants included in the spreadsheet were replaced with constants used in the USEPA PRGs models if different.

The USEPA Region IX PRG models for residential direct-exposure concerns are based on the consideration of mixed childhood and adult exposure, with more conservative assumptions for parameters related to the former category (refer to Appendix 2). The USEPA vapor intrusion model does not directly address this factor. As a means to make the models more consistent, residential indoor air target levels generated by the vapor intrusion spreadsheet were modified by a factor of 0.79 (see Appendix 2). This reduced the action levels generated by vapor intrusion model a similar degree.

All groundwater was assumed to potentially flow offsite and pass under residential areas. Final action levels are therefore based on a residential land use exposure scenario. Groundwater action levels for commercial/industrial areas are included in Table C-1a for reference but were not carried forward for use in subsequent lookup tables. Soil gas and indoor air screening levels for commercial/industrial exposure scenarios are, however, included in Table C of the summary lookup tables.

Default building characteristics presented in the spreadsheet guidance were used in the models. The thickness of the building floor was assumed to be 15 cm. For both residential land use and commercial/industrial exposure scenarios, the models assume a small (9.6m x 9.6m square), one-story building situated on mono-slab concrete base. This may be overly conservative for commercial/industrial sites with existing, larger buildings but is considered to be protective of future redevelopment of such sites. A default value of 1mm was used for the assumed perimeter crack width. For screening level evaluation of larger buildings, an assumed crack spacing of 10m is recommended.

The model also assumes that potential convective flow from the subsurface into buildings (i.e., flow driven by air pressures that are lower inside the building than in the vadose zone) is not short circuited by open crawl spaces or other building designs that negate differences between indoor and subsurface air pressures. Default indoor-air exchange rates of one-time per hour for residences and two-times per hour for commercial/industrial buildings are based on a comparison of risk assessment guidance published by the City of Oakland (Oakland 2000) and comments received during a 2003 peer review of the December 2001 edition of the San Francisco Bay Water Board action levels document (RWQCBSF 2003).

The Johnson and Ettinger model is highly sensitive to the permeability of vadose-zone soil that soil gas must migrate through before being emitted at the ground surface. Action levels generated for sites characterized by fine-grained, vadose-zone soils (clays and silts) of low permeability can be several orders of magnitude less stringent (i.e., higher) than those calculated for more permeable, coarse-grained soils. For this reason, action levels were developed for both soil types. In Table C-1a, the first screening level presented is

intended for use at sites with vadose-zone soils of highly to moderately permeability. The second screening level is intended for use at sites with lower permeability soils in the vadose zone.

The depth from the ground surface to the top of impacted groundwater was assumed to be 3.0 meters. This is just above the minimum thickness allowed for modeling of vapor transport through low/moderate permeability vadose-zone soil profile due to capillary fringe height constraints. For the purposes of this document, the high-permeability vadose-zone soil profile is modeled as one meter of coarse-grained, dry, sandy soil (S) overlying two meters of somewhat more moist clayey loam (CL, 1/3 sand, 1/3 silt, 1/3 clay). This is considered to be reasonably representative of the majority of sites in the oceanside urban areas that overlie "caprock" sediments or inland areas that overlie somewhat more permeable saprolite soils but have deeper depths to groundwater. The low permeability soil profile is modeled as one meter of loamy sand loam (LS) overlying two meters of silt (SI). "Sand" is defined as material that is equal to or greater than 0.075 mm in diameter (i.e., will not pass through a U.S. Standard 200 mesh sieve). Silt and clay are defined as material that is less than 0.075 mm in diameter (i.e., will pass through a U.S. Standard 200 mesh sieve). These definitions are consistent with default parameter values for soil types presented in the USEPA model (USEPA 2003a).

Input soil parameter values for total porosity, water-filled porosity and fraction organic carbon for the upper portion of the soil profiles were set equal to values used by USEPA Region IX in development of the PRGs (USEPA 2004). Soil moisture was assumed to be somewhat higher for the lower soil units than the upper units, at 0.30 (vs 0.15), consistent with the default recommended in the USEPA Johnson and Ettinger model guidance document. Default values presented in the spreadsheet were used for remaining soil properties. For site-specific assessments, soil moisture data should be collected within 1.5m (five feet) of the ground surface and well above the capillary fringe zone.

Default soil vapor permeability values for the selected soil types were used in the models. For site-specific estimation of this parameter, the use of rigorous, in-situ methods intended for the design of soil vapor extraction systems is recommended. Secondary porosity and permeability in fine-grained soils can be significantly enhanced by plant roots, desiccation cracks, disturbance during redevelopment, faulting, etc. Reliance on a small number of borings or laboratory analysis could significantly underestimate the actual vapor permeability of the site and in turn underestimate the risk of potential impacts to indoor air.

Note that when using the spreadsheet to back calculate a groundwater screening level from an input target risk, the values appearing in the spreadsheet for "Csource" (concentration in soil gas) and "Cbuilding" (concentration in indoor air) are based on a theoretical initial soil concentration of 1E-06 g/g or 1,000 micrograms per kilogram and are not directly related to the modeled screening level. The values presented do not represent actual modeled concentrations and should be ignored.

2.4.2 Background and Use of Johnson and Ettinger Model

2.4.2.1 Background

The Johnson and Ettinger model was originally developed to predict impacts to indoor air due to the subsurface emission of naturally occurring radon gas (Johnson and Ettinger, 1991). Pertinent sections of the guidance document published with the model are presented in Appendix 3. Based on concerns over the conservativeness of the model and a lack of field validation studies, the USEPA initially declined to promote use of the model to develop generic action levels (USEPA 1996a). They instead suggested that the model should be used in conjunction with soil gas data to evaluate potential indoor air impacts. In 1997, however, the USEPA published a user's guide to the Johnson and Ettinger model and included a spreadsheet. The 2000 updates to the model allowed direct input of soil gas data (USEPA 2003a, including 2003 update of spreadsheet).

The USEPA version of the Johnson and Ettinger considers both diffusive and convective flow of soil gas into buildings. Diffusive flow occurs as soil gas migrates from areas of higher concentration to areas of lower concentration. Wind effects and indoor heating can cause a decrease in air pressure inside a building and lead to upward, convective flow of subsurface vapors through cracks and gaps in the building floor. As described in the USEPA guidance document, effective convective flow of subsurface vapors into buildings is expected to be limited to deep soils within the "immediate" area of the building.

2.4.2.2 Adjustment of Action Levels

Residential indoor air action levels generated by the USEPA vapor intrusion model were adjusted to incorporate the adjusted childhood exposure inhalation factor used in the USEPA Region IX PRGs (see Appendix 1). This resulted in a reduction of the indoor air goals by a factor of approximately 20%.

Soil and groundwater action levels for vapor intrusion concerns were also adjusted to take into account expected natural biodegradation of nonchlorinated volatile chemicals. Field studies at sites impacted by volatile chemicals have clearly documented impacts to indoor air due to the intrusion of subsurface vapors, particularly for sites where soil or groundwater has been impacted by chlorinated volatile organic compounds. One example is the report *An Evaluation of Vapor Intrusion Into Buildings Through A Study of Field Data* prepared by staff of the Massachusetts DEP (Fitzpatrick and Fitzgerald 1997). Results of the Massachusetts DEP study suggest that the Johnson and Ettinger model may over-predict the concentration of chlorinated, volatile chemicals in soil gas by an order of magnitude or more with respect to the measured concentration of the chemical in groundwater, although in some cases the model appeared to be slightly under conservative. More significantly, the Massachusetts DEP field study indicated that the Johnson and Ettinger model over-predicted the soil gas concentration of petroleum-based volatile organic compounds (e.g., benzene) in the vadose zone by up to three or more

orders of magnitude. This was interpreted to reflect substantial, natural biodegradation of the vapor-phase of these chemicals in the subsurface. This in turn causes the models to over predict impacts to indoor air by several orders of magnitude and makes use of the model for this group of chemicals questionable, particularly in the absence of field-based soil gas data.

To account for the potentially over conservative nature of the Johnson and Ettinger model for nonchlorinated volatile chemicals, action levels generated by the model were adjusted upwards by a factor of ten (refer to Table C-1a). As discussed below, the use of soil gas data in combination with groundwater studies may be most appropriate for evaluating sites where a more detailed evaluation of this issue is warranted. Evaluation of this issue is ongoing.

2.5 Groundwater Gross Contamination Ceiling Levels

Ceiling levels selected for gross contamination concerns in groundwater are summarized in the Table G series. Ceiling levels for groundwater that is considered to be a current or potential source of drinking water are based on the lowest of the chemicals taste and odor threshold (e.g., Secondary MCLs), one-half the solubility and a maximum of 50,000 ug/L for any chemical based on general resource degradation concerns (Tables G-1, after MADEP 1994). Taste and odor thresholds for drinking water were selected in the following order of preference and availability:

- USEPA Secondary MCLs;
- Taste and odor levels developed by Amoores and Hautala 1991 (as presented in RWQCBCV 2000);
- Odor thresholds presented in Massachusetts DEP (MADEP 1994) and Ontario MOEE (MOEE 1996) guidance documents.

With the exception of the MADEP and MOEE odor thresholds, data for each of the listed sources are summarized in the California EPA document *A Compilation of Water Quality Goals* (RWQCBCV 2000 and updates).

Ceiling levels for groundwater that is NOT considered to be a current or potential source of drinking water were selected in a similar manner with the exception that the drinking water taste and odor thresholds were replaced with general nuisance thresholds (Tables G-2). Nuisance thresholds are intended to reflect the concentration at which a chemical in water poses unacceptable odor problems. Thresholds presented in the Massachusetts DEP and Ontario MOEE guidance documents were used as the primary sources of data. Taste and odor levels developed by Amoores and Hautala (in RWQCBCV 2000) were referred to for chemicals that lack odor thresholds in the Ontario guidance, although taste considerations for drinking water could cause these criteria to be overly stringent. It is apparent, however, that similar sources were used to develop both the Ontario MOEE and

the Amoores and Hautala databases (compare Tables G-1). In keeping with the Ontario and Massachusetts guidance documents, a ten-fold dilution/attenuation of chemical concentrations in groundwater upon discharge to surface water was assumed (non-drinking water resources, nuisance thresholds only). The nuisance threshold for MTBE presented in Table G-2 is based on average, upper range at which most subjects in a USEPA study could smell MTBE in water (180 ug/L), as summarized in the public health goals document for MTBE prepared by Cal EPA (CalEPA 1999a). This was selected as a nuisance screening level for MTBE in surface water. Assuming a dilution factor of ten yields the odor threshold of 1,800 ug/L for groundwater.

2.6 Other Groundwater Action Levels

Additional action levels for groundwater provided in the California EPA technical document *A Compilation of Water Quality Goals* include USEPA and National Academy of Sciences "Suggested No-Adverse-Response (SNARL)" goals for toxicity other than cancer risk (RWQCBCV 2000). The SNARL goals largely duplicate risk-based action levels for drinking water presented in Table D-2.

TABLE 2-1. Environmental Concerns Considered in Groundwater Action Levels.

Category	Drinking Water Toxicity	Drinking Water Taste and Odors	Vapor Emissions To Indoor Air	Discharges To Surface Water (Chronic Goals)	Discharges To Surface Water (Acute Goals)	Surface Water Impact Ceiling Levels
Table A-1 Source of Drinking Water; NOT Within 150m of Surface Water Body	X	X	X	X	X	X
Table A-2 Source of Drinking Water; Within 150m of Surface Water Body	X	X	X		X	X
Table B-1 NOT A Source of Drinking Water; NOT Within 150m of Surface Water Body			X	X	X	X
Table B-2 NOT A Source of Drinking Water; Within 150m of Surface Water Body			X		X	X

3

Soil Action Levels

3.1 Introduction

Soil action levels presented in Volume 1 were developed by compiling action levels for the environmental concerns listed below and selecting the lowest action level as the Tier 1 SAL (Figure 3-1):

- Protection of human health
 - Direct exposure
 - Emission of subsurface vapors to building interiors
- Protection of groundwater quality (leaching);
- Protection of terrestrial flora and fauna;
- Protection against nuisance concerns (odors, etc.) and general resource degradation (Ceiling Levels).

Chemical-specific action levels for each applicable environmental concern are summarized in Tables A-1 through B-2 of this appendix. Tier 1 action levels for human health concerns are based on an assumed residential exposure scenario. Alternative action levels for commercial/industrial and construction worker exposure scenarios are also provided in this appendix, as well as alternative ceiling levels for deep and/or isolated soils. Soil action levels for leaching concerns were developed to correlate with each of the four groundwater scenarios used to prepare the lookup tables.

3.2 Soil Action Levels for Direct-Exposure Concerns

3.2.1 USPEA Region IX PRGs

Soil section levels for human-health, direct-exposure concerns are summarized in Tables I-1 (residential land use exposure scenario), I-2 (commercial/industrial exposure scenario) and I-3 (construction/trench worker exposure scenario). Equations and exposure assumptions used in each scenario are summarized in Appendix 2. For the purposes of this document, residential action levels for direct-exposure concerns were carried forward for use in the Tier 1 lookup tables. Direct-exposure screening levels for

commercial/industrial and construction/trench worker exposure scenarios may be useful in site-specific environmental risk assessments.

The direct-exposure action levels are based on residential and commercial/industrial *Preliminary Remediation Goals* ("PRGs") developed by the USEPA Region IX (USEPA 2004). Equations and assumptions used in the PRGs are provided in Appendix 2. Assumptions used to develop direct-exposure action levels for a construction/trench worker exposure scenario are based on information compiled by the San Francisco Bay Regional Water Quality Control Board of the California EPA (RWQCBSF 2003, refer to Appendix 2).

The USEPA Region IX approach for calculation of risk-based PRGs for vinyl chloride was retained for calculation of EALs. Alternative and somewhat more conservative cancer slope factors were used for residential exposure scenarios versus commercial/industrial exposure scenarios (refer to Table H). An exposure duration time of 70 years, versus 30 years, was also used (see Appendix 2). For additional information refer to the October 2004 edition of the USEPA Region IX PRGs (USEPA 2004).

3.2.2 Target Risks

The PRGs are intended to be protective of residents and workers who may be exposed to chemicals in shallow soils on regular basis via incidental ingestion, dermal absorption, and inhalation of vapors and particulate matter. The goals are calculated based on a target risk of 1×10^{-6} (one-in-a-million) for chemicals with carcinogenic health effects and a target Hazard Quotient of 1.0 for chemicals with noncarcinogenic health effects. With the exceptions noted below, this approach was retained for residential and commercial/industrial action levels provided in this document. Due to the short, assumed exposure duration for construction/trench workers, direct-exposure action levels are based on a target excess cancer risk of 10^{-5} (see Appendix 2).

For most carcinogens, the residential and commercial/industrial action levels for direct exposure concerns are based on a target excess cancer risk of 10^{-6} . Exceptions include the direct-exposure soil action levels for PAHs, PCBs and TCE. Low levels of PAHs in soil are ubiquitous in urban environments due to auto exhaust and the use of asphalt. In general, ambient concentrations of PAHs in soil fall within a target risk range of 10^{-5} and 10^{-6} or less. In order to help identify sites with potentially significant levels of PAHs and avoid the need for a more detailed, site-specific evaluation at all sites, a target excess cancer risk of 10^{-5} was used to develop direct-exposure action levels for soil. A target hazard quotient of 1.0 for noncarcinogenic effects was retained. (Note that concentrations of PAHs in coal tar and older formulations of asphalt and can be orders of magnitude higher than direct-exposure action levels set at a target risk of 10^{-5} . Since asphalt is likewise ubiquitous in urban environments, cleanup of soil contaminated with small particles of asphalt that was used in its intended manner is generally not warranted. This exception would not apply to sites where asphalt, coal tar or similar materials was manufactured or disposed of as waste.)

A similar approach was taken for PCBs. Use of PCBs in transformers, capacitors and other electrical equipment was widespread in the 1960s and 1970s. Although less widespread than PAHs, ambient levels in soil often fall within a target risk range of 10^{-5} and 10^{-6} . In order to again help focus attention on sites where significant releases of PCBs occurred, a target excess cancer risk of 10^{-5} was used to develop direct-exposure action levels for soil. A target hazard quotient of 1.0 for noncarcinogenic effects was retained. Note that noncarcinogenic effects drives human health concerns for PCBs in soils under a residential exposure scenario (refer to Table I-1).

In the current edition of their Preliminary Remediation Goals (PRGs) document, USEPA Region IX incorporates more stringent cancer slope factors for development of PRGs for trichlorethylene (TCE) than those used in the past (USEPA 2004, refer to Table H). Due to ongoing uncertainties and debate over use of the slope factors, a target excess cancer risk of 10^{-5} was used to develop the soil, groundwater and indoor-air action levels for TCE presented in this document. Resulting action levels are an order of magnitude higher than those presented in the PRG document but approximately five-times lower than action levels used in the 1996 HDOH document. This issue will be further evaluated in future updates of this document.

In general, direct-exposure soil action levels generated for the residential land use exposure scenario are more stringent (lower) than action levels developed for the commercial/industrial and construction/trench worker exposure scenarios. This is due to the increasingly shorter assumed exposure duration (years) and frequency (days per year) for the latter two scenarios and the assumption that children will not be regularly present under these scenarios (see Appendix 2). Exceptions include the direct-exposure action level developed for cobalt, which is more stringent under the construction/trench worker exposure scenario than under the residential exposure scenario (see Table I-1). The same is true for direct-exposure action levels for barium, beryllium, cadmium, chromium VI and cobalt under the commercial/industrial worker exposure scenario (see Table I-2). This is due to the combined high oral and/or inhalation toxicity of these chemicals and the assumed higher soil ingestion rate and higher level of air-born dust under the construction/trench worker exposure scenario. As noted in Tables I-1 and I-2, commercial/industrial and residential land use direct-exposure action levels for these chemicals were replaced with construction/trench worker action levels for use in the lookup tables if less stringent.

3.3 Soil Action Levels for Vapor Intrusion Concerns

Soil action levels for the evaluation of potential vapor intrusion and indoor-air impact concerns are presented in Table C-1b and referenced in the Table A-B series. Action levels for both residential and commercial/industrial exposure scenarios are provided, although only action levels for residential exposure are carried forward for inclusion in the Tier 1 summary lookup tables. As discussed in Chapter 4, the use of soil gas data and action levels to evaluate this concern is preferred at sites where significant releases of volatile chemicals have occurred.

A spreadsheet included with guidance published by the U.S. Environmental Protection Agency (USEPA 2003a) was used to generate soil action levels for potential indoor-air impact concerns. A summary of these action levels is provided in Table C-1b. Correlative soil gas action levels are provided in Table C-2. Target indoor air goals are provided in Table C-3. The spreadsheet is based on a model presented in the document *Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors Into Buildings* (Johnson and Ettinger, 1991). The model considers both diffusive and convective flow of subsurface vapors into buildings. Summary text from the guidance document accompanying the spreadsheet is provided in Appendix 3, as is a sensitivity evaluation of the Johnson and Ettinger model. Example printouts of the model as used to calculate action levels for this document are included in Appendix 4. A more detailed discussion of models is provided in Section 2.4 for correlative groundwater action levels.

Input parameter values used in the soil models are noted in the example spreadsheets in Appendix 4 (see front pages). Parameter values assumed for, building characteristics and human exposure were consistent with values used in the soil indoor-air models. The aerial extent of impacted soil is assumed to be equal to the footprint of the building. The thickness of impacted soil was assumed to be 200 cm (approximately 6 feet). The soil type was assumed to be a highly permeable sand (intrinsic permeability = $1.0E-07$ cm²). This generated a soil vapor flow rate into the building of 67 cm³/second or 4 liters/minute. The base of the floor was assumed to immediately over impacted soil (depth to top of soil equals thickness of floor). The model is not significantly sensitive to the input "Depth To Top of Contamination" for impacted soil situated within a few meters of the ground surface.

For nonchlorinated VOCs, field experience suggests that the Johnson and Ettinger model typically overestimates in vapor-phase concentrations of these chemicals by an order of magnitude or more, due in part to high rates of natural biodegradation. Evaluation of this issue is ongoing. To address this in the lookup tables, soil action levels generated with the model were adjusted upwards by a factor of ten (see Table C-1b). Collection of soil gas data and concurrent use of soil gas action levels for indoor-air impact concerns is strongly recommended for sites where this pathway may be of significant concern.

The spreadsheet calculates the theoretical emission rate of a chemical at the ground surface based on the properties of the chemical and the soil type. For highly volatile chemicals (e.g., vinyl chloride), however, an unrealistic mass of the chemical per unit area would have to be present at depth to maintain the theoretical emission rates over the assumed exposure duration. To compensate, the model spreadsheet calculates a second, a mass-balanced emission rate by dividing the total mass of the chemical in the soil per unit area by the input exposure duration. This conservatively assumes that the entire mass of the chemical directly beneath the building will ultimately be emitted into the building over the assumed exposure duration. For chemicals where the mass-balanced vapor emission rate is lower than the theoretical emission rate, the mass-balanced emission rate is used to generate a screening level (or calculate risk).

For chemicals that are liquids under ambient conditions, upper limits on action levels are set at the given chemicals theoretical soil saturation limit. This conforms to assumptions used in the USEPA Region IX PRGs (USEPA 2004).

3.4 Soil Action Levels for Groundwater Protection

Soil action levels for groundwater protection concerns are summarized in Table E-1 (rainfall ≤ 200 cm/year) and E-2 (rainfall > 200 cm/year). These action levels are intended to address potential leaching of chemicals from vadose-zone soils and subsequent impact on groundwater. The soil action levels are back calculated based on target groundwater action levels. Target groundwater action levels are summarized in the Table D series and discussed in Chapter 2.

3.4.1 Rainfall ≤ 200 cm/year

The majority of the action levels for scenarios where rainfall is ≤ 200 cm/year were calculated based on an empirical equation presented in guidance published by the Massachusetts DEP (MADEP 1994):

$$C_{\text{soil}} = \text{DAF} \times C_{\text{gw}} \times 0.001 \text{ mg/ug}$$

$$\text{DAF} = (6207 \times H) + (0.166 \times K_{\text{oc}})$$

where: DAF = SESOIL-based dilution/attenuation factor;
H = Henry's Law Constant (atm-m³/mol);
K_{oc} = organic carbon partition coefficient (ug/cm³);
C_{soil} = leaching based soil concentration (mg/kg);
C_{gw} = target groundwater screening level (ug/L).

The algorithm was developed using a combination of the computer applications SESOIL and AT123D to model leaching of chemicals from the vadose zone and subsequent migration of the leachate to groundwater, respectively. The SESOIL computer application models the generation and downward migration of leachate in the vadose zone. The AT123D application models the mixing of leachate with groundwater immediately below the impacted area. The simplified algorithm was originally developed by the state of Oregon (Anderson 1992), slightly modified for use by the Massachusetts DEP (MADEP 1994) and then incorporated into the Ontario MOEE lookup table guidance (MOEE 1996). A more detailed discussion of the derivation of the algorithm is provided in Appendix 5.

Action levels developed with the algorithm are reasonably similar to leaching based action levels presented in the 1996 HIDOH RBCA document that were developed using the full SESOIL application (refer to Appendix F of that document). The algorithm is based on a three-meter thick vadose zone characterized by one meter of impacted soil

sandwiched between two one-meter thick layers of clean soil. The lower layer immediately overlies groundwater. All vadose-zone soil is conservatively assumed to be very permeable sand that freely allows the migration of leachate to groundwater. The organic carbon content of the soil is assumed to be 0.1%. (Note that this is more conservative than the 0.6% organic carbon content assumed in the direct-exposure models.) Mixing with groundwater is modeled over a ten-meter by ten-meter area. Use of a thicker assumed sequence of impacted soil would not significantly alter the results of the model given the assumed one-meter depth to groundwater.

Annual rainfall is assumed to be 110 cm (approximately 43 inches). While this is just over half of the 200 cm rainfall assumed in the 1996 HDOH SESOIL models the assumed surface water infiltration rate of 720 mm (28 inches) is essentially identical to the earlier models. Biodegradation during migration of leachate to groundwater was considered in the earlier models but is not considered in the algorithm. The assumed shallow depth to groundwater in both models negates the significance of this parameter, however. This could cause the model to be overly conservative for non-chlorinated, petroleum compounds and sites where the depth to groundwater is greater than ten meters below the base of impacted soil. The models do, however, allow for resorption and revolatilization of chemicals from the leachate during migration based on the physio-chemical properties of the chemical and the assumed soil properties.

The SESOIL/AT123D algorithm is based on an assumed groundwater flow rate of approximately 73 meters (240 feet) per year. The depth of leachate mixing is assumed to be two meters. This, in combination with the assumed leachate infiltration rate generates a default leachate-to-groundwater dilution factor of approximately 3. Although mixing and dilution of leachate with groundwater was not considered in the 1996 models, a dilution factor of 3 is considered by USEPA to be very conservative.

For moderately volatile and sorptive chemicals (e.g., benzene), action levels developed using the SESOIL-derived algorithm are similar to action levels generated using the full SESOIL application under a scenario where impacted soil is within a few meters of groundwater. Comparison to action levels developed by full but still conservative use of SESOIL suggests, however, that the simplified algorithm may be excessively conservative in the following cases:

- Leaching of highly volatile chemicals (e.g., vinyl chloride);
- Leaching of highly sorptive chemicals (e.g., polynuclear aromatic hydrocarbons);
- Leaching of highly biodegradable chemicals (e.g., common petroleum compounds);
- Sites where the depth to groundwater is greater than ten meters below the base of the impacted soil.

The depth-to-groundwater factor is particularly important for chemicals that exhibit one or more of the above noted characteristics. As the distance between the base of impacted

soil and the top of groundwater increases, there is additional time and area for chemicals to volatilize out of the leachate, resorb to soil particles or degrade by naturally occurring biological processes. Site-specific evaluation of the potential for leaching of chemicals from soil may be warranted in such cases (including more rigorous modeling, laboratory leaching tests, groundwater monitoring, etc.).

SESOIL modeling presented in the 1996 HODOH RBCA document suggests that chemicals with sorption coefficients greater than 30,000 cm³/g will be essentially immobile in the surface under normal soil conditions and not likely to impact groundwater. Based on modeling studies as well as field experience in general, action levels for chemicals with sorption coefficients greater than 30,000 cm³/g were therefore set at the theoretical soil saturation level for that chemical if higher than the screening level generated by use of the SESOIL algorithm (refer to Table E-1). The equation and assumptions used to calculate the saturation levels is presented and discussed in Appendix 2. Exceptions to this approach were the chemicals pentachlorophenol and bis(2-ethylhexyl)phthalate, both of which have a solubility significantly higher than the remainder of the highly sorptive chemicals (see Table H). Leaching based action levels for these chemicals were developed using only the SESOIL algorithm described above (see Table E-1).

The majority of PCBs releases identified in the Hawai'i are related to 1242 to 1260 range Arochlors. The default *koc* of 33,000 cm³/g presented in Table H was considered to be adequately conservative for this range and used in the leaching model. For less chlorinated PCB mixtures, a site-specific evaluation of potential leaching concerns and even possible vapor emission concerns is required.

Leaching based action levels were generated only for chemicals considered to be significantly soluble and mobile in groundwater under normal, ambient conditions (e.g., pH 5.0 to 9.0 and normal redox conditions). Leaching based soil action levels were not developed for metals. Leaching of metals from soil is highly dependent on the species of the metal present and the geochemical nature of the soil. At sites where physio-chemical conditions may promote enhanced leaching of metals and other chemicals from soils or waste piles (e.g., mining related wastes), the use of laboratory-based leaching tests is recommended (refer to Section 3.3.3 in Volume 1).

Leaching based soil action levels were developed for perchlorate (ClO₄). Perchlorate, a salt, is not significantly sorptive, volatile or biodegradable under normal conditions. Use of the SESOIL/AT123D algorithm was therefore not considered appropriate. As an alternative, a simple, chemical partitioning model presented in the USEPA Soil Screening Level Guidance document was referred to (USEPA 1996a):

$$C_{soil} = C_{water} \times \left((Koc \times foc) + \left(\frac{\theta_w + (\theta_a \times H')}{\rho_b} \right) \right) \times DAF$$

where: C_{soil} = Soil screening level for leaching concerns;
 C_{water} = Target dissolved-phase concentration of chemical;
 K_{oc} = Sorption coefficient;
 f_{oc} = fraction organic carbon in soil;
 θ_w = water-filled porosity;
 θ_a = air-filled porosity;
 H' = Dimensionless Henry's Number constant;
 ρ_b = Soil bulk density;
 DAF = Dilution/Attenuation Factor

This model can be used to backcalculate the total soil concentration of a chemical based on a target dissolved-phase concentration of the chemical in the soil (i.e., concentration in leachate). For perchlorate, k_{oc} and H' are presumed to be zero and the equation reduces to:

$$C_{soil} = C_{water} \times \left(\frac{\theta_w}{\rho_b} \right) \times DAF$$

The default water-filled porosity in the models is 0.15 and the default soil bulk density is 1.5. Based on groundwater action levels for perchlorate of 3.6 ug/L for drinking water resources and 600 ug/L for non-drinking water resources (refer to Tables D-1a and D-1b), leaching based soil action levels of 0.00036 mg/kg and 0.06 mg/kg are generated, respectively. A dilution/attenuation factor of 20 was incorporated to account for mixing of leachate with groundwater (USEPA 1996a). This yielded final soil action levels for leaching concerns for perchlorate of 0.007 mg/kg and 1.2 mg/kg (refer to Table E-1). Laboratory-based tests are recommended for more site-specific analysis of potential leaching of perchlorate from soil.

3.4.2 Rainfall >200 cm/year

The 1996 HDOH RBCA document provides additional, more stringent action levels for leaching of contaminants from soil in high rainfall areas (>200cm/year). These action levels were adjusted to reflect target groundwater goals noted in Tables D-1a through D-1d for use in this document (Table E-2, adjusted soil action level = current GAL x (1996 GAL/1996 SAL)). A description of the calculation of these action levels is provided in the appendices of the 1996 document. Action levels are only presented for contaminants that were originally listed in the 1996 RBCA document. Leaching based action levels for other chemicals should be derived on a site-specific basis as needed.

3.4.3 Varying Depth To Groundwater

The 1996 HDOH RBCA document also provides alternative leaching based action levels for varying depths to groundwater from the base of contaminated soil (Appendix F, Tables 1a through 1d). These action levels can be substituted for the more conservative soil action levels used in the Tier 1 lookup tables on a site-specific basis. Soil leaching action levels must be converted to correlate with groundwater action levels used in this document. The ratio of the groundwater action level and soil action level are constant for any given chemical. To adjust the 1996 soil action levels, simply divide the current groundwater action level by the ratio of the 1996 groundwater action level and the 1996 soil leaching level (e.g., adjusted soil action level = current GAL x (1996 GAL/1996 SAL)).

3.5 Soil Action Levels for Terrestrial Habitats

Soil action levels for evaluation of potential terrestrial ecotoxicity concerns are summarized in Table K. The action levels were included in selection of final SALs (refer to Tables A-1, A-2, B-1 and B-2 of this appendix). This is intended to help identify sites where residual levels of contaminants in soil could pose significant toxicity concerns for flora and fauna even after cleanup of the site to meet residential land use goals. This is primarily a concern for metals and some pesticides that are not particularly toxic to humans but can be very toxic to terrestrial flora and fauna (e.g., barium, Cr III, copper, nickel, endrin, etc.).

The soil ecotoxicity action levels were taken directly from guidance developed by the Ontario Ministry of Environment and Energy (MOEE 1996). The MOEE guidance is primarily a compilation of criteria published by environmental agencies in Canada and elsewhere and is an update to previous guidance (e.g., MOEE 1991; CCME 1994). Ecological effects-based soil values developed by the Dutch government (Vegter 1993; van den Berg 1993) were in particular reviewed for inclusion in the MOEE guidance. Earlier versions of the Canadian and Dutch guidance are presented in the U. S. Fish and Wildlife Service document *Evaluation of Soil Contamination* (USFWS 1990). Pertinent sections from the MOEE guidance are presented in Appendix 6. Action levels were available for heavy metals and some high-molecular-weight organic compounds and pesticides.

Soil action levels for terrestrial ecological concerns can be highly specific to the species of fauna or flora potentially impacted as well as the specific form of the metal present and the geochemistry of the soil. The Ontario MOEE intended use of the action levels over a broad range of land-use scenarios, including residential land use, agricultural and parkland. For the purposes of consideration in the Tier 1 lookup tables, however, the action levels are considered to be adequate only for general screening purposes in and around developed, urban areas where receptor exposure can reasonably be anticipated.

The ecotoxicity action levels can be eliminated from consideration in highly developed areas where no significant open spaces are anticipated in a Tier 2 assessment.

The action levels are not intended for use in areas where a significant risk to endangered or threatened species may exist or where there is a potentially significant threat to terrestrial ecological receptors that extends beyond the general boundary of a subject site. This could include sites that are adjacent to wetlands, streams, rivers, lakes, ponds or marine shoreline or sites that otherwise contain or border areas where protected or endangered species may be present. Potential impacts to sediment are also not addressed. The need for a detailed risk assessment should be evaluated on a site-by-site basis for areas where significant ecological concerns may exist.

3.6 Soil Gross Contamination Ceiling Levels

Ceiling levels presented in each of the EAL summary tables for gross contamination of soil are intended to screen for potential odor and general nuisance concerns, restrict the presence of potentially mobile, free product in soil and limit the overall degradation of soil quality. The selection of soil ceiling levels was based on methods originally published by the Massachusetts DEP (MADEP 1994) and also used by the Ontario MOEE (MOEE 1996), as described in the Table F series of this appendix.

Odor Thresholds presented in the Table F series are intended to represent the concentration of a chemical in air at which 50% of the population can detect a chemical odor. An "Odor Index" for a chemical is calculated by dividing the chemicals vapor pressure (in Torr, at 20-30 degrees Celsius) by its odor threshold (in ppm-volume). This provides a relative ranking of chemicals for potential nuisance concerns.

Ceiling levels were then selected based a comparison of a chemicals vapor pressure and odor index to a table of generic action levels (Tables F-1). For chemicals that are liquids under ambient conditions, the final ceiling level was selected as the lowest of the generic level from Table F-1 and the chemicals theoretical saturation level in soil (see Appendix 2). This was intended to prevent the presence of mobile, free product in the subsurface. Ceiling levels "shallow" soils (e.g., <3m (10 ft) below ground surface at residential sites) presented in Table F-2 were carried forward for use in the Tier 1 lookup tables. Ceiling levels for "deep" soils are provided in Table F-3 and can be used on a site-specific basis as appropriate (e.g., soil >3m below ground surface at residential sites or isolated under clean fill, pavement or a building in commercial/industrial sites).

TABLE 3-1. Environmental Concerns Considered in Soil Action Levels.

Category	¹Direct-Exposure	¹Vapor Emissions To Indoor Air	²Leaching	³Ecological Concerns	⁴Ceiling Values
Table A-1 Source of Drinking Water; Within 150m of Surface Water Body	X	X	X	X	X
Table A-2 Source of Drinking Water; NOT Within 150m of Surface Water Body	X	X	X	X	X
Table B-1 NOT A Source of Drinking Water; Within 150m of Surface Water Body	X	X	X	X	X
Table B-2 NOT A Source of Drinking Water; NOT Within 150m of Surface Water Body	X	X	X	X	X

1. Residential Exposure
2. Based on target groundwater goal. See Table 2-1 in text.
3. For urban areas only.
4. Nuisances, general resource degradation.

4

Indoor Air and Soil Gas Action Levels

4.1 Introduction

The USEPA spreadsheet version of the Johnson & Ettinger model for soil gas intrusion into buildings (USEPA 2003a) was used to develop indoor air and soil gas action levels for volatile chemicals. Example printouts of the model are included in Appendix 4. The model can be condensed into three simple steps: 1) calculation of a target indoor-air goal based on input exposure assumptions and chemical toxicity factors; 2) calculation of soil gas-to-indoor air attenuation factors based on a comparison of vapor flow rates into a building and air flow rates through the building and 3) calculation of a soil gas screening level. A summary of these steps is provided below. A more detailed discussion of the model is provided in Appendix 3.

4.2 Indoor Air Action Levels

Indoor air action levels were calculated using the following equation incorporated in the model:

Carcinogens:

$$C_{ia} = \left(\frac{TR \times ATc \times 365 \text{ days/yr}}{URF \times EF \times ED} \right)$$

Noncarcinogens:

$$C_{ia} = \left(\frac{THQ \times ATnc \times 365 \text{ days/yr}}{\left(\frac{1}{RfC} \right) \times EF \times ED} \right)$$

where:

Cia = Target indoor air concentration;

TR = Target risk (carcinogens);

THQ = Target hazard quotient (noncarcinogens);

ATc = Averaging time for carcinogens;

ATnc = Averaging time for noncarcinogens;

URF = Unit risk factor for carcinogens (carcinogens);

RfC = Reference concentration (noncarcinogens);

EF = Exposure frequency;

ED = Exposure duration.

In contrast to the USEPA Region IX PRGs, default exposure parameters incorporated into the USEPA vapor intrusion spreadsheets do not take into account childhood exposure for residential scenarios. For consistency purposes, target indoor air goals for VOCs that are carcinogens were adjusted downward by a factor of approximately 20% to take into account childhood exposure. Indoor air, soil gas, soil and groundwater action levels for vapor intrusion concerns presented in this document reflect this adjustment. This is discussed in more detail in Appendix 2, Section 3.0.

A summary of the indoor-air goals calculated is provided in Table C-3. Goals for both residential and commercial/industrial exposure scenarios are provided. With the exception of TCE (target risk 10^{-5} , see Section 3.2), the target excess cancer risk was set at 10^{-6} . For noncarcinogenic effects, the target hazard quotient was set at 1.0 (refer also to Section 1.3). Inhalation toxicity factors for volatile chemicals are summarized in Table C-3 (see also Appendix 4, VLOOKUP worksheets). Input exposure assumptions were identical to those assumed for direct-exposure models (see summary in Appendix 2 and DATAENTER worksheets in Appendix 4).

4.3 Soil Gas Action Levels

Building design parameter values used in the groundwater and soil vapor-emission models were retained for use in the soil gas model (one story, 100m² foundation area; refer to Section 2.4 and DATAENTER worksheets in Appendix 4). The spreadsheet models the intrusion of soil gas situated immediately beneath the slab-on-grade foundation into the overlying building ("Soil Gas Sampling Depth Below Grade" = 15 cm). Soil underlying the building was assumed to be a very permeable fill material. Default parameter values for a "sand" soil type were used in the model.

Based on the input building characteristics and soil type, a vapor emission rate of 67 cm³/sec was generated (Q_{soil}, equivalent to 4.0 liters/minute). Indoor-air exchange rates

of 1.0 times-per-hour and 2.0 times-per-hour were assumed for residences and commercial/industrial buildings, respectively. Given the assumed dimensions of 10m x 10m x 2.44 m for the modeled buildings, indoor-air exchange rates of approximately 4,000 L/minute for residences and 8,000 L/minute for commercial/industrial buildings were generated.

Calculation of a soil gas-to-indoor air attenuation factor (AF) essentially reduces to:

$$AF = \left(\frac{\text{vapor intrusion rate}}{\text{vapor intrusion rate} + \text{indoor air exchange rate}} \right)$$

For residences, a soil gas-to-indoor air attenuation factor of approximately 0.001 (1/1000) was calculated. For commercial/industrial buildings, a soil gas-to-indoor air attenuation factor of approximately 0.0005 (1/2000) was calculated. The shallow, assumed depth to soil gas and predominance of advective flow over diffusive flow effectively negates small differences in the fate and transport of individual chemicals. This allows the calculated attenuation factors to be used in a generic fashion for all volatile chemicals. Soil-gas action levels (C_{sg}) are subsequently calculated as:

$$C_{sg} = \left(\frac{\text{Indoor Air Goal}}{AF} \right)$$

A summary of soil-gas action levels for volatile chemicals is provided in Tables C-2.

Note that soil-gas action levels do not take into account the actual mass of the chemical present and could be overly conservative for the evaluation of long-term impacts to indoor air. At sites where a limited amount of impacted soil or groundwater is present, the concentration of the chemical in soil gas can be expected to decrease over time as the supply of the chemical is depleted. This would lead to steadily decreasing impacts to indoor air. Thus, while impacts to indoor air may initially exceed target goals, average, long-term impacts could conceivably fall below these goals.

This issue should be evaluated on a sitC-by-site basis as needed. As a conservative measure, and for the purpose of this action levels document, it is recommended that indoor-air goals be used as "not-to-exceed" criteria and adjustment of models and soil gas to address potential mass-balance not be carried out in the absence of long-term monitoring. This issue is currently under reviewed. Additional information will be incorporated into the EAL document as available.

5

Soil And Groundwater Action Levels For TPH

5.1 Introduction

The selection of Total Petroleum Hydrocarbons (TPH) soil and groundwater action levels for use in this document is described below. As discussed in the Volume 1, the use of EALs as final “cleanup levels” for petroleum-related compounds that are known to be highly biodegradable may be unnecessarily conservative. This is especially true for leaching based soil action levels for TPH and petroleum-related compounds. Final cleanup levels should be evaluated on a site-specific basis and in conjunction with guidance from the overseeing regulatory agency.

Petroleum is a complex mixture of hundreds of different compounds composed of hydrogen and carbon (i.e., "hydrocarbon" compounds). For the purposes of this document, petroleum mixtures are subdivided into "gasolines", "middle distillates" and "residual fuels", following the methodology used by the American Petroleum Institute (API 1994). **Gasolines** are defined as petroleum mixtures characterized by a predominance of branched alkanes and aromatic hydrocarbons with carbon ranges of C6 to C12 and lesser amounts of straight-chain alkanes, alkenes and cycloalkanes of the same carbon range. **Middle distillates** (e.g., kerosene, diesel fuel, home heating fuel, jet fuel, etc.) are characterized by a wider variety of straight, branched and cyclic alkanes, polynuclear aromatic hydrocarbons (PAHs, especially naphthalenes and methyl naphthalenes) and heterocyclic compounds with carbon ranges of approximately C9 to C25. **Residual fuels** (e.g., fuel oil Nos. 4, 5, and 6, lubricating oils, "waste oils", asphalts, etc.) are characterized by complex, polar PAHs, naphthoaromatics, asphaltenes and other high-molecular-weight, saturated hydrocarbon compounds with carbon ranges that in general fall between C24 and C40.

Laboratory analysis for TPH as gasolines and middle distillates is commonly carried out using EPA Method 8015 (or equivalent) modified for "gasoline-range" organics ("Volatile Fuel Hydrocarbons") and "diesel-range" organics ("Extractable Fuel

Hydrocarbons"), respectively. Analysis for TPH as residual fuels up to the C40 carbon range can generally be carried out by gas chromatograph methods (e.g., Method 8015 modified for "motor oil" and "waste oil" range organics) but can also include the use of infrared or gravimetric methods. More detailed information on analytical methods for TPH and other chemicals can be obtained from environmental laboratories or the overseeing regulatory agency.

Laboratory measurement and assessment of each individual compound within a petroleum mixture is technically complex and generally not feasible or appropriate under most circumstances. More importantly, data regarding the physio-chemical and toxicity characteristics of the majority of petroleum compounds are lacking. Impacts to soil and water from petroleum mixtures are instead evaluated in terms of both TPH and well characterized "indicator chemicals" (e.g., benzene, toluene, ethylbenzene, xylenes and targeted PAHs). Indicator chemicals typically recommended for petroleum mixtures include (after CalEPA 1996):

Monocyclic Aromatic Compounds (primarily gasolines and middle distillates)

- benzene
- ethylbenzene
- toluene
- xylene

Fuel additives (primarily gasolines)

- MTBE
- other oxygenates as necessary

Polycyclic Aromatic Compounds (primarily middle distillates and residual fuels)

- acenaphthene
- acenaphthylene
- anthracene
- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(g,h,i)perylene
- benzo(a)pyrene
- benzo(k)fluoranthene
- chrysene
- dibenzo(a,h)anthracene
- fluoranthene
- fluorene
- indeno(1,2,3)pyrene
- methylnaphthalene (1- and 2-)
- naphthalene
- phenanthrene
- pyrene

The TPH EALs should be used in conjunction with EALs for these chemicals. Note that volatile chemicals such as butylbenzene, isopropyl benzene, isopropyl toluene and trimethylbenzenes are often reported in analyses of gasoline and other light-end

petroleum products. These chemicals are collectively addressed under action levels for "TPH" and generally do not need to be evaluated separately.

Soil and groundwater impacted by releases of waste oil may also require testing for heavy metals and chemicals such as chlorinated solvents and PCBs. Action levels for these chemicals are included in the lookup tables.

5.2 TPH Action Levels For Groundwater

Regulatory drinking water standards for TPH and petroleum in general have not been developed. For the purposes of this document, the TPH-diesel taste and odor threshold of 100 ug/L referenced in the California EPA technical document *A Compilation of Water Quality Goals* (RWQCBCV 2000) was used as the drinking water screening level for all categories of TPH (see Table G-1). Action levels for benzene and related light-weight hydrocarbon compounds are considered to provide adequate additional protection of drinking water concerns for gasoline-impacted groundwater when used in conjunction with the TPH screening level of 100 ug/L. For the protection of aquatic life, a screening level of 500 ug/L was selected for TPH-gasoline in freshwater and 3,700 ug/L in saltwater (see Table D-3a). A single screening level of 640 ug/L was selected for TPH-diesel and TPH-residual fuels in both freshwater and saltwater. The freshwater screening level for TPH-gasoline is based on a summary of available eco-toxicity data compiled for use at the Presidio of San Francisco under Board Order 96-070 (RWQCBSF 1998b, Montgomery Watson 1999). The TPH-gasoline criteria for saltwater and the TPH criteria for diesel and residual fuels in general are based on action levels developed for use at the San Francisco Airport under Regional Water Board Order No. 99-045 (RWQCBSF 1999a).

A ceiling level of 5,000 ug/L was selected for TPH gasoline in groundwater that is not a source of drinking water (Table G-2), based on guidance developed by Massachusetts DEP risk assessment guidance (MADEP 1997a,b). For middle distillates and residual fuels, a ceiling level of 2,500 ug/L was selected. This also corresponds with one-half of the approximate solubility of diesel fuel and light motor oil in fresh water (ATSDR 2001a) and is intended to address potential nuisance issues (sheens, odors, etc.) should the groundwater discharge to surface water. The solubility of gasoline in freshwater is approximately 150,000 ug/L. A ceiling level of 5,000 ug/L should therefore protect against the presence of a sheen in the absence of heavier range petroleum compounds. Ceiling levels for TPH in groundwater are also used as substitutes for acute surface water goals (see Section 2.3).

5.3 TPH Action Levels For Soil

5.3.1 TPH (gasolines, middle distillates)

Soil action levels for lighter fractions of petroleum (gasolines, middle distillates) were selected based on a "surrogate" approach developed by the Massachusetts Department of Environmental Protection (Hutchinson et. al 1996; MADEP 1997a,b). The Massachusetts approach is similar to guidance developed by the Total Petroleum Hydrocarbon Working Group (TPHCWG 1998).

Massachusetts used six distinct groups of petroleum hydrocarbon compounds with similar carbon makeups and similar physio-chemical and toxicity characteristics to collectively describe the spectrum of all possible petroleum product mixtures (referred to as "carbon ranges"). For example, petroleum-related aromatic compound with five to 22 carbon atoms are grouped in the C11-C22 aromatic carbon range. Surrogate toxicity factors and physio-chemical constants were chosen for each carbon range group. These constants were then used to develop environmental soil and groundwater action levels for each carbon range in the same manner as done for individual chemicals.

Due to the relatively high mobility of compounds included within the C11-C22 aromatics range fraction and the general predominance of these compounds in lighter-weight fuels, Massachusetts elected to use toxicity factors and physio-chemical constants for this carbon range as a "surrogate" for TPH in general. The same approach was adopted for use in this document. This could be potentially under conservative for gasoline-range mixtures with a predominance of more lighter and more mobile compounds. The use of conservative target indicator compounds (e.g., BTEX) in conjunction with the TPH screening level is assumed to adequately address this issue, however.

Massachusetts selected an oral reference dose (RfD) of 0.03 mg/kg-d and an inhalation RfD of 0.14 mg/kg-d for the C11-C22 aromatics fraction, based in part on comparison to the Massachusetts RfD for pyrene. The TPH Working Group selected a slightly less conservative oral RfD of 0.04 mg/kg-d and inhalation RfD of 0.06 mg/kg-d (based on Reference Concentration of 0.20 mg/m³) for the same carbon range group (THPWG 1998). In this document, the MADEP RfDs were used to generate direct-exposure soil action levels for TPH under residential land use, occupational and construction/trench worker exposure scenarios (see Table H). This generated direct-exposure action levels of 890 mg/kg, 4,100 mg/kg and 39,000 mg/kg, respectively (see Tables I-1, I-2 and I-3). The action levels are based on a target hazard quotient of 1.0 (see Section 3.2). Note that the construction/trench worker action levels exceed the default TPH ceiling level of 5,000 mg/kg (see below).

Massachusetts developed generic physio-chemical constants for the C11-C22 aromatics carbon range fraction based on a review of compounds included within this fraction (see Table H). These constants were adopted in this document to develop soil leaching action

levels for TPH as gasolines and middle distillates (see Table E-1) as well as direct exposure action levels (see Table I-1 through I-3). The TPH soil screening level calculated for protection of drinking water (rounded to 100 mg/kg) is coincidental with action levels presented in other technical documents prepared by local California regulatory agencies (RWQCBSF 1990; RWQCBLA 1996). Leaching based soil action levels calculated for protection of surface water habitats of 400 mg/kg for TPH-gasolines and 500 mg/kg for TPH-middle distillates based on target aquatic habitat goals are coincidental with action levels developed for use at other sites in California, including the San Francisco Airport (RWQCB 1999a).

Ceiling levels developed by Massachusetts for TPH as gasoline and diesel (latter included under "middle distillates") were modified for use in this document (MADEP 1997a,b, refer to Table H). For shallow soils, ceiling levels of 100 mg/kg and 500 mg/kg were developed for residential and industrial land-use scenarios, respectively. This is primarily based on odor and general nuisance concerns. For deep and/or isolated soils, a ceiling level of 5,000 mg/kg is generally considered appropriate to primarily intended to prevent the presence of significant, potentially mobile free product (see Table F-3). Care should be taken to avoid adverse vapor emission into buildings when high levels of gasoline or even diesel are left in place at a site. The soil gas screening levels for TPH and related compounds provided in Table C-2 can be used to evaluate this concern.

5.3.2 TPH (residual fuels)

Direct-exposure action levels developed for TPH as gasoline and as middle distillates were retained for use with TPH as residual fuels (refer to Tables I-1 through I-3). Following Massachusetts DEP guidance (MADEP 1997a,b), ceiling levels of 500 mg/kg and 2,500 mg/kg were selected for residential and commercial/industrial shallow soils, respectively. The Massachusetts DEP ceiling level of 5,000 mg/kg was used for deep soils.

The Massachusetts DEP did not develop specific action levels for leaching of heavy hydrocarbons from soil (refer to C19-C36 carbon range summary in Appendix 7). Residual fuels are by definition characterized by a predominance hydrocarbon compounds with carbon ranges greater than C24. These compounds are considered to be substantially less mobile in the subsurface than hydrocarbon compounds that make up the lighter-weight petroleum mixtures. For TPH that is characterized by a predominance of C23-C32 carbon range compounds, the Los Angeles Regional Water Board proposes a screening level of 1,000 mg/kg for protection of drinking water resources (RWQCBLA 1996). The target TPH screening level for groundwater was not specifically stated but is presumably 100 ug/L or less. As noted above, however, this action level may be excessively conservative for use at sites that are not situated directly over a source of drinking water. To address this issue, the leaching based soil action level of 5,000 mg/kg for TPH-residual fuels presented in the 1996 HODOH RBCA document was retained for use in this document (refer to Table E-1). As noted above, a more conservative action

level may be appropriate for sites within close proximity to a producing water supply well. This should again be evaluated on a site-by-site basis.

The Los Angeles Regional Water Board did not present a similar screening level for potential leaching of TPH from soil and subsequent discharge of impacted groundwater to a body of surface water that is not a source of drinking water. A TPH action level of 640 ug/L is used for protection of aquatic habitats. Assuming a linear correlation with action levels developed by the Los Angeles Regional Water Board, this correlates to a leaching based action level for soil of 6,400 mg/kg. Due to uncertainties in the derivation LA action levels, this was reduced to the gross contamination action level for deep soils of 5,000 mg/kg (see Tables E-1 and F-3). This is also consistent with the soil action level for residual petroleum presented in the 1996 HDOH RBCA document. As noted in the previous section, the adequacy of this screening level should be re-evaluated at sites where impacted soil is located in close proximity to a sensitive aquatic habitat.

6

Other Issues

6.1 Laboratory Reporting Levels and Background Concentrations

Laboratory method reporting limits and background concentrations of chemicals were not directly considered in development of the lookup tables. As discussed in Volume 1 of this document, however, reporting limits approved by the overseeing regulatory agency should be used in place of the EALs presented in this document when higher. An EAL should similarly be replaced with the natural background concentration of the chemical if the background value is higher.

Arsenic and chromium, among other metals, may be naturally present in soils at levels above toxicity-based action levels. Based on studies conducted on soils in Hawai'i, background concentrations of total chromium in soils can range from a few parts per million to several thousand parts per million (Nakamura and Sherman, 1958, Feldman, 1979, and DPED, 1985, as referenced in Daugherty 1990). Due to this variability, final soil action levels total chromium is simply noted as "site-specific" in the lookup tables.

Similar compilations of data for background concentration of arsenic in soil were not available at the time that this document was being prepared. Based on a preliminary review of data available in site investigation reports submitted to HDOH, background concentrations of arsenic in soils range from less than 1.0 mg/kg to greater than 20 mg/kg, with typical concentrations in the range of 5 to 15 mg/kg. This is well above the health-based, direct-exposure goals for arsenic in soil of 0.39 mg/kg for residential exposure and 1.6 mg/kg for commercial/industrial exposure (Appendix 1, Tables I-1 and I-2). Based professional judgment and for provisional use in this document, a concentration of 22 mg/kg (correlative to the noncancer, residential direct-exposure soil action level) was assumed for typical maximum, background arsenic in soil (refer to Tables A-1 through B-2). This was then used as the final soil action level for arsenic.

6.2 Reporting of Soil Data

Soil data are calculated by dividing the mass of the chemical of concern detected in the soil by the total weight of the soil. The weight of a soil sample can be measured on either a dry-weight basis (i.e., excluding the weight of water in the soil sample) or a wet-weight basis (i.e., including the weight of water in the soil sample). For a typical soil sample, the inclusion of soil moisture in calculation of chemical concentrations can effectively reduce the reported concentrations by 10-20% or greater, simply because the measured total weight of the sample is greater.

From a site-investigation and risk assessment-standpoint, a difference in the reported concentration of a chemical of 10-20% is not necessarily significant. **For consistency and for comparison to soil EALs presented in this document, however, soil data should be reported on dry-weight basis.** This is in part because soil ingestion rates assumed in direct-exposure models (see Appendices 1 and 2) are based on dry-weight studies (USEPA 1997). Comparison of wet-weight data to direct-exposure screening level would technically require adjustment of the direct-exposure action levels to reflect wet weight-based soil ingestion rates. A site-specific consideration of wet-weight soil data will be dependent on assumptions in the model(s) being used to evaluate risk or generate environmental action levels. Existing wet-weight soil data will generally not need to be adjusted prior to comparison to the EALs unless the introduced bias is considered to be a potentially significant factor at the site. (Note that sediment data should also be reported on a dry-weight basis.)

6.3 Additional Soil Parameters

For surface soils, action levels are also presented for Electrical Conductivity and Sodium Absorption Ratio (after MOEE 1996). Both parameters are intended primarily for evaluation of soils impacted by brines (e.g., from oil and gas field discharges). The Sodium Absorption Ratio reflects the amount of sodium present in the soil with respect to other major cations. An overabundance of sodium can inhibit plant uptake of nutrients, reduce soil cohesion and cause excessive erosion of topsoil. The electrical conductivity of a soil reflects the total concentration of soluble salts in the soil solution. A high concentration of salts can have a significant influence on osmotic processes involved in plant growth. (NOTE: The Electrical Conductivity action levels assumes a fixed 2:1 water:soil solution in the laboratory method. The USEPA Laboratory Method 120.1(Mod) normally calls for a 1:1 dilution ratio. The laboratory should be notified of the need for a 2:1 dilution ratio prior to analysis.)

6.4 Degradation to Daughter Products

Consideration of the degradation of a chemical to more toxic daughter products, such as the breakdown of tetrachloroethylene to vinyl chloride, is an important part of site investigations. Tier 1 lookup tables generated by some regulatory agencies incorporate a very conservative assumption that the entire mass of a parent chemical will be eventually

be transformed to the daughter product at the same initial concentration (e.g., MADEP 1994, MOEE 1996). They in turn reduce the initially derived action levels for these parent compounds to reflect the action levels for the more toxic daughter product, without taking into account issues such as the lower molecular weights (and lower ultimate masses) of the daughter products. While the need to monitor for degradation byproducts is well founded, it is felt that the above approach is overly conservative in most cases and not reflective of naturally occurring conditions. In the case of tetrachlorethylene, for example, degradation to vinyl chloride and further degradation of vinyl chloride to non-toxic ethene gas (and ultimately carbon dioxide and water) can be expected to be a steady-state process at sites where degradation is occurring, removing a portion of the vinyl chloride as it is generated. At most release sites this process has already been initiated, and the already conservative action levels for individual, primary compounds are considered to be adequately protective of human health and the environment. The need to reconsider this assumption should be evaluated on a site-by-site basis.

This issue is currently be evaluated in more detail. It should be pointed out that at some sites degradation of chlorinated solvents in groundwater is minimal (e.g., PCE) but levels of daughter products in soil gas are very elevated (e.g., vinyl chloride). This emphasizes the need to collect soil gas data at sites where vapor intrusion is of potential concern.

7

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FIGURES

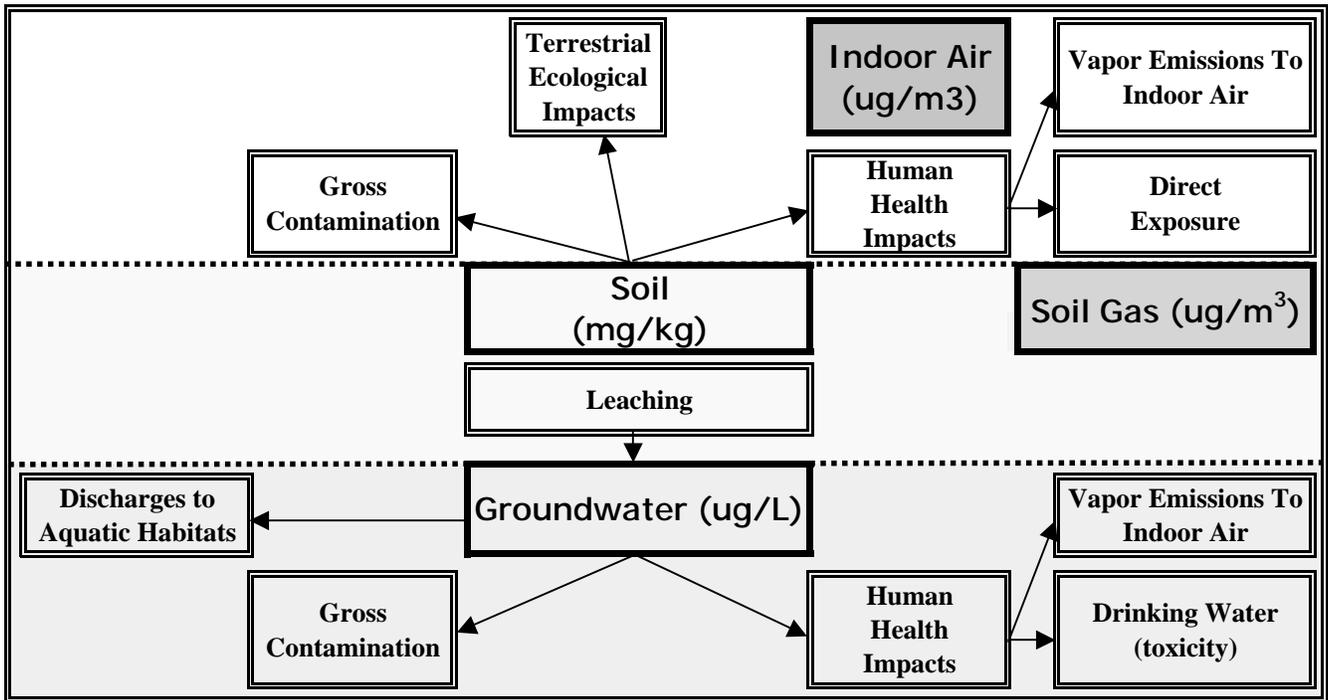


Figure 1. Summary of human health and environmental concerns considered in screening levels. Gross contamination concerns include free product, odors, tastes (drinking water) and general resource degradation. This figure is intended for Tier 1 and Tier 2 assessments only. Evaluation of environmental concerns not shown requires site-specific assessment.

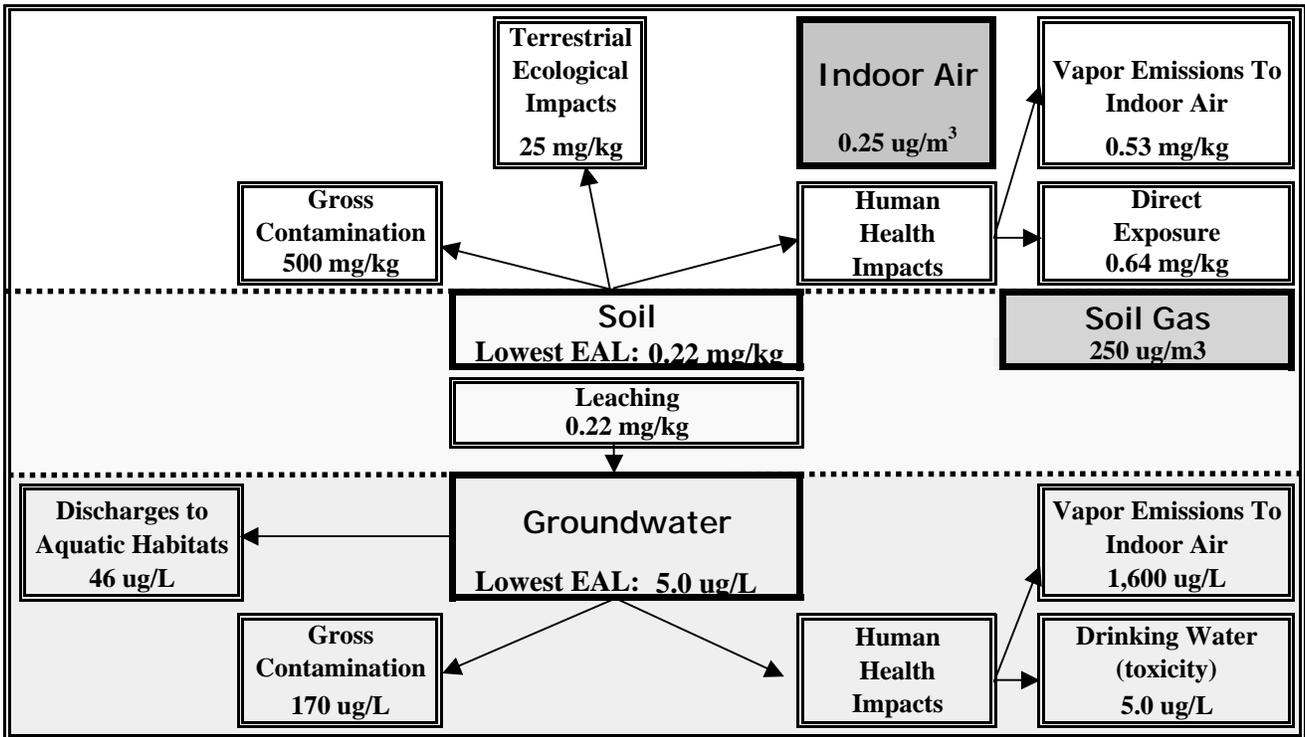


Figure 2. Summary of individual screening levels used to select final, Tier 1 soil and groundwater EALs for benzene in Volume 1, Table A. Refer Appendix 1, Table A-1 (soil), Table C-3 (indoor air and soil gas) and Table D-1a (groundwater).

TABLES

TABLES

- A-1. SOIL ACTION LEVELS (POTENTIALLY IMPACTED GROUNDWATER IS A CURRENT OR POTENTIAL DRINKING WATER RESOURCE; SURFACE WATER BODY IS NOT LOCATED WITHIN 150M OF RELEASE SITE)
- A-2. SOIL ACTION LEVELS (POTENTIALLY IMPACTED GROUNDWATER IS A CURRENT OR POTENTIAL DRINKING WATER RESOURCE; SURFACE WATER BODY IS LOCATED WITHIN 150M OF RELEASE SITE)
- B-1. SOIL ACTION LEVELS (POTENTIALLY IMPACTED GROUNDWATER IS NOT A CURRENT OR POTENTIAL DRINKING WATER RESOURCE; SURFACE WATER BODY IS NOT LOCATED WITHIN 150M OF RELEASE SITE)
- B-2. SOIL ACTION LEVELS (POTENTIALLY IMPACTED GROUNDWATER IS NOT A CURRENT OR POTENTIAL DRINKING WATER RESOURCE; SURFACE WATER BODY IS LOCATED WITHIN 150M OF RELEASE SITE)
- C-1A. GROUNDWATER ACTION LEVELS FOR EVALUATION OF POTENTIAL INDOOR-AIR IMPACTS (VOLATILE CHEMICALS ONLY)
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- D-1B. GROUNDWATER ACTION LEVELS (GROUNDWATER IS A CURRENT OR POTENTIAL DRINKING WATER RESOURCE) (SURFACE WATER BODY IS NOT LOCATED WITHIN 150M OF RELEASE SITE)
- D-1C. GROUNDWATER ACTION LEVELS (GROUNDWATER IS NOT A CURRENT OR POTENTIAL DRINKING WATER RESOURCE) (SURFACE WATER BODY IS LOCATED WITHIN 150M OF RELEASE SITE)
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- H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS
- I-1. DIRECT-EXPOSURE ACTION LEVELS, RESIDENTIAL EXPOSURE SCENARIO
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- J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS
- K. SOIL ACTION LEVELS FOR TERRESTRIAL ECOTOXICITY CONCERNS

TABLE A-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
							Table I-1	Table C-1b	Table E-1
ACENAPHTHENE	1.6E+01	Groundwater Protection	1.0E+03	-			3.7E+03	1.3E+02	1.6E+01
ACENAPHTHYLENE	1.0E+02	Groundwater Protection	5.0E+02	-			1.3E+03	(Use soil gas)	1.0E+02
ACETONE	5.0E-01	Groundwater Protection	5.0E+02	-			1.4E+04	5.6E+03	5.0E-01
ALDRIN	2.9E-02	Direct Exposure	1.0E+03	3.5E-01			2.9E-02		5.0E+00
ANTHRACENE	2.8E+00	Groundwater Protection	5.0E+02	4.0E+01			2.2E+04	6.1E+00	2.8E+00
ANTIMONY	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01			3.1E+01		(site-specific)
ARSENIC	2.2E+01	Background	1.0E+03	2.0E+01	2.2E+01	Background	4.2E-01		(site-specific)
BARIUM	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02			5.4E+03		(site-specific)
BENZENE	2.2E-01	Groundwater Protection	5.0E+02	2.5E+01			6.4E-01	5.3E-01	2.2E-01
BENZO(a)ANTHRACENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01			6.2E+00		1.2E+01
BENZO(a)PYRENE	6.2E-01	Direct Exposure	5.0E+02	4.0E+01			6.2E-01		1.3E+02
BENZO(b)FLUORANTHENE	6.2E+00	Direct Exposure	5.0E+02	-			6.2E+00		4.6E+01
BENZO(g,h,i)PERYLENE	2.7E+01	Groundwater Protection	5.0E+02	4.0E+01			2.3E+03		2.7E+01
BENZO(k)FLUORANTHENE	3.7E+01	Groundwater Protection	5.0E+02	4.0E+01			6.2E+01		3.7E+01
BERYLLIUM	4.0E+00	Ecotoxicity	1.0E+03	4.0E+00			1.5E+02		(site-specific)
BIPHENYL, 1,1-	6.5E-01	Groundwater Protection	5.0E+02	-			3.0E+03	(Use soil gas)	6.5E-01
BIS(2-CHLOROETHYL)ETHER	1.2E-04	Groundwater Protection	5.0E+02	-			2.0E-01	6.7E-03	1.2E-04
BIS(2-CHLOROISOPROPYL)ETHER	3.0E-03	Groundwater Protection	5.0E+02	-			2.9E+00	(Use soil gas)	3.0E-03
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	Direct Exposure	5.0E+02	-			3.5E+01		7.8E+02
BORON	1.6E+00	Ecotoxicity	1.0E+02	1.6E+00			1.2E+04		(site-specific)
BROMODICHLOROMETHANE	3.4E-03	Groundwater Protection	1.0E+03	-			8.2E-01	2.3E-02	3.4E-03
BROMOFORM	2.2E+00	Groundwater Protection	5.0E+02	-			6.1E+01		2.2E+00
BROMOMETHANE	3.4E-01	Groundwater Protection	5.0E+02	-			3.8E+00	8.6E-01	3.4E-01
CADMIUM	1.2E+01	Ecotoxicity	1.0E+03	1.2E+01			3.9E+01		(site-specific)
CARBON TETRACHLORIDE	2.7E-02	Indoor Air Impacts	5.0E+02	-			2.5E-01	2.7E-02	1.1E+00
CHLORDANE	1.6E+00	Direct Exposure	1.0E+03	-			1.6E+00		1.5E+01
CHLOROANILINE, p-	5.3E-02	Groundwater Protection	1.0E+03	-			2.4E+02		5.3E-02
CHLOROBENZENE	3.0E+00	Groundwater Protection	5.0E+02	3.0E+01			1.5E+02	1.0E+01	3.0E+00
CHLOROETHANE	2.7E-01	Groundwater Protection	5.0E+02	-			3.0E+00	5.0E-01	2.7E-01
CHLOROFORM	1.8E-02	Indoor Air Impacts	5.0E+02	-			2.2E-01	1.8E-02	1.8E+00
CHLOROMETHANE	1.6E+01	Indoor Air Impacts	1.0E+02	-			4.6E+01	1.6E+01	2.4E+01
CHLOROPHENOL, 2-	1.2E-02	Groundwater Protection	1.0E+02	1.0E+01			6.3E+01	3.4E+00	1.2E-02
CHROMIUM (Total)	2.1E+02	Direct Exposure	1.0E+03	-			2.1E+02		(site-specific)
CHROMIUM III	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02			1.2E+05		(site-specific)
CHROMIUM VI	8.0E+00	Ecotoxicity	1.0E+03	8.0E+00			3.0E+01		(site-specific)
CHRYSENE	2.3E+01	Groundwater Protection	1.0E+03	4.0E+01			6.2E+02	(Use soil gas)	2.3E+01
COBALT	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01			5.2E+02		(site-specific)

TABLE A-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2	Table L	Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b	Drinking Water Resource Table E-1
COPPER	2.3E+02	Ecotoxicity	1.0E+03	2.3E+02			3.1E+03		(site-specific)
CYANIDE (Free)	1.0E+02	Ceiling Value	1.0E+02	-			1.2E+03	(Use soil gas)	1.2E+04
DIBENZO(a,h)ANTHTRACENE	6.2E-01	Direct Exposure	5.0E+02	-			6.2E-01		9.9E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	Groundwater Protection	5.0E+02	-			4.5E-01	(Use soil gas)	9.0E-04
DIBROMOCHLOROMETHANE	1.1E-02	Groundwater Protection	1.0E+02	-			1.1E+00	1.7E-02	1.1E-02
DIBROMOETHANE, 1,2-	5.2E-05	Groundwater Protection	5.0E+02	-			3.2E-02	7.2E-04	5.2E-05
DICHLOROENZENE, 1,2-	1.1E+00	Groundwater Protection	6.0E+02	3.0E+01			6.0E+02	3.5E+01	1.1E+00
DICHLOROENZENE, 1,3-	2.1E+01	Groundwater Protection	1.0E+02	3.0E+01			5.3E+02	(Use soil gas)	2.1E+01
DICHLOROENZENE, 1,4-	6.5E-02	Indoor Air Impacts	5.0E+02	3.0E+01			3.4E+00	6.5E-02	5.9E-01
DICHLOROBENZIDINE, 3,3-	4.0E-02	Groundwater Protection	5.0E+02	-			1.1E+00		4.0E-02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	Direct Exposure	5.0E+02	-			2.4E+00		7.5E+02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	Direct Exposure	5.0E+02	4.0E+00			2.4E+00		1.1E+03
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	Direct Exposure	1.0E+03	4.0E+00			1.7E+00		4.3E+00
DICHLOROETHANE, 1,1-	1.9E+00	Groundwater Protection	5.0E+02	-			4.9E+02	8.6E+01	1.9E+00
DICHLOROETHANE, 1,2-	1.1E-03	Groundwater Protection	5.0E+02	6.0E+01			2.7E-01	1.6E-02	1.1E-03
DICHLOROETHYLENE, 1,1-	1.2E+00	Groundwater Protection	5.0E+02	-			1.2E+02	3.5E+01	1.2E+00
DICHLOROETHYLENE, Cis 1,2-	2.2E+00	Groundwater Protection	1.0E+02	-			4.2E+01	6.2E+00	2.2E+00
DICHLOROETHYLENE, Trans 1,2-	6.7E+00	Groundwater Protection	5.0E+02	-			6.9E+01	1.2E+01	6.7E+00
DICHLOROPHENOL, 2,4-	3.0E-01	Groundwater Protection	5.0E+02	1.0E+01			1.8E+02		3.0E-01
DICHLOROPROPANE, 1,2-	2.1E-02	Indoor Air Impacts	1.0E+02	-			3.4E-01	2.1E-02	1.2E-01
DICHLOROPROPENE, 1,3-	4.6E-02	Groundwater Protection	5.0E+02	-			7.7E-01	1.0E-01	4.6E-02
DIELDRIN	5.2E-03	Groundwater Protection	1.0E+03	4.0E+00			3.0E-02		5.2E-03
DIETHYLPHTHALATE	2.2E+01	Groundwater Protection	5.0E+02	-			4.9E+04		2.2E+01
DIMETHYLPHENOL, 2,4-	1.8E+00	Groundwater Protection	1.0E+02	-			1.2E+03		1.8E+00
DIMETHYLPHTHALATE	2.2E+01	Groundwater Protection	5.0E+02	-			6.1E+05		2.2E+01
DINITROPHENOL, 2,4-	2.1E-01	Groundwater Protection	5.0E+02	-			1.2E+02		2.1E-01
DINITROTOLUENE, 2,4-	2.5E-01	Groundwater Protection	5.0E+02	-			1.2E+02		2.5E-01
DIOXANE, 1,4-	3.7E-03	Groundwater Protection	5.0E+02	-			4.4E+01		3.7E-03
DIOXIN (2,3,7,8-TCDD)	3.9E-06	Direct Exposure	NA	-			3.9E-06		1.0E+06
ENDOSULFAN	1.8E-02	Groundwater Protection	5.0E+02	-			3.7E+02		1.8E-02
ENDRIN	1.0E-02	Groundwater Protection	5.0E+02	6.0E-02			1.8E+01		1.0E-02
ETHYLBENZENE	3.3E+00	Groundwater Protection	4.0E+02	-			4.0E+02	3.9E+02	3.3E+00
FLUORANTHENE	4.0E+01	Ecotoxicity	5.0E+02	4.0E+01			2.3E+03		2.5E+02
FLUORENE	1.6E+02	Indoor Air Impacts	5.0E+02	-			2.7E+03	1.6E+02	5.6E+02
HEPTACHLOR	1.1E-01	Direct Exposure	1.0E+03	-			1.1E-01		1.9E-01
HEPTACHLOR EPOXIDE	5.3E-02	Direct Exposure	1.0E+03	-			5.3E-02		2.0E-01
HEXACHLOROENZENE	3.0E-01	Direct Exposure	5.0E+02	3.0E+01			3.0E-01		7.9E+02

TABLE A-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
							Table I-1	Table C-1b	Table E-1
HEXACHLOROBUTADIENE	4.3E+00	Groundwater Protection	5.0E+02	-			6.2E+00		4.3E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	9.8E-02	Groundwater Protection	5.0E+02	2.0E+00			4.4E-01		9.8E-02
HEXACHLOROETHANE	1.6E+01	Groundwater Protection	5.0E+02	-			3.5E+01		1.6E+01
INDENO(1,2,3-cd)PYRENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01			6.2E+00		2.4E+01
LEAD	2.0E+02 (4.0E+02)	Ecotoxicity (Direct Exposure)	1.0E+03	2.0E+02			4.0E+02		(site-specific)
MERCURY	1.0E+01	Ecotoxicity	5.0E+02	1.0E+01			1.3E+01		(site-specific)
METHOXYCHLOR	1.9E+01	Groundwater Protection	5.0E+02	-			3.1E+02		1.9E+01
METHYL ETHYL KETONE	6.4E+00	Groundwater Protection	5.0E+02	-			2.2E+04	1.9E+04	6.4E+00
METHYL ISOBUTYL KETONE	3.9E+00	Groundwater Protection	1.0E+02	-			5.3E+03	1.7E+04	3.9E+00
METHYL MERCURY	6.1E+00	Direct Exposure	1.0E+02	1.0E+01			6.1E+00		(site-specific)
METHYL TERT BUTYL ETHER	2.3E-02	Groundwater Protection	1.0E+02	-			3.1E+01	1.6E+00	2.3E-02
METHYLENE CHLORIDE	6.7E-02	Groundwater Protection	5.0E+02	-			9.2E+00	9.0E-01	6.7E-02
METHYLNAPHTHALENE (total 1- & 2-)	1.2E+00	Groundwater Protection	5.0E+02	-			1.4E+03	1.1E+02	1.2E+00
MOLYBDENUM	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01			3.9E+02		(site-specific)
NAPHTHALENE	1.2E+00	Groundwater Protection	5.0E+02	4.0E+01			5.5E+01	1.8E+01	1.2E+00
NICKEL	1.5E+02	Ecotoxicity	1.0E+03	1.5E+02			1.6E+03		(site-specific)
PENTACHLOROPHENOL	3.0E+00	Direct Exposure	5.0E+02	5.0E+00			3.0E+00		1.0E+06
PERCHLORATE	7.0E-03	Groundwater Protection	1.0E+03	-			7.8E+00		7.0E-03
PHENANTHRENE	1.8E+01	Groundwater Protection	5.0E+02	4.0E+01			2.8E+03	(Use soil gas)	1.8E+01
PHENOL	7.6E-02	Groundwater Protection	5.0E+02	4.0E+01			1.8E+04		7.6E-02
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	Direct Exposure	5.0E+02	-			1.1E+00		6.3E+00
PYRENE	8.5E+01	Indoor Air Impacts	5.0E+02	-			2.3E+03	8.5E+01	8.5E+01
SELENIUM	1.0E+01	Ecotoxicity	1.0E+03	1.0E+01			3.9E+02		(site-specific)
SILVER	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01			3.9E+02		(site-specific)
STYRENE	1.5E+00	Groundwater Protection	5.0E+02	-			1.5E+03	1.5E+03	1.5E+00
tert-BUTYL ALCOHOL	2.3E-02	Groundwater Protection	1.0E+02	-			7.0E+01	(Use soil gas)	2.3E-02
TETRACHLOROETHANE, 1,1,1,2-	7.6E-03	Groundwater Protection	1.0E+02	-			3.1E+00	(Use soil gas)	7.6E-03
TETRACHLOROETHANE, 1,1,2,2-	9.9E-04	Groundwater Protection	5.0E+02	-			4.1E-01	7.2E-03	9.9E-04
TETRACHLOROETHYLENE	6.9E-02	Indoor Air Impacts	2.3E+02	-			4.8E-01	6.9E-02	7.0E-01
THALLIUM	5.2E+00	Direct Exposure	1.0E+03	-			5.2E+00		(site-specific)
TOLUENE	2.9E+00	Groundwater Protection	5.0E+02	-			6.5E+02	6.5E+02	2.9E+00
TOXAPHENE	4.0E-01	Direct Exposure	5.0E+02	-			4.0E-01		4.4E-01
TPH (gasolines)	1.0E+02 (2.0E+03)	Ceiling Value (Leaching)	1.0E+02	-			8.0E+02	(Use soil gas)	2.0E+03
TPH (middle distillates)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			8.0E+02	(Use soil gas)	5.0E+03
TPH (residual fuels)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			2.3E+03		5.0E+03
TRICHLOROBENZENE, 1,2,4-	1.6E+00	Indoor Air Impacts	5.0E+02	3.0E+01			6.1E+01	1.6E+00	2.1E+01
TRICHLOROETHANE, 1,1,1-	2.5E+01	Groundwater Protection	5.0E+02	-			1.2E+03	3.9E+02	2.5E+01

TABLE A-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

(mg/kg)									
CONTAMINANT	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2	Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns	Drinking Water Resource
					Table I-1	Table C-1b	Table E-1		
TRICHLOROETHANE, 1,1,2-	2.6E-02	Indoor Air Impacts	1.0E+02	-			7.2E-01	2.6E-02	7.0E-02
TRICHLOROETHYLENE	3.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01			5.2E-01	3.6E-02	4.6E-01
TRICHLOROPHENOL, 2,4,5-	1.6E+00	Groundwater Protection	1.0E+02	1.0E+01			2.5E+03	9.5E+01	1.6E+00
TRICHLOROPHENOL, 2,4,6-	1.2E+00	Groundwater Protection	5.0E+02	1.0E+01			6.1E+00		1.2E+00
VANADIUM	7.8E+01	Direct Exposure	1.0E+03	2.0E+02			7.8E+01		(site-specific)
VINYL CHLORIDE	3.9E-02	Indoor Air Impacts	5.0E+02	6.0E+01			1.5E-01	3.9E-02	3.4E-01
XYLENES	2.3E+00	Groundwater Protection	4.2E+02	-			2.7E+02	1.8E+02	2.3E+00
ZINC	6.0E+02	Ecotoxicity	1.0E+03	6.0E+02			2.3E+04		(site-specific)
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0		-	-			-	-	-
Sodium Adsorption Ratio	5.0		-	-			-	-	-

Notes:

1. Assumes current or future residential land use.
2. Based primarily on phytotoxicity. Included in selection of final soil action levels if less than one-half of the residential soil screening level for human-health, direct-exposure concerns (see Table L and Section 3.9 in text).

Final Soil Action Level is lowest of ceiling value (nuisance concerns etc.), ecotoxicity, direct-exposure, indoor-air impact, and leaching action levels.

Assumes soil pH 5.0 to 9.0.

Soil data should be reported on dry-weight basis (see Section 6.2).

TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Use of leaching based action levels noted in parentheses may be appropriate for deep or otherwise isolated soils that do not threaten a drinking water resource or sensitive aquatic habitat. Refer to Section 2.2.2 in Volume 1.

Background arsenic in soils - assumed maximum (refer to Section 6.1 in text).

TABLE A-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
							Table I-1	Table C-1b	Table E-1
ACENAPHTHENE	1.6E+01	Groundwater Protection	1.0E+03	-			3.7E+03	1.3E+02	1.6E+01
ACENAPHTHYLENE	1.3E+01	Groundwater Protection	5.0E+02	-			1.3E+03	(Use soil gas)	1.3E+01
ACETONE	5.0E-01	Groundwater Protection	5.0E+02	-			1.4E+04	5.6E+03	5.0E-01
ALDRIN	2.9E-02	Direct Exposure	1.0E+03	3.5E-01			2.9E-02		5.0E+00
ANTHRACENE	2.8E+00	Groundwater Protection	5.0E+02	4.0E+01			2.2E+04	6.1E+00	2.8E+00
ANTIMONY	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01			3.1E+01		(site-specific)
ARSENIC	2.2E+01	Background	1.0E+03	2.0E+01	2.2E+01	Background	4.2E-01		(site-specific)
BARIIUM	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02			5.4E+03		(site-specific)
BENZENE	2.2E-01	Groundwater Protection	5.0E+02	2.5E+01			6.4E-01	5.3E-01	2.2E-01
BENZO(a)ANTHRACENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01			6.2E+00		1.2E+01
BENZO(a)PYRENE	6.2E-01	Direct Exposure	5.0E+02	4.0E+01			6.2E-01		1.3E+02
BENZO(b)FLUORANTHENE	6.2E+00	Direct Exposure	5.0E+02	-			6.2E+00		4.6E+01
BENZO(g,h,i)PERYLENE	2.7E+01	Groundwater Protection	5.0E+02	4.0E+01			2.3E+03		2.7E+01
BENZO(k)FLUORANTHENE	3.7E+01	Groundwater Protection	5.0E+02	4.0E+01			6.2E+01		3.7E+01
BERYLLIUM	4.0E+00	Ecotoxicity	1.0E+03	4.0E+00			1.5E+02		(site-specific)
BIPHENYL, 1,1-	6.5E-01	Groundwater Protection	5.0E+02	-			3.0E+03	(Use soil gas)	6.5E-01
BIS(2-CHLOROETHYL)ETHER	1.2E-04	Groundwater Protection	5.0E+02	-			2.0E-01	6.7E-03	1.2E-04
BIS(2-CHLOROISOPROPYL)ETHER	3.0E-03	Groundwater Protection	5.0E+02	-			2.9E+00	(Use soil gas)	3.0E-03
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	Direct Exposure	5.0E+02	-			3.5E+01		7.8E+02
BORON	1.6E+00	Ecotoxicity	1.0E+02	1.6E+00			1.2E+04		(site-specific)
BROMODICHLOROMETHANE	3.4E-03	Groundwater Protection	1.0E+03	-			8.2E-01	2.3E-02	3.4E-03
BROMOFORM	2.2E+00	Groundwater Protection	5.0E+02	-			6.1E+01		2.2E+00
BROMOMETHANE	3.4E-01	Groundwater Protection	5.0E+02	-			3.8E+00	8.6E-01	3.4E-01
CADMIUM	1.2E+01	Ecotoxicity	1.0E+03	1.2E+01			3.9E+01		(site-specific)
CARBON TETRACHLORIDE	2.7E-02	Indoor Air Impacts	5.0E+02	-			2.5E-01	2.7E-02	1.1E+00
CHLORDANE	1.6E+00	Direct Exposure	1.0E+03	-			1.6E+00		1.5E+01
CHLOROANILINE, p-	5.3E-02	Groundwater Protection	1.0E+03	-			2.4E+02		5.3E-02
CHLOROBENZENE	1.5E+00	Groundwater Protection	5.0E+02	3.0E+01			1.5E+02	1.0E+01	1.5E+00
CHLOROETHANE	2.7E-01	Groundwater Protection	5.0E+02	-			3.0E+00	5.0E-01	2.7E-01
CHLOROFORM	1.8E-02	Indoor Air Impacts	5.0E+02	-			2.2E-01	1.8E-02	1.8E+00
CHLOROMETHANE	1.6E+01	Indoor Air Impacts	1.0E+02	-			4.6E+01	1.6E+01	2.4E+01
CHLOROPHENOL, 2-	1.2E-02	Groundwater Protection	1.0E+02	1.0E+01			6.3E+01	3.4E+00	1.2E-02
CHROMIUM (Total)	2.1E+02	Direct Exposure	1.0E+03	-			2.1E+02		(site-specific)
CHROMIUM III	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02			1.2E+05		(site-specific)
CHROMIUM VI	8.0E+00	Ecotoxicity	1.0E+03	8.0E+00			3.0E+01		(site-specific)
CHRYSENE	2.3E+01	Groundwater Protection	1.0E+03	4.0E+01			6.2E+02	(Use soil gas)	2.3E+01
COBALT	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01			5.2E+02		(site-specific)

TABLE A-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2	Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns	Drinking Water Resource
							Table I-1	Table C-1b	Table E-1
COPPER	2.3E+02	Ecotoxicity	1.0E+03	2.3E+02			3.1E+03		(site-specific)
CYANIDE (Free)	1.0E+02	Ceiling Value	1.0E+02	-			1.2E+03	(Use soil gas)	1.2E+04
DIBENZO(a,h)ANTHTRACENE	6.2E-01	Direct Exposure	5.0E+02	-			6.2E-01		9.9E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	Groundwater Protection	5.0E+02	-			4.5E-01	(Use soil gas)	9.0E-04
DIBROMOCHLOROMETHANE	1.1E-02	Groundwater Protection	1.0E+02	-			1.1E+00	1.7E-02	1.1E-02
DIBROMOETHANE, 1,2-	5.2E-05	Groundwater Protection	5.0E+02	-			3.2E-02	7.2E-04	5.2E-05
DICHLOROBENZENE, 1,2-	1.1E+00	Groundwater Protection	6.0E+02	3.0E+01			6.0E+02	3.5E+01	1.1E+00
DICHLOROBENZENE, 1,3-	7.4E+00	Groundwater Protection	1.0E+02	3.0E+01			5.3E+02	(Use soil gas)	7.4E+00
DICHLOROBENZENE, 1,4-	6.5E-02	Indoor Air Impacts	5.0E+02	3.0E+01			3.4E+00	6.5E-02	5.9E-01
DICHLOROBENZIDINE, 3,3-	4.0E-02	Groundwater Protection	5.0E+02	-			1.1E+00		4.0E-02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	Direct Exposure	5.0E+02	-			2.4E+00		7.5E+02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	Direct Exposure	5.0E+02	4.0E+00			2.4E+00		1.1E+03
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	Direct Exposure	5.0E+03	4.0E+00			1.7E+00		4.3E+00
DICHLOROETHANE, 1,1-	1.9E+00	Groundwater Protection	5.0E+02	-			4.9E+02	8.6E+01	1.9E+00
DICHLOROETHANE, 1,2-	1.1E-03	Groundwater Protection	5.0E+02	6.0E+01			2.7E-01	1.6E-02	1.1E-03
DICHLOROETHYLENE, 1,1-	1.2E+00	Groundwater Protection	5.0E+02	-			1.2E+02	3.5E+01	1.2E+00
DICHLOROETHYLENE, Cis 1,2-	2.2E+00	Groundwater Protection	1.0E+02	-			4.2E+01	6.2E+00	2.2E+00
DICHLOROETHYLENE, Trans 1,2-	6.7E+00	Groundwater Protection	5.0E+02	-			6.9E+01	1.2E+01	6.7E+00
DICHLOROPHENOL, 2,4-	3.0E-01	Groundwater Protection	5.0E+02	1.0E+01			1.8E+02		3.0E-01
DICHLOROPROPANE, 1,2-	2.1E-02	Indoor Air Impacts	1.0E+02	-			3.4E-01	2.1E-02	1.2E-01
DICHLOROPROPENE, 1,3-	4.6E-02	Groundwater Protection	5.0E+02	-			7.7E-01	1.0E-01	4.6E-02
DIELDRIN	2.3E-03	Groundwater Protection	1.0E+03	4.0E+00			3.0E-02		2.3E-03
DIETHYLPHTHALATE	3.5E-02	Groundwater Protection	5.0E+02	-			4.9E+04		3.5E-02
DIMETHYLPHENOL, 2,4-	7.3E-01	Groundwater Protection	1.0E+02	-			1.2E+03		7.3E-01
DIMETHYLPHTHALATE	3.5E-02	Groundwater Protection	5.0E+02	-			6.1E+05		3.5E-02
DINITROPHENOL, 2,4-	2.1E-01	Groundwater Protection	5.0E+02	-			1.2E+02		2.1E-01
DINITROTOLUENE, 2,4-	2.5E-01	Groundwater Protection	5.0E+02	-			1.2E+02		2.5E-01
DIOXANE, 1,4-	3.7E-03	Groundwater Protection	5.0E+02	-			4.4E+01		3.7E-03
DIOXIN (2,3,7,8-TCDD)	3.9E-06	Direct Exposure	NA	-			3.9E-06		1.0E+06
ENDOSULFAN	4.6E-03	Groundwater Protection	5.0E+02	-			3.7E+02		4.6E-03
ENDRIN	6.5E-04	Groundwater Protection	5.0E+02	6.0E-02			1.8E+01		6.5E-04
ETHYLBENZENE	3.3E+00	Groundwater Protection	4.0E+02	-			4.0E+02	3.9E+02	3.3E+00
FLUORANTHENE	4.0E+01	Ecotoxicity	5.0E+02	4.0E+01			2.3E+03		6.0E+01
FLUORENE	8.9E+00	Groundwater Protection	5.0E+02	-			2.7E+03	1.6E+02	8.9E+00
HEPTACHLOR	1.3E-02	Groundwater Protection	1.0E+03	-			1.1E-01		1.3E-02
HEPTACHLOR EPOXIDE	1.4E-02	Groundwater Protection	1.0E+03	-			5.3E-02		1.4E-02
HEXACHLOROBENZENE	3.0E-01	Direct Exposure	5.0E+02	3.0E+01			3.0E-01		7.9E+02

TABLE A-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
							Table I-1	Table C-1b	Table E-1
HEXACHLOROBUTADIENE	4.3E+00	Groundwater Protection	5.0E+02	-			6.2E+00		4.3E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	4.9E-02	Groundwater Protection	5.0E+02	2.0E+00			4.4E-01		4.9E-02
HEXACHLOROETHANE	1.6E+01	Groundwater Protection	5.0E+02	-			3.5E+01		1.6E+01
INDENO(1,2,3-cd)PYRENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01			6.2E+00		2.4E+01
LEAD	2.0E+02 (4.0E+02)	Ecotoxicity (Direct Exposure)	1.0E+03	2.0E+02			4.0E+02		(site-specific)
MERCURY	1.0E+01	Ecotoxicity	5.0E+02	1.0E+01			1.3E+01		(site-specific)
METHOXYCHLOR	1.9E+01	Groundwater Protection	5.0E+02	-			3.1E+02		1.9E+01
METHYL ETHYL KETONE	6.4E+00	Groundwater Protection	5.0E+02	-			2.2E+04	1.9E+04	6.4E+00
METHYL ISOBUTYL KETONE	3.9E+00	Groundwater Protection	1.0E+02	-			5.3E+03	1.7E+04	3.9E+00
METHYL MERCURY	6.1E+00	Direct Exposure	1.0E+02	1.0E+01			6.1E+00		(site-specific)
METHYL TERT BUTYL ETHER	2.3E-02	Groundwater Protection	1.0E+02	-			3.1E+01	1.6E+00	2.3E-02
METHYLENE CHLORIDE	6.7E-02	Groundwater Protection	5.0E+02	-			9.2E+00	9.0E-01	6.7E-02
METHYLNAPHTHALENE (total 1- & 2-)	2.5E-01	Groundwater Protection	5.0E+02	-			1.4E+03	1.1E+02	2.5E-01
MOLYBDENUM	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01			3.9E+02		(site-specific)
NAPHTHALENE	1.2E+00	Groundwater Protection	5.0E+02	4.0E+01			5.5E+01	1.8E+01	1.2E+00
NICKEL	1.5E+02	Ecotoxicity	1.0E+03	1.5E+02			1.6E+03		(site-specific)
PENTACHLOROPHENOL	3.0E+00	Direct Exposure	5.0E+02	5.0E+00			3.0E+00		1.0E+06
PERCHLORATE	7.0E-03	Groundwater Protection	1.0E+03	-			7.8E+00		7.0E-03
PHENANTHRENE	1.1E+01	Groundwater Protection	5.0E+02	4.0E+01			2.8E+03	(Use soil gas)	1.1E+01
PHENOL	7.6E-02	Groundwater Protection	5.0E+02	4.0E+01			1.8E+04		7.6E-02
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	Direct Exposure	5.0E+02	-			1.1E+00		6.3E+00
PYRENE	8.5E+01	Indoor Air Impacts	5.0E+02	-			2.3E+03	8.5E+01	8.5E+01
SELENIUM	1.0E+01	Ecotoxicity	1.0E+03	1.0E+01			3.9E+02		(site-specific)
SILVER	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01			3.9E+02		(site-specific)
STYRENE	1.5E+00	Groundwater Protection	5.0E+02	-			1.5E+03	1.5E+03	1.5E+00
tert-BUTYL ALCOHOL	2.3E-02	Groundwater Protection	1.0E+02	-			7.0E+01	(Use soil gas)	2.3E-02
TETRACHLOROETHANE, 1,1,1,2-	7.6E-03	Groundwater Protection	1.0E+02	-			3.1E+00	(Use soil gas)	7.6E-03
TETRACHLOROETHANE, 1,1,2,2-	9.9E-04	Groundwater Protection	5.0E+02	-			4.1E-01	7.2E-03	9.9E-04
TETRACHLOROETHYLENE	6.9E-02	Indoor Air Impacts	2.3E+02	-			4.8E-01	6.9E-02	7.0E-01
THALLIUM	5.2E+00	Direct Exposure	1.0E+03	-			5.2E+00		(site-specific)
TOLUENE	2.9E+00	Groundwater Protection	5.0E+02	-			6.5E+02	6.5E+02	2.9E+00
TOXAPHENE	4.2E-04	Groundwater Protection	5.0E+02	-			4.0E-01		4.2E-04
TPH (gasolines)	1.0E+02 (2.0E+03)	Ceiling Value (Leaching)	1.0E+02	-			8.0E+02	(Use soil gas)	2.0E+03
TPH (middle distillates)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			8.0E+02	(Use soil gas)	5.0E+03
TPH (residual fuels)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			2.3E+03		5.0E+03
TRICHLOROENZENE, 1,2,4-	1.6E+00	Indoor Air Impacts	5.0E+02	3.0E+01			6.1E+01	1.6E+00	7.6E+00
TRICHLOROETHANE, 1,1,1-	7.8E+00	Groundwater Protection	5.0E+02	-			1.2E+03	3.9E+02	7.8E+00

TABLE A-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
			Table F-2	Table L	Value	Basis	Table I-1	Table C-1b	Table E-1
TRICHLOROETHANE, 1,1,2-	2.6E-02	Indoor Air Impacts	1.0E+02	-			7.2E-01	2.6E-02	7.0E-02
TRICHLOROETHYLENE	3.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01			5.2E-01	3.6E-02	4.6E-01
TRICHLOROPHENOL, 2,4,5-	1.8E-01	Groundwater Protection	1.0E+02	1.0E+01			2.5E+03	9.5E+01	1.8E-01
TRICHLOROPHENOL, 2,4,6-	1.2E+00	Groundwater Protection	5.0E+02	1.0E+01			6.1E+00		1.2E+00
VANADIUM	7.8E+01	Direct Exposure	1.0E+03	2.0E+02			7.8E+01		(site-specific)
VINYL CHLORIDE	3.9E-02	Indoor Air Impacts	5.0E+02	6.0E+01			1.5E-01	3.9E-02	3.4E-01
XYLENES	2.3E+00	Groundwater Protection	4.2E+02	-			2.7E+02	1.8E+02	2.3E+00
ZINC	6.0E+02	Ecotoxicity	1.0E+03	6.0E+02			2.3E+04		(site-specific)
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0		-	-			-	-	-
Sodium Adsorption Ratio	5.0		-	-			-	-	-

Notes:

- Assumes current or future residential land use.
- Based primarily on phytotoxicity. Included in selection of final soil action levels if less than one-half of the residential soil screening level for human-health, direct-exposure concerns (see Table L and Section 3.9 in text).

Final Soil Action Level is lowest of ceiling value (nuisance concerns etc.), ecotoxicity, direct-exposure, indoor-air impact, and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Section 6.2).
TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Use of leaching based action levels noted in parentheses may be appropriate for deep or otherwise isolated soils that do not threaten a drinking water resource or sensitive aquatic habitat. Refer to Section 2.2.2 in Volume 1.
Background arsenic in soils - assumed maximum (refer to Section 6.1 in text).

TABLE B-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)									
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)	
			Table F-2		Table L	Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b	NON-Drinking Water Resource Table E-1
ACENAPHTHENE	1.3E+02	Indoor Air Impacts	1.0E+03	-				3.7E+03	1.3E+02	1.6E+02
ACENAPHTHYLENE	1.3E+02	Groundwater Protection	5.0E+02	-				1.3E+03	(Use soil gas)	1.3E+02
ACETONE	5.0E-01	Groundwater Protection	5.0E+02	-				1.4E+04	5.6E+03	5.0E-01
ALDRIN	2.9E-02	Direct Exposure	1.0E+03	3.5E-01				2.9E-02		1.1E+01
ANTHRACENE	2.8E+00	Groundwater Protection	5.0E+02	4.0E+01				2.2E+04	6.1E+00	2.8E+00
ANTIMONY	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01				3.1E+01		(site-specific)
ARSENIC	2.2E+01	Background	1.0E+03	2.0E+01	2.2E+01	Background		4.2E-01		(site-specific)
BARIUM	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02				5.4E+03		(site-specific)
BENZENE	5.3E-01	Indoor Air Impacts	5.0E+02	2.5E+01				6.4E-01	5.3E-01	7.0E+01
BENZO(a)ANTHRACENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01				6.2E+00		1.2E+01
BENZO(a)PYRENE	6.2E-01	Direct Exposure	5.0E+02	4.0E+01				6.2E-01		1.3E+02
BENZO(b)FLUORANTHENE	6.2E+00	Direct Exposure	5.0E+02	-				6.2E+00		4.6E+01
BENZO(g,h,i)PERYLENE	2.7E+01	Groundwater Protection	5.0E+02	4.0E+01				2.3E+03		2.7E+01
BENZO(k)FLUORANTHENE	3.7E+01	Groundwater Protection	5.0E+02	4.0E+01				6.2E+01		3.7E+01
BERYLLIUM	4.0E+00	Ecotoxicity	1.0E+03	4.0E+00				1.5E+02		(site-specific)
BIPHENYL, 1,1-	6.5E+00	Groundwater Protection	5.0E+02	-				3.0E+03	(Use soil gas)	6.5E+00
BIS(2-CHLOROETHYL)ETHER	6.7E-03	Indoor Air Impacts	5.0E+02	-				2.0E-01	6.7E-03	1.3E+00
BIS(2-CHLOROISOPROPYL)ETHER	2.9E+00	Direct Exposure	5.0E+02	-				2.9E+00	(Use soil gas)	3.5E+01
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	Direct Exposure	5.0E+02	-				3.5E+01		7.8E+02
BORON	1.6E+00	Ecotoxicity	1.0E+02	1.6E+00				1.2E+04		(site-specific)
BROMODICHLOROMETHANE	2.3E-02	Indoor Air Impacts	1.0E+03	-				8.2E-01	2.3E-02	5.1E+00
BROMOFORM	6.1E+01	Direct Exposure	5.0E+02	-				6.1E+01		1.1E+02
BROMOMETHANE	8.6E-01	Indoor Air Impacts	5.0E+02	-				3.8E+00	8.6E-01	9.3E+01
CADMIUM	1.2E+01	Ecotoxicity	1.0E+03	1.2E+01				3.9E+01		(site-specific)
CARBON TETRACHLORIDE	2.7E-02	Indoor Air Impacts	5.0E+02	-				2.5E-01	2.7E-02	4.5E+00
CHLORDANE	1.6E+00	Direct Exposure	1.0E+03	-				1.6E+00		1.5E+01
CHLOROANILINE, p-	5.3E-02	Groundwater Protection	1.0E+03	-				2.4E+02		5.3E-02
CHLOROBENZENE	9.5E+00	Groundwater Protection	5.0E+02	3.0E+01				1.5E+02	1.0E+01	9.5E+00
CHLOROETHANE	2.7E-01	Groundwater Protection	5.0E+02	-				3.0E+00	5.0E-01	2.7E-01
CHLOROFORM	1.8E-02	Indoor Air Impacts	5.0E+02	-				2.2E-01	1.8E-02	1.8E+00
CHLOROMETHANE	1.6E+01	Indoor Air Impacts	1.0E+02	-				4.6E+01	1.6E+01	1.5E+03
CHLOROPHENOL, 2-	1.2E-01	Groundwater Protection	1.0E+02	1.0E+01				6.3E+01	3.4E+00	1.2E-01
CHROMIUM (Total)	2.1E+02	Direct Exposure	1.0E+03	-				2.1E+02		(site-specific)
CHROMIUM III	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02				1.2E+05		(site-specific)
CHROMIUM VI	8.0E+00	Ecotoxicity	1.0E+03	8.0E+00				3.0E+01		(site-specific)
CHRYSENE	2.3E+01	Groundwater Protection	1.0E+03	4.0E+01				6.2E+02	(Use soil gas)	2.3E+01
COBALT	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01				5.2E+02		(site-specific)
COPPER	2.3E+02	Ecotoxicity	1.0E+03	2.3E+02				3.1E+03		(site-specific)

TABLE B-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.) Table F-2	² Urban Area Ecotoxicity Criteria Table L	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
					Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b	NON-Drinking Water Resource Table E-1
CYANIDE (Free)	1.0E+02	Ceiling Value	1.0E+02	-			1.2E+03	(Use soil gas)	1.2E+04
DIBENZO(a,h)ANTHTRACENE	6.2E-01	Direct Exposure	5.0E+02	-			6.2E-01		1.4E+02
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	Groundwater Protection	5.0E+02	-			4.5E-01	(Use soil gas)	9.0E-04
DIBROMOCHLOROMETHANE	1.7E-02	Indoor Air Impacts	1.0E+02	-			1.1E+00	1.7E-02	1.3E+01
DIBROMOETHANE, 1,2-	7.2E-04	Indoor Air Impacts	5.0E+02	-			3.2E-02	7.2E-04	1.5E-01
DICHLOROBENZENE, 1,2-	1.1E+01	Groundwater Protection	6.0E+02	3.0E+01			6.0E+02	3.5E+01	1.1E+01
DICHLOROBENZENE, 1,3-	3.0E+01	Ecotoxicity	1.0E+02	3.0E+01			5.3E+02	(Use soil gas)	4.2E+01
DICHLOROBENZENE, 1,4-	6.5E-02	Indoor Air Impacts	5.0E+02	3.0E+01			3.4E+00	6.5E-02	1.3E+01
DICHLOROBENZIDINE, 3,3-	1.1E+00	Direct Exposure	5.0E+02	-			1.1E+00		6.6E+01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	Direct Exposure	5.0E+02	-			2.4E+00		7.5E+02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	Direct Exposure	5.0E+02	4.0E+00			2.4E+00		1.0E+04
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	Direct Exposure	1.0E+03	4.0E+00			1.7E+00		4.3E+00
DICHLOROETHANE, 1,1-	1.9E+00	Groundwater Protection	5.0E+02	-			4.9E+02	8.6E+01	1.9E+00
DICHLOROETHANE, 1,2-	1.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01			2.7E-01	1.6E-02	1.2E+00
DICHLOROETHYLENE, 1,1-	3.5E+01	Indoor Air Impacts	5.0E+02	-			1.2E+02	3.5E+01	6.7E+02
DICHLOROETHYLENE, Cis 1,2-	6.2E+00	Indoor Air Impacts	1.0E+02	-			4.2E+01	6.2E+00	3.6E+02
DICHLOROETHYLENE, Trans 1,2-	1.2E+01	Indoor Air Impacts	5.0E+02	-			6.9E+01	1.2E+01	1.7E+02
DICHLOROPHENOL, 2,4-	3.0E+00	Groundwater Protection	5.0E+02	1.0E+01			1.8E+02		3.0E+00
DICHLOROPROPANE, 1,2-	2.1E-02	Indoor Air Impacts	1.0E+02	-			3.4E-01	2.1E-02	2.5E+00
DICHLOROPROPENE, 1,3-	1.0E-01	Indoor Air Impacts	5.0E+02	-			7.7E-01	1.0E-01	1.8E+01
DIELDRIN	3.0E-02	Direct Exposure	1.0E+03	4.0E+00			3.0E-02		8.7E-01
DIETHYLPHTHALATE	2.2E+01	Groundwater Protection	5.0E+02	-			4.9E+04		2.2E+01
DIMETHYLPHENOL, 2,4-	1.8E+00	Groundwater Protection	1.0E+02	-			1.2E+03		1.8E+00
DIMETHYLPHTHALATE	2.2E+01	Groundwater Protection	5.0E+02	-			6.1E+05		2.2E+01
DINITROPHENOL, 2,4-	6.5E-01	Groundwater Protection	5.0E+02	-			1.2E+02		6.5E-01
DINITROTOLUENE, 2,4-	1.5E+00	Groundwater Protection	5.0E+02	-			1.2E+02		1.5E+00
DIOXANE, 1,4-	3.0E+01	Groundwater Protection	5.0E+02	-			4.4E+01		3.0E+01
DIOXIN (2,3,7,8-TCDD)	3.9E-06	Direct Exposure	NA	-			3.9E-06		1.0E+06
ENDOSULFAN	1.8E-02	Groundwater Protection	5.0E+02	-			3.7E+02		1.8E-02
ENDRIN	1.0E-02	Groundwater Protection	5.0E+02	6.0E-02			1.8E+01		1.0E-02
ETHYLBENZENE	3.3E+01	Groundwater Protection	4.0E+02	-			4.0E+02	3.9E+02	3.3E+01
FLUORANTHENE	4.0E+01	Ecotoxicity	5.0E+02	4.0E+01			2.3E+03		2.5E+02
FLUORENE	1.6E+02	Indoor Air Impacts	5.0E+02	-			2.7E+03	1.6E+02	6.9E+02
HEPTACHLOR	1.1E-01	Direct Exposure	1.0E+03	-			1.1E-01		1.9E-01
HEPTACHLOR EPOXIDE	5.3E-02	Direct Exposure	1.0E+03	-			5.3E-02		2.0E-01
HEXACHLOROBENZENE	3.0E-01	Direct Exposure	5.0E+02	3.0E+01			3.0E-01		1.2E+03
HEXACHLOROBUTADIENE	6.2E+00	Direct Exposure	5.0E+02	-			6.2E+00		5.5E+01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	9.8E-02	Groundwater Protection	5.0E+02	2.0E+00			4.4E-01		9.8E-02

TABLE B-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.) Table F-2	² Urban Area Ecotoxicity Criteria Table L	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
					Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b	NON-Drinking Water Resource Table E-1
HEXACHLOROETHANE	3.5E+01	Direct Exposure	5.0E+02	-			3.5E+01		3.4E+02
INDENO(1,2,3-cd)PYRENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01			6.2E+00		2.4E+01
LEAD	2.0E+02 (4.0E+02)	Ecotoxicity (Direct Exposure)	1.0E+03	2.0E+02			4.0E+02		(site-specific)
MERCURY	1.0E+01	Ecotoxicity	5.0E+02	1.0E+01			1.3E+01		(site-specific)
METHOXYCHLOR	1.9E+01	Groundwater Protection	5.0E+02	-			3.1E+02		1.9E+01
METHYL ETHYL KETONE	1.3E+01	Groundwater Protection	5.0E+02	-			2.2E+04	1.9E+04	1.3E+01
METHYL ISOBUTYL KETONE	3.9E+00	Groundwater Protection	1.0E+02	-			5.3E+03	1.7E+04	3.9E+00
METHYL MERCURY	6.1E+00	Direct Exposure	1.0E+02	1.0E+01			6.1E+00		(site-specific)
METHYL TERT BUTYL ETHER	1.6E+00	Indoor Air Impacts	1.0E+02	-			3.1E+01	1.6E+00	8.4E+00
METHYLENE CHLORIDE	9.0E-01	Indoor Air Impacts	5.0E+02	-			9.2E+00	9.0E-01	6.5E+01
METHYLNAPHTHALENE (total 1- & 2-)	1.2E+01	Groundwater Protection	5.0E+02	-			1.4E+03	1.1E+02	1.2E+01
MOLYBDENUM	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01			3.9E+02		(site-specific)
NAPHTHALENE	1.8E+01	Indoor Air Impacts	5.0E+02	4.0E+01			5.5E+01	1.8E+01	4.2E+01
NICKEL	1.5E+02	Ecotoxicity	1.0E+03	1.5E+02			1.6E+03		(site-specific)
PENTACHLOROPHENOL	3.0E+00	Direct Exposure	5.0E+02	5.0E+00			3.0E+00		1.0E+06
PERCHLORATE	1.2E+00	Groundwater Protection	1.0E+03	-			7.8E+00		1.2E+00
PHENANTHRENE	1.8E+01	Groundwater Protection	5.0E+02	4.0E+01			2.8E+03	(Use soil gas)	1.8E+01
PHENOL	4.0E+01	Ecotoxicity	5.0E+02	4.0E+01			1.8E+04		5.1E+01
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	Direct Exposure	5.0E+02	-			1.1E+00		1.1E+01
PYRENE	8.5E+01	Indoor Air Impacts	5.0E+02	-			2.3E+03	8.5E+01	8.5E+01
SELENIUM	1.0E+01	Ecotoxicity	1.0E+03	1.0E+01			3.9E+02		(site-specific)
SILVER	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01			3.9E+02		(site-specific)
STYRENE	1.5E+01	Groundwater Protection	5.0E+02	-			1.5E+03	1.5E+03	1.5E+01
tert-BUTYL ALCOHOL	7.0E+01	Direct Exposure	1.0E+02	-			7.0E+01	(Use soil gas)	3.1E+02
TETRACHLOROETHANE, 1,1,1,2-	3.1E+00	Direct Exposure	1.0E+02	-			3.1E+00	(Use soil gas)	5.5E+01
TETRACHLOROETHANE, 1,1,2,2-	7.2E-03	Indoor Air Impacts	5.0E+02	-			4.1E-01	7.2E-03	2.7E+00
TETRACHLOROETHYLENE	6.9E-02	Indoor Air Impacts	2.3E+02	-			4.8E-01	6.9E-02	1.4E+01
THALLIUM	5.2E+00	Direct Exposure	1.0E+03	-			5.2E+00		(site-specific)
TOLUENE	2.9E+01	Groundwater Protection	5.0E+02	-			6.5E+02	6.5E+02	2.9E+01
TOXAPHENE	4.0E-01	Direct Exposure	5.0E+02	-			4.0E-01		4.4E-01
TPH (gasolines)	1.0E+02 (2.0E+03)	Ceiling Value (Leaching)	1.0E+02	-			8.0E+02	(Use soil gas)	2.0E+03
TPH (middle distillates)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			8.0E+02	(Use soil gas)	5.0E+03
TPH (residual fuels)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-			2.3E+03		5.0E+03
TRICHLOROENZENE, 1,2,4-	1.6E+00	Indoor Air Impacts	5.0E+02	3.0E+01			6.1E+01	1.6E+00	4.9E+01
TRICHLOROETHANE, 1,1,1-	3.9E+02	Indoor Air Impacts	5.0E+02	-			1.2E+03	3.9E+02	7.5E+02
TRICHLOROETHANE, 1,1,2-	2.6E-02	Indoor Air Impacts	1.0E+02	-			7.2E-01	2.6E-02	3.9E+00
TRICHLOROETHYLENE	3.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01			5.2E-01	3.6E-02	6.8E+00
TRICHLOROPHENOL, 2,4,5-	1.6E+00	Groundwater Protection	1.0E+02	1.0E+01			2.5E+03	9.5E+01	1.6E+00

TABLE B-1. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS NOT located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.) Table F-2	² Urban Area Ecotoxicity Criteria Table L	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
					Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b	NON-Drinking Water Resource Table E-1
TRICHLOROPHENOL, 2,4,6-	6.1E+00	Direct Exposure	5.0E+02	1.0E+01			6.1E+00		1.6E+02
VANADIUM	7.8E+01	Direct Exposure	1.0E+03	2.0E+02			7.8E+01		(site-specific)
VINYL CHLORIDE	3.9E-02	Indoor Air Impacts	5.0E+02	6.0E+01			1.5E-01	3.9E-02	3.8E+00
XYLENES	1.8E+02	Indoor Air Impacts	4.2E+02	-			2.7E+02	1.8E+02	2.3E+02
ZINC	6.0E+02	Ecotoxicity	1.0E+03	6.0E+02			2.3E+04		(site-specific)
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0		-	-			-	-	-
Sodium Adsorption Ratio	5.0		-	-			-	-	-

Notes:

- Assumes current or future residential land use.
- Based primarily on phytotoxicity. Included in selection of final soil action levels if less than one-half of the residential soil screening level for human-health, direct-exposure concerns (see Table L and Section 3.9 in text).

Final Soil Action Level is lowest of ceiling value (nuisance concerns etc.), ecotoxicity, direct-exposure, indoor-air impact, and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Section 6.2).
TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Use of leaching based action levels noted in parentheses may be appropriate for deep or otherwise isolated soils that do not threaten a drinking water resource or sensitive aquatic habitat. Refer to Section 2.2.2 in Volume 1.
Background arsenic in soils - assumed maximum (refer to Section 6.1 in text).

TABLE B-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)									
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)	
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns	NON-Drinking Water Resource
Table E-1	Table I-1	Table C-1b	Table E-1							
ACENAPHTHENE	1.9E+01	Groundwater Protection	1.0E+03	-				3.7E+03	1.3E+02	1.9E+01
ACENAPHTHYLENE	1.3E+01	Groundwater Protection	5.0E+02	-				1.3E+03	(Use soil gas)	1.3E+01
ACETONE	5.0E-01	Groundwater Protection	5.0E+02	-				1.4E+04	5.6E+03	5.0E-01
ALDRIN	2.9E-02	Direct Exposure	1.0E+03	3.5E-01				2.9E-02		5.0E+00
ANTHRACENE	2.8E+00	Groundwater Protection	5.0E+02	4.0E+01				2.2E+04	6.1E+00	2.8E+00
ANTIMONY	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01				3.1E+01		(site-specific)
ARSENIC	2.2E+01	Background	1.0E+03	2.0E+01	2.2E+01	Background		4.2E-01		(site-specific)
BARIUM	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02				5.4E+03		(site-specific)
BENZENE	5.3E-01	Indoor Air Impacts	5.0E+02	2.5E+01				6.4E-01	5.3E-01	2.0E+00
BENZO(a)ANTHRACENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01				6.2E+00		1.2E+01
BENZO(a)PYRENE	6.2E-01	Direct Exposure	5.0E+02	4.0E+01				6.2E-01		1.3E+02
BENZO(b)FLUORANTHENE	6.2E+00	Direct Exposure	5.0E+02	-				6.2E+00		4.6E+01
BENZO(g,h,i)PERYLENE	2.7E+01	Groundwater Protection	5.0E+02	4.0E+01				2.3E+03		2.7E+01
BENZO(k)FLUORANTHENE	3.7E+01	Groundwater Protection	5.0E+02	4.0E+01				6.2E+01		3.7E+01
BERYLLIUM	4.0E+00	Ecotoxicity	1.0E+03	4.0E+00				1.5E+02		(site-specific)
BIPHENYL, 1,1-	6.5E+00	Groundwater Protection	5.0E+02	-				3.0E+03	(Use soil gas)	6.5E+00
BIS(2-CHLOROETHYL)ETHER	6.7E-03	Indoor Air Impacts	5.0E+02	-				2.0E-01	6.7E-03	7.8E-01
BIS(2-CHLOROISOPROPYL)ETHER	6.6E-01	Groundwater Protection	5.0E+02	-				2.9E+00	(Use soil gas)	6.6E-01
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	Direct Exposure	5.0E+02	-				3.5E+01		7.8E+02
BORON	1.6E+00	Ecotoxicity	1.0E+02	1.6E+00				1.2E+04		(site-specific)
BROMODICHLOROMETHANE	2.3E-02	Indoor Air Impacts	1.0E+03	-				8.2E-01	2.3E-02	5.1E+00
BROMOFORM	6.1E+01	Direct Exposure	5.0E+02	-				6.1E+01		6.9E+01
BROMOMETHANE	8.6E-01	Indoor Air Impacts	5.0E+02	-				3.8E+00	8.6E-01	6.4E+00
CADMIUM	1.2E+01	Ecotoxicity	1.0E+03	1.2E+01				3.9E+01		(site-specific)
CARBON TETRACHLORIDE	2.7E-02	Indoor Air Impacts	5.0E+02	-				2.5E-01	2.7E-02	2.1E+00
CHLORDANE	1.6E+00	Direct Exposure	1.0E+03	-				1.6E+00		1.5E+01
CHLOROANILINE, p-	5.3E-02	Groundwater Protection	1.0E+03	-				2.4E+02		5.3E-02
CHLOROBENZENE	1.5E+00	Groundwater Protection	5.0E+02	3.0E+01				1.5E+02	1.0E+01	1.5E+00
CHLOROETHANE	2.7E-01	Groundwater Protection	5.0E+02	-				3.0E+00	5.0E-01	2.7E-01
CHLOROFORM	1.8E-02	Indoor Air Impacts	5.0E+02	-				2.2E-01	1.8E-02	1.8E+00
CHLOROMETHANE	1.6E+01	Indoor Air Impacts	1.0E+02	-				4.6E+01	1.6E+01	5.0E+02
CHLOROPHENOL, 2-	1.2E-01	Groundwater Protection	1.0E+02	1.0E+01				6.3E+01	3.4E+00	1.2E-01
CHROMIUM (Total)	2.1E+02	Direct Exposure	1.0E+03	-				2.1E+02		(site-specific)
CHROMIUM III	7.5E+02	Ecotoxicity	1.0E+03	7.5E+02				1.2E+05		(site-specific)
CHROMIUM VI	8.0E+00	Ecotoxicity	1.0E+03	8.0E+00				3.0E+01		(site-specific)
CHRYSENE	2.3E+01	Groundwater Protection	1.0E+03	4.0E+01				6.2E+02	(Use soil gas)	2.3E+01
COBALT	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01				5.2E+02		(site-specific)
COPPER	2.3E+02	Ecotoxicity	1.0E+03	2.3E+02				3.1E+03		(site-specific)

TABLE B-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)									
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)	
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns	NON-Drinking Water Resource
								Table I-1	Table C-1b	Table E-1
CYANIDE (Free)	1.0E+02	Ceiling Value	1.0E+02	-			1.2E+03	(Use soil gas)	1.2E+04	
DIBENZO(a,h)ANTHTRACENE	6.2E-01	Direct Exposure	5.0E+02	-			6.2E-01		1.4E+02	
DIBROMO-3-CHLOROPROPANE, 1,2-	9.0E-04	Groundwater Protection	5.0E+02	-			4.5E-01	(Use soil gas)	9.0E-04	
DIBROMOCHLOROMETHANE	1.7E-02	Indoor Air Impacts	1.0E+02	-			1.1E+00	1.7E-02	1.3E+01	
DIBROMOETHANE, 1,2-	7.2E-04	Indoor Air Impacts	5.0E+02	-			3.2E-02	7.2E-04	1.5E-01	
DICHLOROENZENE, 1,2-	1.6E+00	Groundwater Protection	6.0E+02	3.0E+01			6.0E+02	3.5E+01	1.6E+00	
DICHLOROENZENE, 1,3-	7.4E+00	Groundwater Protection	1.0E+02	3.0E+01			5.3E+02	(Use soil gas)	7.4E+00	
DICHLOROENZENE, 1,4-	6.5E-02	Indoor Air Impacts	5.0E+02	3.0E+01			3.4E+00	6.5E-02	1.8E+00	
DICHLOROENZIDINE, 3,3-	1.1E+00	Direct Exposure	5.0E+02	-			1.1E+00		6.6E+01	
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	Direct Exposure	5.0E+02	-			2.4E+00		7.5E+02	
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	Direct Exposure	5.0E+02	4.0E+00			2.4E+00		1.1E+03	
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	Direct Exposure	1.0E+03	4.0E+00			1.7E+00		4.3E+00	
DICHLOROETHANE, 1,1-	1.9E+00	Groundwater Protection	5.0E+02	-			4.9E+02	8.6E+01	1.9E+00	
DICHLOROETHANE, 1,2-	1.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01			2.7E-01	1.6E-02	1.2E+00	
DICHLOROETHYLENE, 1,1-	4.3E+00	Groundwater Protection	5.0E+02	-			1.2E+02	3.5E+01	4.3E+00	
DICHLOROETHYLENE, Cis 1,2-	6.2E+00	Indoor Air Impacts	1.0E+02	-			4.2E+01	6.2E+00	1.8E+01	
DICHLOROETHYLENE, Trans 1,2-	1.2E+01	Indoor Air Impacts	5.0E+02	-			6.9E+01	1.2E+01	3.9E+01	
DICHLOROPHENOL, 2,4-	3.0E+00	Groundwater Protection	5.0E+02	1.0E+01			1.8E+02		3.0E+00	
DICHLOROPROPANE, 1,2-	2.1E-02	Indoor Air Impacts	1.0E+02	-			3.4E-01	2.1E-02	2.5E+00	
DICHLOROPROPENE, 1,3-	1.0E-01	Indoor Air Impacts	5.0E+02	-			7.7E-01	1.0E-01	1.4E+01	
DIELDRIN	2.3E-03	Groundwater Protection	1.0E+03	4.0E+00			3.0E-02		2.3E-03	
DIETHYLPHTHALATE	3.5E-02	Groundwater Protection	5.0E+02	-			4.9E+04		3.5E-02	
DIMETHYLPHENOL, 2,4-	7.3E-01	Groundwater Protection	1.0E+02	-			1.2E+03		7.3E-01	
DIMETHYLPHTHALATE	3.5E-02	Groundwater Protection	5.0E+02	-			6.1E+05		3.5E-02	
DINITROPHENOL, 2,4-	2.1E-01	Groundwater Protection	5.0E+02	-			1.2E+02		2.1E-01	
DINITROTOLUENE, 2,4-	8.6E-01	Groundwater Protection	5.0E+02	-			1.2E+02		8.6E-01	
DIOXANE, 1,4-	3.0E+01	Groundwater Protection	5.0E+02	-			4.4E+01		3.0E+01	
DIOXIN (2,3,7,8-TCDD)	3.9E-06	Direct Exposure	NA	-			3.9E-06		1.0E+06	
ENDOSULFAN	4.6E-03	Groundwater Protection	5.0E+02	-			3.7E+02		4.6E-03	
ENDRIN	6.5E-04	Groundwater Protection	5.0E+02	6.0E-02			1.8E+01		6.5E-04	
ETHYLBENZENE	3.2E+01	Groundwater Protection	4.0E+02	-			4.0E+02	3.9E+02	3.2E+01	
FLUORANTHENE	4.0E+01	Ecotoxicity	5.0E+02	4.0E+01			2.3E+03		6.0E+01	
FLUORENE	8.9E+00	Groundwater Protection	5.0E+02	-			2.7E+03	1.6E+02	8.9E+00	
HEPTACHLOR	1.3E-02	Groundwater Protection	1.0E+03	-			1.1E-01		1.3E-02	
HEPTACHLOR EPOXIDE	1.4E-02	Groundwater Protection	1.0E+03	-			5.3E-02		1.4E-02	
HEXACHLOROBENZENE	3.0E-01	Direct Exposure	5.0E+02	3.0E+01			3.0E-01		7.9E+02	
HEXACHLOROBUTADIENE	6.2E+00	Direct Exposure	5.0E+02	-			6.2E+00		2.3E+01	
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	4.9E-02	Groundwater Protection	5.0E+02	2.0E+00			4.4E-01		4.9E-02	

TABLE B-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure Table I-1	Vapor Intrusion Concerns Table C-1b
HEXACHLOROETHANE	3.5E+01	Direct Exposure	5.0E+02	-				3.5E+01	4.1E+01
INDENO(1,2,3-cd)PYRENE	6.2E+00	Direct Exposure	5.0E+02	4.0E+01				6.2E+00	2.4E+01
LEAD	2.0E+02 (4.0E+02)	Ecotoxicity (Direct Exposure)	1.0E+03	2.0E+02				4.0E+02	(site-specific)
MERCURY	1.0E+01	Ecotoxicity	5.0E+02	1.0E+01				1.3E+01	(site-specific)
METHOXYCHLOR	1.9E+01	Groundwater Protection	5.0E+02	-				3.1E+02	1.9E+01
METHYL ETHYL KETONE	1.3E+01	Groundwater Protection	5.0E+02	-				2.2E+04	1.3E+01
METHYL ISOBUTYL KETONE	3.9E+00	Groundwater Protection	1.0E+02	-				5.3E+03	3.9E+00
METHYL MERCURY	6.1E+00	Direct Exposure	1.0E+02	1.0E+01				6.1E+00	(site-specific)
METHYL TERT BUTYL ETHER	1.6E+00	Indoor Air Impacts	1.0E+02	-				3.1E+01	1.6E+00
METHYLENE CHLORIDE	9.0E-01	Indoor Air Impacts	5.0E+02	-				9.2E+00	9.0E-01
METHYLNAPHTHALENE (total 1- & 2-)	2.5E-01	Groundwater Protection	5.0E+02	-				1.4E+03	2.5E-01
MOLYBDENUM	4.0E+01	Ecotoxicity	1.0E+03	4.0E+01				3.9E+02	(site-specific)
NAPHTHALENE	4.8E+00	Groundwater Protection	5.0E+02	4.0E+01				5.5E+01	4.8E+00
NICKEL	1.5E+02	Ecotoxicity	1.0E+03	1.5E+02				1.6E+03	(site-specific)
PENTACHLOROPHENOL	3.0E+00	Direct Exposure	5.0E+02	5.0E+00				3.0E+00	1.0E+06
PERCHLORATE	1.2E+00	Groundwater Protection	1.0E+03	-				7.8E+00	1.2E+00
PHENANTHRENE	1.1E+01	Groundwater Protection	5.0E+02	4.0E+01				2.8E+03	(Use soil gas)
PHENOL	1.9E+01	Groundwater Protection	5.0E+02	4.0E+01				1.8E+04	1.9E+01
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	Direct Exposure	5.0E+02	-				1.1E+00	6.3E+00
PYRENE	8.5E+01	Indoor Air Impacts	5.0E+02	-				2.3E+03	8.5E+01
SELENIUM	1.0E+01	Ecotoxicity	1.0E+03	1.0E+01				3.9E+02	(site-specific)
SILVER	2.0E+01	Ecotoxicity	1.0E+03	2.0E+01				3.9E+02	(site-specific)
STYRENE	1.5E+01	Groundwater Protection	5.0E+02	-				1.5E+03	1.5E+01
tert-BUTYL ALCOHOL	7.0E+01	Direct Exposure	1.0E+02	-				7.0E+01	(Use soil gas)
TETRACHLOROETHANE, 1,1,1,2-	3.1E+00	Direct Exposure	1.0E+02	-				3.1E+00	(Use soil gas)
TETRACHLOROETHANE, 1,1,2,2-	7.2E-03	Indoor Air Impacts	5.0E+02	-				4.1E-01	7.2E-03
TETRACHLOROETHYLENE	6.9E-02	Indoor Air Impacts	2.3E+02	-				4.8E-01	6.9E-02
THALLIUM	5.2E+00	Direct Exposure	1.0E+03	-				5.2E+00	(site-specific)
TOLUENE	9.3E+00	Groundwater Protection	5.0E+02	-				6.5E+02	6.5E+02
TOXAPHENE	4.2E-04	Groundwater Protection	5.0E+02	-				4.0E-01	4.2E-04
TPH (gasolines)	1.0E+02 (2.0E+03)	Ceiling Value (Leaching)	1.0E+02	-				8.0E+02	(Use soil gas)
TPH (middle distillates)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-				8.0E+02	(Use soil gas)
TPH (residual fuels)	5.0E+02 (5.0E+03)	Ceiling Value (Leaching)	5.0E+02	-				2.3E+03	5.0E+03
TRICHLOROBENZENE, 1,2,4-	1.6E+00	Indoor Air Impacts	5.0E+02	3.0E+01				6.1E+01	1.6E+00
TRICHLOROETHANE, 1,1,1-	7.8E+00	Groundwater Protection	5.0E+02	-				1.2E+03	3.9E+02
TRICHLOROETHANE, 1,1,2-	2.6E-02	Indoor Air Impacts	1.0E+02	-				7.2E-01	2.6E-02
TRICHLOROETHYLENE	3.6E-02	Indoor Air Impacts	5.0E+02	6.0E+01				5.2E-01	3.6E-02
TRICHLOROPHENOL, 2,4,5-	1.8E-01	Groundwater Protection	1.0E+02	1.0E+01				2.5E+03	9.5E+01

TABLE B-2. SOIL ACTION LEVELS
(Potentially impacted groundwater IS NOT a current or potential drinking water resource;
Surface water body IS located within 150m of release site)

CONTAMINANT	(mg/kg)								
	Final SAL	Basis	Gross Contamination Ceiling Value (Odors, etc.)	² Urban Area Ecotoxicity Criteria	Other		¹ Human Health		Groundwater Protection (Soil Leaching)
			Table F-2		Table L	Value	Basis	Direct Exposure	Vapor Intrusion Concerns
							Table I-1	Table C-1b	Table E-1
TRICHLOROPHENOL, 2,4,6-	6.1E+00	Direct Exposure	5.0E+02	1.0E+01			6.1E+00		1.6E+02
VANADIUM	7.8E+01	Direct Exposure	1.0E+03	2.0E+02			7.8E+01		(site-specific)
VINYL CHLORIDE	3.9E-02	Indoor Air Impacts	5.0E+02	6.0E+01			1.5E-01	3.9E-02	3.8E+00
XYLENES	1.1E+01	Groundwater Protection	4.2E+02	-			2.7E+02	1.8E+02	1.1E+01
ZINC	6.0E+02	Ecotoxicity	1.0E+03	6.0E+02			2.3E+04		(site-specific)
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0		-	-			-	-	-
Sodium Adsorption Ratio	5.0		-	-			-	-	-

Notes:
1. Assumes current or future residential land use.
2. Based primarily on phytotoxicity. Included in selection of final soil action levels if less than one-half of the residential soil screening level for human-health, direct-exposure concerns (see Table L and Section 3.9 in text).
Final Soil Action Level is lowest of ceiling value (nuisance concerns etc.), ecotoxicity, direct-exposure, indoor-air impact, and leaching action levels.
Assumes soil pH 5.0 to 9.0.
Soil data should be reported on dry-weight basis (see Section 6.2).
TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Use of leaching based action levels noted in parentheses may be appropriate for deep or otherwise isolated soils that do not threaten a drinking water resource or sensitive aquatic habitat. Refer to Section 2.2.2 in Volume 1.
Background arsenic in soils - assumed maximum (refer to Section 6.1 in text).

**TABLE C-1a. GROUNDWATER ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		^{1,4} Residential Land Use		Commercial/Industrial Land Use	
			Vadose-Zone Soil Type		Vadose-Zone Soil Type	
			² High Permeability	³ Low/Moderate Permeability	² High Permeability	³ Low/Moderate Permeability
			(ug/L)	(ug/L)	(ug/L)	(ug/L)
#ACENAPHTHENE	V	S	4.2E+03	4.2E+03	4.2E+03	4.2E+03
ACENAPHTHYLENE	V	S	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
#ACETONE	V	L	2.1E+08	2.8E+08	7.5E+08	1.0E+09
ALDRIN	NV	S				
#ANTHRACENE	V	S	4.3E+01	4.3E+01	4.3E+01	4.3E+01
ANTIMONY	NV	S				
ARSENIC	NV	S				
BARIUM	NV	S				
#BENZENE	V	L	1.6E+03	5.7E+03	6.7E+03	2.4E+04
BENZO(a)ANTHRACENE	NV	S				
BENZO(a)PYRENE	NV	S				
BENZO(b)FLUORANTHENE	NV	S				
BENZO(g,h,i)PERYLENE	NV	S				
BENZO(k)FLUORANTHENE	NV	S				
BERYLLIUM	NV	S				
BIPHENYL, 1,1-	V	S	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
BIS(2-CHLOROETHYL)ETHER	V	L	1.0E+02	1.4E+02	4.4E+02	5.8E+02
BIS(2-CHLOROISOPROPYL)ETHER	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S				
BORON	NV	S				
BROMODICHLOROMETHANE	V	L	2.7E+02	5.1E+02	1.1E+03	2.2E+03
BROMOFORM	NV	S				
BROMOMETHANE	V	G	2.3E+03	8.0E+03	8.2E+03	2.8E+04
CADMIUM	NV	S				
CARBON TETRACHLORIDE	V	L	2.1E+01	8.9E+01	8.8E+01	3.8E+02
CHLORDANE	NV	S				
CHLOROANILINE, p-	NV	S				
CHLOROBENZENE	V	L	5.3E+04	1.7E+05	1.9E+05	4.7E+05
CHLOROETHANE	V	G	6.5E+02	2.6E+03	2.8E+03	1.1E+04
CHLOROFORM	V	L	6.2E+01	2.1E+02	2.6E+02	9.0E+02
CHLOROMETHANE	V	G	9.5E+03	4.2E+04	3.4E+04	1.5E+05
CHLOROPHENOL, 2-	V	L	2.1E+04	6.3E+04	7.5E+04	2.2E+05
CHROMIUM (Total)	NV	S				
CHROMIUM III	NV	S				
CHROMIUM VI	NV	S				
CHRYSENE	NV	S	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
COBALT	NV	S				
COPPER	NV	S				

**TABLE C-1a. GROUNDWATER ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		^{1,4} Residential Land Use		Commercial/Industrial Land Use	
			Vadose-Zone Soil Type		Vadose-Zone Soil Type	
			² High Permeability	³ Low/Moderate Permeability	² High Permeability	³ Low/Moderate Permeability
			(ug/L)	(ug/L)	(ug/L)	(ug/L)
CYANIDE (Free)	NV	S	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
DIBENZO(a,h)ANTHTRACENE	NV	S				
DIBROMO-3-CHLOROPROPANE, 1,2-	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
DIBROMOCHLOROMETHANE	V	S	1.6E+02	3.7E+02	1.2E+03	2.7E+03
DIBROMOETHANE, 1,2-	V	S	1.6E+01	2.5E+01	6.9E+01	1.1E+02
DICHLOROBENZENE, 1,2-	V	L	1.6E+05	1.6E+05	1.6E+05	1.6E+05
DICHLOROBENZENE, 1,3-	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
DICHLOROBENZENE, 1,4-	V	S	4.9E+02	1.4E+03	2.1E+03	5.9E+03
DICHLOROBENZIDINE, 3,3-	NV	S				
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S				
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S				
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S				
DICHLOROETHANE, 1,1-	V	L	2.8E+05	9.5E+05	9.8E+05	3.4E+06
DICHLOROETHANE, 1,2-	V	L	1.3E+02	3.2E+02	5.5E+02	1.4E+03
DICHLOROETHYLENE, 1,1-	V	L	2.5E+04	1.1E+05	8.8E+04	3.7E+05
DICHLOROETHYLENE, Cis 1,2-	V	L	2.4E+04	7.7E+04	8.6E+04	2.7E+05
DICHLOROETHYLENE, Trans 1,2-	V	L	2.7E+04	9.7E+04	9.4E+04	3.4E+05
DICHLOROPHENOL, 2,4-	NV	S				
DICHLOROPROPANE, 1,2-	V	L	1.2E+02	3.6E+02	5.0E+02	1.5E+03
DICHLOROPROPENE, 1,3-	V	L	1.6E+02	6.2E+02	6.6E+02	2.6E+03
DIELDRIN	NV	S				
DIETHYLPHTHALATE	NV	S				
#DIMETHYLPHENOL, 2,4-	V	S				
DIMETHYLPHTHALATE	NV	S				
DINITROPHENOL, 2,4-	NV	S				
DINITROTOLUENE, 2,4-	NV	S				
DIOXANE, 1,4-	NV	L				
DIOXIN (2,3,7,8-TCDD)	NV	S				
ENDOSULFAN	NV	S				
ENDRIN	NV	S				
#ETHYLBENZENE	V	L	1.7E+05	1.7E+05	1.7E+05	1.7E+05
FLUORANTHENE	NV	S				
#FLUORENE	V	S	1.9E+03	1.9E+03	1.9E+03	1.9E+03
HEPTACHLOR	NV	S				
HEPTACHLOR EPOXIDE	NV	S				
HEXACHLOROBENZENE	NV	S				
HEXACHLOROBUTADIENE	NV	S				

**TABLE C-1a. GROUNDWATER ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		^{1,4} Residential Land Use		Commercial/Industrial Land Use	
			Vadose-Zone Soil Type		Vadose-Zone Soil Type	
			² High Permeability	³ Low/Moderate Permeability	² High Permeability	³ Low/Moderate Permeability
			(ug/L)	(ug/L)	(ug/L)	(ug/L)
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S				
HEXACHLOROETHANE	NV	S				
INDENO(1,2,3-cd)PYRENE	NV	S				
LEAD	NV	S				
MERCURY	NV	S				
METHOXYCHLOR	NV	S				
#METHYL ETHYL KETONE	V	L	2.7E+08	2.7E+08	2.7E+08	2.7E+08
#METHYL ISOBUTYL KETONE	V	L	1.9E+07	1.9E+07	1.9E+07	1.9E+07
METHYL MERCURY	NV	S				
METHYL TERT BUTYL ETHER	V	L	1.9E+04	3.8E+04	8.0E+04	1.6E+05
METHYLENE CHLORIDE	V	L	4.2E+03	1.2E+04	1.8E+04	5.3E+04
#METHYLNAPHTHALENE (total 1- & 2-)	V	S	2.6E+04	2.6E+04	2.6E+04	2.6E+04
MOLYBDENUM	NV	S				
#NAPHTHALENE	V	S	3.1E+04	3.1E+04	3.1E+04	3.1E+04
NICKEL	NV	S				
PENTACHLOROPHENOL	NV	S				
PERCHLORATE	NV	S				
PHENANTHRENE	V	S	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
PHENOL	NV	S				
POLYCHLORINATED BIPHENYLS (PCBs)	NV	S				
#PYRENE	V	S	1.4E+02	1.4E+02	1.4E+02	1.4E+02
SELENIUM	NV	S				
SILVER	NV	S				
#STYRENE	V	L	3.1E+05	3.1E+05	3.1E+05	3.1E+05
tert-BUTYL ALCOHOL			(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
TETRACHLOROETHANE, 1,1,1,2-	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
TETRACHLOROETHANE, 1,1,2,2-	V	L	1.5E+02	2.5E+02	6.4E+02	1.0E+03
TETRACHLOROETHYLENE	V	L	9.9E+01	4.0E+02	4.2E+02	1.7E+03
THALLIUM	NV	S				
#TOLUENE	V	L	5.3E+05	5.3E+05	5.3E+05	5.3E+05
TOXAPHENE	NV	S				
TPH (gasolines)	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
TPH (middle distillates)	V	L	(Use soil gas)	(Use soil gas)	(Use soil gas)	(Use soil gas)
TPH (residual fuels)	NV	L/S				
TRICHLOROENZENE, 1,2,4-	V	L	1.0E+04	1.8E+04	3.6E+04	6.4E+04
TRICHLOROETHANE, 1,1,1-	V	L	5.0E+05	1.3E+06	1.3E+06	1.3E+06
TRICHLOROETHANE, 1,1,2-	V	L	2.8E+02	6.3E+02	1.2E+03	2.7E+03

**TABLE C-1a. GROUNDWATER ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		^{1,4} Residential Land Use		Commercial/Industrial Land Use	
			Vadose-Zone Soil Type		Vadose-Zone Soil Type	
			² High Permeability	³ Low/Moderate Permeability	² High Permeability	³ Low/Moderate Permeability
			(ug/L)	(ug/L)	(ug/L)	(ug/L)
TRICHLOROETHYLENE	V	L	7.4E+01	2.9E+02	3.1E+02	1.2E+03
TRICHLOROPHENOL, 2,4,5-	V	S	1.2E+06	1.2E+06	1.2E+06	1.2E+06
TRICHLOROPHENOL, 2,4,6-	NV	S				
VANADIUM	NV	S				
VINYL CHLORIDE	V	G	2.2E+01	9.9E+01	2.2E+02	9.8E+02
#XYLENES	V	L	1.6E+05	1.6E+05	1.6E+05	1.6E+05
ZINC	NV	S				

Notes:

- "Residential" action levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).
- High permeability soil model: One meter dry sandy soil (92% sand, 5% silt, 3% clay) over one meter moist clayey loam (33% sand, 34% silt, 33% clay).
- Low/Moderate permeability soil model: One meter dry loamy sand (83% sand, 11% silt, 6% clay) over one meter moist silt (7% sand, 87% silt, 6% clay).
- For inclusion in Tier 1 action levels, all groundwater assumed to potentially migrate under a residential area. Action levels for protection of indoor air under a residential exposure scenario carried forward for use at both residential and commercial/industrial sites (see Table D series).

Action level for high-permeability vadose zone soils and residential land use used as default for screening purposes (refer to Table D-1a and D-1b).
 Action levels calculated using spreadsheet provided with *User's Guide for the Johnson and Ettinger Indoor Air model (1991) for Subsurface Vapor Intrusion Into Buildings* (USEPA 2001). Assumed vadose-zone thickness/depth to groundwater three meters. See Appendix 1 text for model details.
 Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).
 Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.
 Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2002).
 Target cancer risk = 1E-06 unless otherwise noted, Target Hazard Quotient = 1.0; TCE target cancer risk = 1E-05.
 "#": Nonchlorinated VOCs (except MTBE) adjusted upwards by factor of ten to account for assumed biodegradation in vadose-zone prior to emission at surface.
 (Use Soil Gas): Chemical constants not available for modeling. Use soil gas data to evaluate potential indoor-air impact concerns.

**TABLE C-1b. SOIL ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)
(Use with Soil Gas Screening Levels for sites with significant VOC releases)**

CONTAMINANT	Physical State		¹ Residential Exposure	Commercial/Industrial Exposure
			(mg/kg)	(mg/kg)
#ACENAPHTHENE	V	S	1.3E+02	1.3E+02
ACENAPHTHYLENE	V	S	(Use soil gas)	(Use soil gas)
#ACETONE	V	L	5.6E+03	1.6E+04
ALDRIN	NV	S		
#ANTHRACENE	V	S	6.1E+00	6.1E+00
ANTIMONY	NV	S		
ARSENIC	NV	S		
BARIUM	NV	S		
#BENZENE	V	L	5.3E-01	1.9E+00
BENZO(a)ANTHRACENE	NV	S		
BENZO(a)PYRENE	NV	S		
BENZO(b)FLUORANTHENE	NV	S		
BENZO(g,h,i)PERYLENE	NV	S		
BENZO(k)FLUORANTHENE	NV	S		
BERYLLIUM	NV	S		
BIPHENYL, 1,1-	V	S	(Use soil gas)	(Use soil gas)
BIS(2-CHLOROETHYL)ETHER	V	L	6.7E-03	2.8E-02
BIS(2-CHLOROISOPROPYL)ETHER	V	L	(Use soil gas)	(Use soil gas)
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S		
BORON	NV	S		
BROMODICHLOROMETHANE	V	L	2.3E-02	8.2E-02
BROMOFORM	NV	S		
BROMOMETHANE	V	G	8.6E-01	2.5E+00
CADMIUM	NV	S		
CARBON TETRACHLORIDE	V	L	2.7E-02	9.6E-02
CHLORDANE	NV	S		
CHLOROANILINE, p-	NV	S		
CHLOROBENZENE	V	L	1.0E+01	3.1E+01
CHLOROETHANE	V	G	5.0E-01	1.8E+00
CHLOROFORM	V	L	1.8E-02	6.3E-02
CHLOROMETHANE	V	G	1.6E+01	4.7E+01
CHLOROPHENOL, 2-	V	L	3.4E+00	1.2E+01
CHROMIUM (Total)	NV	S		
CHROMIUM III	NV	S		
CHROMIUM VI	NV	S		
CHRYSENE	NV	S	(Use soil gas)	(Use soil gas)
COBALT	NV	S		
COPPER	NV	S		
CYANIDE (Free)	NV	S	(Use soil gas)	(Use soil gas)
DIBENZO(a,h)ANTHTRACENE	NV	S		
DIBROMO-3-CHLOROPROPANE, 1,2-	V	L	(Use soil gas)	(Use soil gas)
DIBROMOCHLOROMETHANE	V	S	1.7E-02	1.1E-01
DIBROMOETHANE, 1,2-	V	S	7.2E-04	2.5E-03
DICHLOROBENZENE, 1,2-	V	L	3.5E+01	1.0E+02
DICHLOROBENZENE, 1,3-	V	L	(Use soil gas)	(Use soil gas)
DICHLOROBENZENE, 1,4-	V	S	6.5E-02	2.3E-01
DICHLOROBENZIDINE, 3,3-	NV	S		
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S		
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S		
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S		
DICHLOROETHANE, 1,1-	V	L	8.6E+01	2.5E+02

**TABLE C-1b. SOIL ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)
(Use with Soil Gas Screening Levels for sites with significant VOC releases)**

CONTAMINANT	Physical State		¹ Residential Exposure	Commercial/Industrial Exposure
			(mg/kg)	(mg/kg)
DICHLOROETHANE, 1,2-	V	L	1.6E-02	5.6E-02
DICHLOROETHYLENE, 1,1-	V	L	3.5E+01	1.0E+02
DICHLOROETHYLENE, Cis 1,2-	V	L	6.2E+00	1.8E+01
DICHLOROETHYLENE, Trans 1,2-	V	L	1.2E+01	3.6E+01
DICHLOROPHENOL, 2,4-	NV	S		
DICHLOROPROPANE, 1,2-	V	L	2.1E-02	7.5E-02
DICHLOROPROPENE, 1,3-	V	L	1.0E-01	3.6E-01
DIELDRIN	NV	S		
DIETHYLPHTHALATE	NV	S		
#DIMETHYLPHENOL, 2,4-	V	S		
DIMETHYLPHTHALATE	NV	S		
DINITROPHENOL, 2,4-	NV	S		
DINITROTOLUENE, 2,4-	NV	S		
DIOXANE, 1,4-	NV	L		
DIOXIN (2,3,7,8-TCDD)	NV	S		
ENDOSULFAN	NV	S		
ENDRIN	NV	S		
#ETHYLBENZENE	V	L	3.9E+02	3.9E+02
FLUORANTHENE	NV	S		
#FLUORENE	V	S	1.6E+02	1.6E+02
HEPTACHLOR	NV	S		
HEPTACHLOR EPOXIDE	NV	S		
HEXACHLOROBENZENE	NV	S		
HEXACHLOROBUTADIENE	NV	S		
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S		
HEXACHLOROETHANE	NV	S		
INDENO(1,2,3-cd)PYRENE	NV	S		
LEAD	NV	S		
MERCURY	NV	S		
METHOXYCHLOR	NV	S		
#METHYL ETHYL KETONE	V	L	1.9E+04	3.4E+04
#METHYL ISOBUTYL KETONE	V	L	1.7E+04	1.7E+04
METHYL MERCURY	NV	S		
METHYL TERT BUTYL ETHER	V	L	1.6E+00	5.6E+00
METHYLENE CHLORIDE	V	L	9.0E-01	3.2E+00
#METHYLNAPHTHALENE (total 1- & 2-)	V	S	1.1E+02	1.1E+02
MOLYBDENUM	NV	S		
#NAPHTHALENE	V	S	1.8E+01	6.1E+01
NICKEL	NV	S		
PENTACHLOROPHENOL	NV	S		
PERCHLORATE	NV	S		
PHENANTHRENE	V	S	(Use soil gas)	(Use soil gas)
PHENOL	NV	S		
POLYCHLORINATED BIPHENYLS (PCBs)	NV	S		
#PYRENE	V	S	8.5E+01	8.5E+01
SELENIUM	NV	S		
SILVER	NV	S		
#STYRENE	V	L	1.5E+03	1.5E+03
tert-BUTYL ALCOHOL	V	L	(Use soil gas)	(Use soil gas)
TETRACHLOROETHANE, 1,1,1,2-	V	L	(Use soil gas)	(Use soil gas)
TETRACHLOROETHANE, 1,1,1,2,2-	V	L	7.2E-03	2.5E-02

**TABLE C-1b. SOIL ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)
(Use with Soil Gas Screening Levels for sites with significant VOC releases)**

CONTAMINANT	Physical State		¹ Residential Exposure	Commercial/Industrial Exposure
			(mg/kg)	(mg/kg)
TETRACHLOROETHYLENE	V	L	6.9E-02	2.4E-01
THALLIUM	NV	S		
#TOLUENE	V	L	6.5E+02	6.5E+02
TOXAPHENE	NV	S		
TPH (gasolines)	V	L	(Use soil gas)	(Use soil gas)
TPH (middle distillates)	V	L	(Use soil gas)	(Use soil gas)
TPH (residual fuels)	NV	L/S		
TRICHLOROENZENE, 1,2,4-	V	L	1.6E+00	5.3E+00
TRICHLOROETHANE, 1,1,1-	V	L	3.9E+02	1.1E+03
TRICHLOROETHANE, 1,1,2-	V	L	2.6E-02	9.1E-02
TRICHLOROETHYLENE	V	L	3.6E-02	1.3E-01
TRICHLOROPHENOL, 2,4,5-	V	S	9.5E+01	3.1E+02
TRICHLOROPHENOL, 2,4,6-	NV	S		
VANADIUM	NV	S		
VINYL CHLORIDE	V	G	3.9E-02	1.6E-01
#XYLENES	V	L	1.8E+02	4.2E+02
ZINC	NV	S		

Notes:

1. "Residential" action levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

Action levels calculated using spreadsheet provided with *User's Guide for the Johnson and Ettinger Indoor Air Model (1991) for Subsurface Vapor Intrusion Into Buildings* (USEPA 2000 and updates).

Soil model: Two meters dry sandy soil (92% sand, 5% silt, 3% clay) directly underlying building foundation.

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S -solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2002).

Target cancer risk = 1E-06 unless otherwise noted, Target Hazard Quotient = 1.0; TCE target cancer risk = 1E-05.

"#": Nonchlorinated VOCs (except MTBE) adjusted upwards by factor of ten to account for assumed biodegradation in vadose-zone prior to emission at surface.

(Use Soil Gas): Chemical constants not available for modeling. Use soil gas data to evaluate potential indoor-air impact concerns.

**TABLE C-2. ¹SHALLOW SOIL GAS ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		² Residential Exposure			Commercial/Industrial Land Use		
			Lowest Residential	Carcinogenic Effects	Noncarcinogenic Effects	Lowest C/I	Carcinogenic Effects	Noncarcinogenic Effects
			(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)
ACENAPHTHENE	V	S	2.2E+05		2.2E+05	6.1E+05		6.1E+05
ACENAPHTHYLENE	V	S	1.5E+05		1.5E+05	4.1E+05		4.1E+05
ACETONE	V	L	3.3E+06		3.3E+06	9.2E+06		9.2E+06
ALDRIN	NV	S						
ANTHRACENE	V	S	1.1E+06		1.1E+06	3.1E+06		3.1E+06
ANTIMONY	NV	S						
ARSENIC	NV	S						
BARIUM	NV	S						
BENZENE	V	L	2.5E+02	2.5E+02	3.1E+04	1.1E+03	1.1E+03	8.8E+04
BENZO(a)ANTHRACENE	NV	S						
BENZO(a)PYRENE	NV	S						
BENZO(b)FLUORANTHENE	NV	S						
BENZO(g,h,i)PERYLENE	NV	S						
BENZO(k)FLUORANTHENE	NV	S						
BERYLLIUM	NV	S						
BIPHENYL, 1,1-	V	S	1.8E+05		1.8E+05	5.1E+05		5.1E+05
BIS(2-CHLOROETHYL)ETHER	V	L	5.6E+00	5.6E+00		2.4E+01	2.4E+01	
BIS(2-CHLOROISOPROPYL)ETHER	V	L	1.9E+02	1.9E+02	1.5E+05	8.2E+02	8.2E+02	4.1E+05
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S						
BORON	NV	S						
BROMODICHLOROMETHANE	V	L	1.1E+02	1.1E+02	7.3E+04	4.6E+02	4.6E+02	2.0E+05
BROMOFORM	NV	S						
BROMOMETHANE	V	G	5.1E+03		5.1E+03	1.4E+04		1.4E+04
CADMIUM	NV	S						
CARBON TETRACHLORIDE	V	L	1.3E+02	1.3E+02	2.6E+03	5.4E+02	5.4E+02	7.2E+03
CHLORDANE	NV	S						
CHLOROANILINE, p-	NV	S						
CHLOROBENZENE	V	L	6.2E+04		6.2E+04	1.7E+05		1.7E+05
CHLOROETHANE	V	G	2.3E+03	2.3E+03	1.1E+07	9.9E+03	9.9E+03	3.0E+07
CHLOROFORM	V	L	8.3E+01	8.3E+01	5.1E+04	3.5E+02	3.5E+02	1.4E+05
CHLOROMETHANE	V	G	9.5E+04		9.5E+04	2.7E+05		2.7E+05
CHLOROPHENOL, 2-	V	L	1.8E+04		1.8E+04	5.1E+04		5.1E+04
CHROMIUM (Total)	NV	S						
CHROMIUM III	NV	S						
CHROMIUM VI	NV	S						
CHRYSENE	NV	S						
COBALT	NV	S						
COPPER	NV	S						

**TABLE C-2. ¹SHALLOW SOIL GAS ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		² Residential Exposure			Commercial/Industrial Land Use		
			Lowest Residential	Carcinogenic Effects	Noncarcinogenic Effects	Lowest C/I	Carcinogenic Effects	Noncarcinogenic Effects
			(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)
CYANIDE (Free)	NV	S						
DIBENZO(a,h)ANTHTRACENE	NV	S						
DIBROMO-3-CHLOROPROPANE, 1,2-	V	L	2.1E+02	2.8E+03	2.1E+02	5.8E+02	1.2E+04	5.8E+02
DIBROMOCHLOROMETHANE	V	S	8.0E+01	8.0E+01	7.3E+04	3.4E+02	3.4E+02	2.0E+05
DIBROMOETHANE, 1,2-	V	S	3.4E+00	3.4E+00	9.5E+03	1.4E+01	1.4E+01	2.7E+04
DICHLOROBENZENE, 1,2-	V	L	2.1E+05		2.1E+05	5.8E+05		5.8E+05
DICHLOROBENZENE, 1,3-	V	L	1.1E+05		1.1E+05	3.1E+05		3.1E+05
DICHLOROBENZENE, 1,4-	V	S	3.1E+02	3.1E+02	1.1E+05	1.3E+03	1.3E+03	3.1E+05
DICHLOROBENZIDINE, 3,3-	NV	S						
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S						
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S						
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S						
DICHLOROETHANE, 1,1-	V	L	5.1E+05		5.1E+05	1.4E+06		1.4E+06
DICHLOROETHANE, 1,2-	V	L	7.4E+01	7.4E+01	5.1E+03	3.1E+02	3.1E+02	1.4E+04
DICHLOROETHYLENE, 1,1-	V	L	2.1E+05		2.1E+05	5.8E+05		5.8E+05
DICHLOROETHYLENE, Cis 1,2-	V	L	3.7E+04		3.7E+04	1.0E+05		1.0E+05
DICHLOROETHYLENE, Trans 1,2-	V	L	7.3E+04		7.3E+04	2.0E+05		2.0E+05
DICHLOROPHENOL, 2,4-	NV	S						
DICHLOROPROPANE, 1,2-	V	L	9.9E+01	9.9E+01	4.0E+03	4.2E+02	4.2E+02	1.1E+04
DICHLOROPROPENE, 1,3-	V	L	4.8E+02	4.8E+02	2.1E+04	2.0E+03	2.0E+03	5.8E+04
DIELDRIN	NV	S						
DIETHYLPHTHALATE	NV	S						
DIMETHYLPHENOL, 2,4-	V	S						
DIMETHYLPHTHALATE	NV	S						
DINITROPHENOL, 2,4-	NV	S						
DINITROTOLUENE, 2,4-	NV	S						
DIOXANE, 1,4-	NV	L						
DIOXIN (2,3,7,8-TCDD)	NV	S						
ENDOSULFAN	NV	S						
ENDRIN	NV	S						
ETHYLBENZENE	V	L	1.1E+06		1.1E+06	3.0E+06		3.0E+06
FLUORANTHENE	NV	S						
FLUORENE	V	S	1.5E+05		1.5E+05	4.1E+05		4.1E+05
HEPTACHLOR	NV	S						
HEPTACHLOR EPOXIDE	NV	S						
HEXACHLOROBENZENE	NV	S						
HEXACHLOROBUTADIENE	NV	S						
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S						

**TABLE C-2. ¹SHALLOW SOIL GAS ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		² Residential Exposure			Commercial/Industrial Land Use		
			Lowest Residential	Carcinogenic Effects	Noncarcinogenic Effects	Lowest C/I	Carcinogenic Effects	Noncarcinogenic Effects
			(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)
HEXACHLOROETHANE	NV	S						
INDENO(1,2,3-cd)PYRENE	NV	S						
LEAD	NV	S						
MERCURY	NV	S						
METHOXYCHLOR	NV	S						
METHYL ETHYL KETONE	V	L	5.1E+06		5.1E+06	1.4E+07		1.4E+07
METHYL ISOBUTYL KETONE	V	L	3.1E+06		3.1E+06	8.8E+06		8.8E+06
METHYL MERCURY	NV	S						
METHYL TERT BUTYL ETHER	V	L	7.4E+03	7.4E+03	3.1E+06	3.1E+04	3.1E+04	8.8E+06
METHYLENE CHLORIDE	V	L	4.2E+03	4.2E+03	3.1E+06	1.8E+04	1.8E+04	8.8E+06
METHYLNAPHTHALENE (total 1- & 2-)	V	S	1.5E+05		1.5E+05	4.1E+05		4.1E+05
MOLYBDENUM	NV	S						
NAPHTHALENE	V	S	3.1E+03		3.1E+03	8.8E+03		8.8E+03
NICKEL	NV	S						
PENTACHLOROPHENOL	NV	S						
PERCHLORATE	NV	S						
PHENANTHRENE	V	S	1.5E+05		1.5E+05	4.1E+05		4.1E+05
PHENOL	NV	S						
POLYCHLORINATED BIPHENYLS (PCBs)	NV	S						
PYRENE	V	S	1.1E+05		1.1E+05	3.1E+05		3.1E+05
SELENIUM	NV	S						
SILVER	NV	S						
STYRENE	V	L	1.1E+06		1.1E+06	3.0E+06		3.0E+06
tert-BUTYL ALCOHOL	V	L	2.2E+03	2.2E+03		9.5E+03	9.5E+03	
TETRACHLOROETHANE, 1,1,1,2-	V	L	2.6E+02	2.6E+02	1.1E+05	1.1E+03	1.1E+03	3.1E+05
TETRACHLOROETHANE, 1,1,2,2-	V	L	3.4E+01	3.4E+01	2.2E+05	1.4E+02	1.4E+02	6.1E+05
TETRACHLOROETHYLENE	V	L	3.2E+02	3.2E+02	3.7E+04	1.4E+03	1.4E+03	1.0E+05
THALLIUM	NV	S						
TOLUENE	V	L	4.0E+05		4.0E+05	1.1E+06		1.1E+06
TOXAPHENE	NV	S						
TPH (gasolines)	V	L	5.1E+04		5.1E+04	1.4E+05		1.4E+05
TPH (middle distillates)	V	L	5.1E+04		5.1E+04	1.4E+05		1.4E+05
TPH (residual fuels)	NV	L/S						
TRICHLOROETHANE, 1,2,4-	V	L	3.7E+03		3.7E+03	1.0E+04		1.0E+04
TRICHLOROETHANE, 1,1,1-	V	L	2.3E+06		2.3E+06	6.4E+06		6.4E+06
TRICHLOROETHANE, 1,1,2-	V	L	1.2E+02	1.2E+02	1.5E+04	5.1E+02	5.1E+02	4.1E+04
TRICHLOROETHYLENE	V	L	1.7E+02	1.7E+02	3.7E+04	7.2E+02	7.2E+02	1.0E+05
TRICHLOROPHENOL, 2,4,5-	V	S	3.7E+05		3.7E+05	1.0E+06		1.0E+06

**TABLE C-2. ¹SHALLOW SOIL GAS ACTION LEVELS
FOR EVALUATION OF POTENTIAL VAPOR INTRUSION CONCERNS
(volatile chemicals only)**

CONTAMINANT	Physical State		² Residential Exposure			Commercial/Industrial Land Use		
			Lowest Residential	Carcinogenic Effects	Noncarcinogenic Effects	Lowest C/I	Carcinogenic Effects	Noncarcinogenic Effects
			(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)	(ug/m ³)
TRICHLOROPHENOL, 2,4,6-	NV	S						
VANADIUM	NV	S						
VINYL CHLORIDE (nonresidential exposure)	V	G	4.2E+02	4.2E+02	1.0E+05	1.8E+03	1.8E+03	2.9E+05
VINYL CHLORIDE (residential exposure)	V	G	9.3E+01	9.3E+01	1.0E+05	9.2E+02	9.2E+02	2.9E+05
XYLENES	V	L	1.1E+05		1.1E+05	3.0E+05		3.0E+05
ZINC	NV	S						

Notes:

1. Shallow soil gas defined as soil gas sample data collected within 1.5 meters (five feet) from a building foundation or the ground surface. Assumes very permeable (e.g., sandy) fill material is present below building foundation or could be present below future buildings following redevelopment. Evaluation of deeper soil gas data (e.g., >1.5m bgs) should be carried out on a site-specific basis.

2. "Residential" action levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

Soil gas action levels intended to be protective of indoor air quality, calculated for volatile chemicals only.

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2002).

Target cancer risk = 1E-06 unless otherwise noted, Target Hazard Quotient = 1.0; TCE target cancer risk = 1E-05.

Residential soil gas:indoor air attenuation factor = 0.001 (1/1000). Commercial/industrial soil gas:indoor air attenuation factor = 0.0005 (1/2000).

Soil gas action levels do not address mass-balance issues. May be overly conservative for sites with low permeability shallow soils or limited soil impacts and no groundwater source of VOCs.

Indoor-air sampling and/or passive vapor mitigation measures may be prudent for sites where concentrations of chemicals in soil gas approach but do not exceed screening levels.

**TABLE C-3. INDOOR AIR ACTION LEVELS
(volatile chemicals only)**

CONTAMINANT	Physical State		Health-Based Action Levels							50% Odor Recognition Threshold (Table F-2) (ug/m ³)	
			Unit Risk Factor URF (ug/m ³) ⁻¹	Reference Concentration RFC (ug/m ³)	Residential Exposure			Commercial/Industrial Exposure			
					Lowest Residential (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	Lowest C/I (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)		Indoor Air (noncarcinogens) (ug/m ³)
ACENAPHTHENE	V	S		2.1E+02	2.2E+02		2.2E+02	3.1E+02		3.1E+02	5.13E+02
ACENAPHTHYLENE	V	S		1.4E+02	1.5E+02		1.5E+02	2.0E+02		2.0E+02	-
ACETONE	V	L		3.2E+03	3.3E+03		3.3E+03	4.6E+03		4.6E+03	3.09E+04
ALDRIN	NV	S									2.63E+02
ANTHRACENE	V	S		1.1E+03	1.1E+03		1.1E+03	1.5E+03		1.5E+03	-
ANTIMONY	NV	S									-
ARSENIC	NV	S									-
BARIUM	NV	S									-
BENZENE	V	L	7.7E-06	3.0E+01	2.5E-01	2.5E-01	3.1E+01	5.3E-01	5.3E-01	4.4E+01	4.89E+03
BENZO(a)ANTHRACENE	NV	S									-
BENZO(a)PYRENE	NV	S									-
BENZO(b)FLUORANTHENE	NV	S									-
BENZO(g,h,i)PERYLENE	NV	S									-
BENZO(k)FLUORANTHENE	NV	S									-
BERYLLIUM	NV	S									-
BIPHENYL, 1,1-	V	S		1.8E+02	1.8E+02		1.8E+02	2.6E+02		2.6E+02	6.00E+01
BIS(2-CHLOROETHYL)ETHER	V	L	3.4E-04		5.6E-03	5.6E-03		1.2E-02	1.2E-02		2.87E+02
BIS(2-CHLOROISOPROPYL)ETHER	V	L	1.0E-05	1.4E+02	1.9E-01	1.9E-01	1.5E+02	4.1E-01	4.1E-01	2.0E+02	2.24E+03
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S									-
BORON	NV	S									-
BROMODICHLOROMETHANE	V	L	1.8E-05	7.0E+01	1.1E-01	1.1E-01	7.3E+01	2.3E-01	2.3E-01	1.0E+02	1.10E+07
BROMOFORM	NV	S									1.35E+04
BROMOMETHANE	V	G		4.9E+00	5.1E+00		5.1E+00	7.2E+00		7.2E+00	8.00E+04
CADMIUM	NV	S									-
CARBON TETRACHLORIDE	V	L	1.5E-05	2.5E+00	1.3E-01	1.3E-01	2.6E+00	2.7E-01	2.7E-01	3.6E+00	6.30E+04
CHLORDANE	NV	S									8.40E+00
CHLOROANILINE, p-	NV	S									-
CHLOROBENZENE	V	L		6.0E+01	6.2E+01		6.2E+01	8.7E+01		8.7E+01	1.00E+03
CHLOROETHANE	V	G	8.3E-07	1.0E+04	2.3E+00	2.3E+00	1.1E+04	4.9E+00	4.9E+00	1.5E+04	3.80E+05
CHLOROFORM	V	L	2.3E-05	4.9E+01	8.3E-02	8.3E-02	5.1E+01	1.8E-01	1.8E-01	7.2E+01	4.22E+05
CHLOROMETHANE	V	G		9.1E+01	9.5E+01		9.5E+01	1.3E+02		1.3E+02	-
CHLOROPHENOL, 2-	V	L		1.8E+01	1.8E+01		1.8E+01	2.6E+01		2.6E+01	1.90E+01
CHROMIUM (Total)	NV	S									-
CHROMIUM III	NV	S									-
CHROMIUM VI	NV	S									-
CHRYSENE	NV	S									-
COBALT	NV	S									-
COPPER	NV	S									-
CYANIDE (Free)	NV	S									6.52E+02
DIBENZO(a,h)ANTHRACENE	NV	S									-
DIBROMO-3-CHLOROPROPANE, 1,2-	V	L	6.9E-07	2.0E-01	2.1E-01	2.8E+00	2.1E-01	2.9E-01	6.0E+00	2.9E-01	-
DIBROMOCHLOROMETHANE	V	S	2.4E-05	7.0E+01	8.0E-02	8.0E-02	7.3E+01	1.7E-01	1.7E-01	1.0E+02	-

**TABLE C-3. INDOOR AIR ACTION LEVELS
(volatile chemicals only)**

CONTAMINANT	Physical State		Health-Based Action Levels								50% Odor Recognition Threshold (Table F-2) (ug/m ³)
			Unit Risk Factor URF (ug/m ³) ⁻¹	Reference Concentration RFC (ug/m ³)	Residential Exposure			Commercial/Industrial Exposure			
					Lowest Residential (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	Lowest C/I (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	
DIBROMOETHANE, 1,2-	V	S	5.7E-04	9.1E+00	3.4E-03	3.4E-03	9.5E+00	7.2E-03	7.2E-03	1.3E+01	2.00E+05
DICHLOROBENZENE, 1,2-	V	L		2.0E+02	2.1E+02		2.1E+02	2.9E+02		2.9E+02	3.05E+05
DICHLOROBENZENE, 1,3-	V	L		1.1E+02	1.1E+02		1.1E+02	1.5E+02		1.5E+02	-
DICHLOROBENZENE, 1,4-	V	S	6.3E-06	1.1E+02	3.1E-01	3.1E-01	1.1E+02	6.5E-01	6.5E-01	1.5E+02	1.10E+03
DICHLOROBENZIDINE, 3,3-	NV	S									-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S									-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S									-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S									-
DICHLOROETHANE, 1,1-	V	L		4.9E+02	5.1E+02		5.1E+02	7.2E+02		7.2E+02	1.25E+05
DICHLOROETHANE, 1,2-	V	L	2.6E-05	4.9E+00	7.4E-02	7.4E-02	5.1E+00	1.6E-01	1.6E-01	7.2E+00	2.42E+03
DICHLOROETHYLENE, 1,1-	V	L		2.0E+02	2.1E+02		2.1E+02	2.9E+02		2.9E+02	2.00E+06
DICHLOROETHYLENE, Cis 1,2-	V	L		3.5E+01	3.7E+01		3.7E+01	5.1E+01		5.1E+01	-
DICHLOROETHYLENE, Trans 1,2-	V	L		7.0E+01	7.3E+01		7.3E+01	1.0E+02		1.0E+02	6.73E+04
DICHLOROPHENOL, 2,4-	NV	S									1.40E+03
DICHLOROPROPANE, 1,2-	V	L	1.9E-05	3.9E+00	9.9E-02	9.9E-02	4.0E+00	2.1E-01	2.1E-01	5.6E+00	1.19E+03
DICHLOROPROPENE, 1,3-	V	L	4.0E-06	2.0E+01	4.8E-01	4.8E-01	2.1E+01	1.0E+00	1.0E+00	2.9E+01	4.16E+03
DIELDRIN	NV	S									-
DIETHYLPHthalate	NV	S									-
DIMETHYLPHENOL, 2,4-	V	S									1.00E+00
DIMETHYLPHthalate	NV	S									-
DINITROPHENOL, 2,4-	NV	S									-
DINITROToluene, 2,4-	NV	S									-
DIOXANE, 1,4-	NV	L									6.12E+05
DIOXIN (2,3,7,8-TCDD)	NV	S									-
ENDOSULFAN	NV	S									-
ENDRIN	NV	S									-
ETHYLBENZENE	V	L		1.0E+03	1.1E+03		1.1E+03	1.5E+03		1.5E+03	2.00E+03
FLUORANTHENE	NV	S									-
FLUORENE	V	S		1.4E+02	1.5E+02		1.5E+02	2.0E+02		2.0E+02	-
HEPTACHLOR	NV	S									3.00E+02
HEPTACHLOR EPOXIDE	NV	S									3.00E+02
HEXACHLORO BENZENE	NV	S									-
HEXACHLOROBUTADIENE	NV	S									1.20E+04
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S									-
HEXACHLOROETHANE	NV	S									-
INDENO(1,2,3-cd)PYRENE	NV	S									-
LEAD	NV	S									-
MERCURY	NV	S									-
METHOXYCHLOR	NV	S									-
METHYL ETHYL KETONE	V	L		4.9E+03	5.1E+03		5.1E+03	7.2E+03		7.2E+03	3.20E+04
METHYL ISOBUTYL KETONE	V	L		3.0E+03	3.1E+03		3.1E+03	4.4E+03		4.4E+03	4.20E+02
METHYL MERCURY	NV	S									-

**TABLE C-3. INDOOR AIR ACTION LEVELS
(volatile chemicals only)**

CONTAMINANT	Physical State		Health-Based Action Levels								50% Odor Recognition Threshold (Table F-2) (ug/m ³)
			Unit Risk Factor URF (ug/m ³) ⁻¹	Reference Concentration RFC (ug/m ³)	Residential Exposure			Commercial/Industrial Exposure			
					Lowest Residential (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	Lowest C/I (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	
METHYL TERT BUTYL ETHER	V	L	2.6E-07	3.0E+03	7.4E+00	7.4E+00	3.1E+03	1.6E+01	1.6E+01	4.4E+03	5.30E+02
METHYLENE CHLORIDE	V	L	4.6E-07	3.0E+03	4.2E+00	4.2E+00	3.1E+03	8.9E+00	8.9E+00	4.4E+03	5.60E+05
METHYLNAPHTHALENE (total 1- & 2-)	V	S		1.4E+02	1.5E+02		1.5E+02	2.0E+02		2.0E+02	6.80E+01
MOLYBDENUM	NV	S									-
NAPHTHALENE	V	S		3.0E+00	3.1E+00		3.1E+00	4.4E+00		4.4E+00	4.40E+02
NICKEL	NV	S									-
PENTACHLOROPHENOL	NV	S									-
PERCHLORATE	NV	S									-
PHENANTHRENE	V	S		1.4E+02	1.5E+02		1.5E+02	2.0E+02		2.0E+02	5.50E+01
PHENOL	NV	S									1.56E+02
POLYCHLORINATED BIPHENYLS (PCBs)	NV	S									-
PYRENE	V	S		1.1E+02	1.1E+02		1.1E+02	1.5E+02		1.5E+02	-
SELENIUM	NV	S									-
SILVER	NV	S									-
STYRENE	V	L		1.0E+03	1.1E+03		1.1E+03	1.5E+03		1.5E+03	1.36E+03
tert-BUTYL ALCOHOL	V	L	8.6E-07		2.2E+00	2.2E+00	4.8E+00	4.8E+00	4.8E+00	1.5E+02	-
TETRACHLOROETHANE, 1,1,1,2-	V	L	7.4E-06	1.1E+02	2.6E-01	2.6E-01	1.1E+02	5.5E-01	5.5E-01	1.5E+02	-
TETRACHLOROETHANE, 1,1,2,2-	V	L	5.7E-05	2.1E+02	3.4E-02	3.4E-02	2.2E+02	7.2E-02	7.2E-02	3.1E+02	1.05E+04
TETRACHLOROETHYLENE	V	L	6.0E-06	3.5E+01	3.2E-01	3.2E-01	3.7E+01	6.8E-01	6.8E-01	5.1E+01	3.17E+04
THALLIUM	NV	S									-
TOLUENE	V	L		3.9E+02	4.0E+02		4.0E+02	5.6E+02		5.6E+02	3.00E+04
TOXAPHENE	NV	S									-
TPH (gasolines)	V	L		4.9E+01	5.1E+01		5.1E+01	7.2E+01		7.2E+01	1.00E+02
TPH (middle distillates)	V	L		4.9E+01	5.1E+01		5.1E+01	7.2E+01		7.2E+01	1.00E+03
TPH (residual fuels)	NV	L/S									-
TRICHLOROETHANE, 1,2,4-	V	L		3.5E+00	3.7E+00		3.7E+00	5.1E+00		5.1E+00	2.20E+04
TRICHLOROETHANE, 1,1,1-	V	L		2.2E+03	2.3E+03		2.3E+03	3.2E+03		3.2E+03	6.51E+04
TRICHLOROETHANE, 1,1,2-	V	L	1.6E-05	1.4E+01	1.2E-01	1.2E-01	1.5E+01	2.6E-01	2.6E-01	2.0E+01	-
TRICHLOROETHYLENE	V	L	1.1E-04	3.5E+01	1.7E-01	1.7E-01	3.7E+01	3.6E-01	3.6E-01	5.1E+01	1.36E+06
TRICHLOROPHENOL, 2,4,5-	V	S		3.5E+02	3.7E+02		3.7E+02	5.1E+02		5.1E+02	-
TRICHLOROPHENOL, 2,4,6-	NV	S									3.00E-01
VANADIUM	NV	S									-

**TABLE C-3. INDOOR AIR ACTION LEVELS
(volatile chemicals only)**

CONTAMINANT	Physical State		Health-Based Action Levels								50% Odor Recognition Threshold (Table F-2) (ug/m ³)
			Unit Risk Factor URF (ug/m ³) ⁻¹	Reference Concentration RfC (ug/m ³)	Residential Exposure			Commercial/Industrial Exposure			
					Lowest Residential (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	Lowest C/I (ug/m ³)	Indoor Air (carcinogens) (ug/m ³)	Indoor Air (noncarcinogens) (ug/m ³)	
VINYL CHLORIDE (nonresidential exposure)	V	G	4.6E-06	1.0E+02	4.2E-01	4.2E-01	1.0E+02	8.9E-01	8.9E-01	1.5E+02	7.71E+05
VINYL CHLORIDE (residential exposure)	V	G	8.9E-06	1.0E+02	9.3E-02	9.3E-02	1.0E+02	4.6E-01	4.6E-01	1.5E+02	4.41E+02
XYLENES	V	L		1.0E+02	1.1E+02		1.1E+02	1.5E+02		1.5E+02	4.41E+02
ZINC	NV	S									-

Notes:

1. "Residential" action levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

Target cancer risk = 1E-06 unless otherwise noted, Target Hazard Quotient = 1.0; TCE target cancer risk = 1E-05.

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number (atm m³/mole) >0.00001 and molecular weight <200.

Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2002).

Calculated based on spreadsheet provided with User's Guide for the Johnson and Ettinger Indoor Air model (1991) for Subsurface Vapor Intrusion Into Buildings (USEPA 1997) using default input parameter values noted in Appendix 4 (see text for equations).

Indoor air action levels listed only for volatile chemicals included in database of referenced model spreadsheet (plus MTBE).

URFs from referenced spreadsheet (USEPA 2000). RfCs presented in spreadsheet or added as indicated in Appendix 4 (refer to footnotes to VLOOKUP worksheet).

URF for TBA based on conversion of CSF presented in Table H.

50% Odor Recognition Thresholds from Massachusetts Department of Environmental Protection (MADEP, 1994) and ATSDR; included for reference (potential nuisance concerns, see Table F series).

TABLE D-1a. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS located within 150 meters of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3b (Chronic)
ACENAPHTHENE	2.0E+01	Ceiling Value	2.0E+01	3.7E+02	4.2E+03	2.3E+01
ACENAPHTHYLENE	3.0E+01	Chronic Aquatic Habitat Goal	2.0E+03	2.4E+02	(Use soil gas)	3.0E+01
ACETONE	1.5E+03	Chronic Aquatic Habitat Goal	2.0E+04	5.5E+03	2.1E+08	1.5E+03
ALDRIN	4.0E-03	Drinking Water Toxicity	8.5E+00	4.0E-03		1.3E-01
ANTHRACENE	7.3E-01	Chronic Aquatic Habitat Goal	2.2E+01	1.8E+03	4.3E+01	7.3E-01
ANTIMONY	6.0E+00	Drinking Water Toxicity	5.0E+04	6.0E+00		3.0E+01
ARSENIC	1.0E+01	Drinking Water Toxicity	5.0E+04	1.0E+01		3.6E+01
BARIUM	2.0E+03	Chronic Aquatic Habitat Goal	5.0E+04	2.0E+03		2.0E+03
BENZENE	5.0E+00	Drinking Water Toxicity	1.7E+02	5.0E+00	1.6E+03	4.6E+01
BENZO(a)ANTHRACENE	2.7E-02	Chronic Aquatic Habitat Goal	5.0E+00	9.2E-02		2.7E-02
BENZO(a)PYRENE	1.4E-02	Chronic Aquatic Habitat Goal	1.9E+00	2.0E-01		1.4E-02
BENZO(b)FLUORANTHENE	9.2E-02	Chronic Aquatic Habitat Goal	7.0E+00	9.2E-02		9.2E-02
BENZO(g,h,i)PERYLENE	1.0E-01	Chronic Aquatic Habitat Goal	1.3E-01	1.5E+03		1.0E-01
BENZO(k)FLUORANTHENE	4.0E-01	Ceiling Value	4.0E-01	9.2E-01		3.7E+00
BERYLLIUM	2.7E+00	Chronic Aquatic Habitat Goal	5.0E+04	4.0E+00		2.7E+00
BIPHENYL, 1,1-	5.0E-01	Ceiling Value	5.0E-01	3.0E+02	(Use soil gas)	1.4E+01
BIS(2-CHLOROETHYL)ETHER	9.5E-03	Drinking Water Toxicity	3.6E+02	9.5E-03	1.0E+02	6.1E+01
BIS(2-CHLOROISOPROPYL)ETHER	2.7E-01	Drinking Water Toxicity	3.2E+02	2.7E-01	(Use soil gas)	6.1E+01
BIS(2-ETHYLHEXYL)PHTHALATE	6.0E+00	Drinking Water Toxicity	6.5E+02	6.0E+00		3.2E+01
BORON	1.6E+00	Chronic Aquatic Habitat Goal	5.0E+04	7.3E+03		1.6E+00
BROMODICHLOROMETHANE	1.8E-01	Drinking Water Toxicity	5.0E+04	1.8E-01	2.7E+02	3.2E+03
BROMOFORM	1.0E+02	Drinking Water Toxicity	5.1E+02	1.0E+02		3.2E+03
BROMOMETHANE	8.5E+00	Drinking Water Toxicity	5.0E+04	8.5E+00	2.3E+03	1.6E+02
CADMIUM	3.0E+00	Chronic Aquatic Habitat Goal	5.0E+04	5.0E+00		3.0E+00
CARBON TETRACHLORIDE	5.0E+00	Drinking Water Toxicity	5.2E+02	5.0E+00	2.1E+01	9.8E+00
CHLORDANE	4.0E-03	Chronic Aquatic Habitat Goal	2.5E+00	2.0E+00		4.0E-03
CHLOROANILINE, p-	5.0E+00	Chronic Aquatic Habitat Goal	5.0E+04	1.5E+02		5.0E+00
CHLOROBENZENE	2.5E+01	Chronic Aquatic Habitat Goal	5.0E+01	1.0E+02	5.3E+04	2.5E+01
CHLOROETHANE	3.9E+00	Chronic Aquatic Habitat Goal	1.6E+01	3.9E+00	6.5E+02	3.9E+00
CHLOROFORM	6.2E+01	Indoor Air Impacts	2.4E+03	1.0E+02	6.2E+01	6.2E+02
CHLOROMETHANE	1.6E+02	Drinking Water Toxicity	5.0E+04	1.6E+02	9.5E+03	3.2E+03
CHLOROPHENOL, 2-	1.8E-01	Ceiling Value	1.8E-01	3.0E+01	2.1E+04	1.4E+02
CHROMIUM (Total)	7.4E+01	Chronic Aquatic Habitat Goal	5.0E+04	1.0E+02		7.4E+01
CHROMIUM III	7.4E+01	Chronic Aquatic Habitat Goal	5.0E+04	5.5E+04		7.4E+01
CHROMIUM VI	1.1E+01	Chronic Aquatic Habitat Goal	5.0E+04	1.1E+02		1.1E+01
CHRYSENE	3.5E-01	Chronic Aquatic Habitat Goal	8.0E-01	9.2E+00	(Use soil gas)	3.5E-01
COBALT	3.0E+00	Chronic Aquatic Habitat Goal	5.0E+04	7.3E+02		3.0E+00
COPPER	2.9E+00	Chronic Aquatic Habitat Goal	1.0E+03	1.3E+03		2.9E+00

TABLE D-1a. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS located within 150 meters of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3b (Chronic)
CYANIDE (Free)	1.0E+00	Chronic Aquatic Habitat Goal	1.7E+02	2.0E+02	(Use soil gas)	1.0E+00
DIBENZO(a,h)ANTHTRACENE	9.2E-03	Drinking Water Toxicity	2.5E-01	9.2E-03		7.5E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	Chronic Aquatic Habitat Goal	1.0E+01	4.0E-02	(Use soil gas)	4.0E-02
DIBROMOCHLOROMETHANE	1.3E-01	Drinking Water Toxicity	5.0E+04	1.3E-01	1.6E+02	3.2E+03
DIBROMOETHANE, 1,2-	5.6E-03	Drinking Water Toxicity	5.0E+04	5.6E-03	1.6E+01	1.4E+03
DICHLOROBENZENE, 1,2-	1.0E+01	Ceiling Value	1.0E+01	6.0E+02	1.6E+05	1.4E+01
DICHLOROBENZENE, 1,3-	6.5E+01	Chronic Aquatic Habitat Goal	5.0E+04	1.8E+02	(Use soil gas)	6.5E+01
DICHLOROBENZENE, 1,4-	5.0E+00	Ceiling Value	5.0E+00	7.5E+01	4.9E+02	1.5E+01
DICHLOROBENZIDINE, 3,3-	1.5E-01	Drinking Water Toxicity	1.6E+03	1.5E-01		2.5E+02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E-03	Chronic Aquatic Habitat Goal	8.0E+01	2.8E-01		1.0E-03
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E-03	Chronic Aquatic Habitat Goal	2.0E+01	2.8E-01		1.0E-03
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03	Chronic Aquatic Habitat Goal	1.5E+00	2.0E-01		1.0E-03
DICHLOROETHANE, 1,1-	4.7E+01	Chronic Aquatic Habitat Goal	5.0E+04	8.0E+02	2.8E+05	4.7E+01
DICHLOROETHANE, 1,2-	1.2E-01	Drinking Water Toxicity	7.0E+03	1.2E-01	1.3E+02	1.0E+04
DICHLOROETHYLENE, 1,1-	7.0E+00	Drinking Water Toxicity	1.5E+03	7.0E+00	2.5E+04	2.5E+01
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	Drinking Water Toxicity	5.0E+04	7.0E+01	2.4E+04	5.9E+02
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	Drinking Water Toxicity	2.6E+02	1.0E+02	2.7E+04	5.9E+02
DICHLOROPHENOL, 2,4-	3.0E-01	Ceiling Value	3.0E-01	1.1E+02		1.8E+02
DICHLOROPROPANE, 1,2-	5.0E+00	Drinking Water Toxicity	1.0E+01	5.0E+00	1.2E+02	1.5E+03
DICHLOROPROPENE, 1,3-	4.0E-01	Drinking Water Toxicity	5.0E+04	4.0E-01	1.6E+02	1.2E+02
DIELDRIN	1.9E-03	Chronic Aquatic Habitat Goal	4.1E+01	4.2E-03		1.9E-03
DIETHYLPHTHALATE	1.5E+00	Chronic Aquatic Habitat Goal	5.0E+04	2.9E+04		1.5E+00
DIMETHYLPHENOL, 2,4-	1.1E+02	Chronic Aquatic Habitat Goal	4.0E+02	7.3E+02		1.1E+02
DIMETHYLPHTHALATE	1.5E+00	Chronic Aquatic Habitat Goal	5.0E+04	3.7E+05		1.5E+00
DINITROPHENOL, 2,4-	7.3E+01	Drinking Water Toxicity	5.0E+04	7.3E+01		7.5E+01
DINITROTOLUENE, 2,4-	3.4E+01	Drinking Water Toxicity	5.0E+04	3.4E+01		1.2E+02
DIOXANE, 1,4-	6.1E+00	Drinking Water Toxicity	5.0E+04	6.1E+00		3.4E+05
DIOXIN (2,3,7,8-TCDD)	5.0E-06	Chronic Aquatic Habitat Goal	7.0E+03	3.0E-05		5.0E-06
ENDOSULFAN	8.7E-03	Chronic Aquatic Habitat Goal	7.5E+01	2.2E+02		8.7E-03
ENDRIN	2.3E-03	Chronic Aquatic Habitat Goal	4.1E+01	2.0E+00		2.3E-03
ETHYLBENZENE	3.0E+01	Ceiling Value	3.0E+01	7.0E+02	1.7E+05	2.9E+02
FLUORANTHENE	8.0E+00	Chronic Aquatic Habitat Goal	1.3E+02	1.5E+03		8.0E+00
FLUORENE	3.9E+00	Chronic Aquatic Habitat Goal	9.5E+02	2.4E+02	1.9E+03	3.9E+00
HEPTACHLOR	3.6E-03	Chronic Aquatic Habitat Goal	2.0E+01	4.0E-01		3.6E-03
HEPTACHLOR EPOXIDE	3.6E-03	Chronic Aquatic Habitat Goal	1.8E+02	2.0E-01		3.6E-03
HEXACHLOROBENZENE	1.0E+00	Drinking Water Toxicity	5.5E+01	1.0E+00		3.7E+00
HEXACHLOROBUTADIENE	8.6E-01	Drinking Water Toxicity	6.0E+00	8.6E-01		4.7E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	8.0E-02	Chronic Aquatic Habitat Goal	3.5E+03	2.0E-01		8.0E-02

TABLE D-1a. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS located within 150 meters of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3b (Chronic)
HEXACHLOROETHANE	4.8E+00	Drinking Water Toxicity	1.0E+01	4.8E+00		1.2E+01
INDENO(1,2,3-cd)PYRENE	9.2E-02	Chronic Aquatic Habitat Goal	2.7E-01	9.2E-02		9.2E-02
LEAD	5.6E+00	Chronic Aquatic Habitat Goal	5.0E+04	1.5E+01		5.6E+00
MERCURY	2.5E-02	Chronic Aquatic Habitat Goal	5.0E+04	2.0E+00		2.5E-02
METHOXYCHLOR	3.0E-02	Chronic Aquatic Habitat Goal	2.0E+01	4.0E+01		3.0E-02
METHYL ETHYL KETONE	7.0E+03	Drinking Water Toxicity	8.4E+03	7.0E+03	2.7E+08	1.4E+04
METHYL ISOBUTYL KETONE	1.7E+02	Chronic Aquatic Habitat Goal	1.3E+03	2.0E+03	1.9E+07	1.7E+02
METHYL MERCURY	3.0E-03	Chronic Aquatic Habitat Goal	5.0E+04	3.7E+00		3.0E-03
METHYL TERT BUTYL ETHER	5.0E+00	Ceiling Value	5.0E+00	1.1E+01	1.9E+04	8.0E+03
METHYLENE CHLORIDE	4.3E+00	Drinking Water Toxicity	9.1E+03	4.3E+00	4.2E+03	2.2E+03
METHYLNAPHTHALENE (total 1- & 2-)	2.1E+00	Chronic Aquatic Habitat Goal	1.0E+01	2.4E+02	2.6E+04	2.1E+00
MOLYBDENUM	1.8E+02	Drinking Water Toxicity	5.0E+04	1.8E+02		2.4E+02
NAPHTHALENE	6.2E+00	Drinking Water Toxicity	2.1E+01	6.2E+00	3.1E+04	2.4E+01
NICKEL	5.0E+00	Chronic Aquatic Habitat Goal	5.0E+04	1.0E+02		5.0E+00
PENTACHLOROPHENOL	1.0E+00	Drinking Water Toxicity	3.0E+01	1.0E+00		7.9E+00
PERCHLORATE	3.7E+00	Drinking Water Toxicity	5.0E+04	3.7E+00		6.0E+02
PHENANTHRENE	4.6E+00	Chronic Aquatic Habitat Goal	4.1E+02	2.4E+02	(Use soil gas)	4.6E+00
PHENOL	5.0E+00	Ceiling Value	5.0E+00	1.1E+04		1.3E+03
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02	Chronic Aquatic Habitat Goal	1.6E+01	5.0E-01		1.4E-02
PYRENE	2.0E+00	Chronic Aquatic Habitat Goal	6.8E+01	1.8E+02	1.4E+02	2.0E+00
SELENIUM	5.0E+00	Chronic Aquatic Habitat Goal	5.0E+04	5.0E+01		5.0E+00
SILVER	1.0E+00	Chronic Aquatic Habitat Goal	1.0E+02	1.8E+02		1.0E+00
STYRENE	1.0E+01	Ceiling Value	1.0E+01	1.0E+02	3.1E+05	1.0E+02
tert-BUTYL ALCOHOL	3.7E+00	Drinking Water Toxicity	5.0E+04	3.7E+00	(Use soil gas)	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	4.3E-01	Drinking Water Toxicity	5.0E+04	4.3E-01	(Use soil gas)	3.1E+02
TETRACHLOROETHANE, 1,1,2,2-	5.6E-02	Drinking Water Toxicity	5.0E+02	5.6E-02	1.5E+02	4.2E+02
TETRACHLOROETHYLENE	5.0E+00	Drinking Water Toxicity	1.7E+02	5.0E+00	9.9E+01	1.2E+02
THALLIUM	2.0E+00	Drinking Water Toxicity	5.0E+04	2.0E+00		2.0E+01
TOLUENE	4.0E+01	Ceiling Value	4.0E+01	1.0E+03	5.3E+05	1.3E+02
TOXAPHENE	2.0E-04	Chronic Aquatic Habitat Goal	1.4E+02	3.0E+00		2.0E-04
TPH (gasolines)	1.0E+02	Ceiling Value	1.0E+02	1.0E+02	(Use soil gas)	5.0E+02
TPH (middle distillates)	1.0E+02	Ceiling Value	1.0E+02	1.0E+02	(Use soil gas)	6.4E+02
TPH (residual fuels)	1.0E+02	Ceiling Value	1.0E+02	1.0E+03		6.4E+02
TRICHLOROBENZENE, 1,2,4-	2.5E+01	Chronic Aquatic Habitat Goal	3.0E+03	7.0E+01	1.0E+04	2.5E+01
TRICHLOROETHANE, 1,1,1-	6.2E+01	Chronic Aquatic Habitat Goal	9.7E+02	2.0E+02	5.0E+05	6.2E+01
TRICHLOROETHANE, 1,1,2-	5.0E+00	Drinking Water Toxicity	5.0E+04	5.0E+00	2.8E+02	4.7E+03
TRICHLOROETHYLENE	5.0E+00	Drinking Water Toxicity	3.1E+02	5.0E+00	7.4E+01	3.6E+02
TRICHLOROPHENOL, 2,4,5-	1.1E+01	Chronic Aquatic Habitat Goal	2.0E+02	6.1E+02	1.2E+06	1.1E+01

TABLE D-1a. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS located within 150 meters of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3b (Chronic)
TRICHLOROPHENOL, 2,4,6-	3.7E+00	Drinking Water Toxicity	1.0E+02	3.7E+00		4.9E+02
VANADIUM	1.9E+01	Chronic Aquatic Habitat Goal	5.0E+04	3.7E+01		1.9E+01
VINYL CHLORIDE	2.0E+00	Drinking Water Toxicity	3.4E+03	2.0E+00	2.2E+01	7.8E+02
XYLENES	2.0E+01	Ceiling Value	2.0E+01	1.0E+04	1.6E+05	1.0E+02
ZINC	2.2E+01	Chronic Aquatic Habitat Goal	5.0E+03	1.1E+04		2.2E+01

Notes:

1. Lowest of Ceiling Value, Indoor-Air Impact goal and chronic Aquatic Habitat goal. Used to develop soil leaching levels for protection of groundwater quality (see Table E-1).

(Use Soil Gas): Use soil gas data to evaluate potential indoor-air impact concerns.

TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.

sol - solubility threshold

Ceiling Level: Taste and odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation and address nuisance concerns.

Human Toxicity: Based on primary maximum concentration levels (MCLs) or equivalent; considered protective of human health.

Indoor Air Impact: Addresses potential emission of volatile chemicals from groundwater and subsequent impact on indoor air. Action level for very permeable (e.g., sandy) vadose-zone soils used.

Aquatic Habitat Goal: Addresses potential discharge of groundwater to surface waterbody and subsequent impact on aquatic life. Potential dilution upon discharge to surface water not considered.

Method detection limits and background concentrations replace final action level as appropriate.

TABLE D-1b. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3c (Acute)
ACENAPHTHENE	2.0E+01	Ceiling Value	2.0E+01	3.7E+02	4.2E+03	3.2E+02
ACENAPHTHYLENE	2.4E+02	Drinking Water Toxicity	2.0E+03	2.4E+02	(Use soil gas)	3.0E+02
ACETONE	1.5E+03	Acute Aquatic Habitat Goal	2.0E+04	5.5E+03	2.1E+08	1.5E+03
ALDRIN	4.0E-03	Drinking Water Toxicity	8.5E+00	4.0E-03		1.3E+00
ANTHRACENE	7.3E-01	Acute Aquatic Habitat Goal	2.2E+01	1.8E+03	4.3E+01	7.3E-01
ANTIMONY	6.0E+00	Drinking Water Toxicity	5.0E+04	6.0E+00		1.5E+03
ARSENIC	1.0E+01	Drinking Water Toxicity	5.0E+04	1.0E+01		6.9E+01
BARIUM	2.0E+03	Acute Aquatic Habitat Goal	5.0E+04	2.0E+03		2.0E+03
BENZENE	5.0E+00	Drinking Water Toxicity	1.7E+02	5.0E+00	1.6E+03	1.7E+03
BENZO(a)ANTHRACENE	2.7E-02	Acute Aquatic Habitat Goal	5.0E+00	9.2E-02		2.7E-02
BENZO(a)PYRENE	1.4E-02	Acute Aquatic Habitat Goal	1.9E+00	2.0E-01		1.4E-02
BENZO(b)FLUORANTHENE	9.2E-02	Acute Aquatic Habitat Goal	7.0E+00	9.2E-02		9.2E-02
BENZO(g,h,i)PERYLENE	1.0E-01	Acute Aquatic Habitat Goal	1.3E-01	1.5E+03		1.0E-01
BENZO(k)FLUORANTHENE	4.0E-01	Ceiling Value	4.0E-01	9.2E-01		3.7E+00
BERYLLIUM	4.0E+00	Drinking Water Toxicity	5.0E+04	4.0E+00		4.3E+01
BIPHENYL, 1,1-	5.0E-01	Ceiling Value	5.0E-01	3.0E+02	(Use soil gas)	1.4E+01
BIS(2-CHLOROETHYL)ETHER	9.5E-03	Drinking Water Toxicity	3.6E+02	9.5E-03	1.0E+02	2.4E+05
BIS(2-CHLOROISOPROPYL)ETHER	2.7E-01	Drinking Water Toxicity	3.2E+02	2.7E-01	(Use soil gas)	2.4E+05
BIS(2-ETHYLHEXYL)PHTHALATE	6.0E+00	Drinking Water Toxicity	6.5E+02	6.0E+00		3.2E+01
BORON	1.6E+00	Acute Aquatic Habitat Goal	5.0E+04	7.3E+03		1.6E+00
BROMODICHLOROMETHANE	1.8E-01	Drinking Water Toxicity	5.0E+04	1.8E-01	2.7E+02	1.1E+04
BROMOFORM	1.0E+02	Drinking Water Toxicity	5.1E+02	1.0E+02		1.1E+04
BROMOMETHANE	8.5E+00	Drinking Water Toxicity	5.0E+04	8.5E+00	2.3E+03	1.1E+04
CADMIUM	3.0E+00	Acute Aquatic Habitat Goal	5.0E+04	5.0E+00		3.0E+00
CARBON TETRACHLORIDE	5.0E+00	Drinking Water Toxicity	5.2E+02	5.0E+00	2.1E+01	1.2E+04
CHLORDANE	9.0E-02	Acute Aquatic Habitat Goal	2.5E+00	2.0E+00		9.0E-02
CHLOROANILINE, p-	5.0E+00	Acute Aquatic Habitat Goal	5.0E+04	1.5E+02		5.0E+00
CHLOROBENZENE	5.0E+01	Ceiling Value	5.0E+01	1.0E+02	5.3E+04	1.6E+02
CHLOROETHANE	3.9E+00	Acute Aquatic Habitat Goal	1.6E+01	3.9E+00	6.5E+02	3.9E+00
CHLOROFORM	6.2E+01	Indoor Air Impacts	2.4E+03	1.0E+02	6.2E+01	9.6E+03
CHLOROMETHANE	1.6E+02	Drinking Water Toxicity	5.0E+04	1.6E+02	9.5E+03	1.1E+04
CHLOROPHENOL, 2-	1.8E-01	Ceiling Value	1.8E-01	3.0E+01	2.1E+04	1.4E+03
CHROMIUM (Total)	7.4E+01	Acute Aquatic Habitat Goal	5.0E+04	1.0E+02		7.4E+01
CHROMIUM III	5.7E+02	Acute Aquatic Habitat Goal	5.0E+04	5.5E+04		5.7E+02
CHROMIUM VI	1.6E+01	Acute Aquatic Habitat Goal	5.0E+04	1.1E+02		1.6E+01
CHRYSENE	3.5E-01	Acute Aquatic Habitat Goal	8.0E-01	9.2E+00	(Use soil gas)	3.5E-01
COBALT	3.0E+00	Acute Aquatic Habitat Goal	5.0E+04	7.3E+02		3.0E+00
COPPER	2.9E+00	Acute Aquatic Habitat Goal	1.0E+03	1.3E+03		2.9E+00
CYANIDE (Free)	1.0E+00	Acute Aquatic Habitat Goal	1.7E+02	2.0E+02	(Use soil gas)	1.0E+00

TABLE D-1b. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3c (Acute)
						7.5E+00
DIBENZO(a,h)ANTHTRACENE	9.2E-03	Drinking Water Toxicity	2.5E-01	9.2E-03		4.0E-02
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	Acute Aquatic Habitat Goal	1.0E+01	4.0E-02	(Use soil gas)	1.1E+04
DIBROMOCHLOROMETHANE	1.3E-01	Drinking Water Toxicity	5.0E+04	1.3E-01	1.6E+02	1.4E+03
DIBROMOETHANE, 1,2-	5.6E-03	Drinking Water Toxicity	5.0E+04	5.6E-03	1.6E+01	3.7E+02
DICHLOROENZENE, 1,2-	1.0E+01	Ceiling Value	1.0E+01	6.0E+02	1.6E+05	3.7E+02
DICHLOROENZENE, 1,3-	1.8E+02	Drinking Water Toxicity	5.0E+04	1.8E+02	(Use soil gas)	3.7E+02
DICHLOROENZENE, 1,4-	5.0E+00	Ceiling Value	5.0E+00	7.5E+01	4.9E+02	2.5E+02
DICHLOROENZIDINE, 3,3-	1.5E-01	Drinking Water Toxicity	1.6E+03	1.5E-01		6.0E-01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.8E-01	Drinking Water Toxicity	8.0E+01	2.8E-01		1.4E+01
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.8E-01	Drinking Water Toxicity	2.0E+01	2.8E-01		1.3E-02
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.3E-02	Acute Aquatic Habitat Goal	1.5E+00	2.0E-01		4.7E+01
DICHLOROETHANE, 1,1-	4.7E+01	Acute Aquatic Habitat Goal	5.0E+04	8.0E+02	2.8E+05	3.8E+04
DICHLOROETHANE, 1,2-	1.2E-01	Drinking Water Toxicity	7.0E+03	1.2E-01	1.3E+02	3.9E+03
DICHLOROETHYLENE, 1,1-	7.0E+00	Drinking Water Toxicity	1.5E+03	7.0E+00	2.5E+04	1.2E+04
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	Drinking Water Toxicity	5.0E+04	7.0E+01	2.4E+04	1.2E+04
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	Drinking Water Toxicity	2.6E+02	1.0E+02	2.7E+04	6.7E+02
DICHLOROPHENOL, 2,4-	3.0E-01	Ceiling Value	3.0E-01	1.1E+02		3.4E+03
DICHLOROPROPANE, 1,2-	5.0E+00	Drinking Water Toxicity	1.0E+01	5.0E+00	1.2E+02	2.6E+02
DICHLOROPROPENE, 1,3-	4.0E-01	Drinking Water Toxicity	5.0E+04	4.0E-01	1.6E+02	7.1E-01
DIELDRIN	4.2E-03	Drinking Water Toxicity	4.1E+01	4.2E-03		9.4E+02
DIETHYLPHTHALATE	9.4E+02	Acute Aquatic Habitat Goal	5.0E+04	2.9E+04		2.7E+02
DIMETHYLPHENOL, 2,4-	2.7E+02	Acute Aquatic Habitat Goal	4.0E+02	7.3E+02		9.4E+02
DIMETHYLPHTHALATE	9.4E+02	Acute Aquatic Habitat Goal	5.0E+04	3.7E+05		2.3E+02
DINITROPHENOL, 2,4-	7.3E+01	Drinking Water Toxicity	5.0E+04	7.3E+01		2.0E+02
DINITROTOLUENE, 2,4-	3.4E+01	Drinking Water Toxicity	5.0E+04	3.4E+01		6.7E+06
DIOXANE, 1,4-	6.1E+00	Drinking Water Toxicity	5.0E+04	6.1E+00		3.0E-03
DIOXIN (2,3,7,8-TCDD)	3.0E-05	Drinking Water Toxicity	7.0E+03	3.0E-05		3.4E-02
ENDOSULFAN	3.4E-02	Acute Aquatic Habitat Goal	7.5E+01	2.2E+02		3.7E-02
ENDRIN	3.7E-02	Acute Aquatic Habitat Goal	4.1E+01	2.0E+00		4.3E+02
ETHYLBENZENE	3.0E+01	Ceiling Value	3.0E+01	7.0E+02	1.7E+05	4.0E+01
FLUORANTHENE	4.0E+01	Acute Aquatic Habitat Goal	1.3E+02	1.5E+03		3.0E+02
FLUORENE	2.4E+02	Drinking Water Toxicity	9.5E+02	2.4E+02	1.9E+03	5.3E-02
HEPTACHLOR	5.3E-02	Acute Aquatic Habitat Goal	2.0E+01	4.0E-01		5.3E-02
HEPTACHLOR EPOXIDE	5.3E-02	Acute Aquatic Habitat Goal	1.8E+02	2.0E-01		6.0E+00
HEXACHLOROENZENE	1.0E+00	Drinking Water Toxicity	5.5E+01	1.0E+00		1.1E+01
HEXACHLOROBUTADIENE	8.6E-01	Drinking Water Toxicity	6.0E+00	8.6E-01		1.6E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	1.6E-01	Acute Aquatic Habitat Goal	3.5E+03	2.0E-01		3.1E+02
HEXACHLOROETHANE	4.8E+00	Drinking Water Toxicity	1.0E+01	4.8E+00		9.2E-02
INDENO(1,2,3-cd)PYRENE	9.2E-02	Acute Aquatic Habitat Goal	2.7E-01	9.2E-02		

TABLE D-1b. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3c (Acute)
LEAD	1.5E+01	Drinking Water Toxicity	5.0E+04	1.5E+01		2.9E+01
MERCURY	2.0E+00	Drinking Water Toxicity	5.0E+04	2.0E+00		2.1E+00
METHOXYCHLOR	3.0E-02	Acute Aquatic Habitat Goal	2.0E+01	4.0E+01		3.0E-02
METHYL ETHYL KETONE	7.0E+03	Drinking Water Toxicity	8.4E+03	7.0E+03	2.7E+08	1.4E+04
METHYL ISOBUTYL KETONE	1.7E+02	Acute Aquatic Habitat Goal	1.3E+03	2.0E+03	1.9E+07	1.7E+02
METHYL MERCURY	3.0E-03	Acute Aquatic Habitat Goal	5.0E+04	3.7E+00		3.0E-03
METHYL TERT BUTYL ETHER	5.0E+00	Ceiling Value	5.0E+00	1.1E+01	1.9E+04	8.0E+03
METHYLENE CHLORIDE	4.3E+00	Drinking Water Toxicity	9.1E+03	4.3E+00	4.2E+03	1.1E+04
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+01	Ceiling Value	1.0E+01	2.4E+02	2.6E+04	3.0E+02
MOLYBDENUM	1.8E+02	Drinking Water Toxicity	5.0E+04	1.8E+02		2.4E+02
NAPHTHALENE	6.2E+00	Drinking Water Toxicity	2.1E+01	6.2E+00	3.1E+04	7.7E+02
NICKEL	5.0E+00	Acute Aquatic Habitat Goal	5.0E+04	1.0E+02		5.0E+00
PENTACHLOROPHENOL	1.0E+00	Drinking Water Toxicity	3.0E+01	1.0E+00		1.3E+01
PERCHLORATE	3.7E+00	Drinking Water Toxicity	5.0E+04	3.7E+00		6.0E+02
PHENANTHRENE	7.7E+00	Acute Aquatic Habitat Goal	4.1E+02	2.4E+02	(Use soil gas)	7.7E+00
PHENOL	5.0E+00	Ceiling Value	5.0E+00	1.1E+04		3.4E+03
POLYCHLORINATED BIPHENYLS (PCBs)	5.0E-01	Drinking Water Toxicity	1.6E+01	5.0E-01		2.0E+00
PYRENE	2.0E+00	Acute Aquatic Habitat Goal	6.8E+01	1.8E+02	1.4E+02	2.0E+00
SELENIUM	2.0E+01	Acute Aquatic Habitat Goal	5.0E+04	5.0E+01		2.0E+01
SILVER	1.0E+00	Acute Aquatic Habitat Goal	1.0E+02	1.8E+02		1.0E+00
STYRENE	1.0E+01	Ceiling Value	1.0E+01	1.0E+02	3.1E+05	1.0E+02
tert-BUTYL ALCOHOL	3.7E+00	Drinking Water Toxicity	5.0E+04	3.7E+00	(Use soil gas)	1.8E+05
TETRACHLOROETHANE, 1,1,1,2-	4.3E-01	Drinking Water Toxicity	5.0E+04	4.3E-01	(Use soil gas)	3.1E+03
TETRACHLOROETHANE, 1,1,2,2-	5.6E-02	Drinking Water Toxicity	5.0E+02	5.6E-02	1.5E+02	3.0E+03
TETRACHLOROETHYLENE	5.0E+00	Drinking Water Toxicity	1.7E+02	5.0E+00	9.9E+01	1.8E+03
THALLIUM	2.0E+00	Drinking Water Toxicity	5.0E+04	2.0E+00		4.7E+02
TOLUENE	4.0E+01	Ceiling Value	4.0E+01	1.0E+03	5.3E+05	5.8E+03
TOXAPHENE	2.1E-01	Acute Aquatic Habitat Goal	1.4E+02	3.0E+00		2.1E-01
TPH (gasolines)	1.0E+02	Ceiling Value	1.0E+02	1.0E+02	(Use soil gas)	5.0E+03
TPH (middle distillates)	1.0E+02	Ceiling Value	1.0E+02	1.0E+02	(Use soil gas)	2.5E+03
TPH (residual fuels)	1.0E+02	Ceiling Value	1.0E+02	1.0E+03		2.5E+03
TRICHLOROBENZENE, 1,2,4-	7.0E+01	Drinking Water Toxicity	3.0E+03	7.0E+01	1.0E+04	1.6E+02
TRICHLOROETHANE, 1,1,1-	2.0E+02	Drinking Water Toxicity	9.7E+02	2.0E+02	5.0E+05	6.0E+03
TRICHLOROETHANE, 1,1,2-	5.0E+00	Drinking Water Toxicity	5.0E+04	5.0E+00	2.8E+02	6.0E+03
TRICHLOROETHYLENE	5.0E+00	Drinking Water Toxicity	3.1E+02	5.0E+00	7.4E+01	7.0E+02
TRICHLOROPHENOL, 2,4,5-	1.0E+02	Acute Aquatic Habitat Goal	2.0E+02	6.1E+02	1.2E+06	1.0E+02
TRICHLOROPHENOL, 2,4,6-	3.7E+00	Drinking Water Toxicity	1.0E+02	3.7E+00		4.9E+02
VANADIUM	1.9E+01	Acute Aquatic Habitat Goal	5.0E+04	3.7E+01		1.9E+01
VINYL CHLORIDE	2.0E+00	Drinking Water Toxicity	3.4E+03	2.0E+00	2.2E+01	7.8E+02

TABLE D-1b. GROUNDWATER ACTION LEVELS
(Groundwater IS a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Taste & Odors, etc.)	Drinking Water Toxicity	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-1	Table D-2	Table C-1a	Table D-3c (Acute)
XYLENES	2.0E+01	Ceiling Value	2.0E+01	1.0E+04	1.6E+05	2.0E+03
ZINC	2.2E+01	Acute Aquatic Habitat Goal	5.0E+03	1.1E+04		2.2E+01

Notes:
1. Lowest of Ceiling Value, Indoor-Air Impact goal and acute Aquatic Habitat goal. Used to develop soil leaching levels for protection of groundwater quality (see Table E-1).

(Use Soil Gas): Use soil gas data to evaluate potential indoor-air impact concerns.
TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
sol - solubility threshold
Ceiling Level: Taste and odor threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation and address nuisance concerns.
Human Toxicity: Based on primary maximum concentration levels (MCLs) or equivalent; considered protective of human health.
Indoor Air Impact: Addresses potential emission of volatile chemicals from groundwater and subsequent impact on indoor air. Action level for very permeable (e.g., sandy) vadose-zone soils used.
Aquatic Habitat Goal: Addresses potential discharge of groundwater to surface waterbody and subsequent impact on aquatic life. Potential dilution upon discharge to surface water not considered.
Method detection limits and background concentrations replace final action level as appropriate.

TABLE D-1c. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS located within 150m of release site)
(ug/l)

CONTAMINANT	1 Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3b (Chronic)
ACENAPHTHENE	2.3E+01	Aquatic Habitat Goal	2.0E+02	4.2E+03	2.3E+01
ACENAPHTHYLENE	3.0E+01	Aquatic Habitat Goal	2.0E+03	(Use soil gas)	3.0E+01
ACETONE	1.5E+03	Aquatic Habitat Goal	5.0E+04	2.1E+08	1.5E+03
ALDRIN	1.3E-01	Aquatic Habitat Goal	8.5E+00		1.3E-01
ANTHRACENE	7.3E-01	Aquatic Habitat Goal	2.2E+01	4.3E+01	7.3E-01
ANTIMONY	3.0E+01	Aquatic Habitat Goal	5.0E+04		3.0E+01
ARSENIC	3.6E+01	Aquatic Habitat Goal	5.0E+04		3.6E+01
BARIUM	2.0E+03	Aquatic Habitat Goal	5.0E+04		2.0E+03
BENZENE	4.6E+01	Aquatic Habitat Goal	2.0E+04	1.6E+03	4.6E+01
BENZO(a)ANTHRACENE	2.7E-02	Aquatic Habitat Goal	5.0E+00		2.7E-02
BENZO(a)PYRENE	1.4E-02	Aquatic Habitat Goal	1.9E+00		1.4E-02
BENZO(b)FLUORANTHENE	9.2E-02	Aquatic Habitat Goal	7.0E+00		9.2E-02
BENZO(g,h,i)PERYLENE	1.0E-01	Aquatic Habitat Goal	1.3E-01		1.0E-01
BENZO(k)FLUORANTHENE	4.0E-01	Ceiling Value	4.0E-01		3.7E+00
BERYLLIUM	2.7E+00	Aquatic Habitat Goal	5.0E+04		2.7E+00
BIPHENYL, 1,1-	5.0E+00	Ceiling Value	5.0E+00	(Use soil gas)	1.4E+01
BIS(2-CHLOROETHYL)ETHER	6.1E+01	Aquatic Habitat Goal	3.6E+03	1.0E+02	6.1E+01
BIS(2-CHLOROISOPROPYL)ETHER	6.1E+01	Aquatic Habitat Goal	3.2E+03	(Use soil gas)	6.1E+01
BIS(2-ETHYLHEXYL)PHTHALATE	3.2E+01	Aquatic Habitat Goal	6.5E+02		3.2E+01
BORON	1.6E+00	Aquatic Habitat Goal	5.0E+04		1.6E+00
BROMODICHLOROMETHANE	2.7E+02	Indoor Air Impacts	5.0E+04	2.7E+02	3.2E+03
BROMOFORM	3.2E+03	Aquatic Habitat Goal	5.1E+03		3.2E+03
BROMOMETHANE	1.6E+02	Aquatic Habitat Goal	5.0E+04	2.3E+03	1.6E+02
CADMIUM	3.0E+00	Aquatic Habitat Goal	5.0E+04		3.0E+00
CARBON TETRACHLORIDE	9.8E+00	Aquatic Habitat Goal	5.2E+03	2.1E+01	9.8E+00
CHLORDANE	4.0E-03	Aquatic Habitat Goal	2.5E+01		4.0E-03
CHLOROANILINE, p-	5.0E+00	Aquatic Habitat Goal	5.0E+04		5.0E+00
CHLOROBENZENE	2.5E+01	Aquatic Habitat Goal	5.0E+02	5.3E+04	2.5E+01
CHLOROETHANE	3.9E+00	Aquatic Habitat Goal	1.6E+02	6.5E+02	3.9E+00
CHLOROFORM	6.2E+01	Indoor Air Impacts	2.4E+01	6.2E+01	6.2E+02
CHLOROMETHANE	3.2E+03	Aquatic Habitat Goal	5.0E+04	9.5E+03	3.2E+03
CHLOROPHENOL, 2-	1.8E+00	Ceiling Value	1.8E+00	2.1E+04	1.4E+02
CHROMIUM (Total)	7.4E+01	Aquatic Habitat Goal	5.0E+04		7.4E+01
CHROMIUM III	7.4E+01	Aquatic Habitat Goal	5.0E+04		7.4E+01
CHROMIUM VI	1.1E+01	Aquatic Habitat Goal	5.0E+04		1.1E+01
CHRYSENE	3.5E-01	Aquatic Habitat Goal	8.0E-01	(Use soil gas)	3.5E-01
COBALT	3.0E+00	Aquatic Habitat Goal	5.0E+04		3.0E+00
COPPER	2.9E+00	Aquatic Habitat Goal	5.0E+04		2.9E+00

TABLE D-1c. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3b (Chronic)
CYANIDE (Free)	1.0E+00	Aquatic Habitat Goal	1.7E+03	(Use soil gas)	1.0E+00
DIBENZO(a,h)ANTHTRACENE	2.5E-01	Ceiling Value	2.5E-01		7.5E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	Aquatic Habitat Goal	1.0E+02	(Use soil gas)	4.0E-02
DIBROMOCHLOROMETHANE	1.6E+02	Indoor Air Impacts	5.0E+04	1.6E+02	3.2E+03
DIBROMOETHANE, 1,2-	1.6E+01	Indoor Air Impacts	5.0E+04	1.6E+01	1.4E+03
DICHLOROBENZENE, 1,2-	1.4E+01	Aquatic Habitat Goal	1.0E+02	1.6E+05	1.4E+01
DICHLOROBENZENE, 1,3-	6.5E+01	Aquatic Habitat Goal	5.0E+04	(Use soil gas)	6.5E+01
DICHLOROBENZENE, 1,4-	1.5E+01	Aquatic Habitat Goal	1.1E+02	4.9E+02	1.5E+01
DICHLOROBENZIDINE, 3,3-	2.5E+02	Aquatic Habitat Goal	1.6E+03		2.5E+02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E-03	Aquatic Habitat Goal	8.0E+01		1.0E-03
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E-03	Aquatic Habitat Goal	2.0E+01		1.0E-03
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03	Aquatic Habitat Goal	1.5E+00		1.0E-03
DICHLOROETHANE, 1,1-	4.7E+01	Aquatic Habitat Goal	5.0E+04	2.8E+05	4.7E+01
DICHLOROETHANE, 1,2-	1.3E+02	Indoor Air Impacts	5.0E+04	1.3E+02	1.0E+04
DICHLOROETHYLENE, 1,1-	2.5E+01	Aquatic Habitat Goal	1.5E+04	2.5E+04	2.5E+01
DICHLOROETHYLENE, Cis 1,2-	5.9E+02	Aquatic Habitat Goal	5.0E+04	2.4E+04	5.9E+02
DICHLOROETHYLENE, Trans 1,2-	5.9E+02	Aquatic Habitat Goal	2.6E+03	2.7E+04	5.9E+02
DICHLOROPHENOL, 2,4-	3.0E+00	Ceiling Value	3.0E+00		1.8E+02
DICHLOROPROPANE, 1,2-	1.0E+02	Ceiling Value	1.0E+02	1.2E+02	1.5E+03
DICHLOROPROPENE, 1,3-	1.2E+02	Aquatic Habitat Goal	5.0E+04	1.6E+02	1.2E+02
DIELDRIN	1.9E-03	Aquatic Habitat Goal	9.3E+01		1.9E-03
DIETHYLPHTHALATE	1.5E+00	Aquatic Habitat Goal	5.0E+04		1.5E+00
DIMETHYLPHENOL, 2,4-	1.1E+02	Aquatic Habitat Goal	4.0E+03		1.1E+02
DIMETHYLPHTHALATE	1.5E+00	Aquatic Habitat Goal	5.0E+04		1.5E+00
DINITROPHENOL, 2,4-	7.5E+01	Aquatic Habitat Goal	5.0E+04		7.5E+01
DINITROTOLUENE, 2,4-	1.2E+02	Aquatic Habitat Goal	5.0E+04		1.2E+02
DIOXANE, 1,4-	5.0E+04	Ceiling Value	5.0E+04		3.4E+05
DIOXIN (2,3,7,8-TCDD)	5.0E-06	Aquatic Habitat Goal	7.0E+03		5.0E-06
ENDOSULFAN	8.7E-03	Aquatic Habitat Goal	7.5E+01		8.7E-03
ENDRIN	2.3E-03	Aquatic Habitat Goal	1.3E+02		2.3E-03
ETHYLBENZENE	2.9E+02	Aquatic Habitat Goal	3.0E+02	1.7E+05	2.9E+02
FLUORANTHENE	8.0E+00	Aquatic Habitat Goal	1.3E+02		8.0E+00
FLUORENE	3.9E+00	Aquatic Habitat Goal	9.5E+02	1.9E+03	3.9E+00
HEPTACHLOR	3.6E-03	Aquatic Habitat Goal	2.8E+01		3.6E-03
HEPTACHLOR EPOXIDE	3.6E-03	Aquatic Habitat Goal	1.8E+02		3.6E-03
HEXACHLOROBENZENE	3.7E+00	Aquatic Habitat Goal	5.5E+01		3.7E+00
HEXACHLOROBUTADIENE	4.7E+00	Aquatic Habitat Goal	6.0E+01		4.7E+00
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	8.0E-02	Aquatic Habitat Goal	3.5E+03		8.0E-02

TABLE D-1c. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3b (Chronic)
HEXACHLOROETHANE	1.2E+01	Aquatic Habitat Goal	1.0E+02		1.2E+01
INDENO(1,2,3-cd)PYRENE	9.2E-02	Aquatic Habitat Goal	2.7E-01		9.2E-02
LEAD	5.6E+00	Aquatic Habitat Goal	5.0E+04		5.6E+00
MERCURY	2.5E-02	Aquatic Habitat Goal	5.0E+04		2.5E-02
METHOXYCHLOR	3.0E-02	Aquatic Habitat Goal	2.0E+01		3.0E-02
METHYL ETHYL KETONE	1.4E+04	Aquatic Habitat Goal	5.0E+04	2.7E+08	1.4E+04
METHYL ISOBUTYL KETONE	1.7E+02	Aquatic Habitat Goal	1.3E+04	1.9E+07	1.7E+02
METHYL MERCURY	3.0E-03	Aquatic Habitat Goal	5.0E+04		3.0E-03
METHYL TERT BUTYL ETHER	1.8E+03	Ceiling Value	1.8E+03	1.9E+04	8.0E+03
METHYLENE CHLORIDE	2.2E+03	Aquatic Habitat Goal	5.0E+04	4.2E+03	2.2E+03
METHYLNAPHTHALENE (total 1- & 2-)	2.1E+00	Aquatic Habitat Goal	1.0E+02	2.6E+04	2.1E+00
MOLYBDENUM	2.4E+02	Aquatic Habitat Goal	5.0E+04		2.4E+02
NAPHTHALENE	2.4E+01	Aquatic Habitat Goal	2.1E+02	3.1E+04	2.4E+01
NICKEL	5.0E+00	Aquatic Habitat Goal	5.0E+04		5.0E+00
PENTACHLOROPHENOL	7.9E+00	Aquatic Habitat Goal	5.9E+03		7.9E+00
PERCHLORATE	6.0E+02	Aquatic Habitat Goal	5.0E+04		6.0E+02
PHENANTHRENE	4.6E+00	Aquatic Habitat Goal	4.1E+02	(Use soil gas)	4.6E+00
PHENOL	1.3E+03	Aquatic Habitat Goal	5.0E+04		1.3E+03
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02	Aquatic Habitat Goal	1.6E+01		1.4E-02
PYRENE	2.0E+00	Aquatic Habitat Goal	6.8E+01	1.4E+02	2.0E+00
SELENIUM	5.0E+00	Aquatic Habitat Goal	5.0E+04		5.0E+00
SILVER	1.0E+00	Aquatic Habitat Goal	5.0E+04		1.0E+00
STYRENE	1.0E+02	Aquatic Habitat Goal	1.1E+02	3.1E+05	1.0E+02
tert-BUTYL ALCOHOL	1.8E+04	Aquatic Habitat Goal	5.0E+04	(Use soil gas)	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	3.1E+02	Aquatic Habitat Goal	5.0E+04	(Use soil gas)	3.1E+02
TETRACHLOROETHANE, 1,1,2,2-	1.5E+02	Indoor Air Impacts	5.0E+03	1.5E+02	4.2E+02
TETRACHLOROETHYLENE	9.9E+01	Indoor Air Impacts	3.0E+03	9.9E+01	1.2E+02
THALLIUM	2.0E+01	Aquatic Habitat Goal	5.0E+04		2.0E+01
TOLUENE	1.3E+02	Aquatic Habitat Goal	4.0E+02	5.3E+05	1.3E+02
TOXAPHENE	2.0E-04	Aquatic Habitat Goal	1.4E+02		2.0E-04
TPH (gasolines)	5.0E+02	Aquatic Habitat Goal	5.0E+03	(Use soil gas)	5.0E+02
TPH (middle distillates)	6.4E+02	Aquatic Habitat Goal	2.5E+03	(Use soil gas)	6.4E+02
TPH (residual fuels)	6.4E+02	Aquatic Habitat Goal	2.5E+03		6.4E+02
TRICHLOROENZENE, 1,2,4-	2.5E+01	Aquatic Habitat Goal	3.0E+04	1.0E+04	2.5E+01
TRICHLOROETHANE, 1,1,1-	6.2E+01	Aquatic Habitat Goal	5.0E+04	5.0E+05	6.2E+01
TRICHLOROETHANE, 1,1,2-	2.8E+02	Indoor Air Impacts	5.0E+04	2.8E+02	4.7E+03
TRICHLOROETHYLENE	7.4E+01	Indoor Air Impacts	5.0E+04	7.4E+01	3.6E+02
TRICHLOROPHENOL, 2,4,5-	1.1E+01	Aquatic Habitat Goal	2.0E+03	1.2E+06	1.1E+01

TABLE D-1c. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3b (Chronic)
TRICHLOROPHENOL, 2,4,6-	4.9E+02	Aquatic Habitat Goal	1.0E+03		4.9E+02
VANADIUM	1.9E+01	Aquatic Habitat Goal	5.0E+04		1.9E+01
VINYL CHLORIDE	2.2E+01	Indoor Air Impacts	3.4E+04	2.2E+01	7.8E+02
XYLENES	1.0E+02	Aquatic Habitat Goal	5.3E+03	1.6E+05	1.0E+02
ZINC	2.2E+01	Aquatic Habitat Goal	5.0E+04		2.2E+01

Notes:

1. Lowest of Ceiling Value, Indoor-Air Impact goal and chronic Aquatic Habitat goal. Used to develop soil leaching levels for protection of groundwater quality (see Table E-1).

(Use Soil Gas): Use soil gas data to evaluate potential indoor-air impact concerns.

TPH - Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.

sol - solubility threshold

Ceiling Level: Odor/nuisance threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation and address nuisance concerns.

Indoor Air Impact: Addresses potential emission of volatile chemicals from groundwater and subsequent impact on indoor air. Action level for very permeable (e.g., sandy) vadose zone soils used.

Aquatic Habitat Goal: Addresses potential discharge of groundwater to surface waterbody and subsequent impact on aquatic life. Potential dilution upon discharge to surface water not considered.

Method detection limits and background concentrations replace final action level as appropriate.

TABLE D-1d. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3c (Acute)
ACENAPHTHENE	2.0E+02	Ceiling Value	2.0E+02	4.2E+03	3.2E+02
ACENAPHTHYLENE	3.0E+02	Acute Aquatic Habitat Goal	2.0E+03	(Use soil gas)	3.0E+02
ACETONE	1.5E+03	Acute Aquatic Habitat Goal	5.0E+04	2.1E+08	1.5E+03
ALDRIN	1.3E+00	Acute Aquatic Habitat Goal	8.5E+00		1.3E+00
ANTHRACENE	7.3E-01	Acute Aquatic Habitat Goal	2.2E+01	4.3E+01	7.3E-01
ANTIMONY	1.5E+03	Acute Aquatic Habitat Goal	5.0E+04		1.5E+03
ARSENIC	6.9E+01	Acute Aquatic Habitat Goal	5.0E+04		6.9E+01
BARIUM	2.0E+03	Acute Aquatic Habitat Goal	5.0E+04		2.0E+03
BENZENE	1.6E+03	Indoor Air Impacts	2.0E+04	1.6E+03	1.7E+03
BENZO(a)ANTHRACENE	2.7E-02	Acute Aquatic Habitat Goal	5.0E+00		2.7E-02
BENZO(a)PYRENE	1.4E-02	Acute Aquatic Habitat Goal	1.9E+00		1.4E-02
BENZO(b)FLUORANTHENE	9.2E-02	Acute Aquatic Habitat Goal	7.0E+00		9.2E-02
BENZO(g,h,i)PERYLENE	1.0E-01	Acute Aquatic Habitat Goal	1.3E-01		1.0E-01
BENZO(k)FLUORANTHENE	4.0E-01	Ceiling Value	4.0E-01		3.7E+00
BERYLLIUM	4.3E+01	Acute Aquatic Habitat Goal	5.0E+04		4.3E+01
BIPHENYL, 1,1-	5.0E+00	Ceiling Value	5.0E+00	(Use soil gas)	1.4E+01
BIS(2-CHLOROETHYL)ETHER	1.0E+02	Indoor Air Impacts	3.6E+03	1.0E+02	2.4E+05
BIS(2-CHLOROISOPROPYL)ETHER	3.2E+03	Ceiling Value	3.2E+03	(Use soil gas)	2.4E+05
BIS(2-ETHYLHEXYL)PHTHALATE	3.2E+01	Acute Aquatic Habitat Goal	6.5E+02		3.2E+01
BORON	1.6E+00	Acute Aquatic Habitat Goal	5.0E+04		1.6E+00
BROMODICHLOROMETHANE	2.7E+02	Indoor Air Impacts	5.0E+04	2.7E+02	1.1E+04
BROMOFORM	5.1E+03	Ceiling Value	5.1E+03		1.1E+04
BROMOMETHANE	2.3E+03	Indoor Air Impacts	5.0E+04	2.3E+03	1.1E+04
CADMIUM	3.0E+00	Acute Aquatic Habitat Goal	5.0E+04		3.0E+00
CARBON TETRACHLORIDE	2.1E+01	Indoor Air Impacts	5.2E+03	2.1E+01	1.2E+04
CHLORDANE	9.0E-02	Acute Aquatic Habitat Goal	2.5E+01		9.0E-02
CHLOROANILINE, p-	5.0E+00	Acute Aquatic Habitat Goal	5.0E+04		5.0E+00
CHLOROENZENE	1.6E+02	Acute Aquatic Habitat Goal	5.0E+02	5.3E+04	1.6E+02
CHLOROETHANE	3.9E+00	Acute Aquatic Habitat Goal	1.6E+02	6.5E+02	3.9E+00
CHLOROFORM	6.2E+01	Indoor Air Impacts	2.4E+04	6.2E+01	9.6E+03
CHLOROMETHANE	9.5E+03	Indoor Air Impacts	5.0E+04	9.5E+03	1.1E+04
CHLOROPHENOL, 2-	1.8E+00	Ceiling Value	1.8E+00	2.1E+04	1.4E+03
CHROMIUM (Total)	7.4E+01	Acute Aquatic Habitat Goal	5.0E+04		7.4E+01
CHROMIUM III	5.7E+02	Acute Aquatic Habitat Goal	5.0E+04		5.7E+02
CHROMIUM VI	1.6E+01	Acute Aquatic Habitat Goal	5.0E+04		1.6E+01
CHRYSENE	3.5E-01	Acute Aquatic Habitat Goal	8.0E-01	(Use soil gas)	3.5E-01
COBALT	3.0E+00	Acute Aquatic Habitat Goal	5.0E+04		3.0E+00
COPPER	2.9E+00	Acute Aquatic Habitat Goal	5.0E+04		2.9E+00
CYANIDE (Free)	1.0E+00	Acute Aquatic Habitat Goal	1.7E+03	(Use soil gas)	1.0E+00

TABLE D-1d. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3c (Acute)
DIBENZO(a,h)ANTHTRACENE	2.5E-01	Ceiling Value	2.5E-01		7.5E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	Acute Aquatic Habitat Goal	1.0E+02	(Use soil gas)	4.0E-02
DIBROMOCHLOROMETHANE	1.6E+02	Indoor Air Impacts	5.0E+04	1.6E+02	1.1E+04
DIBROMOETHANE, 1,2-	1.6E+01	Indoor Air Impacts	5.0E+04	1.6E+01	1.4E+03
DICHLOROBENZENE, 1,2-	1.0E+02	Ceiling Value	1.0E+02	1.6E+05	3.7E+02
DICHLOROBENZENE, 1,3-	3.7E+02	Acute Aquatic Habitat Goal	5.0E+04	(Use soil gas)	3.7E+02
DICHLOROBENZENE, 1,4-	1.1E+02	Ceiling Value	1.1E+02	4.9E+02	3.7E+02
DICHLOROBENZIDINE, 3,3-	2.5E+02	Acute Aquatic Habitat Goal	1.6E+03		2.5E+02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	6.0E-01	Acute Aquatic Habitat Goal	8.0E+01		6.0E-01
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.4E+01	Acute Aquatic Habitat Goal	2.0E+01		1.4E+01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.3E-02	Acute Aquatic Habitat Goal	1.5E+00		1.3E-02
DICHLOROETHANE, 1,1-	4.7E+01	Acute Aquatic Habitat Goal	5.0E+04	2.8E+05	4.7E+01
DICHLOROETHANE, 1,2-	1.3E+02	Indoor Air Impacts	5.0E+04	1.3E+02	3.8E+04
DICHLOROETHYLENE, 1,1-	3.9E+03	Acute Aquatic Habitat Goal	1.5E+04	2.5E+04	3.9E+03
DICHLOROETHYLENE, Cis 1,2-	1.2E+04	Acute Aquatic Habitat Goal	5.0E+04	2.4E+04	1.2E+04
DICHLOROETHYLENE, Trans 1,2-	2.6E+03	Ceiling Value	2.6E+03	2.7E+04	1.2E+04
DICHLOROPHENOL, 2,4-	3.0E+00	Ceiling Value	3.0E+00		6.7E+02
DICHLOROPROPANE, 1,2-	1.0E+02	Ceiling Value	1.0E+02	1.2E+02	3.4E+03
DICHLOROPROPENE, 1,3-	1.6E+02	Indoor Air Impacts	5.0E+04	1.6E+02	2.6E+02
DIELDRIN	7.1E-01	Acute Aquatic Habitat Goal	9.3E+01		7.1E-01
DIETHYLPHTHALATE	9.4E+02	Acute Aquatic Habitat Goal	5.0E+04		9.4E+02
DIMETHYLPHENOL, 2,4-	2.7E+02	Acute Aquatic Habitat Goal	4.0E+03		2.7E+02
DIMETHYLPHTHALATE	9.4E+02	Acute Aquatic Habitat Goal	5.0E+04		9.4E+02
DINITROPHENOL, 2,4-	2.3E+02	Acute Aquatic Habitat Goal	5.0E+04		2.3E+02
DINITROTOLUENE, 2,4-	2.0E+02	Acute Aquatic Habitat Goal	5.0E+04		2.0E+02
DIOXANE, 1,4-	5.0E+04	Ceiling Value	5.0E+04		6.7E+06
DIOXIN (2,3,7,8-TCDD)	3.0E-03	Acute Aquatic Habitat Goal	7.0E+03		3.0E-03
ENDOSULFAN	3.4E-02	Acute Aquatic Habitat Goal	7.5E+01		3.4E-02
ENDRIN	3.7E-02	Acute Aquatic Habitat Goal	1.3E+02		3.7E-02
ETHYLBENZENE	3.0E+02	Ceiling Value	3.0E+02	1.7E+05	4.3E+02
FLUORANTHENE	4.0E+01	Acute Aquatic Habitat Goal	1.3E+02		4.0E+01
FLUORENE	3.0E+02	Acute Aquatic Habitat Goal	9.5E+02	1.9E+03	3.0E+02
HEPTACHLOR	5.3E-02	Acute Aquatic Habitat Goal	2.8E+01		5.3E-02
HEPTACHLOR EPOXIDE	5.3E-02	Acute Aquatic Habitat Goal	1.8E+02		5.3E-02
HEXACHLOROBENZENE	6.0E+00	Acute Aquatic Habitat Goal	5.5E+01		6.0E+00
HEXACHLOROBUTADIENE	1.1E+01	Acute Aquatic Habitat Goal	6.0E+01		1.1E+01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	1.6E-01	Acute Aquatic Habitat Goal	3.5E+03		1.6E-01
HEXACHLOROETHANE	1.0E+02	Ceiling Value	1.0E+02		3.1E+02
INDENO(1,2,3-cd)PYRENE	9.2E-02	Acute Aquatic Habitat Goal	2.7E-01		9.2E-02

TABLE D-1d. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3c (Acute)
LEAD	2.9E+01	Acute Aquatic Habitat Goal	5.0E+04		2.9E+01
MERCURY	2.1E+00	Acute Aquatic Habitat Goal	5.0E+04		2.1E+00
METHOXYCHLOR	3.0E-02	Acute Aquatic Habitat Goal	2.0E+01		3.0E-02
METHYL ETHYL KETONE	1.4E+04	Acute Aquatic Habitat Goal	5.0E+04	2.7E+08	1.4E+04
METHYL ISOBUTYL KETONE	1.7E+02	Acute Aquatic Habitat Goal	1.3E+04	1.9E+07	1.7E+02
METHYL MERCURY	3.0E-03	Acute Aquatic Habitat Goal	5.0E+04		3.0E-03
METHYL TERT BUTYL ETHER	1.8E+03	Ceiling Value	1.8E+03	1.9E+04	8.0E+03
METHYLENE CHLORIDE	4.2E+03	Indoor Air Impacts	5.0E+04	4.2E+03	1.1E+04
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+02	Ceiling Value	1.0E+02	2.6E+04	3.0E+02
MOLYBDENUM	2.4E+02	Acute Aquatic Habitat Goal	5.0E+04		2.4E+02
NAPHTHALENE	2.1E+02	Ceiling Value	2.1E+02	3.1E+04	7.7E+02
NICKEL	5.0E+00	Acute Aquatic Habitat Goal	5.0E+04		5.0E+00
PENTACHLOROPHENOL	1.3E+01	Acute Aquatic Habitat Goal	5.9E+03		1.3E+01
PERCHLORATE	6.0E+02	Acute Aquatic Habitat Goal	5.0E+04		6.0E+02
PHENANTHRENE	7.7E+00	Acute Aquatic Habitat Goal	4.1E+02	(Use soil gas)	7.7E+00
PHENOL	3.4E+03	Acute Aquatic Habitat Goal	5.0E+04		3.4E+03
POLYCHLORINATED BIPHENYLS (PCBs)	2.0E+00	Acute Aquatic Habitat Goal	1.6E+01		2.0E+00
PYRENE	2.0E+00	Acute Aquatic Habitat Goal	6.8E+01	1.4E+02	2.0E+00
SELENIUM	2.0E+01	Acute Aquatic Habitat Goal	5.0E+04		2.0E+01
SILVER	1.0E+00	Acute Aquatic Habitat Goal	5.0E+04		1.0E+00
STYRENE	1.0E+02	Acute Aquatic Habitat Goal	1.1E+02	3.1E+05	1.0E+02
tert-BUTYL ALCOHOL	5.0E+04	Ceiling Value	5.0E+04	(Use soil gas)	1.8E+05
TETRACHLOROETHANE, 1,1,1,2-	3.1E+03	Acute Aquatic Habitat Goal	5.0E+04	(Use soil gas)	3.1E+03
TETRACHLOROETHANE, 1,1,2,2-	1.5E+02	Indoor Air Impacts	5.0E+03	1.5E+02	3.0E+03
TETRACHLOROETHYLENE	9.9E+01	Indoor Air Impacts	3.0E+03	9.9E+01	1.8E+03
THALLIUM	4.7E+02	Acute Aquatic Habitat Goal	5.0E+04		4.7E+02
TOLUENE	4.0E+02	Ceiling Value	4.0E+02	5.3E+05	5.8E+03
TOXAPHENE	2.1E-01	Acute Aquatic Habitat Goal	1.4E+02		2.1E-01
TPH (gasolines)	5.0E+03	Ceiling Value	5.0E+03	(Use soil gas)	5.0E+03
TPH (middle distillates)	2.5E+03	Ceiling Value	2.5E+03	(Use soil gas)	2.5E+03
TPH (residual fuels)	2.5E+03	Ceiling Value	2.5E+03		2.5E+03
TRICHLOROETHANE, 1,2,4-	1.6E+02	Acute Aquatic Habitat Goal	3.0E+04	1.0E+04	1.6E+02
TRICHLOROETHANE, 1,1,1-	6.0E+03	Acute Aquatic Habitat Goal	5.0E+04	5.0E+05	6.0E+03
TRICHLOROETHANE, 1,1,2-	2.8E+02	Indoor Air Impacts	5.0E+04	2.8E+02	6.0E+03
TRICHLOROETHYLENE	7.4E+01	Indoor Air Impacts	5.0E+04	7.4E+01	7.0E+02
TRICHLOROPHENOL, 2,4,5-	1.0E+02	Acute Aquatic Habitat Goal	2.0E+03	1.2E+06	1.0E+02
TRICHLOROPHENOL, 2,4,6-	4.9E+02	Acute Aquatic Habitat Goal	1.0E+03		4.9E+02
VANADIUM	1.9E+01	Acute Aquatic Habitat Goal	5.0E+04		1.9E+01
VINYL CHLORIDE	2.2E+01	Indoor Air Impacts	3.4E+04	2.2E+01	7.8E+02

TABLE D-1d. GROUNDWATER ACTION LEVELS
(Groundwater IS NOT a current or potential drinking water resource)
(Surface water body IS NOT located within 150m of release site)
(ug/l)

CONTAMINANT	¹ Final Groundwater Action Level	Basis	Groundwater Ceiling Value (Odors, etc.)	Vapor Intrusion Concerns	Aquatic Habitat Goal
			Table G-2	Table C-1a	Table D-3c (Acute)
XYLENES	2.0E+03	Acute Aquatic Habitat Goal	5.3E+03	1.6E+05	2.0E+03
ZINC	2.2E+01	Acute Aquatic Habitat Goal	5.0E+04		2.2E+01

Notes:
1. Lowest of Ceiling Value, Indoor-Air Impact goal and acute Aquatic Habitat goal. Used to develop soil leaching levels for protection of groundwater quality (see Table E-1).

(Use Soil Gas): Use soil gas data to evaluate potential indoor-air impact concerns.
 TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
 sol - solubility threshold
 Ceiling Level: Odor/nuisance threshold, 1/2 solubility or 50000 ug/L maximum, whichever is lower. Intended to limit general groundwater resource degradation and address nuisance concerns.
 Indoor Air Impact: Addresses potential emission of volatile chemicals from groundwater and subsequent impact on indoor air. Action level for very permeable (e.g., sandy) vadose zone soils used.
 Aquatic Habitat Goal: Addresses potential discharge of groundwater to surface waterbody and subsequent impact on aquatic life. Potential dilution upon discharge to surface water not considered.
 Method detection limits and background concentrations replace final screening level as appropriate.

**TABLE D-2. SUMMARY OF DRINKING WATER ACTION LEVELS FOR HUMAN TOXICITY
(ug/L)**

CONTAMINANT	Final Action Level	Basis	USEPA Primary MCL	USEPA Region IX Tapwater Goal (Table D-4)	Basis
ACENAPHTHENE	3.7E+02	noncarcinogenic effects		3.7E+02	noncarcinogenic effects
ACENAPHTHYLENE	2.4E+02	noncarcinogenic effects		2.4E+02	noncarcinogenic effects
ACETONE	5.5E+03	noncarcinogenic effects		5.5E+03	noncarcinogenic effects
ALDRIN	4.0E-03	carcinogenic effects		4.0E-03	carcinogenic effects
ANTHRACENE	1.8E+03	noncarcinogenic effects		1.8E+03	noncarcinogenic effects
ANTIMONY	6.0E+00	HI DOH Primary MCL	6.0E+00	1.5E+01	noncarcinogenic effects
ARSENIC	1.0E+01	HI DOH Primary MCL	1.0E+01	4.5E-02	carcinogenic effects
BARIUM	2.0E+03	HI DOH Primary MCL	2.0E+03	2.6E+03	noncarcinogenic effects
BENZENE	5.0E+00	HI DOH Primary MCL	5.0E+00	3.5E-01	carcinogenic effects
BENZO(a)ANTHRACENE	9.2E-02	carcinogenic effects		9.2E-02	carcinogenic effects
BENZO(a)PYRENE	2.0E-01	HI DOH Primary MCL	2.0E-01	9.2E-03	carcinogenic effects
BENZO(b)FLUORANTHENE	9.2E-02	carcinogenic effects		9.2E-02	carcinogenic effects
BENZO(g,h,i)PERYLENE	1.5E+03	noncarcinogenic effects		1.5E+03	noncarcinogenic effects
BENZO(k)FLUORANTHENE	9.2E-01	carcinogenic effects		9.2E-01	carcinogenic effects
BERYLLIUM	4.0E+00	HI DOH Primary MCL	4.0E+00	7.3E+01	noncarcinogenic effects
BIPHENYL, 1,1-	3.0E+02	noncarcinogenic effects		3.0E+02	noncarcinogenic effects
BIS(2-CHLOROETHYL)ETHER	9.5E-03	carcinogenic effects		9.5E-03	carcinogenic effects
BIS(2-CHLOROISOPROPYL)ETHER	2.7E-01	carcinogenic effects		2.7E-01	carcinogenic effects
BIS(2-ETHYLHEXYL)PHTHALATE	6.0E+00	HI DOH Primary MCL	6.0E+00	4.8E+00	carcinogenic effects
BORON	7.3E+03	noncarcinogenic effects		7.3E+03	noncarcinogenic effects
BROMODICHLOROMETHANE	1.8E-01	carcinogenic effects		1.8E-01	carcinogenic effects
BROMOFORM	1.0E+02	HI DOH Primary MCL	1.0E+02	8.5E+00	carcinogenic effects
BROMOMETHANE	8.5E+00	noncarcinogenic effects		8.5E+00	noncarcinogenic effects
CADMIUM	5.0E+00	HI DOH Primary MCL	5.0E+00	1.8E+01	noncarcinogenic effects
CARBON TETRACHLORIDE	5.0E+00	HI DOH Primary MCL	5.0E+00	1.7E-01	carcinogenic effects
CHLORDANE	2.0E+00	HI DOH Primary MCL	2.0E+00	1.9E-01	carcinogenic effects
CHLOROANILINE, p-	1.5E+02	noncarcinogenic effects		1.5E+02	noncarcinogenic effects
CHLOROBENZENE	1.0E+02	HI DOH Primary MCL	1.0E+02	1.1E+02	noncarcinogenic effects
CHLOROETHANE	3.9E+00	carcinogenic effects		3.9E+00	carcinogenic effects
CHLOROFORM	1.0E+02	HI DOH Primary MCL	1.0E+02	1.7E-01	carcinogenic effects
CHLOROMETHANE	1.6E+02	noncarcinogenic effects		1.6E+02	noncarcinogenic effects
CHLOROPHENOL, 2-	3.0E+01	noncarcinogenic effects		3.0E+01	noncarcinogenic effects
CHROMIUM (Total)	1.0E+02	HI DOH Primary MCL	1.0E+02	0.0E+00	carcinogenic effects
CHROMIUM III	5.5E+04	noncarcinogenic effects		5.5E+04	noncarcinogenic effects

**TABLE D-2. SUMMARY OF DRINKING WATER ACTION LEVELS FOR HUMAN TOXICITY
(ug/L)**

CONTAMINANT	Final Action Level	Basis	USEPA Primary MCL	USEPA Region IX Tapwater Goal (Table D-4)	Basis
CHROMIUM VI	1.1E+02	noncarcinogenic effects		1.1E+02	noncarcinogenic effects
CHRYSENE	9.2E+00	carcinogenic effects		9.2E+00	carcinogenic effects
COBALT	7.3E+02	noncarcinogenic effects		7.3E+02	noncarcinogenic effects
COPPER	1.3E+03	HI DOH Primary MCL	1.3E+03	1.5E+03	noncarcinogenic effects
CYANIDE (Free)	2.0E+02	HI DOH Primary MCL	2.0E+02	7.3E+02	noncarcinogenic effects
DIBENZO(a,h)ANTHTRACENE	9.2E-03	carcinogenic effects		9.2E-03	carcinogenic effects
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	HI DOH Primary MCL	4.0E-02	4.8E-02	carcinogenic effects
DIBROMOCHLOROMETHANE	1.3E-01	carcinogenic effects		1.3E-01	carcinogenic effects
DIBROMOETHANE, 1,2-	5.6E-03	carcinogenic effects		5.6E-03	carcinogenic effects
DICHLOROBENZENE, 1,2-	6.0E+02	HI DOH Primary MCL	6.0E+02	3.7E+02	noncarcinogenic effects
DICHLOROBENZENE, 1,3-	1.8E+02	noncarcinogenic effects		1.8E+02	noncarcinogenic effects
DICHLOROBENZENE, 1,4-	7.5E+01	HI DOH Primary MCL	7.5E+01	5.0E-01	carcinogenic effects
DICHLOROBENZIDINE, 3,3-	1.5E-01	carcinogenic effects		1.5E-01	carcinogenic effects
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.8E-01	carcinogenic effects		2.8E-01	carcinogenic effects
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.8E-01	carcinogenic effects		2.8E-01	carcinogenic effects
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.0E-01	carcinogenic effects		2.0E-01	carcinogenic effects
DICHLOROETHANE, 1,1-	8.0E+02	noncarcinogenic effects		8.0E+02	noncarcinogenic effects
DICHLOROETHANE, 1,2-	1.2E-01	carcinogenic effects		1.2E-01	carcinogenic effects
DICHLOROETHYLENE, 1,1-	7.0E+00	HI DOH Primary MCL	7.0E+00	3.4E+02	noncarcinogenic effects
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	HI DOH Primary MCL	7.0E+01	6.1E+01	noncarcinogenic effects
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	HI DOH Primary MCL	1.0E+02	1.2E+02	noncarcinogenic effects
DICHLOROPHENOL, 2,4-	1.1E+02	noncarcinogenic effects		1.1E+02	noncarcinogenic effects
DICHLOROPROPANE, 1,2-	5.0E+00	HI DOH Primary MCL	5.0E+00	1.6E-01	carcinogenic effects
DICHLOROPROPENE, 1,3-	4.0E-01	carcinogenic effects		4.0E-01	carcinogenic effects
DIELDRIN	4.2E-03	carcinogenic effects		4.2E-03	carcinogenic effects
DIETHYLPHTHALATE	2.9E+04	noncarcinogenic effects		2.9E+04	noncarcinogenic effects
DIMETHYLPHENOL, 2,4-	7.3E+02	noncarcinogenic effects		7.3E+02	noncarcinogenic effects
DIMETHYLPHTHALATE	3.7E+05	noncarcinogenic effects		3.7E+05	noncarcinogenic effects
DINITROPHENOL, 2,4-	7.3E+01	noncarcinogenic effects		7.3E+01	noncarcinogenic effects
DINITROTOLUENE, 2,4-	3.4E+01	carcinogenic effects		3.4E+01	carcinogenic effects
DIOXANE, 1,4-	6.1E+00	carcinogenic effects		6.1E+00	carcinogenic effects
DIOXIN (2,3,7,8-TCDD)	3.0E-05	HI DOH Primary MCL	3.0E-05	4.5E-07	carcinogenic effects
ENDOSULFAN	2.2E+02	noncarcinogenic effects		2.2E+02	noncarcinogenic effects
ENDRIN	2.0E+00	HI DOH Primary MCL	2.0E+00	1.1E+01	noncarcinogenic effects

**TABLE D-2. SUMMARY OF DRINKING WATER ACTION LEVELS FOR HUMAN TOXICITY
(ug/L)**

CONTAMINANT	Final Action Level	Basis	USEPA Primary MCL	USEPA Region IX Tapwater Goal (Table D-4)	Basis
ETHYLBENZENE	7.0E+02	HI DOH Primary MCL	7.0E+02	1.3E+03	noncarcinogenic effects
FLUORANTHENE	1.5E+03	noncarcinogenic effects		1.5E+03	noncarcinogenic effects
FLUORENE	2.4E+02	noncarcinogenic effects		2.4E+02	noncarcinogenic effects
HEPTACHLOR	4.0E-01	HI DOH Primary MCL	4.0E-01	1.5E-02	carcinogenic effects
HEPTACHLOR EPOXIDE	2.0E-01	HI DOH Primary MCL	2.0E-01	7.4E-03	carcinogenic effects
HEXACHLOROBENZENE	1.0E+00	HI DOH Primary MCL	1.0E+00	4.2E-02	carcinogenic effects
HEXACHLOROBUTADIENE	8.6E-01	carcinogenic effects		8.6E-01	carcinogenic effects
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.0E-01	HI DOH Primary MCL	2.0E-01	5.2E-02	carcinogenic effects
HEXACHLOROETHANE	4.8E+00	carcinogenic effects		4.8E+00	carcinogenic effects
INDENO(1,2,3-cd)PYRENE	9.2E-02	carcinogenic effects		9.2E-02	carcinogenic effects
LEAD	1.5E+01	HI DOH Primary MCL	1.5E+01	0.0E+00	carcinogenic effects
MERCURY	2.0E+00	HI DOH Primary MCL	2.0E+00	5.8E+00	noncarcinogenic effects
METHOXYCHLOR	4.0E+01	HI DOH Primary MCL	4.0E+01	1.8E+02	noncarcinogenic effects
METHYL ETHYL KETONE	7.0E+03	noncarcinogenic effects		7.0E+03	noncarcinogenic effects
METHYL ISOBUTYL KETONE	2.0E+03	noncarcinogenic effects		2.0E+03	noncarcinogenic effects
METHYL MERCURY	3.7E+00	noncarcinogenic effects		3.7E+00	noncarcinogenic effects
METHYL TERT BUTYL ETHER	1.1E+01	carcinogenic effects		1.1E+01	carcinogenic effects
METHYLENE CHLORIDE	4.3E+00	carcinogenic effects		4.3E+00	carcinogenic effects
METHYLNAPHTHALENE (total 1- & 2-)	2.4E+02	noncarcinogenic effects		2.4E+02	noncarcinogenic effects
MOLYBDENUM	1.8E+02	noncarcinogenic effects		1.8E+02	noncarcinogenic effects
NAPHTHALENE	6.2E+00	noncarcinogenic effects		6.2E+00	noncarcinogenic effects
NICKEL	1.0E+02	HI DOH Primary MCL	1.0E+02	7.3E+02	noncarcinogenic effects
PENTACHLOROPHENOL	1.0E+00	HI DOH Primary MCL	1.0E+00	5.6E-01	carcinogenic effects
PERCHLORATE	3.7E+00	noncarcinogenic effects		3.7E+00	noncarcinogenic effects
PHENANTHRENE	2.4E+02	noncarcinogenic effects		2.4E+02	noncarcinogenic effects
PHENOL	1.1E+04	noncarcinogenic effects		1.1E+04	noncarcinogenic effects
POLYCHLORINATED BIPHENYLS (PCBs)	5.0E-01	HI DOH Primary MCL	5.0E-01	3.4E-02	carcinogenic effects
PYRENE	1.8E+02	noncarcinogenic effects		1.8E+02	noncarcinogenic effects
SELENIUM	5.0E+01	HI DOH Primary MCL	5.0E+01	1.8E+02	noncarcinogenic effects
SILVER	1.8E+02	noncarcinogenic effects		1.8E+02	noncarcinogenic effects
STYRENE	1.0E+02	HI DOH Primary MCL	1.0E+02	1.6E+03	noncarcinogenic effects
tert-BUTYL ALCOHOL	3.7E+00	carcinogenic effects		3.7E+00	carcinogenic effects
TETRACHLOROETHANE, 1,1,1,2-	4.3E-01	carcinogenic effects		4.3E-01	carcinogenic effects
TETRACHLOROETHANE, 1,1,2,2-	5.6E-02	carcinogenic effects		5.6E-02	carcinogenic effects

**TABLE D-2. SUMMARY OF DRINKING WATER ACTION LEVELS FOR HUMAN TOXICITY
(ug/L)**

CONTAMINANT	Final Action Level	Basis	USEPA Primary MCL	USEPA Region IX Tapwater Goal (Table D-4)	Basis
TETRACHLOROETHYLENE	5.0E+00	HI DOH Primary MCL	5.0E+00	1.0E-01	carcinogenic effects
THALLIUM	2.0E+00	HI DOH Primary MCL	2.0E+00	2.4E+00	noncarcinogenic effects
TOLUENE	1.0E+03	HI DOH Primary MCL	1.0E+03	7.2E+02	noncarcinogenic effects
TOXAPHENE	3.0E+00	HI DOH Primary MCL	3.0E+00	5.6E-02	carcinogenic effects
TPH (gasolines)	1.0E+02	noncarcinogenic effects		1.0E+02	noncarcinogenic effects
TPH (middle distillates)	1.0E+02	noncarcinogenic effects		1.0E+02	noncarcinogenic effects
TPH (residual fuels)	1.0E+03	noncarcinogenic effects		1.0E+03	noncarcinogenic effects
TRICHLOROBENZENE, 1,2,4-	7.0E+01	HI DOH Primary MCL	7.0E+01	7.2E+00	noncarcinogenic effects
TRICHLOROETHANE, 1,1,1-	2.0E+02	HI DOH Primary MCL	2.0E+02	3.2E+03	noncarcinogenic effects
TRICHLOROETHANE, 1,1,2-	5.0E+00	HI DOH Primary MCL	5.0E+00	2.0E-01	carcinogenic effects
TRICHLOROETHYLENE	5.0E+00	HI DOH Primary MCL	5.0E+00	2.8E-02	carcinogenic effects
TRICHLOROPHENOL, 2,4,5-	6.1E+02	noncarcinogenic effects		6.1E+02	noncarcinogenic effects
TRICHLOROPHENOL, 2,4,6-	3.7E+00	noncarcinogenic effects		3.7E+00	noncarcinogenic effects
VANADIUM	3.7E+01	noncarcinogenic effects		3.7E+01	noncarcinogenic effects
VINYL CHLORIDE	2.0E+00	HI DOH Primary MCL	2.0E+00	8.1E-02	carcinogenic effects
XYLENES	1.0E+04	HI DOH Primary MCL	1.0E+04	2.1E+02	noncarcinogenic effects
ZINC	1.1E+04	noncarcinogenic effects		1.1E+04	noncarcinogenic effects

Notes:
 Used for development of groundwater and soil screening levels.
 TPH -Total Petroleum Hydrocarbons. Default toxicity-based action levels rounded to 100 ug/L or 1,000 ug/L, as shown. See text for TPH category discussion.
 USEPA MCL: USEPA Primary Maximum Concentration Level.
 Final health-based action level for drinking water: USEPA Primary MCL or USEPA Region IX Tapwater goal if no Primary MCL

TABLE D-3a. SUMMARY OF AQUATIC HABITAT GOALS

CONTAMINANT	Freshwater		Marine	
	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)
ACENAPHTHENE	2.3E+01	5.7E+02	4.0E+01	3.2E+02
ACENAPHTHYLENE	3.0E+01	3.0E+02	3.0E+01	3.0E+02
ACETONE	1.5E+03	1.5E+03	1.5E+03	1.5E+03
ALDRIN	3.0E+01	3.0E+00	1.3E+01	1.3E+00
ANTHRACENE	7.3E-01	7.3E-01	7.3E-01	7.3E-01
ANTIMONY	3.0E+01	3.0E+03	5.0E+02	1.5E+03
ARSENIC	1.9E+02	3.6E+02	3.6E+01	6.9E+01
BARIUM	2.0E+03	2.0E+03	2.0E+03	2.0E+03
BENZENE	4.6E+01	1.8E+03	3.5E+02	1.7E+03
BENZO(a)ANTHRACENE	2.7E-02	2.7E-02	2.7E-02	2.7E-02
BENZO(a)PYRENE	3.7E+00	3.7E+00	3.7E+00	3.7E+00
BENZO(b)FLUORANTHENE	1.4E-02	1.4E-02	1.4E-02	1.4E-02
BENZO(g,h,i)PERYLENE	1.0E-01	1.0E-01	1.0E-01	1.0E-01
BENZO(k)FLUORANTHENE	9.2E-02	9.2E-02	9.2E-02	9.2E-02
BERYLLIUM	2.7E+00	4.3E+01	2.7E+00	4.3E+01
BIPHENYL, 1,1'-	1.4E+01	1.4E+01	1.4E+01	1.4E+01
BIS(2-CHLOROETHYL)ETHER	6.1E+01	2.4E+05	6.1E+01	2.4E+05
BIS(2-CHLOROISOPROPYL)ETHER	6.1E+01	2.4E+05	6.1E+01	2.4E+05
BIS(2-ETHYLHEXYL)PHTHALATE	3.2E+01	3.2E+01	3.2E+01	3.2E+01
BORON	1.6E+00	1.6E+00	1.6E+00	1.6E+00
BROMODICHLOROMETHANE	3.2E+03	1.1E+04	3.2E+03	1.2E+04
BROMOFORM	3.2E+03	1.1E+04	3.2E+03	1.2E+04
BROMOMETHANE	1.6E+02	1.1E+04	3.2E+03	1.2E+04
CADMIUM	3.0E+00	3.0E+00	9.3E+00	4.3E+01
CARBON TETRACHLORIDE	9.8E+00	1.2E+04	3.2E+03	1.6E+04
CHLORDANE	4.3E+03	2.4E+00	4.0E+03	9.0E-02
CHLORANILINE, p-	5.0E+00	5.0E+00	5.0E+00	5.0E+00
CHLOROBENZENE	2.5E+01	2.5E+02	6.5E+01	1.6E+02
CHLOROETHANE	3.9E+00	3.9E+00	3.9E+00	3.9E+00
CHLOROFORM	6.2E+02	9.6E+03	3.2E+03	1.2E+04
CHLOROMETHANE	3.2E+03	1.1E+04	3.2E+03	1.2E+04
CHLOROPHENOL, 2-	1.4E+02	1.4E+03	1.4E+02	1.4E+03
CHROMIUM (Total)	7.4E+01	7.4E+01	1.0E+04	1.0E+04
CHROMIUM III	7.4E+01	5.7E+02	7.4E+01	1.0E+04
CHROMIUM VI	1.1E+01	1.6E+01	5.0E+01	1.1E+03
CHRYSENE	3.5E-01	3.5E-01	3.5E-01	3.5E-01
COBALT	3.0E+00	3.0E+00	3.0E+00	3.0E+00
COPPER	6.0E+00	6.0E+00	2.9E+00	2.9E+00
CYANIDE (Free)	5.2E+00	2.2E+01	1.0E+00	1.0E+00
DIBENZO(a,h)ANTHRACENE	7.5E+00	7.5E+00	7.5E+00	7.5E+00
DIBROMO-3-CHLOROPROPANE, 1,2-	3.2E+03	1.1E+04	3.2E+03	1.2E+04
DIBROMOCHLOROMETHANE	4.0E-02	4.0E-02	4.0E-02	4.0E-02
DIBROMOETHANE, 1,2-	1.4E+03	1.4E+03	1.4E+03	1.4E+03
DICHLOROBENZENE, 1,2-	1.4E+01	3.7E+02	6.5E+01	6.6E+02
DICHLOROBENZENE, 1,3-	7.1E+01	3.7E+02	6.5E+01	6.6E+02
DICHLOROBENZENE, 1,4-	1.5E+01	3.7E+02	6.5E+01	6.6E+02
DICHLORO BENZIDINE, 3,3-	2.5E+02	2.5E+02	2.5E+02	2.5E+02

TABLE D-3a. SUMMARY OF AQUATIC HABITAT GOALS

CONTAMINANT	Freshwater		Marine	
	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E-03	6.0E-01	1.0E-03	3.6E+00
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E-03	1.1E+03	1.0E-03	1.4E+01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03	1.1E+00	1.0E-03	1.3E+02
DICHLOROETHANE, 1,1-	4.7E+01	4.7E+01	4.7E+01	4.7E+01
DICHLOROETHANE, 1,2-	1.0E+04	3.9E+04	1.0E+04	3.8E+04
DICHLOROETHYLENE, 1,1-	2.5E+01	3.9E+03	2.5E+01	7.5E+04
DICHLOROETHYLENE, Cis 1,2-	5.9E+02	1.2E+04	5.9E+02	2.2E+05
DICHLOROETHYLENE, Trans 1,2-	5.9E+02	1.2E+04	5.9E+02	2.2E+05
DICHLOROPHENOL, 2,4-	1.8E+02	6.7E+02	1.8E+02	6.7E+02
DICHLOROPROPANE, 1,2-	2.9E+03	7.7E+03	1.5E+03	3.4E+03
DICHLOROPROPENE, 1,3-	1.2E+02	2.0E+03	1.2E+02	2.6E+02
DIELDRIN	1.9E-03	2.5E+00	1.9E-03	7.1E-01
DIETHYLPHTHALATE	1.5E+00	9.4E+02	1.7E+00	2.9E+03
DIMETHYLPHENOL, 2,4-	1.5E+00	9.4E+02	1.7E+00	2.9E+03
DIMETHYLPHTHALATE	5.3E+02	7.0E+02	1.1E+02	2.7E+02
DINITROPHENOL, 2,4-	7.5E+01	2.3E+02	7.5E+01	4.9E+03
DINITROTOLUENE, 2,4-	1.2E+02	3.3E+02	1.9E+02	2.0E+02
DIOXANE, 1,4-	3.4E+05	6.7E+06	5.0E+05	1.0E+07
DIOXIN (2,3,7,8-TCDD)	5.0E-06	3.0E-03	5.0E-06	3.0E-03
ENDOSULFAN	5.6E-02	2.2E-01	8.7E-03	3.4E-02
ENDRIN	2.3E-03	1.8E-01	2.3E-03	3.7E-02
ETHYLBENZENE	2.9E+02	1.1E+04	2.9E+02	4.3E+02
FLUORANTHENE	8.1E+00	1.3E+03	8.0E+00	4.0E+01
FLUORENE	3.9E+00	3.0E+02	3.9E+00	3.0E+02
HEPTACHLOR	3.8E-03	5.2E-01	3.6E-03	5.3E-02
HEPTACHLOR EPOXIDE	3.8E-03	5.2E-01	3.6E-03	5.3E-02
HEXACHLORO BENZENE	3.7E+00	6.0E+00	6.5E+01	1.6E+02
HEXACHLORO BUTADIENE	4.7E+00	3.0E+01	4.7E+00	1.1E+01
HEXACHLORO CYCLOHEXANE (gamma) LINDANE	8.0E-02	2.0E+00	8.0E-02	1.6E-01
HEXACHLOROETHANE	1.2E+01	3.3E+02	1.2E+01	3.1E+02
INDENO(1,2,3-cd)PYRENE	9.2E-02	9.2E-02	9.2E-02	9.2E-02
LEAD	2.9E+01	2.9E+01	5.6E+00	1.4E+02
MERCURY	5.5E-01	2.4E+00	2.5E-02	2.1E+00
METHOXYCHLOR	3.0E-02	3.0E-02	3.0E-02	3.0E-02
METHYL ETHYL KETONE	1.7E+02	1.7E+02	1.7E+02	1.7E+02
METHYL ISOBUTYL KETONE	3.0E-03	3.0E-03	3.0E-03	3.0E-03
METHYL MERCURY	6.6E+04	6.6E+04	8.0E+03	8.0E+03
METHYL TERT BUTYL ETHER	2.1E+00	3.0E+02	2.1E+00	3.0E+02
METHYLENE CHLORIDE	1.4E+04	1.4E+04	1.4E+04	1.4E+04
METHYLNAPHTHALENE (total 1- & 2-)	2.2E+03	1.1E+04	3.2E+03	1.2E+04
MOLYBDENUM	2.4E+02	2.4E+02	2.4E+02	2.4E+02
NAPHTHALENE	2.4E+01	7.7E+02	2.4E+01	7.8E+02
NICKEL	5.0E+00	5.0E+00	8.3E+00	7.5E+01
PENTACHLOROPHENOL	1.3E+01	2.0E+01	7.9E+00	1.3E+01
PERCHLORATE	6.0E+02	6.0E+02	6.0E+02	6.0E+02
PHENANTHRENE	6.3E+00	3.0E+01	4.6E+00	7.7E+00
PHENOL	1.3E+03	3.4E+03	1.3E+03	5.8E+03

TABLE D-3a. SUMMARY OF AQUATIC HABITAT GOALS

CONTAMINANT	Freshwater		Marine	
	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)	Chronic Aquatic Toxicity (ug/L)	Acute Aquatic Toxicity (ug/L)
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02	2.0E+00	3.0E-02	1.0E+01
PYRENE	2.0E+00	2.0E+00	2.0E+00	2.0E+00
SELENIUM	5.0E+00	2.0E+01	7.1E+01	3.0E+02
SILVER	1.0E+00	1.0E+00	1.0E+00	2.3E+00
STYRENE	1.0E+02	1.0E+02	1.0E+02	1.0E+02
tert-BUTYL ALCOHOL	1.8E+04	1.8E+05	1.8E+04	1.8E+05
TETRACHLOROETHANE, 1,1,1,2-	3.1E+02	3.1E+03	3.1E+02	3.1E+03
TETRACHLOROETHANE, 1,1,2,2-	4.2E+02	9.3E+03	4.2E+02	3.0E+03
TETRACHLOROETHYLENE	1.2E+02	1.8E+03	1.5E+02	3.4E+03
THALLIUM	2.0E+01	4.7E+02	2.0E+01	7.1E+02
TOLUENE	1.3E+02	5.8E+03	2.5E+03	6.3E+03
TOXAPHENE	2.0E-04	7.3E-01	2.0E-04	2.1E-01
TPH (gasolines)	5.0E+02	5.0E+03	3.7E+03	5.0E+03
TPH (middle distillates)	6.4E+02	2.5E+03	6.4E+02	2.5E+03
TPH (residual fuels)	6.4E+02	2.5E+03	6.4E+02	2.5E+03
TRICHLOROBEZENE, 1,2,4-	2.5E+01	2.5E+02	6.5E+01	1.6E+02
TRICHLOROETHANE, 1,1,1-	6.2E+01	6.0E+03	6.2E+01	1.0E+04
TRICHLOROETHANE, 1,1,2-	4.7E+03	6.0E+03	4.7E+03	6.0E+03
TRICHLOROETHYLENE	3.6E+02	1.5E+04	3.6E+02	7.0E+02
TRICHLOROPHENOL, 2,4,5-	6.3E+01	1.0E+02	1.1E+01	2.4E+02
TRICHLOROPHENOL, 2,4,6-	4.9E+02	4.9E+02	4.9E+02	4.9E+02
VANADIUM	1.9E+01	1.9E+01	1.9E+01	1.9E+01
VINYL CHLORIDE	7.8E+02	7.8E+02	7.8E+02	7.8E+02
XYLENES	1.0E+02	2.0E+03	1.0E+02	2.0E+03
ZINC	2.2E+01	2.2E+01	8.6E+01	9.5E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	not applicable	not applicable	not applicable	not applicable
Sodium Adsorption Ratio	not applicable	not applicable	not applicable	not applicable

Notes:

Reference: Appendix 1, Table D-3b (chronic) and D-3c (acute).

For estuary environments use lowest of lowest of freshwater and marine goals.

TABLE D-3b. SUMMARY OF SELECTED CHRONIC AQUATIC HABITAT GOALS
(ug/l)

CONTAMINANT	¹ Lowest Chronic Aquatic Habitat Goal	Basis	Lowest Freshwater Chronic Aquatic Habitat Goal	Basis	Lowest Saltwater Chronic Aquatic Habitat Goal	Basis
ACENAPHTHENE	2.3E+01	USEPA Ecotox FW Chronic	2.3E+01	USEPA Ecotox FW Chronic	4.0E+01	USEPA Ecotox SW Chronic
ACENAPHTHYLENE	3.0E+01	10% USEPA SW Acute LOEL	3.0E+01	10% USEPA SW Acute LOEL	3.0E+01	10% USEPA SW Acute LOEL
ACETONE	1.5E+03	USDOE FW Chronic PRG	1.5E+03	USDOE FW Chronic PRG	1.5E+03	USDOE FW Chronic PRG
ALDRIN	1.3E-01	10% HI DOH SW Acute	3.0E-01	10% HI DOH FW Acute	1.3E-01	10% HI DOH SW Acute
ANTHRACENE	7.3E-01	USDOE FW Chronic PRG	7.3E-01	USDOE FW Chronic PRG	7.3E-01	USDOE FW Chronic PRG
ANTIMONY	3.0E+01	USEPA FW CCC	3.0E+01	USEPA FW CCC	5.0E+02	USEPA SW CCC
ARSENIC	3.6E+01	HI DOH SW Chronic	1.9E+02	HI DOH FW Chronic	3.6E+01	HI DOH SW Chronic
BARIUM	2.0E+03	=Drinking Water (Table D-2)	2.0E+03	=Drinking Water (Table D-2)	2.0E+03	=Drinking Water (Table D-2)
BENZENE	4.6E+01	USEPA Ecotox FW Chronic	4.6E+01	USEPA Ecotox FW Chronic	3.5E+02	50% USEPA SW Chronic LOEL
BENZO(a)ANTHRACENE	2.7E-02	USDOE FW Chronic PRG	2.7E-02	USDOE FW Chronic PRG	2.7E-02	USDOE FW Chronic PRG
BENZO(a)PYRENE	1.4E-02	USEPA Ecotox FW Chronic	1.4E-02	USEPA Ecotox FW Chronic	1.4E-02	USEPA Ecotox FW Chronic
BENZO(b)FLUORANTHENE	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)
BENZO(g,h,i)PERYLENE	1.0E-01	50% MOEE FW Chronic LOEL	1.0E-01	50% MOEE FW Chronic LOEL	1.0E-01	50% MOEE FW Chronic LOEL
BENZO(k)FLUORANTHENE	3.7E+00	50% MOEE FW Chronic LOEL	3.7E+00	50% MOEE FW Chronic LOEL	3.7E+00	50% MOEE FW Chronic LOEL
BERYLLIUM	2.7E+00	50% USEPA FW Chronic LOEL	2.7E+00	50% USEPA FW Chronic LOEL	2.7E+00	50% USEPA FW Chronic LOEL
BIPHENYL, 1,1-	1.4E+01	USEPA Ecotox FW Chronic	1.4E+01	USEPA Ecotox FW Chronic	1.4E+01	USEPA Ecotox FW Chronic
BIS(2-CHLOROETHYL)ETHER	6.1E+01	50% USEPA FW Chronic LOEL	6.1E+01	50% USEPA FW Chronic LOEL	6.1E+01	50% USEPA FW Chronic LOEL
BIS(2-CHLOROISOPROPYL)ETHER	6.1E+01	50% USEPA FW Chronic LOEL	6.1E+01	50% USEPA FW Chronic LOEL	6.1E+01	50% USEPA FW Chronic LOEL
BIS(2-ETHYLHEXYL)PHTHALATE	3.2E+01	USEPA Ecotox FW Chronic	3.2E+01	USEPA Ecotox FW Chronic	3.2E+01	USEPA Ecotox FW Chronic
BORON	1.6E+00	USDOE FW Chronic PRG	1.6E+00	USDOE FW Chronic PRG	1.6E+00	USDOE FW Chronic PRG
BROMODICHLOROMETHANE	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
BROMOFORM	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
BROMOMETHANE	1.6E+02	50% MOEE FW Chronic LOEL	1.6E+02	50% MOEE FW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
CADMIUM	3.0E+00	HI DOH FW Chronic	3.0E+00	HI DOH FW Chronic	9.3E+00	HI DOH SW Chronic
CARBON TETRACHLORIDE	9.8E+00	USDOE FW Chronic PRG	9.8E+00	USDOE FW Chronic PRG	3.2E+03	50% USEPA SW Chronic LOEL
CHLORDANE	4.0E-03	HI DOH SW Chronic	4.3E-03	HI DOH FW Chronic	4.0E-03	HI DOH SW Chronic
CHLOROANILINE, p-	5.0E+00	50% MOEE FW Chronic LOEL	5.0E+00	50% MOEE FW Chronic LOEL	5.0E+00	50% MOEE FW Chronic LOEL
CHLOROBENZENE	2.5E+01	50% USEPA FW Chronic LOEL	2.5E+01	50% USEPA FW Chronic LOEL	6.5E+01	50% USEPA SW Chronic LOEL
CHLOROETHANE	3.9E+00	=Drinking Water (Table D-2)	3.9E+00	=Drinking Water (Table D-2)	3.9E+00	=Drinking Water (Table D-2)
CHLOROFORM	6.2E+02	50% USEPA FW Chronic LOEL	6.2E+02	50% USEPA FW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
CHLOROMETHANE	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
CHLOROPHENOL, 2-	1.4E+02	10% HI DOH FW Acute	1.4E+02	10% HI DOH FW Acute	1.4E+02	10% HI DOH FW Acute
CHROMIUM (Total)	7.4E+01	=Cr III	7.4E+01	=Cr III	1.0E+04	=Cr III
CHROMIUM III	7.4E+01	USEPA FW CCC	7.4E+01	USEPA FW CCC	7.4E+01	USEPA FW CCC
CHROMIUM VI	1.1E+01	HI DOH FW Chronic	1.1E+01	HI DOH FW Chronic	5.0E+01	HI DOH SW Chronic
CHRYSENE	3.5E-01	50% MOEE FW Chronic LOEL	3.5E-01	50% MOEE FW Chronic LOEL	3.5E-01	50% MOEE FW Chronic LOEL
COBALT	3.0E+00	USEPA Ecotox FW Chronic	3.0E+00	USEPA Ecotox FW Chronic	3.0E+00	USEPA Ecotox FW Chronic
COPPER	2.9E+00	HI DOH SW Chronic	6.0E+00	HI DOH FW Chronic	2.9E+00	HI DOH SW Chronic
CYANIDE (Free)	1.0E+00	HI DOH SW Chronic	5.2E+00	HI DOH FW Chronic	1.0E+00	HI DOH SW Chronic
DIBENZO(a,h)ANTHRACENE	7.5E+00	50% MOEE FW Chronic LOEL	7.5E+00	50% MOEE FW Chronic LOEL	7.5E+00	50% MOEE FW Chronic LOEL
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	=Drinking Water (Table D-2)	4.0E-02	=Drinking Water (Table D-2)	4.0E-02	=Drinking Water (Table D-2)
DIBROMOCHLOROMETHANE	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL	3.2E+03	50% USEPA SW Chronic LOEL
DIBROMOETHANE, 1,2-	1.4E+03	50% MOEE FW Chronic AWQC	1.4E+03	50% MOEE FW Chronic AWQC	1.4E+03	50% MOEE FW Chronic AWQC

TABLE D-3b. SUMMARY OF SELECTED CHRONIC AQUATIC HABITAT GOALS
(ug/l)

CONTAMINANT	Lowest Chronic Aquatic Habitat Goal	Basis	Lowest Freshwater Chronic Aquatic Habitat Goal	Basis	Lowest Saltwater Chronic Aquatic Habitat Goal	Basis
DICHLOROBENZENE, 1,2-	1.4E+01	USEPA Ecotox FW Chronic	1.4E+01	USEPA Ecotox FW Chronic	6.5E+01	50% USEPA SW Chronic LOEL
DICHLOROBENZENE, 1,3-	6.5E+01	50% USEPA SW Chronic LOEL	7.1E+01	USEPA Ecotox FW Chronic	6.5E+01	50% USEPA SW Chronic LOEL
DICHLOROBENZENE, 1,4-	1.5E+01	USEPA Ecotox FW Chronic	1.5E+01	USEPA Ecotox FW Chronic	6.5E+01	50% USEPA SW Chronic LOEL
DICHLOROBENZIDINE, 3,3-	2.5E+02	50% MOEE FW Chronic LOEL	2.5E+02	50% MOEE FW Chronic LOEL	2.5E+02	50% MOEE FW Chronic LOEL
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E-03	=DDT	1.0E-03	=DDT	1.0E-03	=DDT
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E-03	=DDT	1.0E-03	=DDT	1.0E-03	=DDT
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03	HI DOH FW Chronic	1.0E-03	HI DOH FW Chronic	1.0E-03	HI DOH SW Chronic
DICHLOROETHANE, 1,1-	4.7E+01	USEPA Ecotox FW Chronic	4.7E+01	USEPA Ecotox FW Chronic	4.7E+01	USEPA Ecotox FW Chronic
DICHLOROETHANE, 1,2-	1.0E+04	50% USEPA FW Chronic LOEL	1.0E+04	50% USEPA FW Chronic LOEL	1.0E+04	50% USEPA FW Chronic LOEL
DICHLOROETHYLENE, 1,1-	2.5E+01	USDOE FW Chronic PRG	2.5E+01	USDOE FW Chronic PRG	2.5E+01	USDOE FW Chronic PRG
DICHLOROETHYLENE, Cis 1,2-	5.9E+02	USDOE FW Chronic PRG	5.9E+02	USDOE FW Chronic PRG	5.9E+02	USDOE FW Chronic PRG
DICHLOROETHYLENE, Trans 1,2-	5.9E+02	USDOE FW Chronic PRG	5.9E+02	USDOE FW Chronic PRG	5.9E+02	USDOE FW Chronic PRG
DICHLOROPHENOL, 2,4-	1.8E+02	50% USEPA FW Chronic LOEL	1.8E+02	50% USEPA FW Chronic LOEL	1.8E+02	50% USEPA FW Chronic LOEL
DICHLOROPROPANE, 1,2-	1.5E+03	50% USEPA SW Chronic LOEL	2.9E+03	50% USEPA FW Chronic LOEL	1.5E+03	50% USEPA SW Chronic LOEL
DICHLOROPROPENE, 1,3-	1.2E+02	50% USEPA FW Chronic LOEL	1.2E+02	50% USEPA FW Chronic LOEL	1.2E+02	50% USEPA FW Chronic LOEL
DIELDRIN	1.9E-03	HI DOH FW Chronic	1.9E-03	HI DOH FW Chronic	1.9E-03	HI DOH SW Chronic
DIETHYLPHTHALATE	1.5E+00	50% USEPA FW Chronic LOEL	1.5E+00	50% USEPA FW Chronic LOEL	1.7E+00	50% USEPA SW Chronic LOEL
DIMETHYLPHENOL, 2,4-	1.1E+02	USEPA SW CCC	5.3E+02	USEPA FW CCC	1.1E+02	USEPA SW CCC
DIMETHYLPHTHALATE	1.5E+00	50% USEPA FW Chronic LOEL	1.5E+00	50% USEPA FW Chronic LOEL	1.7E+00	50% USEPA SW Chronic LOEL
DINITROPHENOL, 2,4-	7.5E+01	50% USEPA FW Chronic LOEL	7.5E+01	50% USEPA FW Chronic LOEL	7.5E+01	50% USEPA FW Chronic LOEL
DINITROTOLUENE, 2,4-	1.2E+02	50% USEPA FW Chronic LOEL	1.2E+02	50% USEPA FW Chronic LOEL	1.9E+02	50% USEPA SW Chronic LOEL
DIOXANE, 1,4-	3.4E+05	5% Acute FW LC 50	3.4E+05	5% Acute FW LC 50	5.0E+05	5% Acute SW LC 50
DIOXIN (2,3,7,8-TCDD)	5.0E-06	50% USEPA FW Chronic LOEL	5.0E-06	50% USEPA FW Chronic LOEL	5.0E-06	50% USEPA FW Chronic LOEL
ENDOSULFAN	8.7E-03	HI DOH SW Chronic	5.6E-02	HI DOH FW Chronic	8.7E-03	HI DOH SW Chronic
ENDRIN	2.3E-03	HI DOH FW Chronic	2.3E-03	HI DOH FW Chronic	2.3E-03	HI DOH SW Chronic
ETHYLBENZENE	2.9E+02	USEPA Ecotox FW Chronic	2.9E+02	USEPA Ecotox FW Chronic	2.9E+02	USEPA Ecotox FW Chronic
FLUORANTHENE	8.0E+00	50% USEPA SW Chronic LOEL	8.1E+00	USEPA Ecotox FW Chronic	8.0E+00	50% USEPA SW Chronic LOEL
FLUORENE	3.9E+00	USEPA Ecotox FW Chronic	3.9E+00	USEPA Ecotox FW Chronic	3.9E+00	USEPA Ecotox FW Chronic
HEPTACHLOR	3.6E-03	HI DOH SW Chronic	3.8E-03	HI DOH FW Chronic	3.6E-03	HI DOH SW Chronic
HEPTACHLOR EPOXIDE	3.6E-03	USEPA SW CCC	3.8E-03	USEPA FW CCC	3.6E-03	USEPA SW CCC
HEXACHLOROBENZENE	3.7E+00	USEPA FW CCC	3.7E+00	USEPA FW CCC	6.5E+01	50% USEPA SW Chronic LOEL
HEXACHLOROBUTADIENE	4.7E+00	50% USEPA FW Chronic LOEL	4.7E+00	50% USEPA FW Chronic LOEL	4.7E+00	50% USEPA FW Chronic LOEL
HEXACHLOROXYCLOHEXANE (gamma) LINDANE	8.0E-02	HI DOH FW Chronic	8.0E-02	HI DOH FW Chronic	8.0E-02	HI DOH FW Chronic
HEXACHLOROETHANE	1.2E+01	USEPA Ecotox FW Chronic	1.2E+01	USEPA Ecotox FW Chronic	1.2E+01	USEPA Ecotox FW Chronic
INDENO(1,2,3-cd)PYRENE	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)
LEAD	5.6E+00	HI DOH SW Chronic	2.9E+01	HI DOH FW Chronic	5.6E+00	HI DOH SW Chronic
MERCURY	2.5E-02	HI DOH SW Chronic	5.5E-01	HI DOH FW Chronic	2.5E-02	HI DOH SW Chronic
METHOXYCHLOR	3.0E-02	HI DOH FW Chronic	3.0E-02	HI DOH FW Chronic	3.0E-02	HI DOH SW Chronic
METHYL ETHYL KETONE	1.4E+04	USDOE FW Chronic PRG	1.4E+04	USDOE FW Chronic PRG	1.4E+04	USDOE FW Chronic PRG
METHYL ISOBUTYL KETONE	1.7E+02	USDOE FW Chronic PRG	1.7E+02	USDOE FW Chronic PRG	1.7E+02	USDOE FW Chronic PRG
METHYL MERCURY	3.0E-03	USEPA Ecotox FW Chronic	3.0E-03	USEPA Ecotox FW Chronic	3.0E-03	USEPA Ecotox FW Chronic
METHYL TERT BUTYL ETHER	8.0E+03	CalEPA SW Chronic	6.6E+04	CA FW Chronic	8.0E+03	CalEPA SW Chronic
METHYLENE CHLORIDE	2.2E+03	USDOE FW Chronic PRG	2.2E+03	USDOE FW Chronic PRG	3.2E+03	50% USEPA SW Chronic LOEL

TABLE D-3b. SUMMARY OF SELECTED CHRONIC AQUATIC HABITAT GOALS
(ug/l)

CONTAMINANT	¹ Lowest Chronic Aquatic Habitat Goal	Basis	Lowest Freshwater Chronic Aquatic Habitat Goal	Basis	Lowest Saltwater Chronic Aquatic Habitat Goal	Basis
METHYLNAPHTHALENE (total 1- & 2-)	2.1E+00	USDOE FW Chronic PRG	2.1E+00	USDOE FW Chronic PRG	2.1E+00	USDOE FW Chronic PRG
MOLYBDENUM	2.4E+02	USEPA Ecotox FW Chronic	2.4E+02	USEPA Ecotox FW Chronic	2.4E+02	USEPA Ecotox FW Chronic
NAPHTHALENE	2.4E+01	USEPA Ecotox FW Chronic	2.4E+01	USEPA Ecotox FW Chronic	2.4E+01	USEPA Ecotox FW Chronic
NICKEL	5.0E+00	HI DOH FW Chronic	5.0E+00	HI DOH FW Chronic	8.3E+00	HI DOH SW Chronic
PENTACHLOROPHENOL	7.9E+00	USEPA SW CCC	1.3E+01	HI DOH FW Chronic	7.9E+00	USEPA SW CCC
PERCHLORATE	6.0E+02	USEPA Ecotox FW Chronic	6.0E+02	USEPA Ecotox FW Chronic	6.0E+02	USEPA Ecotox FW Chronic
PHENANTHRENE	4.6E+00	USEPA SW CCC	6.3E+00	USEPA FW CCC	4.6E+00	USEPA SW CCC
PHENOL	1.3E+03	50% USEPA FW Chronic LOEL	1.3E+03	50% USEPA FW Chronic LOEL	1.3E+03	50% USEPA FW Chronic LOEL
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02	HI DOH FW Chronic	1.4E-02	HI DOH FW Chronic	3.0E-02	HI DOH SW Chronic
PYRENE	2.0E+00	50% MOEE FW Chronic LOEL	2.0E+00	50% MOEE FW Chronic LOEL	2.0E+00	50% MOEE FW Chronic LOEL
SELENIUM	5.0E+00	HI DOH FW Chronic	5.0E+00	HI DOH FW Chronic	7.1E+01	HI DOH SW Chronic
SILVER	1.0E+00	HI DOH FW Chronic	1.0E+00	HI DOH FW Chronic	1.0E+00	HI DOH FW Chronic
STYRENE	1.0E+02	=Drinking Water (Table D-2)	1.0E+02	=Drinking Water (Table D-2)	1.0E+02	=Drinking Water (Table D-2)
tert-BUTYL ALCOHOL	1.8E+04	10% Acute FW LC0	1.8E+04	10% Acute FW LC0	1.8E+04	10% Acute FW LC0
TETRACHLOROETHANE, 1,1,1,2-	3.1E+02	10% HI DOH FW Acute	3.1E+02	10% HI DOH FW Acute	3.1E+02	10% HI DOH FW Acute
TETRACHLOROETHANE, 1,1,2,2-	4.2E+02	USEPA Ecotox FW Chronic	4.2E+02	USEPA Ecotox FW Chronic	4.2E+02	USEPA Ecotox FW Chronic
TETRACHLOROETHYLENE	1.2E+02	USEPA Ecotox FW Chronic	1.2E+02	USEPA Ecotox FW Chronic	1.5E+02	HI DOH SW Chronic
THALLIUM	2.0E+01	50% USEPA FW Chronic LOEL	2.0E+01	50% USEPA FW Chronic LOEL	2.0E+01	50% USEPA FW Chronic LOEL
TOLUENE	1.3E+02	USEPA Ecotox FW Chronic	1.3E+02	USEPA Ecotox FW Chronic	2.5E+03	50% USEPA SW Chronic LOEL
TOXAPHENE	2.0E-04	HI DOH FW Chronic	2.0E-04	HI DOH FW Chronic	2.0E-04	HI DOH SW Chronic
TPH (gasolines)	5.0E+02	CA FW Chronic	5.0E+02	CA FW Chronic	3.7E+03	CalEPA SW Chronic
TPH (middle distillates)	6.4E+02	CA FW Chronic	6.4E+02	CA FW Chronic	6.4E+02	CA FW Chronic
TPH (residual fuels)	6.4E+02	CA FW Chronic	6.4E+02	CA FW Chronic	6.4E+02	CA FW Chronic
TRICHLOROBENZENE, 1,2,4-	2.5E+01	50% USEPA FW Chronic LOEL	2.5E+01	50% USEPA FW Chronic LOEL	6.5E+01	50% USEPA SW Chronic LOEL
TRICHLOROETHANE, 1,1,1-	6.2E+01	USEPA Ecotox FW Chronic	6.2E+01	USEPA Ecotox FW Chronic	6.2E+01	USEPA Ecotox FW Chronic
TRICHLOROETHANE, 1,1,2-	4.7E+03	50% USEPA FW Chronic LOEL	4.7E+03	50% USEPA FW Chronic LOEL	4.7E+03	50% USEPA FW Chronic LOEL
TRICHLOROETHYLENE	3.6E+02	USEPA Ecotox FW Chronic	3.6E+02	USEPA Ecotox FW Chronic	3.6E+02	USEPA Ecotox FW Chronic
TRICHLOROPHENOL, 2,4,5-	1.1E+01	USEPA SW CCC	6.3E+01	USEPA FW CCC	1.1E+01	USEPA SW CCC
TRICHLOROPHENOL, 2,4,6-	4.9E+02	50% USEPA FW Chronic LOEL	4.9E+02	50% USEPA FW Chronic LOEL	4.9E+02	50% USEPA FW Chronic LOEL
VANADIUM	1.9E+01	USEPA Ecotox FW Chronic	1.9E+01	USEPA Ecotox FW Chronic	1.9E+01	USEPA Ecotox FW Chronic

**TABLE D-3b. SUMMARY OF SELECTED CHRONIC AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	¹ Lowest Chronic Aquatic Habitat Goal	Basis	Lowest Freshwater Chronic Aquatic Habitat Goal	Basis	Lowest Saltwater Chronic Aquatic Habitat Goal	Basis
VINYL CHLORIDE	7.8E+02	USDOE FW Chronic PRG	7.8E+02	USDOE FW Chronic PRG	7.8E+02	USDOE FW Chronic PRG
XYLENES	1.0E+02	5% Acute SW LC 50	1.0E+02	5% Acute SW LC 50	1.0E+02	5% Acute SW LC 50
ZINC	2.2E+01	HI DOH FW Chronic	2.2E+01	HI DOH FW Chronic	8.6E+01	HI DOH SW Chronic

Notes:

1. Lowest Chronic Goal = Lowest of Freshwater vs Saltwater chronic goals. Used for development of groundwater and soil action levels.
 Aquatic Habitat Goals: Addresses potential impact on freshwater or saltwater aquatic habitats.
 See text for prioritization and selection of aquatic habitat quality goals. Hawai'i DOH standard for potential bioaccumulation of chemicals in fish (and other aquatic organisms) and subsequent consumption by humans not considered for groundwater action levels (refer to Table D-4).
 Drinking water goal substituted as aquatic habitat goal if later was not available (see text).
 AWQC: Aquatic Water Quality Criteria
 CCC: Criterion for Continuous Concentration
 CMC: Criterion for Maximum Concentration
 HI DOH: Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria, April 2000.
 FCV: Final Chronic Value
 FW: Freshwater
 LOEL: Lowest Observed Effects Level
 MOEE: Ontario Ministry of Environment and Energy (MOEE 1996)
 PRG: USDOE Preliminary Remediation Goal for ecological concerns.
 SW: Saltwater
 TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
 USDOE: U. S. Department of Energy
 USEPA: U.S. Environmental Protection Agency

**TABLE D-3c. SUMMARY OF SELECTED ACUTE AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	¹ Lowest Acute Aquatic Habitat Goal	Basis	Lowest Freshwater Acute Aquatic Habitat Goal	Basis	Lowest Saltwater Acute Aquatic Habitat Goal	Basis
ACENAPHTHENE	3.2E+02	HI DOH SW Acute	5.7E+02	HI DOH FW Acute	3.2E+02	HI DOH SW Acute
ACENAPHTHYLENE	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL
ACETONE	1.5E+03	USDOE FW Chronic PRG	1.5E+03	USDOE FW Chronic PRG	1.5E+03	USDOE FW Chronic PRG
ALDRIN	1.3E+00	HI DOH SW Acute	3.0E+00	HI DOH FW Acute	1.3E+00	HI DOH SW Acute
ANTHRACENE	7.3E-01	USDOE FW Chronic PRG	7.3E-01	USDOE FW Chronic PRG	7.3E-01	USDOE FW Chronic PRG
ANTIMONY	1.5E+03	USEPA SW CMC	3.0E+03	HI DOH FW Acute	1.5E+03	USEPA SW CMC
ARSENIC	6.9E+01	HI DOH SW Acute	3.6E+02	HI DOH FW Acute	6.9E+01	HI DOH SW Acute
BARIUM	2.0E+03	=Drinking Water (Table D-2)	2.0E+03	=Drinking Water (Table D-2)	2.0E+03	=Drinking Water (Table D-2)
BENZENE	1.7E+03	HI DOH SW Acute	1.8E+03	HI DOH FW Acute	1.7E+03	HI DOH SW Acute
BENZO(a)ANTHRACENE	2.7E-02	USDOE FW Chronic PRG	2.7E-02	USDOE FW Chronic PRG	2.7E-02	USDOE FW Chronic PRG
BENZO(a)PYRENE	1.4E-02	USEPA Ecotox FW Chronic	1.4E-02	USEPA Ecotox FW Chronic	1.4E-02	USEPA Ecotox FW Chronic
BENZO(b)FLUORANTHENE	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)
BENZO(g,h,i)PERYLENE	1.0E-01	50% MOEE FW Chronic LOEL	1.0E-01	50% MOEE FW Chronic LOEL	1.0E-01	50% MOEE FW Chronic LOEL
BENZO(k)FLUORANTHENE	3.7E+00	50% MOEE FW Chronic LOEL	3.7E+00	50% MOEE FW Chronic LOEL	3.7E+00	50% MOEE FW Chronic LOEL
BERYLLIUM	4.3E+01	HI DOH FW Acute	4.3E+01	HI DOH FW Acute	4.3E+01	HI DOH FW Acute
BIPHENYL, 1,1-	1.4E+01	USEPA Ecotox FW Chronic	1.4E+01	USEPA Ecotox FW Chronic	1.4E+01	USEPA Ecotox FW Chronic
BIS(2-CHLOROETHYL)ETHER	2.4E+05	USEPA FW Acute LOEL	2.4E+05	USEPA FW Acute LOEL	2.4E+05	USEPA FW Acute LOEL
BIS(2-CHLOROISOPROPYL)ETHER	2.4E+05	USEPA FW Acute LOEL	2.4E+05	USEPA FW Acute LOEL	2.4E+05	USEPA FW Acute LOEL
BIS(2-ETHYLHEXYL)PHTHALATE	3.2E+01	USEPA Ecotox FW Chronic	3.2E+01	USEPA Ecotox FW Chronic	3.2E+01	USEPA Ecotox FW Chronic
BORON	1.6E+00	USDOE FW Chronic PRG	1.6E+00	USDOE FW Chronic PRG	1.6E+00	USDOE FW Chronic PRG
BROMODICHLOROMETHANE	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
BROMOFORM	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
BROMOMETHANE	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
CADMIUM	3.0E+00	HI DOH FW Acute	3.0E+00	HI DOH FW Acute	4.3E+01	HI DOH SW Acute
CARBON TETRACHLORIDE	1.2E+04	HI DOH FW Acute	1.2E+04	HI DOH FW Acute	1.6E+04	HI DOH SW Acute
CHLORDANE	9.0E-02	HI DOH SW Acute	2.4E+00	HI DOH FW Acute	9.0E-02	HI DOH SW Acute
CHLOROANILINE, p-	5.0E+00	50% MOEE FW Chronic LOEL	5.0E+00	50% MOEE FW Chronic LOEL	5.0E+00	50% MOEE FW Chronic LOEL
CHLOROENZENE	1.6E+02	USEPA SW Acute LOEL	2.5E+02	USEPA FW Acute LOEL	1.6E+02	USEPA SW Acute LOEL
CHLOROETHANE	3.9E+00	=Drinking Water (Table D-2)	3.9E+00	=Drinking Water (Table D-2)	3.9E+00	=Drinking Water (Table D-2)
CHLOROFORM	9.6E+03	HI DOH FW Acute	9.6E+03	HI DOH FW Acute	1.2E+04	USEPA SW Acute LOEL
CHLOROMETHANE	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
CHLOROPHENOL, 2-	1.4E+03	HI DOH FW Acute	1.4E+03	HI DOH FW Acute	1.4E+03	HI DOH FW Acute
CHROMIUM (Total)	7.4E+01	=Cr III	7.4E+01	=Cr III	1.0E+04	=Cr III
CHROMIUM III	5.7E+02	USEPA FW CMC	5.7E+02	USEPA FW CMC	1.0E+04	USEPA SW Acute LOEL
CHROMIUM VI	1.6E+01	HI DOH FW Acute	1.6E+01	HI DOH FW Acute	1.1E+03	HI DOH SW Acute
CHRYSENE	3.5E-01	50% MOEE FW Chronic LOEL	3.5E-01	50% MOEE FW Chronic LOEL	3.5E-01	50% MOEE FW Chronic LOEL
COBALT	3.0E+00	USEPA Ecotox FW Chronic	3.0E+00	USEPA Ecotox FW Chronic	3.0E+00	USEPA Ecotox FW Chronic
COPPER	2.9E+00	HI DOH SW Acute	6.0E+00	HI DOH FW Acute	2.9E+00	HI DOH SW Acute
CYANIDE (Free)	1.0E+00	HI DOH SW Acute	2.2E+01	HI DOH FW Acute	1.0E+00	HI DOH SW Acute

**TABLE D-3c. SUMMARY OF SELECTED ACUTE AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	¹ Lowest Acute Aquatic Habitat Goal	Basis	Lowest Freshwater Acute Aquatic Habitat Goal	Basis	Lowest Saltwater Acute Aquatic Habitat Goal	Basis
DIBENZO(a,h)ANTHTRACENE	7.5E+00	50% MOEE FW Chronic LOEL	7.5E+00	50% MOEE FW Chronic LOEL	7.5E+00	50% MOEE FW Chronic LOEL
DIBROMO-3-CHLOROPROPANE, 1,2-	4.0E-02	=Drinking Water (Table D-2)	4.0E-02	=Drinking Water (Table D-2)	4.0E-02	=Drinking Water (Table D-2)
DIBROMOCHLOROMETHANE	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
DIBROMOETHANE, 1,2-	1.4E+03	50% MOEE FW Chronic AWQC	1.4E+03	50% MOEE FW Chronic AWQC	1.4E+03	50% MOEE FW Chronic AWQC
DICHLOROBENZENE, 1,2-	3.7E+02	HI DOH FW Acute	3.7E+02	HI DOH FW Acute	6.6E+02	HI DOH SW Acute
DICHLOROBENZENE, 1,3-	3.7E+02	HI DOH FW Acute	3.7E+02	HI DOH FW Acute	6.6E+02	HI DOH SW Acute
DICHLOROBENZENE, 1,4-	3.7E+02	HI DOH FW Acute	3.7E+02	HI DOH FW Acute	6.6E+02	HI DOH SW Acute
DICHLOROBENZIDINE, 3,3-	2.5E+02	50% MOEE FW Chronic LOEL	2.5E+02	50% MOEE FW Chronic LOEL	2.5E+02	50% MOEE FW Chronic LOEL
DICHLORODIPHENYLDICHLOROETHANE (DDD)	6.0E-01	USEPA FW Acute LOEL	6.0E-01	USEPA FW Acute LOEL	3.6E+00	USEPA SW Acute LOEL
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.4E+01	USEPA SW Acute LOEL	1.1E+03	USEPA FW Acute LOEL	1.4E+01	USEPA SW Acute LOEL
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.3E-02	HI DOH SW Acute	1.1E+00	HI DOH FW Acute	1.3E-02	HI DOH SW Acute
DICHLOROETHANE, 1,1-	4.7E+01	USEPA Ecotox FW Chronic	4.7E+01	USEPA Ecotox FW Chronic	4.7E+01	USEPA Ecotox FW Chronic
DICHLOROETHANE, 1,2-	3.8E+04	HI DOH SW Acute	3.9E+04	HI DOH FW Acute	3.8E+04	HI DOH SW Acute
DICHLOROETHYLENE, 1,1-	3.9E+03	HI DOH FW Acute	3.9E+03	HI DOH FW Acute	7.5E+04	HI DOH SW Acute
DICHLOROETHYLENE, Cis 1,2-	1.2E+04	USEPA FW Acute LOEL	1.2E+04	USEPA FW Acute LOEL	2.2E+05	USEPA SW Acute LOEL
DICHLOROETHYLENE, Trans 1,2-	1.2E+04	USEPA FW Acute LOEL	1.2E+04	USEPA FW Acute LOEL	2.2E+05	USEPA SW Acute LOEL
DICHLOROPHENOL, 2,4-	6.7E+02	HI DOH FW Acute	6.7E+02	HI DOH FW Acute	6.7E+02	HI DOH FW Acute
DICHLOROPROPANE, 1,2-	3.4E+03	HI DOH SW Acute	7.7E+03	HI DOH FW Acute	3.4E+03	HI DOH SW Acute
DICHLOROPROPENE, 1,3-	2.6E+02	HI DOH SW Acute	2.0E+03	HI DOH FW Acute	2.6E+02	HI DOH SW Acute
DIELDRIN	7.1E-01	HI DOH SW Acute	2.5E+00	HI DOH FW Acute	7.1E-01	HI DOH SW Acute
DIETHYLPHTHALATE	9.4E+02	USEPA FW Acute LOEL	9.4E+02	USEPA FW Acute LOEL	2.9E+03	USEPA SW Acute LOEL
DIMETHYLPHENOL, 2,4-	2.7E+02	USEPA SW CMC	7.0E+02	HI DOH FW Acute	2.7E+02	USEPA SW CMC
DIMETHYLPHTHALATE	9.4E+02	USEPA FW Acute LOEL	9.4E+02	USEPA FW Acute LOEL	2.9E+03	USEPA SW Acute LOEL
DINITROPHENOL, 2,4-	2.3E+02	USEPA FW Acute LOEL	2.3E+02	USEPA FW Acute LOEL	4.9E+03	USEPA SW Acute LOEL
DINITROTOLUENE, 2,4-	2.0E+02	HI DOH SW Acute	3.3E+02	USEPA FW Acute LOEL	2.0E+02	HI DOH SW Acute
DIOXANE, 1,4-	6.7E+06	FW LC50	6.7E+06	FW LC50	1.0E+07	SW LC50
DIOXIN (2,3,7,8-TCDD)	3.0E-03	HI DOH FW Acute	3.0E-03	HI DOH FW Acute	3.0E-03	HI DOH FW Acute
ENDOSULFAN	3.4E-02	HI DOH SW Acute	2.2E-01	HI DOH FW Acute	3.4E-02	HI DOH SW Acute
ENDRIN	3.7E-02	HI DOH SW Acute	1.8E-01	HI DOH FW Acute	3.7E-02	HI DOH SW Acute
ETHYLBENZENE	4.3E+02	USEPA SW Acute LOEL	1.1E+04	HI DOH FW Acute	4.3E+02	USEPA SW Acute LOEL
FLUORANTHENE	4.0E+01	USEPA SW Acute LOEL	1.3E+03	HI DOH FW Acute	4.0E+01	USEPA SW Acute LOEL
FLUORENE	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL
HEPTACHLOR	5.3E-02	HI DOH SW Acute	5.2E-01	HI DOH FW Acute	5.3E-02	HI DOH SW Acute
HEPTACHLOR EPOXIDE	5.3E-02	USEPA SW CMC	5.2E-01	USEPA FW CMC	5.3E-02	USEPA SW CMC
HEXACHLOROBENZENE	6.0E+00	USEPA FW CMC	6.0E+00	USEPA FW CMC	1.6E+02	USEPA SW Acute LOEL
HEXACHLOROBUTADIENE	1.1E+01	HI DOH SW Acute	3.0E+01	HI DOH FW Acute	1.1E+01	HI DOH SW Acute
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	1.6E-01	HI DOH SW Acute	2.0E+00	HI DOH FW Acute	1.6E-01	HI DOH SW Acute
HEXACHLOROETHANE	3.1E+02	HI DOH SW Acute	3.3E+02	HI DOH FW Acute	3.1E+02	HI DOH SW Acute
INDENO(1,2,3-cd)PYRENE	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)	9.2E-02	=Drinking Water (Table D-2)

**TABLE D-3c. SUMMARY OF SELECTED ACUTE AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	¹ Lowest Acute Aquatic Habitat Goal	Basis	Lowest Freshwater Acute Aquatic Habitat Goal	Basis	Lowest Saltwater Acute Aquatic Habitat Goal	Basis
LEAD	2.9E+01	HI DOH FW Acute	2.9E+01	HI DOH FW Acute	1.4E+02	HI DOH SW Acute
MERCURY	2.1E+00	HI DOH SW Acute	2.4E+00	HI DOH FW Acute	2.1E+00	HI DOH SW Acute
METHOXYCHLOR	3.0E-02	USEPA SW CMC	3.0E-02	USEPA SW CMC	3.0E-02	USEPA SW CMC
METHYL ETHYL KETONE	1.4E+04	USDOE FW Chronic PRG	1.4E+04	USDOE FW Chronic PRG	1.4E+04	USDOE FW Chronic PRG
METHYL ISOBUTYL KETONE	1.7E+02	USDOE FW Chronic PRG	1.7E+02	USDOE FW Chronic PRG	1.7E+02	USDOE FW Chronic PRG
METHYL MERCURY	3.0E-03	USEPA Ecotox FW Chronic	3.0E-03	USEPA Ecotox FW Chronic	3.0E-03	USEPA Ecotox FW Chronic
METHYL TERT BUTYL ETHER	8.0E+03	CalEPA SW Chronic	6.6E+04	CA FW Chronic	8.0E+03	CalEPA SW Chronic
METHYLENE CHLORIDE	1.1E+04	USEPA FW Acute LOEL	1.1E+04	USEPA FW Acute LOEL	1.2E+04	USEPA SW Acute LOEL
METHYLNAPHTHALENE (total 1- & 2-)	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL	3.0E+02	USEPA SW Acute LOEL
MOLYBDENUM	2.4E+02	USEPA Ecotox FW Chronic	2.4E+02	USEPA Ecotox FW Chronic	2.4E+02	USEPA Ecotox FW Chronic
NAPHTHALENE	7.7E+02	HI DOH FW Acute	7.7E+02	HI DOH FW Acute	7.8E+02	HI DOH SW Acute
NICKEL	5.0E+00	HI DOH FW Acute	5.0E+00	HI DOH FW Acute	7.5E+01	HI DOH SW Acute
PENTACHLOROPHENOL	1.3E+01	HI DOH SW Acute	2.0E+01	HI DOH FW Acute	1.3E+01	HI DOH SW Acute
PERCHLORATE	6.0E+02	USEPA Ecotox FW Chronic	6.0E+02	USEPA Ecotox FW Chronic	6.0E+02	USEPA Ecotox FW Chronic
PHENANTHRENE	7.7E+00	USEPA SW CMC	3.0E+01	USEPA FW CMC	7.7E+00	USEPA SW CMC
PHENOL	3.4E+03	HI DOH FW Acute	3.4E+03	HI DOH FW Acute	5.8E+03	USEPA SW Acute LOEL
POLYCHLORINATED BIPHENYLS (PCBs)	2.0E+00	HI DOH FW Acute	2.0E+00	HI DOH FW Acute	1.0E+01	HI DOH SW Acute
PYRENE	2.0E+00	50% MOEE FW Chronic LOEL	2.0E+00	50% MOEE FW Chronic LOEL	2.0E+00	50% MOEE FW Chronic LOEL
SELENIUM	2.0E+01	HI DOH FW Acute	2.0E+01	HI DOH FW Acute	3.0E+02	HI DOH SW Acute
SILVER	1.0E+00	HI DOH FW Acute	1.0E+00	HI DOH FW Acute	2.3E+00	HI DOH SW Acute
STYRENE	1.0E+02	=Drinking Water (Table D-2)	1.0E+02	=Drinking Water (Table D-2)	1.0E+02	=Drinking Water (Table D-2)
tert-BUTYL ALCOHOL	1.8E+05	FW LCO	1.8E+05	FW LCO	1.8E+05	10% Acute FW LCO
TETRACHLOROETHANE, 1,1,1,2-	3.1E+03	HI DOH FW Acute	3.1E+03	HI DOH FW Acute	3.1E+03	HI DOH FW Acute
TETRACHLOROETHANE, 1,1,2,2-	3.0E+03	HI DOH SW Acute	9.3E+03	USEPA FW Acute LOEL	3.0E+03	HI DOH SW Acute
TETRACHLOROETHYLENE	1.8E+03	HI DOH FW Acute	1.8E+03	HI DOH FW Acute	3.4E+03	HI DOH SW Acute
THALLIUM	4.7E+02	HI DOH FW Acute	4.7E+02	HI DOH FW Acute	7.1E+02	HI DOH SW Acute
TOLUENE	5.8E+03	HI DOH FW Acute	5.8E+03	HI DOH FW Acute	6.3E+03	USEPA SW Acute LOEL
TOXAPHENE	2.1E-01	HI DOH SW Acute	7.3E-01	HI DOH FW Acute	2.1E-01	HI DOH SW Acute
TPH (gasolines)	5.0E+03	Ceiling Level	5.0E+03	Ceiling Level	5.0E+03	Ceiling Level
TPH (middle distillates)	2.5E+03	Ceiling Level	2.5E+03	Ceiling Level	2.5E+03	Ceiling Level
TPH (residual fuels)	2.5E+03	Ceiling Level	2.5E+03	Ceiling Level	2.5E+03	Ceiling Level
TRICHLOROBEZENE, 1,2,4-	1.6E+02	USEPA SW Acute LOEL	2.5E+02	USEPA FW Acute LOEL	1.6E+02	USEPA SW Acute LOEL
TRICHLOROETHANE, 1,1,1-	6.0E+03	HI DOH FW Acute	6.0E+03	HI DOH FW Acute	1.0E+04	HI DOH SW Acute
TRICHLOROETHANE, 1,1,2-	6.0E+03	HI DOH FW Acute	6.0E+03	HI DOH FW Acute	6.0E+03	HI DOH FW Acute
TRICHLOROETHYLENE	7.0E+02	HI DOH SW Acute	1.5E+04	HI DOH FW Acute	7.0E+02	HI DOH SW Acute
TRICHLOROPHENOL, 2,4,5-	1.0E+02	USEPA FW CMC	1.0E+02	USEPA FW CMC	2.4E+02	USEPA SW CMC
TRICHLOROPHENOL, 2,4,6-	4.9E+02	50% USEPA FW Chronic LOEL	4.9E+02	50% USEPA FW Chronic LOEL	4.9E+02	50% USEPA FW Chronic LOEL
VANADIUM	1.9E+01	USEPA Ecotox FW Chronic	1.9E+01	USEPA Ecotox FW Chronic	1.9E+01	USEPA Ecotox FW Chronic
VINYL CHLORIDE	7.8E+02	USDOE FW Chronic PRG	7.8E+02	USDOE FW Chronic PRG	7.8E+02	USDOE FW Chronic PRG

**TABLE D-3c. SUMMARY OF SELECTED ACUTE AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	¹ Lowest Acute Aquatic Habitat Goal	Basis	Lowest Freshwater Acute Aquatic Habitat Goal	Basis	Lowest Saltwater Acute Aquatic Habitat Goal	Basis
XYLENES	2.0E+03	SW LC50	2.0E+03	SW LC50	2.0E+03	SW LC50
ZINC	2.2E+01	HI DOH FW Acute	2.2E+01	HI DOH FW Acute	9.5E+01	HI DOH SW Acute

Notes:

1. Lowest Goal = Lowest of Freshwater vs Saltwater chronic goals.
 Aquatic Habitat Goals: Addresses potential impact on freshwater or saltwater aquatic habitats.
 See text for prioritization and selection of surface water quality goals. Hawai'i DOH standard for potential bioaccumulation of chemicals
 Chronic surface water goal referred to if no acute goal available (see Table D-3a (chronic))
 AWQC: Aquatic Water Quality Criteria
 CCC: Criterion for Continuous Concentration
 CMC: Criterion for Maximum Concentration
 HI DOH: Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria, April 2000.
 FCV: Final Chronic Value
 FW: Freshwater
 LOEL: Lowest Observed Effects Level
 MOEE: Ontario Ministry of Environment and Energy (MOEE 1996)
 PRG: USDOE Preliminary Remediation Goal for ecological concerns.
 SW: Saltwater
 TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
 USDOE: U. S. Department of Energy
 USEPA: U.S. Environmental Protection Agency

**TABLE D-3d. SUMMARY OF HAWAI'I CHRONIC AND ACUTE
SURFACE WATER (AQUATIC HABITAT) STANDARDS
(ug/l)**

CONTAMINANT	Freshwater		Saltwater	
	Chronic	Acute	Chronic	Acute
ACENAPHTHENE		5.7E+02		3.2E+02
ACENAPHTHYLENE				
ACETONE				
ALDRIN		3.0E+00		1.3E+00
ANTHRACENE				
ANTIMONY		3.0E+03		
ARSENIC	1.9E+02	3.6E+02	3.6E+01	6.9E+01
BARIUM				
BENZENE		1.8E+03		1.7E+03
BENZO(a)ANTHRACENE				
BENZO(a)PYRENE				
BENZO(b)FLUORANTHENE				
BENZO(g,h,i)PERYLENE				
BENZO(k)FLUORANTHENE				
BERYLLIUM		4.3E+01		
BIPHENYL, 1,1-				
BIS(2-CHLOROETHYL)ETHER				
BIS(2-CHLOROISOPROPYL)ETHER				
BIS(2-ETHYLHEXYL)PHTHALATE				
BORON				
BROMODICHLOROMETHANE				
BROMOFORM				
BROMOMETHANE				
CADMIUM	3.0E+00	3.0E+00	9.3E+00	4.3E+01
CARBON TETRACHLORIDE		1.2E+04		1.6E+04
CHLORDANE	4.3E-03	2.4E+00	4.0E-03	9.0E-02
CHLOROANILINE, p-				
CHLOROBENZENE				
CHLOROETHANE				
CHLOROFORM		9.6E+03		
CHLOROMETHANE				
CHLOROPHENOL, 2-		1.4E+03		
CHROMIUM (Total)				
CHROMIUM III				
CHROMIUM VI	1.1E+01	1.6E+01	5.0E+01	1.1E+03
CHRYSENE				

**TABLE D-3d. SUMMARY OF HAWAI'I CHRONIC AND ACUTE
SURFACE WATER (AQUATIC HABITAT) STANDARDS
(ug/l)**

CONTAMINANT	Freshwater		Saltwater	
	Chronic	Acute	Chronic	Acute
COBALT				
COPPER	6.0E+00	6.0E+00	2.9E+00	2.9E+00
CYANIDE (Free)	5.2E+00	2.2E+01	1.0E+00	1.0E+00
DIBENZO(a,h)ANTHTRACENE				
DIBROMO-3-CHLOROPROPANE, 1,2-				
DIBROMOCHLOROMETHANE				
DIBROMOETHANE, 1,2-				
DICHLOROBENZENE, 1,2-		3.7E+02		6.6E+02
DICHLOROBENZENE, 1,3-		3.7E+02		6.6E+02
DICHLOROBENZENE, 1,4-		3.7E+02		6.6E+02
DICHLOROBENZIDINE, 3,3-				
DICHLORODIPHENYLDICHLOROETHANE (DDD)				
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)				
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03	1.1E+00	1.0E-03	1.3E-02
DICHLOROETHANE, 1,1-				
DICHLOROETHANE, 1,2-		3.9E+04		3.8E+04
DICHLOROETHYLENE, 1,1-		3.9E+03		7.5E+04
DICHLOROETHYLENE, Cis 1,2-				
DICHLOROETHYLENE, Trans 1,2-				
DICHLOROPHENOL, 2,4-		6.7E+02		
DICHLOROPROPANE, 1,2-		7.7E+03		3.4E+03
DICHLOROPROPENE, 1,3-		2.0E+03		2.6E+02
DIELDRIN	1.9E-03	2.5E+00	1.9E-03	7.1E-01
DIETHYLPHTHALATE				
DIMETHYLPHENOL, 2,4-		7.0E+02		
DIMETHYLPHTHALATE				
DINITROPHENOL, 2,4-				2.0E+02
DINITROTOLUENE, 2,4-				
DIOXANE, 1,4-				
DIOXIN (2,3,7,8-TCDD)		3.0E-03		
ENDOSULFAN	5.6E-02	2.2E-01	8.7E-03	3.4E-02
ENDRIN	2.3E-03	1.8E-01	2.3E-03	3.7E-02
ETHYLBENZENE		1.1E+04		
FLUORANTHENE		1.3E+03		
FLUORENE				
HEPTACHLOR	3.8E-03	5.2E-01	3.6E-03	5.3E-02

**TABLE D-3d. SUMMARY OF HAWAI'I CHRONIC AND ACUTE
SURFACE WATER (AQUATIC HABITAT) STANDARDS
(ug/l)**

CONTAMINANT	Freshwater		Saltwater	
	Chronic	Acute	Chronic	Acute
HEPTACHLOR EPOXIDE				
HEXACHLOROBENZENE				
HEXACHLOROBUTADIENE		3.0E+01		1.1E+01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	8.0E-02	2.0E+00		1.6E-01
HEXACHLOROETHANE		3.3E+02		3.1E+02
INDENO(1,2,3-cd)PYRENE				
LEAD	2.9E+01	2.9E+01	5.6E+00	1.4E+02
MERCURY	5.5E-01	2.4E+00	2.5E-02	2.1E+00
METHOXYCHLOR	3.0E-02		3.0E-02	
METHYL ETHYL KETONE				
METHYL ISOBUTYL KETONE				
METHYL MERCURY				
METHYL TERT BUTYL ETHER				
METHYLENE CHLORIDE				
METHYLNAPHTHALENE (total 1- & 2-)				
MOLYBDENUM				
NAPHTHALENE		7.7E+02		7.8E+02
NICKEL	5.0E+00	5.0E+00	8.3E+00	7.5E+01
PENTACHLOROPHENOL	1.3E+01	2.0E+01		1.3E+01
PERCHLORATE				
PHENANTHRENE				
PHENOL		3.4E+03		
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02	2.0E+00	3.0E-02	1.0E+01
PYRENE				
SELENIUM	5.0E+00	2.0E+01	7.1E+01	3.0E+02
SILVER	1.0E+00	1.0E+00		2.3E+00
STYRENE				
tert-BUTYL ALCOHOL				
TETRACHLOROETHANE, 1,1,1,2-		3.1E+03		
TETRACHLOROETHANE, 1,1,2,2-				3.0E+03
TETRACHLOROETHYLENE		1.8E+03	1.45E+02	3.4E+03
THALLIUM		4.7E+02		7.1E+02
TOLUENE		5.8E+03		
TOXAPHENE	2.0E-04	7.3E-01	2.0E-04	2.1E-01
TPH (gasolines)				
TPH (middle distillates)				

**TABLE D-3d. SUMMARY OF HAWAI'I CHRONIC AND ACUTE
SURFACE WATER (AQUATIC HABITAT) STANDARDS
(ug/l)**

CONTAMINANT	Freshwater		Saltwater	
	Chronic	Acute	Chronic	Acute
TPH (residual fuels)				
TRICHLOROBENZENE, 1,2,4-				
TRICHLOROETHANE, 1,1,1-		6.0E+03		1.0E+04
TRICHLOROETHANE, 1,1,2-		6.0E+03		
TRICHLOROETHYLENE		1.5E+04		7.0E+02
TRICHLOROPHENOL, 2,4,5-				
TRICHLOROPHENOL, 2,4,6-				
VANADIUM				
VINYL CHLORIDE				
XYLENES				
ZINC	2.2E+01	2.2E+01	8.6E+01	9.5E+01

Primary Reference:
1. Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria, April 2000.
 Acute freshwater standard for dinitrotoluene and saltwater standards for antimony, ethylbenzene, phenol and toluene not used due to higher, more recent USEPA chronic goals.

TABLE D-3e. SUMMARY OF USEPA AND OTHER PUBLISHED AQUATIC HABITAT GOALS
(ug/l)

CONTAMINANT	Freshwater									Marine									
	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis	
ACENAPHTHENE		5.2E+02		1.7E+03	2.3E+01								7.1E+02	9.7E+02	4.0E+01				
ACENAPHTHYLENE								1.5E+03	USDOE FW Chronic PRG					3.0E+02					
ACETONE												1.3E+00							
ALDRIN			3.0E+00					7.3E-01	USDOE FW Chronic PRG										
ANTHRACENE																			
ANTIMONY	3.0E+01		8.8E+01							5.0E+02		1.5E+03							
ARSENIC	1.5E+02		3.4E+02		1.9E+02					3.6E+01		6.9E+01		3.6E+01					
BARIUM																			
BENZENE				5.3E+03	4.6E+01								7.0E+02	5.1E+03					
BENZO(a)ANTHRACENE								2.7E-02	USDOE FW Chronic PRG										
BENZO(a)PYRENE					1.4E-02														
BENZO(b)FLUORANTHENE																			
BENZO(g,h,i)PERYLENE								1.0E-01	50% MOEE FW Chronic LOEL										
BENZO(k)FLUORANTHENE								3.7E+00	50% MOEE FW Chronic LOEL										
BERYLLIUM		5.3E+00		1.3E+02	5.1E+00														
BIPHENYL, 1,1-					1.4E+01														
BIS(2-CHLOROETHYL)ETHER		1.2E+02		2.4E+05															
BIS(2-CHLOROISOPROPYL)ETHER		1.2E+02		2.4E+05															
BIS(2-ETHYLHEXYL)PHTHALATE					3.2E+01														
BORON								1.6E+00	USDOE FW Chronic PRG										
BROMODICHLOROMETHANE				1.1E+04								6.4E+03		1.2E+04					
BROMOFORM				1.1E+04								6.4E+03		1.2E+04					
BROMOMETHANE				1.1E+04				1.6E+02	50% MOEE FW Chronic LOEL			6.4E+03		1.2E+04					
CADMIUM	2.5E-01		2.0E+00		1.0E+00					8.8E+00		4.0E+01		9.3E+00					
CARBON TETRACHLORIDE				3.5E+04				9.8E+00	USDOE FW Chronic PRG			6.4E+03		5.0E+04					
CHLORDANE	4.3E-03		2.4E+00							4.0E-03		9.0E-02							
CHLOROANILINE, p-								5.0E+00	50% MOEE FW Chronic LOEL				1.3E+02	1.6E+02					
CHLOROBENZENE		5.0E+01		2.5E+02	1.3E+02														
CHLOROETHANE																			
CHLOROFORM		1.2E+03		2.9E+04				2.8E+01	USDOE FW Chronic PRG			6.4E+03		1.2E+04					
CHLOROMETHANE				1.1E+04								6.4E+03		1.2E+04					
CHLOROPHENOL, 2-				4.4E+03														1.0E+04	=Cr III
CHROMIUM (Total)								7.4E+01	=Cr III					1.03E+04					
CHROMIUM III	7.4E+01		5.7E+02		1.8E+02														
CHROMIUM VI	1.1E+01		1.6E+01		1.0E+01					5.0E+01		1.1E+03							
CHRYSENE																			
COBALT					3.0E+00														
COPPER	9.0E+00		1.3E+01		1.1E+01					3.1E+00		4.8E+00		2.4E+00					
CYANIDE (Free)	5.2E+00		2.2E+01		5.2E+00							1.0E+00		1.0E+00					
DIBENZO(a,h)ANTHRACENE								7.5E+00	50% MOEE FW Chronic LOEL										
DIBROMO-3-CHLOROPROPANE, 1,2-																			
DIBROMOCHLOROMETHANE				1.1E+04								6.4E+03		1.2E+04					
DIBROMOETHANE, 1,2-								1.4E+03	50% MOEE FW Chronic AWQC										
DICHLOROBENZENE, 1,2-		7.6E+02		1.1E+03	1.4E+01							1.3E+02		1.97E+03					
DICHLOROBENZENE, 1,3-		7.6E+02		1.1E+03	7.1E+01							1.3E+02		1.97E+03					
DICHLOROBENZENE, 1,4-		7.6E+02		1.1E+03	1.5E+01							1.3E+02		1.97E+03					
DICHLOROBENZIDINE, 3,3-								2.5E+02	50% MOEE FW Chronic LOEL										
DICHLORODIPHENYLDICHLOROETHANE (DDD)				6.0E-01				1.0E-03	=DDT					3.6E+00				1.0E-03	=DDT
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)				1.1E+03				1.0E-03	=DDT					1.4E+01				1.0E-03	=DDT
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E-03		1.1E+00		1.3E-02					1.0E-03		1.3E-01							
DICHLOROETHANE, 1,1-					4.7E+01														
DICHLOROETHANE, 1,2-		2.0E+04		1.2E+05				9.1E+02	USDOE FW Chronic PRG					1.13E+05					
DICHLOROETHYLENE, 1,1-				1.2E+04				2.5E+01	USDOE FW Chronic PRG					2.24E+05					
DICHLOROETHYLENE, Cis 1,2-				1.2E+04				5.9E+02	USDOE FW Chronic PRG					2.24E+05					
DICHLOROETHYLENE, Trans 1,2-				1.2E+04				5.9E+02	USDOE FW Chronic PRG					2.24E+05					
DICHLOROPHENOL, 2,4-		3.7E+02		2.0E+03								3.0E+03		1.03E+04					
DICHLOROPROPANE, 1,2-		5.7E+03		2.3E+04															
DICHLOROPROPENE, 1,3-		2.4E+02		6.1E+03										7.9E+02					

TABLE D-3e. SUMMARY OF USEPA AND OTHER PUBLISHED AQUATIC HABITAT GOALS
(ug/l)

CONTAMINANT	Freshwater									Marine								
	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis
DIELDRIN	5.6E-02		2.4E-01		6.2E-02					1.9E-03		7.1E-01		1.1E-01				
DIETHYLPHTHALATE		3.0E+00		9.4E+02	2.2E+02						3.4E+00		2.94E+03					
DIMETHYLPHENOL, 2,4-	5.3E+02		1.3E+03							1.1E+02		2.7E+02						
DIMETHYLPHTHALATE		3.0E+00		9.4E+02							3.4E+00		2.94E+03					
DINITROPHENOL, 2,4-		1.5E+02		2.3E+02									4.85E+03					
DINITROTOLUENE, 2,4-		2.3E+02		3.3E+02							3.7E+02		5.9E+02					
DIOXANE, 1,4						6.7E+06	FW LC50	3.4E+05	5% Acute FW LC 50						1.0E+07	SW LC50	5.0E+05	5% Acute SW LC 50
DIOXIN (2,3,7,8-TCDD)		1.0E-05		1.0E-02														
ENDOSULFAN	5.6E-02		2.2E-01		5.6E-02					8.7E-03		3.4E-02		1.0E-02				
ENDRIN	3.6E-02		8.6E-02		6.1E-02					2.3E-03		3.7E-02						
ETHYLBENZENE				3.2E+04	2.9E+02								4.3E+02					
FLUORANTHENE				3.98E+03	8.1E+00						1.6E+01		4.0E+01	1.1E+01				
FLUORENE					3.9E+00								3.0E+02					
HEPTACHLOR	3.8E-03		5.2E-01		6.9E-03					3.6E-03		5.3E-02						
HEPTACHLOR EPOXIDE	3.8E-03		5.2E-01							3.6E-03		5.3E-02						
HEXACHLOROBENZENE	3.7E+00		6.0E+00								1.3E+02		1.6E+02					
HEXACHLOROBUTADIENE		9.3E+00		9.0E+01									3.2E+01					
HEXACHLOROCYCLOHEXANE (gamma) LINDANE			9.5E-01		8.0E-02							1.6E-01						
HEXACHLOROETHANE		5.4E+02		9.8E+02	1.2E+01								9.4E+02					
INDENO(1,2,3-cd)PYRENE																		
LEAD	2.5E+00		6.5E+01		2.5E+00					8.1E+00		2.1E+02		8.1E+00				
MERCURY	7.7E-01		1.4E+00		1.3E+00					9.4E-01		1.8E+00		1.1E+00				
METHOXYCHLOR			3.0E-02		1.9E-02							3.0E-02						
METHYL ETHYL KETONE								1.4E+04	USDOE FW Chronic PRG									
METHYL ISOBUTYL KETONE								1.7E+02	USDOE FW Chronic PRG									
METHYL MERCURY					3.0E-03												8.0E+03	CalEPA SW Chronic
METHYL TERT BUTYL ETHER								6.6E+04	CA FW Chronic				1.2E+04					
METHYLENE CHLORIDE				1.1E+04				2.2E+03	USDOE FW Chronic PRG		6.4E+03		3.0E+02					
METHYLNAPHTHALENE (total 1- & 2-)								2.1E+00	USDOE FW Chronic PRG									
MOLYBDENUM					2.4E+02													
NAPHTHALENE		6.2E+02		2.3E+03	2.4E+01								2.4E+03					
NICKEL	5.2E+01		4.7E+02		1.6E+02					8.2E+00		7.4E+01		8.2E+00				
PENTACHLOROPHENOL	1.5E+01		1.9E+01		1.3E+01					7.9E+00		1.3E+01		7.9E+00				
PERCHLORATE					6.0E+02													
PHENANTHRENE	6.3E+00		3.0E+01		6.3E+00					4.6E+00		7.7E+00		8.3E+00				
PHENOL		2.56E+03		1.02E+04									5.8E+03					
POLYCHLORINATED BIPHENYLS (PCBs)	1.4E-02				1.9E-01					3.0E-02								
PYRENE								2.0E+00	50% MOEE FW Chronic LOEL									
SELENIUM	5.0E+00				5.0E+00					7.1E+01		2.9E+02		7.1E+01				
SILVER			3.2E+00									1.9E+00						
STYRENE																		
tert-BUTYL ALCOHOL						1.8E+05	FW LC0	1.8E+04	10% Acute FW LC0									
TETRACHLOROETHANE, 1,1,1,2-				9.32E+03									9.02E+03					
TETRACHLOROETHANE, 1,1,2,2-		2.4E+03		9.32E+03	4.2E+02								1.02E+04					
TETRACHLOROETHYLENE		8.4E+02		5.28E+03	1.2E+02						4.5E+02		2.13E+03					
THALLIUM		4.0E+01		1.4E+03								5.0E+03		6.3E+03				
TOLUENE				1.75E+04	1.3E+02													
TOXAPHENE	2.0E-04		7.3E-01		1.1E-02					2.0E-04		2.1E-01		2.1E-01			5.0E+03	Ceiling Level
TPH (gasolines)						5.0E+03	Ceiling Level	5.0E+02	CA FW Chronic						2.5E+03	Ceiling Level		
TPH (middle distillates)						2.5E+03	Ceiling Level	6.4E+02	CA FW Chronic						2.5E+03	Ceiling Level		
TPH (residual fuels)						2.5E+03	Ceiling Level	6.4E+02	CA FW Chronic						2.5E+03	Ceiling Level		
TRICHLOROETHANE, 1,2,4-		5.0E+01		2.5E+02	1.1E+02						1.29E+02		1.6E+02					
TRICHLOROETHANE, 1,1,1-				1.8E+04	6.2E+01								3.12E+04					
TRICHLOROETHANE, 1,1,2-		9.4E+03		1.8E+04														
TRICHLOROETHYLENE		2.19E+04		4.5E+04	3.6E+02								2.0E+03					
TRICHLOROPHENOL, 2,4,5-	6.3E+01		1.0E+02							1.1E+01		2.4E+02						
TRICHLOROPHENOL, 2,4,6-		9.7E+02																
VANADIUM					1.9E+01													

**TABLE D-3e. SUMMARY OF USEPA AND OTHER PUBLISHED AQUATIC HABITAT GOALS
(ug/l)**

CONTAMINANT	Freshwater									Marine								
	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis	USEPA CCC	USEPA Chronic LOEL	USEPA CMC	USEPA Acute LOEL	Ecotox Chronic Threshold (AWQC, FCV Or Tier II)	Other Acute	Basis	Other Chronic	Basis
VINYL CHLORIDE								7.82E+02	USDOE FW Chronic PRG									
XYLENES														2.0E+03	SW LC50		1.0E+02	5% Acute SW LC 50
ZINC	1.2E+02		1.2E+02		1.0E+02					8.1E+01		9.0E+01		8.1E+01				

References:
Primary sources USEPA (1996b,c), MOEE (1996), USDOE (1997). USEPA criteria summarized in *A Compilation of Water Quality Goals*, CalEPA RWQCB Central Valley Region (RWQCBV 2000).

Notes:
Used for development of groundwater and soil screening levels.
See text for prioritization and selection of surface water quality screening levels.
Lowest Chronic Aquatic Habitat Goal: Addresses potential impact on freshwater or marine aquatic life.
Acute LOEL, CMC and LC0 goals divided by a factor of ten if selected as lowest action level. LC 50 divided by factor of twenty.
1,4 Dioxane: LC 50 values for presented in "Solvent Stabilizers White Paper" (Mohr 2001).
Methyl tert-Butyl Ether: Interim aquatic surface water criteria proposed by California Region 2 Water Quality Control Board (RWQCBSF, 1998a).
Perchlorate: Chronic goal from "Perchlorate Environmental Contamination (draft)" (USEPA 1998).
tert Butyl Alcohol (TBA): Chronic aquatic goal based on in-house review of USEPA ECOTOX database for TBA (USEPA 2003). Ten percent of LC0 concentration for *Lepomis macrochirus* (Bluegill) selected as most conservative goal of data presented.
TPH screening levels: Gasoline freshwater screening level based on studies carried out for Presidio of San Francisco (RWQCBSF 1998b). Gasoline screening level for saltwater and diesel and residual fuels screening levels in general based on studies carried out for San Francisco Airport (RWQCBSF 1999). Acute action levels based on TPH ceiling levels. See Appendix 1, Chapter 5.
Xylenes: Acute freshwater and saltwater based on review on data in UK Marine SAC summary (UKSAC 2003). Confidence in USDOE PRG and USEPA Ecotox goals low.
AWQC: Aquatic Water Quality Criteria
CCC: Criterion for Continuous Concentration
CMC: Criterion for Maximum Concentration
FCV: Final Chronic Value
FW: Freshwater
LOEL: Lowest Observed Effects Level
MOEE: Ontario Ministry of Environment and Energy (MOEE 1996)
PRG: USDOE Preliminary Remediation Goal for ecological concerns
SW: Saltwater
TPH Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
USDOE: U. S. Department of Energy
USEPA: U. S. Environmental Protection Agency

**TABLE D-3f. SURFACE WATER QUALITY STANDARDS FOR BIOACCUMULATION
AND HUMAN CONSUMPTION OF AQUATIC ORGANISMS
(ug/l)**

CONTAMINANT	Selected Criteria	Basis	¹ HI DOH WQS	² USEPA NWQC
ACENAPHTHENE	9.9E+02	USEPA Aquatic Organism Consumption		9.9E+02
ACENAPHTHYLENE				
ACETONE				
ALDRIN	2.6E-05	HI DOH Fish Consumption	2.6E-05	5.0E-05
ANTHRACENE	4.0E+04	USEPA Aquatic Organism Consumption		4.0E+04
ANTIMONY	1.5E+04	HI DOH Fish Consumption	1.5E+04	6.4E+02
ARSENIC	1.4E-01	USEPA Aquatic Organism Consumption		1.4E-01
BARIUM				
BENZENE	1.3E+01	HI DOH Fish Consumption	1.3E+01	5.1E+01
BENZO(a)ANTHRACENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
BENZO(a)PYRENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
BENZO(b)FLUORANTHENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
BENZO(g,h,i)PERYLENE				
BENZO(k)FLUORANTHENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
BERYLLIUM	3.8E-02	HI DOH Fish Consumption	3.8E-02	
BIPHENYL, 1,1-				
BIS(2-CHLOROETHYL)ETHER	4.4E-01	HI DOH Fish Consumption	4.4E-01	5.3E-01
BIS(2-CHLOROISOPROPYL)ETHER	1.4E+03	HI DOH Fish Consumption	1.4E+03	6.5E+04
BIS(2-ETHYLHEXYL)PHTHALATE	2.2E+00	USEPA Aquatic Organism Consumption		2.2E+00
BORON				
BROMODICHLOROMETHANE				
BROMOFORM	1.4E+02	USEPA Aquatic Organism Consumption		1.4E+02
BROMOMETHANE	1.5E+03	USEPA Aquatic Organism Consumption		1.5E+03
CADMIUM				
CARBON TETRACHLORIDE	2.3E+00	HI DOH Fish Consumption	2.3E+00	1.6E+00
CHLORDANE	1.6E-05	HI DOH Fish Consumption	1.6E-05	8.1E-04
CHLOROANILINE, p-				
CHLOROBENZENE	2.1E+04	USEPA Aquatic Organism Consumption		2.1E+04
CHLOROETHANE				
CHLOROFORM	5.1E+00	HI DOH Fish Consumption	5.1E+00	4.7E+02
CHLOROMETHANE				
CHLOROPHENOL, 2-	1.5E+02	USEPA Aquatic Organism Consumption		1.5E+02
CHROMIUM (Total)				
CHROMIUM III				
CHROMIUM VI				
CHRYSENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
COBALT				
COPPER				

**TABLE D-3f. SURFACE WATER QUALITY STANDARDS FOR BIOACCUMULATION
AND HUMAN CONSUMPTION OF AQUATIC ORGANISMS
(ug/l)**

CONTAMINANT	Selected Criteria	Basis	¹ HI DOH WQS	² USEPA NWQC
CYANIDE (Free)	2.2E+05	USEPA Aquatic Organism Consumption		2.2E+05
DIBENZO(a,h)ANTHTRACENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
DIBROMO-3-CHLOROPROPANE, 1,2-				
DIBROMOCHLOROMETHANE	1.3E+01	USEPA Aquatic Organism Consumption		1.3E+01
DIBROMOETHANE, 1,2-				
DICHLOROBENZENE, 1,2-	8.5E+02	HI DOH Fish Consumption	8.5E+02	1.7E+04
DICHLOROBENZENE, 1,3-	8.5E+02	HI DOH Fish Consumption	8.5E+02	9.6E+02
DICHLOROBENZENE, 1,4-	8.5E+02	HI DOH Fish Consumption	8.5E+02	2.6E+03
DICHLOROBENZIDINE, 3,3-	7.0E-03	HI DOH Fish Consumption	7.0E-03	2.8E-02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	3.1E-04	USEPA Aquatic Organism Consumption		3.1E-04
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.2E-04	USEPA Aquatic Organism Consumption		2.2E-04
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	8.0E-06	HI DOH Fish Consumption	8.0E-06	2.2E-04
DICHLOROETHANE, 1,1-				
DICHLOROETHANE, 1,2-	7.9E+01	HI DOH Fish Consumption	7.9E+01	3.7E+01
DICHLOROETHYLENE, 1,1-	6.0E-01	HI DOH Fish Consumption	6.0E-01	3.2E+00
DICHLOROETHYLENE, Cis 1,2-				
DICHLOROETHYLENE, Trans 1,2-	140000	USEPA Aquatic Organism Consumption		140000
DICHLOROPHENOL, 2,4-	2.9E+02	USEPA Aquatic Organism Consumption		2.9E+02
DICHLOROPROPANE, 1,2-	1.5E+01	USEPA Aquatic Organism Consumption		1.5E+01
DICHLOROPROPENE, 1,3-	4.6E+00	HI DOH Fish Consumption	4.6E+00	1.7E+03
DIELDRIN	2.5E-05	HI DOH Fish Consumption	2.5E-05	5.4E-05
DIETHYLPHTHALATE	4.4E+04	USEPA Aquatic Organism Consumption		4.4E+04
DIMETHYLPHENOL, 2,4-	8.5E+02	USEPA Aquatic Organism Consumption		8.5E+02
DIMETHYLPHTHALATE	1.1E+06	USEPA Aquatic Organism Consumption		1.1E+06
DINITROPHENOL, 2,4-	5.3E+03	USEPA Aquatic Organism Consumption		5.3E+03
DINITROTOLUENE, 2,4-	3.0E+00	HI DOH Fish Consumption	3.0E+00	3.4E+00
DIOXANE, 1,4-				
DIOXIN (2,3,7,8-TCDD)	5.0E-09	HI DOH Fish Consumption	5.0E-09	5.1E-09
ENDOSULFAN	5.2E+01	HI DOH Fish Consumption	5.2E+01	8.9E+01
ENDRIN	8.1E-01	USEPA Aquatic Organism Consumption		8.1E-01
ETHYLBENZENE	1.1E+03	HI DOH Fish Consumption	1.1E+03	2.9E+04
FLUORANTHENE	1.8E+01	HI DOH Fish Consumption	1.8E+01	1.4E+02
FLUORENE	5.3E+03	USEPA Aquatic Organism Consumption		5.3E+03
HEPTACHLOR	9.0E-05	HI DOH Fish Consumption	9.0E-05	7.9E-05
HEPTACHLOR EPOXIDE	3.9E-05	USEPA Aquatic Organism Consumption		3.9E-05
HEXACHLOROBENZENE	2.4E-04	HI DOH Fish Consumption	2.4E-04	2.9E-04
HEXACHLOROBUTADIENE	1.6E+01	HI DOH Fish Consumption	1.6E+01	1.8E+01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.0E-02	HI DOH Fish Consumption	2.0E-02	6.3E-02

**TABLE D-3f. SURFACE WATER QUALITY STANDARDS FOR BIOACCUMULATION
AND HUMAN CONSUMPTION OF AQUATIC ORGANISMS
(ug/l)**

CONTAMINANT	Selected Criteria	Basis	¹ HI DOH WQS	² USEPA NWQC
HEXACHLOROETHANE	2.9E+00	HI DOH Fish Consumption	2.9E+00	3.3E+00
INDENO(1,2,3-cd)PYRENE	1.8E-02	USEPA Aquatic Organism Consumption		1.8E-02
LEAD				
MERCURY	4.7E-02	HI DOH Fish Consumption	4.7E-02	3.0E-01
METHOXYCHLOR				
METHYL ETHYL KETONE				
METHYL ISOBUTYL KETONE				
METHYL MERCURY				
METHYL TERT BUTYL ETHER				
METHYLENE CHLORIDE	5.9E+02	USEPA Aquatic Organism Consumption		5.9E+02
METHYLNAPHTHALENE (total 1- & 2-)				
MOLYBDENUM				
NAPHTHALENE				
NICKEL	3.3E+01	HI DOH Fish Consumption	3.3E+01	4.6E+03
PENTACHLOROPHENOL	3.0E+00	USEPA Aquatic Organism Consumption		3.0E+00
PERCHLORATE				
PHENANTHRENE				
PHENOL	1.7E+06	USEPA Aquatic Organism Consumption		1.7E+06
POLYCHLORINATED BIPHENYLS (PCBs)	7.9E-05	HI DOH Fish Consumption	7.9E-05	6.4E-05
PYRENE	4.0E+03	USEPA Aquatic Organism Consumption		4.0E+03
SELENIUM				
SILVER				
STYRENE				
tert-BUTYL ALCOHOL				
TETRACHLOROETHANE, 1,1,1,2-				
TETRACHLOROETHANE, 1,1,2,2-	3.5E+00	HI DOH Fish Consumption	3.5E+00	4.0E+00
TETRACHLOROETHYLENE	2.9E+00	HI DOH Fish Consumption	2.90E+00	3.3E+00
THALLIUM	1.6E+01	HI DOH Fish Consumption	1.6E+01	6.3E+00
TOLUENE	1.4E+05	HI DOH Fish Consumption	1.4E+05	2.0E+05
TOXAPHENE	2.4E-04	HI DOH Fish Consumption	2.4E-04	2.8E-04
TPH (gasolines)				
TPH (middle distillates)				
TPH (residual fuels)				
TRICHLOROENZENE, 1,2,4-				
TRICHLOROETHANE, 1,1,1-	3.4E+05	HI DOH Fish Consumption	3.4E+05	
TRICHLOROETHANE, 1,1,2-	1.4E+01	HI DOH Fish Consumption	1.4E+01	1.6E+01
TRICHLOROETHYLENE	2.6E+01	HI DOH Fish Consumption	2.6E+01	3.0E+01
TRICHLOROPHENOL, 2,4,5-	3.6E+03	USEPA Aquatic Organism Consumption		3.6E+03

**TABLE D-3f. SURFACE WATER QUALITY STANDARDS FOR BIOACCUMULATION
AND HUMAN CONSUMPTION OF AQUATIC ORGANISMS
(ug/l)**

CONTAMINANT	Selected Criteria	Basis	¹ HI DOH WQS	² USEPA NWQC
TRICHLOROPHENOL, 2,4,6-	1.2E+00	HI DOH Fish Consumption	1.2E+00	
VANADIUM				
VINYL CHLORIDE	1.7E+02	HI DOH Fish Consumption	1.70E+02	5.30E+02
XYLENES				
ZINC				

References:
1. Hawai'i Administrative Rules, Title 11, Chapter 54, Section 11-54-04: Basic Water Quality Criteria, April 2000.
2. USEPA National Recommended Water Quality Criteria: 2002, EPA-822-R-02-047.

Notes:
Hawai'i Surface Water Quality Standards for fish consumption considered if available.
Addresses potential accumulation of chemical in aquatic organisms and subsequent consumption by humans.

**TABLE D-4. USEPA REGION IX
TAP WATER GOALS
(ug/l)**

CONTAMINANT	Lowest Tapwater Goal (ug/L)	Basis	Tap Water Goal (Noncarcinogenic Effects)	Tap Water Goal (Carcinogenic Effects)
ACENAPHTHENE	3.7E+02	noncarcinogenic effects	3.7E+02	
ACENAPHTHYLENE	2.4E+02	noncarcinogenic effects	2.4E+02	
ACETONE	5.5E+03	noncarcinogenic effects	5.5E+03	
ALDRIN	4.0E-03	carcinogenic effects	1.1E+00	4.0E-03
ANTHRACENE	1.8E+03	noncarcinogenic effects	1.8E+03	
ANTIMONY	1.5E+01	noncarcinogenic effects	1.5E+01	
ARSENIC	4.5E-02	carcinogenic effects	1.1E+01	4.5E-02
BARIUM	2.6E+03	noncarcinogenic effects	2.6E+03	
BENZENE	3.5E-01	carcinogenic effects	4.4E+01	3.5E-01
BENZO(a)ANTHRACENE	9.2E-02	carcinogenic effects		9.2E-02
BENZO(a)PYRENE	9.2E-03	carcinogenic effects		9.2E-03
BENZO(b)FLUORANTHENE	9.2E-02	carcinogenic effects		9.2E-02
BENZO(g,h,i)PERYLENE	1.5E+03	noncarcinogenic effects	1.5E+03	
BENZO(k)FLUORANTHENE	9.2E-01	carcinogenic effects		9.2E-01
BERYLLIUM	7.3E+01	noncarcinogenic effects	7.3E+01	
BIPHENYL, 1,1-	3.0E+02	noncarcinogenic effects	3.0E+02	
BIS(2-CHLOROETHYL)ETHER	9.5E-03	carcinogenic effects		9.5E-03
BIS(2-CHLOROISOPROPYL)ETHER	2.7E-01	carcinogenic effects	2.4E+02	2.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	4.8E+00	carcinogenic effects	7.3E+02	4.8E+00
BORON	7.3E+03	noncarcinogenic effects	7.3E+03	
BROMODICHLOROMETHANE	1.8E-01	carcinogenic effects	1.2E+02	1.8E-01
BROMOFORM	8.5E+00	carcinogenic effects	7.3E+02	8.5E+00
BROMOMETHANE	8.5E+00	noncarcinogenic effects	8.5E+00	
CADMIUM	1.8E+01	noncarcinogenic effects	1.8E+01	
CARBON TETRACHLORIDE	1.7E-01	carcinogenic effects	4.3E+00	1.7E-01
CHLORDANE	1.9E-01	carcinogenic effects	1.8E+01	1.9E-01
CHLOROANILINE, p-	1.5E+02	noncarcinogenic effects	1.5E+02	
CHLORO BENZENE	1.1E+02	noncarcinogenic effects	1.1E+02	
CHLOROETHANE	3.9E+00	carcinogenic effects	8.6E+03	3.9E+00
CHLOROFORM	1.7E-01	carcinogenic effects	8.0E+01	1.7E-01
CHLOROMETHANE	1.6E+02	noncarcinogenic effects	1.6E+02	
CHLOROPHENOL, 2-	3.0E+01	noncarcinogenic effects	3.0E+01	
CHROMIUM (Total)	0.0E+00	carcinogenic effects		
CHROMIUM III	5.5E+04	noncarcinogenic effects	5.5E+04	
CHROMIUM VI	1.1E+02	noncarcinogenic effects	1.1E+02	
CHRYSENE	9.2E+00	carcinogenic effects		9.2E+00
COBALT	7.3E+02	noncarcinogenic effects	7.3E+02	
COPPER	1.5E+03	noncarcinogenic effects	1.5E+03	
CYANIDE (Free)	7.3E+02	noncarcinogenic effects	7.3E+02	
DIBENZO(a,h)ANTHRACENE	9.2E-03	carcinogenic effects		9.2E-03
DIBROMO-3-CHLOROPROPANE, 1,2-	4.8E-02	carcinogenic effects	3.5E-01	4.8E-02
DIBROMOCHLOROMETHANE	1.3E-01	carcinogenic effects	1.2E+02	1.3E-01
DIBROMOETHANE, 1,2-	5.6E-03	carcinogenic effects	1.8E+01	5.6E-03
DICHLOROBENZENE, 1,2-	3.7E+02	noncarcinogenic effects	3.7E+02	
DICHLOROBENZENE, 1,3-	1.8E+02	noncarcinogenic effects	1.8E+02	
DICHLOROBENZENE, 1,4-	5.0E-01	carcinogenic effects	1.8E+02	5.0E-01
DICHLOROBENZIDINE, 3,3-	1.5E-01	carcinogenic effects		1.5E-01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.8E-01	carcinogenic effects		2.8E-01
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.8E-01	carcinogenic effects		2.8E-01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.0E-01	carcinogenic effects	1.8E+01	2.0E-01
DICHLOROETHANE, 1,1-	8.0E+02	noncarcinogenic effects	8.0E+02	
DICHLOROETHANE, 1,2-	1.2E-01	carcinogenic effects	1.0E+01	1.2E-01

**TABLE D-4. USEPA REGION IX
TAP WATER GOALS
(ug/l)**

CONTAMINANT	Lowest Tapwater Goal (ug/L)	Basis	Tap Water Goal (Noncarcinogenic Effects)	Tap Water Goal (Carcinogenic Effects)
DICHLOROETHYLENE, 1,1-	3.4E+02	noncarcinogenic effects	3.4E+02	
DICHLOROETHYLENE, Cis 1,2-	6.1E+01	noncarcinogenic effects	6.1E+01	
DICHLOROETHYLENE, Trans 1,2-	1.2E+02	noncarcinogenic effects	1.2E+02	
DICHLOROPHENOL, 2,4-	1.1E+02	noncarcinogenic effects	1.1E+02	
DICHLOROPROPANE, 1,2-	1.6E-01	carcinogenic effects	6.7E+00	1.6E-01
DICHLOROPROPENE, 1,3-	4.0E-01	carcinogenic effects	4.0E+01	4.0E-01
DIELDRIN	4.2E-03	carcinogenic effects	1.8E+00	4.2E-03
DIETHYLPHTHALATE	2.9E+04	noncarcinogenic effects	2.9E+04	
DIMETHYLPHENOL, 2,4-	7.3E+02	noncarcinogenic effects	7.3E+02	
DIMETHYLPHTHALATE	3.7E+05	noncarcinogenic effects	3.7E+05	
DINITROPHENOL, 2,4-	7.3E+01	noncarcinogenic effects	7.3E+01	
DINITROTOLUENE, 2,4-	3.4E+01	carcinogenic effects	7.3E+01	3.4E+01
DIOXANE, 1,4-	6.1E+00	carcinogenic effects		6.1E+00
DIOXIN (2,3,7,8-TCDD)	4.5E-07	carcinogenic effects		4.5E-07
ENDOSULFAN	2.2E+02	noncarcinogenic effects	2.2E+02	
ENDRIN	1.1E+01	noncarcinogenic effects	1.1E+01	
ETHYLBENZENE	1.3E+03	noncarcinogenic effects	1.3E+03	
FLUORANTHENE	1.5E+03	noncarcinogenic effects	1.5E+03	
FLUORENE	2.4E+02	noncarcinogenic effects	2.4E+02	
HEPTACHLOR	1.5E-02	carcinogenic effects	1.8E+01	1.5E-02
HEPTACHLOR EPOXIDE	7.4E-03	carcinogenic effects	4.7E-01	7.4E-03
HEXACHLOROBENZENE	4.2E-02	carcinogenic effects	2.9E+01	4.2E-02
HEXACHLOROBUTADIENE	8.6E-01	carcinogenic effects	1.1E+01	8.6E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	5.2E-02	carcinogenic effects	1.1E+01	5.2E-02
HEXACHLOROETHANE	4.8E+00	carcinogenic effects	3.7E+01	4.8E+00
INDENO(1,2,3-cd)PYRENE	9.2E-02	carcinogenic effects		9.2E-02
LEAD	0.0E+00	carcinogenic effects		
MERCURY	5.8E+00	noncarcinogenic effects	5.8E+00	
METHOXYCHLOR	1.8E+02	noncarcinogenic effects	1.8E+02	
METHYL ETHYL KETONE	7.0E+03	noncarcinogenic effects	7.0E+03	
METHYL ISOBUTYL KETONE	2.0E+03	noncarcinogenic effects	2.0E+03	
METHYL MERCURY	3.7E+00	noncarcinogenic effects	3.7E+00	
METHYL TERT BUTYL ETHER	1.1E+01	carcinogenic effects	5.2E+03	1.1E+01
METHYLENE CHLORIDE	4.3E+00	carcinogenic effects	1.6E+03	4.3E+00
METHYLNAPHTHALENE (total 1- & 2-)	2.4E+02	noncarcinogenic effects	2.4E+02	
MOLYBDENUM	1.8E+02	noncarcinogenic effects	1.8E+02	
NAPHTHALENE	6.2E+00	noncarcinogenic effects	6.2E+00	
NICKEL	7.3E+02	noncarcinogenic effects	7.3E+02	
PENTACHLOROPHENOL	5.6E-01	carcinogenic effects	1.1E+03	5.6E-01
PERCHLORATE	3.7E+00	noncarcinogenic effects	3.7E+00	
PHENANTHRENE	2.4E+02	noncarcinogenic effects	2.4E+02	
PHENOL	1.1E+04	noncarcinogenic effects	1.1E+04	
POLYCHLORINATED BIPHENYLS (PCBs)	3.4E-02	carcinogenic effects	7.3E-01	3.4E-02
PYRENE	1.8E+02	noncarcinogenic effects	1.8E+02	
SELENIUM	1.8E+02	noncarcinogenic effects	1.8E+02	
SILVER	1.8E+02	noncarcinogenic effects	1.8E+02	
STYRENE	1.6E+03	noncarcinogenic effects	1.6E+03	
tert-BUTYL ALCOHOL	3.7E+00	carcinogenic effects		3.7E+00
TETRACHLOROETHANE, 1,1,1,2-	4.3E-01	carcinogenic effects	1.8E+02	4.3E-01
TETRACHLOROETHANE, 1,1,2,2-	5.6E-02	carcinogenic effects	3.7E+02	5.6E-02
TETRACHLOROETHYLENE	1.0E-01	carcinogenic effects	6.1E+01	1.0E-01
THALLIUM	2.4E+00	noncarcinogenic effects	2.4E+00	

**TABLE D-4. USEPA REGION IX
TAP WATER GOALS
(ug/l)**

CONTAMINANT	Lowest Tapwater Goal (ug/L)	Basis	Tap Water Goal (Noncarcinogenic Effects)	Tap Water Goal (Carcinogenic Effects)
TOLUENE	7.2E+02	noncarcinogenic effects	7.2E+02	
TOXAPHENE	5.6E-02	carcinogenic effects		5.6E-02
TPH (gasolines)	9.3E+01	noncarcinogenic effects	9.3E+01	
TPH (middle distillates)	9.3E+01	noncarcinogenic effects	9.3E+01	
TPH (residual fuels)	1.1E+03	noncarcinogenic effects	1.1E+03	
TRICHLOROBENZENE, 1,2,4-	7.2E+00	noncarcinogenic effects	7.2E+00	
TRICHLOROETHANE, 1,1,1-	3.2E+03	noncarcinogenic effects	3.2E+03	
TRICHLOROETHANE, 1,1,2-	2.0E-01	carcinogenic effects	2.4E+01	2.0E-01
TRICHLOROETHYLENE	2.8E-02	carcinogenic effects	9.5E+00	2.8E-02
TRICHLOROPHENOL, 2,4,5-	6.1E+02	noncarcinogenic effects	6.1E+02	
TRICHLOROPHENOL, 2,4,6-	3.7E+00	noncarcinogenic effects	3.7E+00	6.1E+00
VANADIUM	3.7E+01	noncarcinogenic effects	3.7E+01	
VINYL CHLORIDE	8.1E-02	carcinogenic effects	7.2E+01	8.1E-02
XYLENES	2.1E+02	noncarcinogenic effects	2.1E+02	
ZINC	1.1E+04	noncarcinogenic effects	1.1E+04	

References:

Calculated using Tap Water equations in USEPA Region IX Preliminary Remediation Goals document (USEPA 2002).

Notes:

Addresses use of water for drinking water and inhalation of volatile chemicals during showering.

Target risk = 10⁻⁶. Target HQ = 1.0. See Appendix 2 for equations.

TPH gasoline and middle distillates tapwater goals round to 100 ug/L. TPH residual fuels goal rounded to 1,000 ug/L.

TABLE E-1. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL <=200 cm/year

CONTAMINANT	Organic Carbon Coefficient (Koc) (cm ³ /g)	Henry's Law Constant (H) (atm·m ³ /mol)	Dilution/Attenuation Factor (DAF)	Saturation Limit (mg/kg)	Target Groundwater Concentrations				Soil Leaching Action Levels			
					Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
					Target Groundwater Concentration (Surface Water Within 150m; Table D-1a) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b) (ug/L)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d) (ug/L)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)
ACENAPHTHENE	4.90E+03	1.55E-04	8.14E+02	1.3E+02	2.0E+01	2.0E+01	2.3E+01	2.0E+02	1.6E+01	1.6E+01	1.9E+01	1.6E+02
ACENAPHTHYLENE	2.50E+03	1.45E-03	4.24E+02	5.9E+01	3.0E+01	2.4E+02	3.0E+01	3.0E+02	1.3E+01	1.0E+02	1.3E+01	1.3E+02
ACETONE	5.75E-01	3.88E-05	3.36E-01	1.0E+05	1.5E+03	1.5E+03	1.5E+03	1.5E+03	5.0E-01	5.0E-01	5.0E-01	5.0E-01
#ALDRIN	4.90E+04	4.96E-05	8.13E+03	5.0E+00	4.0E-03	4.0E-03	1.3E-01	1.3E+00	5.0E+00	5.0E+00	5.0E+00	1.1E+01
ANTHRACENE	2.35E+04	6.50E-05	3.90E+03	6.1E+00	7.3E-01	7.3E-01	7.3E-01	7.3E-01	2.8E+00	2.8E+00	2.8E+00	2.8E+00
ANTIMONY					6.0E+00	6.0E+00	3.0E+01	1.5E+03	(site-specific)	(site-specific)	(site-specific)	(site-specific)
ARSENIC					1.0E+01	1.0E+01	3.6E+01	6.9E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
BARIIUM					2.0E+03	2.0E+03	2.0E+03	2.0E+03	(site-specific)	(site-specific)	(site-specific)	(site-specific)
BENZENE	5.89E+01	5.55E-03	4.42E+01	8.7E+02	5.0E+00	5.0E+00	4.6E+01	1.6E+03	2.2E-01	2.2E-01	2.0E+00	7.0E+01
#BENZO(a)ANTHRACENE	2.00E+05	1.00E-06	3.32E+04	1.2E+01	2.7E-02	2.7E-02	2.7E-02	2.7E-02	1.2E+01	1.2E+01	1.2E+01	1.2E+01
#BENZO(a)PYRENE	5.50E+06	4.90E-07	9.13E+05	1.3E+02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.3E+02	1.3E+02	1.3E+02	1.3E+02
#BENZO(b)FLUORANTHENE	5.50E+05	1.22E-05	9.13E+04	4.6E+01	9.2E-02	9.2E-02	9.2E-02	9.2E-02	4.6E+01	4.6E+01	4.6E+01	4.6E+01
#BENZO(g,h,i)PERYLENE	1.60E+06	1.44E-07	2.66E+05	2.6E+00	1.0E-01	1.0E-01	1.3E-01	1.3E+00	2.7E+01	2.7E+01	2.7E+01	2.7E+01
#BENZO(k)FLUORANTHENE	5.50E+05	3.87E-05	9.13E+04	2.6E+00	4.0E-01	4.0E-01	4.0E-01	4.0E-01	3.7E+01	3.7E+01	3.7E+01	3.7E+01
BERYLLIUM					2.7E+00	4.0E+00	2.7E+00	4.3E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
BIPHENYL, 1,1-	7.76E+03	3.00E-04	1.29E+03	3.5E+02	5.0E-01	5.0E-01	5.0E+00	5.0E+00	6.5E-01	6.5E-01	6.5E+00	6.5E+00
BIS(2-CHLOROETHYL)ETHER	7.60E+01	1.80E-05	1.27E+01	9.6E+03	9.5E-03	9.5E-03	6.1E+01	1.0E+02	1.2E-04	1.2E-04	7.8E-01	1.3E+00
BIS(2-CHLOROISOPROPYL)ETHER	6.10E+01	1.13E-04	1.08E+01	7.9E+02	2.7E-01	2.7E-01	6.1E+01	3.2E+03	3.0E-03	3.0E-03	6.6E-01	3.6E+01
BIS(2-ETHYLHEXYL)PHTHALATE	1.00E+05	3.00E-07	1.66E+04	7.8E+02	6.0E+00	6.0E+00	3.2E+01	3.2E+01	7.8E+02	7.8E+02	7.8E+02	7.8E+02
BORON					1.6E+00	1.6E+00	1.6E+00	1.6E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
BROMODICHLOROMETHANE	5.50E+01	1.60E-03	1.91E+01	3.0E+03	1.8E-01	1.8E-01	2.7E+02	2.7E+02	3.4E-03	3.4E-03	5.1E+00	5.1E+00
BROMOFORM	1.10E+02	5.32E-04	2.16E+01	2.4E+03	1.0E+02	1.0E+02	3.2E+03	5.1E+03	2.2E+00	2.2E+00	6.9E+01	1.1E+02
BROMOMETHANE	9.00E+00	6.24E-03	4.02E+01	3.1E+03	8.5E+00	8.5E+00	1.6E+02	2.3E+03	3.4E-01	3.4E-01	6.4E+00	9.3E+01
CADMIUM					3.0E+00	3.0E+00	3.0E+00	3.0E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
CARBON TETRACHLORIDE	1.74E+02	3.04E-02	2.18E+02	1.1E+03	5.0E+00	5.0E+00	9.8E+00	2.1E+01	1.1E+00	1.1E+00	2.1E+00	4.5E+00
#CHLORDANE	4.40E+04	4.79E-05	7.30E+03	1.5E+01	4.0E-03	9.0E-02	4.0E-03	9.0E-02	1.5E+01	1.5E+01	1.5E+01	1.5E+01
CHLOROANILINE, p-	6.40E+01	3.31E-07	1.06E+01	1.3E+03	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.3E-02	5.3E-02	5.3E-02	5.3E-02
CHLOROBENZENE	2.19E+02	3.70E-03	5.93E+01	6.8E+02	2.5E+01	5.0E+01	2.5E+01	1.6E+02	1.5E+00	3.0E+00	1.5E+00	9.5E+00
CHLOROETHANE	1.47E+01	1.10E-02	7.07E+01	1.6E+03	3.9E+00	3.9E+00	3.9E+00	3.9E+00	2.7E-01	2.7E-01	2.7E-01	2.7E-01
CHLOROFORM	3.98E+01	3.67E-03	2.94E+01	2.9E+03	6.2E+01	6.2E+01	6.2E+01	6.2E+01	1.8E+00	1.8E+00	1.8E+00	1.8E+00
CHLOROMETHANE	3.50E+01	2.40E-02	1.55E+02	4.1E+03	1.6E+02	1.6E+02	3.2E+03	9.5E+03	2.4E+01	2.4E+01	5.0E+02	1.5E+03
CHLOROPHENOL, 2-	3.98E+02	3.91E-04	6.85E+01	5.5E+04	1.8E-01	1.8E-01	1.8E+00	1.8E+00	1.2E-02	1.2E-02	1.2E-01	1.2E-01
CHROMIUM (Total)					7.4E+01	7.4E+01	7.4E+01	7.4E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
CHROMIUM III					7.4E+01	5.7E+02	7.4E+01	5.7E+02	(site-specific)	(site-specific)	(site-specific)	(site-specific)
CHROMIUM VI					1.1E+01	1.6E+01	1.1E+01	1.6E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
#CHRYSENE	4.00E+05	9.46E-05	6.64E+04	3.8E+00	3.5E-01	3.5E-01	3.5E-01	3.5E-01	2.3E+01	2.3E+01	2.3E+01	2.3E+01
COBALT					3.0E+00	3.0E+00	3.0E+00	3.0E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
COPPER					2.9E+00	2.9E+00	2.9E+00	2.9E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
CYANIDE (Free)	9.20E+00	1.90E+03	1.18E+07	1.0E+06	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+04	1.2E+04	1.2E+04	1.2E+04
#DIBENZO(a,h)ANTHRACENE	3.30E+06	7.30E-08	5.48E+05	9.9E+00	9.2E-03	9.2E-03	2.5E-01	2.5E-01	9.9E+00	9.9E+00	1.4E+02	1.4E+02
DIBROMO-3-CHLOROPROPANE, 1,2-	1.30E+02	1.47E-04	2.25E+01	1.1E+03	4.0E-02	4.0E-02	4.0E-02	4.0E-02	9.0E-04	9.0E-04	9.0E-04	9.0E-04
DIBROMOCHLOROMETHANE	4.68E+02	8.50E-04	8.30E+01	1.3E+04	1.3E-01	1.3E-01	1.6E+02	1.6E+02	1.1E-02	1.1E-02	1.3E+01	1.3E+01
DIBROMOETHANE, 1,2-	4.40E+01	3.20E-04	9.29E+00	1.2E+03	5.6E-03	5.6E-03	1.6E+01	1.6E+01	5.2E-05	5.2E-05	1.5E-01	1.5E-01
DICHLOROBENZENE, 1,2-	6.17E+02	1.90E-03	1.14E+02	6.0E+02	1.0E+01	1.0E+01	1.4E+01	1.0E+02	1.1E+00	1.1E+00	1.6E+00	1.1E+01
DICHLOROBENZENE, 1,3-	6.17E+02	1.90E-03	1.14E+02	6.0E+02	6.5E+01	1.8E+02	6.5E+01	3.7E+02	7.4E+00	2.1E+01	7.4E+00	4.2E+01
DICHLOROBENZENE, 1,4-	6.17E+02	2.43E-03	1.18E+02	2.8E+02	5.0E+00	5.0E+00	1.5E+01	1.1E+02	5.9E-01	5.9E-01	1.8E+00	1.3E+01
DICHLOROBENZIDINE, 3,3-	1.60E+03	8.33E-07	2.66E+02	3.0E+01	1.5E-01	1.5E-01	2.5E+02	2.5E+02	4.0E-02	4.0E-02	6.6E+01	6.6E+01
#DICHLORODIPHENYLDICHLOROETHANE (DDD)	7.80E+05	7.96E-06	1.29E+05	7.5E+02	1.0E-03	2.8E-01	1.0E-03	6.0E-01	7.5E+02	7.5E+02	7.5E+02	7.5E+02
#DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	4.40E+06	6.80E-05	7.30E+05	1.1E+03	1.0E-03	2.8E-01	1.0E-03	1.4E+01	1.1E+03	1.1E+03	1.1E+03	1.0E+04
#DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.40E+05	3.89E-05	3.98E+04	4.3E+00	1.0E-03	1.3E-02	1.0E-03	1.3E-02	4.3E+00	4.3E+00	4.3E+00	4.3E+00
DICHLOROETHANE, 1,1-	3.16E+01	5.62E-03	4.01E+01	1.7E+03	4.7E+01	4.7E+01	4.7E+01	4.7E+01	1.9E+00	1.9E+00	1.9E+00	1.9E+00
DICHLOROETHANE, 1,2-	1.74E+01	9.79E-04	8.97E+00	1.8E+03	1.2E-01	1.2E-01	1.3E+02	1.3E+02	1.1E-03	1.1E-03	1.2E+00	1.2E+00
DICHLOROETHYLENE, 1,1-	5.89E+01	2.61E-02	1.72E+02	1.5E+03	7.0E+00	7.0E+00	2.5E+01	3.9E+03	1.2E+00	1.2E+00	4.3E+00	6.7E+02

TABLE E-1. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL <200 cm/year

CONTAMINANT	Organic Carbon Coefficient (Koc) (cm ³ /g)	Henry's Law Constant (H) (atm-m ³ /mol)	Dilution/Attenuation Factor (DAF)	Saturation Limit (mg/kg)	Target Groundwater Concentrations				Soil Leaching Action Levels			
					Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
					Target Groundwater Concentration (Surface Water Within 150m; Table D-1a) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b) (ug/L)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d) (ug/L)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)
DICHLOROETHYLENE, Cis 1,2-	3.55E+01	4.08E-03	3.12E+01	1.2E+03	7.0E+01	7.0E+01	5.9E+02	1.2E+04	2.2E+00	2.2E+00	1.8E+01	3.6E+02
DICHLOROETHYLENE, Trans 1,2-	5.25E+01	9.38E-03	6.69E+01	3.1E+03	1.0E+02	1.0E+02	5.9E+02	2.6E+03	6.7E+00	6.7E+00	3.9E+01	1.7E+02
DICHLOROPHENOL, 2,4-	6.00E+03	2.80E-06	9.96E+02	1.6E+05	3.0E-01	3.0E-01	3.0E+00	3.0E+00	3.0E-01	3.0E-01	3.0E+00	3.0E+00
DICHLOROPROPANE, 1,2-	4.37E+01	2.80E-03	2.46E+01	1.1E+03	5.0E+00	5.0E+00	1.0E+02	1.0E+02	1.2E+02	1.6E+02	4.6E-02	4.6E-02
DICHLOROPROPENE, 1,3-	4.57E+01	1.77E-02	1.17E+02	1.4E+03	4.0E-01	4.0E-01	1.2E+02	1.6E+02	4.6E-02	4.6E-02	1.4E+01	1.8E+01
DIELDRIN	7.40E+03	5.84E-05	1.23E+03	8.3E+00	1.9E-03	4.2E-03	1.9E-03	7.1E-01	2.3E-03	5.2E-03	2.3E-03	8.7E-01
DIETHYLPHTHALATE	1.40E+02	1.14E-06	2.32E+01	8.4E+02	1.5E+00	9.4E+02	1.5E+00	9.4E+02	3.5E-02	2.2E+01	3.5E-02	2.2E+01
DIMETHYLPHENOL, 2,4-	4.00E+01	2.00E-06	6.65E+00	2.7E+03	1.1E+02	2.7E+02	1.1E+02	2.7E+02	7.3E-01	1.8E+00	7.3E-01	1.8E+00
DIMETHYLPHTHALATE	1.40E+02	1.05E-07	2.32E+01	4.7E+03	1.5E+00	9.4E+02	1.5E+00	9.4E+02	3.5E-02	2.2E+01	3.5E-02	2.2E+01
DINITROPHENOL, 2,4-	1.70E+01	6.45E-10	2.82E+00	1.1E+03	7.3E+01	7.3E+01	7.3E+01	2.3E+02	2.1E-01	2.1E-01	2.1E-01	6.5E-01
DINITROTOLUENE, 2,4-	4.50E+01	4.50E-06	7.50E+00	1.0E+02	3.4E+01	3.4E+01	1.2E+02	2.0E+02	2.5E-01	2.5E-01	8.6E-01	1.5E+00
DIOXANE, 1,4-	3.50E+00	3.00E-06	6.00E-01	1.2E+05	6.1E+00	6.1E+00	5.0E+04	5.0E+04	3.7E-03	3.7E-03	3.0E+01	3.0E+01
DIOXIN (2,3,7,8-TCDD)	1.30E+07	8.10E-05	2.16E+06	1.0E+06	5.0E-06	3.0E-05	5.0E-06	3.0E-03	1.0E+06	1.0E+06	1.0E+06	1.0E+06
ENDOSULFAN	3.20E+03	1.00E-05	5.31E+02	2.9E+00	8.7E-03	3.4E-02	8.7E-03	3.4E-02	4.6E-03	1.8E-02	4.6E-03	1.8E-02
ENDRIN	1.70E+03	7.51E-06	2.82E+02	2.7E+00	2.3E-03	3.7E-02	2.3E-03	3.7E-02	6.5E-04	1.0E-02	6.5E-04	1.0E-02
ETHYLBENZENE	3.63E+02	7.88E-03	1.09E+02	4.0E+02	3.0E+01	3.0E+01	2.9E+02	3.0E+02	3.3E+00	3.3E+00	3.2E+01	3.3E+01
#FLUORANTHENE	3.80E+04	6.50E-06	6.31E+03	6.0E+01	8.0E+00	4.0E+01	8.0E+00	4.0E+01	6.0E+01	2.5E+02	6.0E+01	2.5E+02
FLUORENE	1.38E+04	7.70E-05	2.29E+03	1.6E+02	3.9E+00	2.4E+02	3.9E+00	3.0E+02	8.9E+00	5.6E+02	8.9E+00	6.9E+02
HEPTACHLOR	2.20E+04	1.48E-03	3.66E+03	7.4E+00	3.6E-03	5.3E-02	3.6E-03	5.3E-02	1.3E-02	1.9E-01	1.3E-02	1.9E-01
HEPTACHLOR EPOXIDE	2.30E+04	3.16E-05	3.82E+03	4.8E+01	3.6E-03	5.3E-02	3.6E-03	5.3E-02	1.4E-02	2.0E-01	1.4E-02	2.0E-01
#HEXACHLORO BENZENE	1.20E+06	1.70E-03	1.99E+05	7.9E+02	1.0E+00	1.0E+00	3.7E+00	6.0E+00	7.9E+02	7.9E+02	7.9E+02	1.2E+03
HEXACHLOROBUTADIENE	2.90E+04	2.56E-02	4.97E+03	3.5E+02	8.6E-01	8.6E-01	4.7E+00	1.1E+01	4.3E+00	4.3E+00	2.3E+01	5.5E+01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	3.70E+03	4.93E-07	6.14E+02	1.6E+02	8.0E-02	1.6E-01	8.0E-02	1.6E-01	4.9E-02	9.8E-02	4.9E-02	9.8E-02
HEXACHLOROETHANE	2.00E+04	9.85E-03	3.38E+03	6.0E+03	4.8E+00	4.8E+00	1.2E+01	1.0E+02	1.6E+01	1.6E+01	4.1E+01	3.4E+02
#INDENO(1,2,3-cd)PYRENE	1.60E+06	6.95E-08	2.66E+05	5.1E+00	9.2E-02	9.2E-02	9.2E-02	9.2E-02	2.4E+01	2.4E+01	2.4E+01	2.4E+01
LEAD					5.6E+00	1.6E+01	5.6E+00	2.9E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
MERCURY					2.5E-02	2.0E+00	2.5E-02	2.1E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
#METHOXYCHLOR	7.90E+04	1.58E-05	1.31E+04	1.9E+01	3.0E-02	3.0E-02	3.0E-02	3.0E-02	1.9E+01	1.9E+01	1.9E+01	1.9E+01
METHYL ETHYL KETONE	4.50E+00	2.74E-05	9.17E-01	3.4E+04	7.0E+03	7.0E+03	1.4E+04	1.4E+04	6.4E+00	6.4E+00	1.3E+01	1.3E+01
METHYL ISOBUTYL KETONE	1.34E+02	1.40E-04	2.31E+01	1.7E+04	1.7E+02	1.7E+02	1.7E+02	1.7E+02	3.9E+00	3.9E+00	3.9E+00	3.9E+00
METHYL MERCURY					3.0E-03	3.0E-03	3.0E-03	3.0E-03	(site-specific)	(site-specific)	(site-specific)	(site-specific)
METHYL TERT BUTYL ETHER	6.00E+00	5.87E-04	4.64E+00	2.1E+04	5.0E+00	5.0E+00	1.8E+03	1.8E+03	2.3E-02	2.3E-02	8.4E+00	8.4E+00
METHYLENE CHLORIDE	1.11E+01	2.19E-03	1.54E+01	2.4E+03	4.3E+00	4.3E+00	2.2E+03	4.2E+03	6.7E-02	6.7E-02	3.4E+01	6.5E+01
METHYLNAPHTHALENE (total 1- & 2-)	7.20E+02	2.90E-04	1.21E+02	1.1E+02	2.1E+00	1.0E+01	2.1E+00	1.0E+02	2.5E-01	1.2E+00	2.5E-01	1.2E+01
MOLYBDENUM					1.8E+02	1.8E+02	2.4E+02	2.4E+02	(site-specific)	(site-specific)	(site-specific)	(site-specific)
NAPHTHALENE	1.19E+03	4.83E-04	2.01E+02	2.2E+02	6.2E+00	6.2E+00	2.4E+01	2.1E+02	1.2E+00	1.2E+00	4.8E+00	4.2E+01
NICKEL					5.0E+00	5.0E+00	5.0E+00	5.0E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
PENTACHLOROPHENOL	3.20E+04	2.80E-06	5.31E+03	1.0E+06	1.0E+00	1.0E+00	7.9E+00	1.3E+01	1.0E+06	1.0E+06	1.0E+06	1.0E+06
PERCHLORATE					3.7E+00	3.7E+00	6.0E+02	6.0E+02	7.0E-03	7.0E-03	1.2E+00	1.2E+00
PHENANTHRENE	1.40E+04	3.93E-05	2.32E+03	6.9E+01	4.6E+00	7.7E+00	4.6E+00	7.7E+00	1.1E+01	1.8E+01	1.1E+01	1.8E+01
PHENOL	9.10E+01	1.30E-06	1.51E+01	5.2E+04	5.0E+00	5.0E+00	1.3E+03	3.4E+03	7.6E-02	7.6E-02	1.9E+01	5.1E+01
#POLYCHLORINATED BIPHENYLS (PCBs)	3.30E+04	5.20E-04	5.48E+03	6.3E+00	1.4E-02	5.0E-01	1.4E-02	5.0E-01	6.3E+00	6.3E+00	6.3E+00	1.1E+01
#PYRENE	1.05E+05	1.10E-05	1.74E+04	8.5E+01	2.0E+00	2.0E+00	2.0E+00	2.0E+00	8.5E+01	8.5E+01	8.5E+01	8.5E+01
SELENIUM					5.0E+00	2.0E+01	5.0E+00	2.0E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
SILVER					1.0E+00	1.0E+00	1.0E+00	1.0E+00	(site-specific)	(site-specific)	(site-specific)	(site-specific)
STYRENE	7.76E+02	2.75E-03	1.46E+02	1.5E+03	1.0E+01	1.0E+01	1.0E+02	1.0E+02	1.5E+00	1.5E+00	1.5E+01	1.5E+01
tert-BUTYL ALCOHOL	3.70E+01	1.17E-05	6.21E+00	3.2E+05	3.7E+00	3.7E+00	1.8E+04	5.0E+04	2.3E-02	2.3E-02	1.1E+02	3.1E+02
TETRACHLOROETHANE, 1,1,1,2-	9.37E+01	3.45E-04	1.77E+01	2.0E+03	4.3E-01	4.3E-01	3.1E+02	3.1E+03	7.6E-03	7.6E-03	5.5E+00	5.5E+01
TETRACHLOROETHANE, 1,1,2,2-	9.37E+01	3.45E-04	1.77E+01	2.0E+03	5.6E-02	5.6E-02	1.5E+02	1.5E+02	9.9E-04	9.9E-04	2.7E+00	2.7E+00
TETRACHLOROETHYLENE	1.55E+02	1.84E-02	1.40E+02	2.3E+02	5.0E+00	5.0E+00	9.9E+01	9.9E+01	7.0E-01	7.0E-01	1.4E+01	1.4E+01
THALLIUM					2.0E+00	2.0E+00	2.0E+01	4.7E+02	(site-specific)	(site-specific)	(site-specific)	(site-specific)
TOLUENE	1.82E+02	6.64E-03	7.14E+01	6.5E+02	4.0E+01	4.0E+01	1.3E+02	4.0E+02	2.9E+00	2.9E+00	9.3E+00	2.9E+01

TABLE E-1. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL \leq 200 cm/year

CONTAMINANT	Organic Carbon Coefficient (Koc) (cm ³ /g)	Henry's Law Constant (H) (atm·m ³ /mol)	Dilution/Attenuation Factor (DAF)	Saturation Limit (mg/kg)	Target Groundwater Concentrations				Soil Leaching Action Levels			
					Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
					Target Groundwater Concentration (Surface Water Within 150m; Table D-1a) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b) (ug/L)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c) (ug/L)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d) (ug/L)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water Within 150m) (mg/kg)	Soil Leaching Action Level (Surface Water NOT Within 150m) (mg/kg)
TOXAPHENE	4.90E+03	2.10E-01	2.12E+03	9.3E+01	2.0E-04	2.1E-01	2.0E-04	2.1E-01	4.2E-04	4.4E-01	4.2E-04	4.4E-01
TPH (gasolines)	5.00E+03	7.20E-04	8.34E+02	4.5E+03	1.0E+02	1.0E+02	5.0E+02	5.0E+03	8.3E+01	8.3E+01	4.2E+02	4.2E+03
TPH (middle distillates)	5.00E+03	7.20E-04	8.34E+02	1.5E+02	1.0E+02	1.0E+02	6.4E+02	2.5E+03	8.3E+01	8.3E+01	5.3E+02	2.1E+03
TPH (residual fuels)					1.0E+02	1.0E+02	6.4E+02	2.5E+03	(site-specific)	(site-specific)	(site-specific)	(site-specific)
TRICHLOROBENZENE, 1,2,4-	1.78E+03	1.42E-03	3.04E+02	3.2E+03	2.5E+01	7.0E+01	2.5E+01	1.6E+02	7.6E+00	2.1E+01	7.6E+00	4.9E+01
TRICHLOROETHANE, 1,1,1-	1.10E+02	1.72E-02	1.25E+02	1.2E+03	6.2E+01	2.0E+02	6.2E+01	6.0E+03	7.8E+00	2.5E+01	7.8E+00	7.5E+02
TRICHLOROETHANE, 1,1,2-	5.01E+01	9.13E-04	1.40E+01	1.8E+03	5.0E+00	5.0E+00	2.8E+02	2.8E+02	7.0E-02	7.0E-02	3.9E+00	3.9E+00
TRICHLOROETHYLENE	1.66E+02	1.03E-02	9.15E+01	1.3E+03	5.0E+00	5.0E+00	7.4E+01	7.4E+01	4.6E-01	4.6E-01	6.8E+00	6.8E+00
TRICHLOROPHENOL, 2,4,5-	8.90E+01	2.18E-04	1.61E+01	7.6E+02	1.1E+01	1.0E+02	1.1E+01	1.0E+02	1.8E-01	1.6E+00	1.8E-01	1.6E+00
TRICHLOROPHENOL, 2,4,6-	2.00E+03	4.00E-06	3.32E+02	9.7E+03	3.7E+00	3.7E+00	4.9E+02	4.9E+02	1.2E+00	1.2E+00	1.6E+02	1.6E+02
VANADIUM					1.9E+01	1.9E+01	1.9E+01	1.9E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)
VINYL CHLORIDE	1.86E+01	2.70E-02	1.71E+02	1.2E+03	2.0E+00	2.0E+00	2.2E+01	2.2E+01	3.4E-01	3.4E-01	3.8E+00	3.8E+00
XYLENES	4.07E+02	7.34E-03	1.13E+02	4.2E+02	2.0E+01	2.0E+01	1.0E+02	2.0E+03	2.3E+00	2.3E+00	1.1E+01	2.3E+02
ZINC					2.2E+01	2.2E+01	2.2E+01	2.2E+01	(site-specific)	(site-specific)	(site-specific)	(site-specific)

Notes:

Soil leaching equation from Ontario MOEE guidance (see text).
 #. Leaching model used considered to be excessively conservative for highly sorptive chemicals. For chemicals with koc values greater than 30,000 cm³/g, theoretical soil saturation level ("sat") used in place of leaching model screening level if higher (see text). Soil saturation levels calculated using equation presented in USEPA Region IX PRG guidance (USEPA 2002, see Appendix 2). Exceptions include bis(2-ethylhexyl)phthalate and pentachlorophenol (see text).
 TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. TPH action levels presented in 1996 HIDOH RBCA document used in final lookup tables (refer to Tables A-1 through B-2 and Section 5.3 in text).
 Use of above model-generated TPH action levels (or approved alternatives) may be required in highly sensitive areas. Refer to Section 2.2.2 in Volume 1 text.
 Physio-Chemical constants for chemicals from USEPA Region IX (USEPA 2002) or Ontario MOEE (MOEE 1996) when not available.
 Physio-Chemical constants for TPH (gasolines and middle distillates) based on constants developed for C11 to C22 aromatic carbon range fraction by Massachusetts DEP and used to develop action levels for leaching of TPH in general from soil (MADEP 1997).
 Soil Action Levels for TPH rounded to nearest 100 mg/kg (gasolines, middle distillates) or 1,000 mg/kg (residual fuels).
 TPH (residual fuels) soil action level for leaching from California Regional Water Board, Region 4 - drinking water protection, C23-C32 carbon range (RWQCBLA 1996).
 TPH action levels for sites that do not threaten drinking water resources and are not within 150m of a surface water body adjusted to reflect action levels presented in 1996 HIDOH RBCA document. Used as default soil action levels for leaching concerns in final tables (see Tables A-1 through B-2 and Section 5.3 in text).
 Action levels for perchlorate calculated using leaching equation in USEPA Soil Screening Guidance and assumed Dilution/Attenuation Factor of 20 (see text).

TABLE E-2. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL >200cm/year

CONTAMINANT	Adjusted 1996 HIDOH RBCA Action Levels For High Rainfall Areas										
	1996 HIDOH RBCA (Rainfall >200 cm/yr)			Target Groundwater Concentrations				Soil Leaching Action Levels			
	Groundwater IS a Drinking Water Source	Soil Leaching Action Level	GAL:SAL ratio	Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
				Target Groundwater Concentration (Surface Water Within 150m; Table D-1a)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)
(ug/L)	(mg/kg)		(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
ACENAPHTHENE											
ACENAPHTHYLENE											
ACETONE	6.1E+02	6.00E-02	1.0E+04	1.5E+03	1.5E+03	1.5E+03	1.5E+03	1.5E-01	1.5E-01	1.5E-01	1.5E-01
#ALDRIN											
ANTHRACENE											
ANTIMONY											
ARSENIC											
BARIUM											
BENZENE	5.0E+00	2.00E-03	2.5E+03	5.0E+00	5.0E+00	4.6E+01	1.6E+03	2.0E-03	2.0E-03	1.8E-02	6.4E-01
#BENZO(a)ANTHRACENE											
#BENZO(a)PYRENE											
#BENZO(b)FLUORANTHENE											
#BENZO(g,h,i)PERYLENE											
#BENZO(k)FLUORANTHENE											
BERYLLIUM											
BIPHENYL, 1,1-											
BIS(2-CHLOROETHYL)ETHER											
BIS(2-CHLOROISOPROPYL)ETHER											
BIS(2-ETHYLHEXYL)PHTHALATE											
BORON											
BROMODICHLOROMETHANE											
BROMOFORM											
BROMOMETHANE											
CADMIUM											
CARBON TETRACHLORIDE	5.0E+00	2.40E-02	2.1E+02	5.0E+00	5.0E+00	9.8E+00	2.1E+01	2.4E-02	2.4E-02	4.7E-02	1.0E-01
#CHLORDANE											
CHLOROANILINE, p-											
CHLOROBENZENE	1.0E+02	5.00E-02	2.0E+03	2.5E+01	5.0E+01	2.5E+01	1.6E+02	1.3E-02	2.5E-02	1.3E-02	8.0E-02
CHLOROETHANE											
CHLOROFORM	1.6E-01	1.00E-04	1.6E+03	6.2E+01	6.2E+01	6.2E+01	6.2E+01	3.9E-02	3.9E-02	3.9E-02	3.9E-02
CHLOROMETHANE											
CHLOROPHENOL, 2-											
CHROMIUM (Total)											
CHROMIUM III											
CHROMIUM VI											
#CHRYSENE											
COBALT											
COPPER											
CYANIDE (Free)											
#DIBENZO(a,h)ANTHTRACENE											
1,2-DIBROMO-3-CHLOROPROPANE											
DIBROMOCHLOROMETHANE											
DIBROMOETHANE, 1,2-											
DICHLOROBENZENE, 1,2-											
DICHLOROBENZENE, 1,3-											
DICHLOROBENZENE, 1,4-											
DICHLOROBENZIDINE, 3,3-											

TABLE E-2. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL >200cm/year

CONTAMINANT	Adjusted 1996 HDOH RBCA Action Levels For High Rainfall Areas										
	1996 HDOH RBCA (Rainfall >200 cm/yr)			Target Groundwater Concentrations				Soil Leaching Action Levels			
	Groundwater IS a Drinking Water Source	Soil Leaching Action Level	GAL:SAL ratio	Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
				Target Groundwater Concentration (Surface Water Within 150m; Table D-1a)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)
(ug/L)	(mg/kg)		(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
#DICHLORODIPHENYLDICHLOROETHANE (DDD)											
#DICHLORODIPHENYLDICHLOROETHYLENE (DDE)											
#DICHLORODIPHENYLTRICHLOROETHANE (DDT)											
DICHLOROETHANE, 1,1-											
DICHLOROETHANE, 1,2-											
DICHLOROETHYLENE, 1,1-											
DICHLOROETHYLENE, Cis 1,2-											
DICHLOROETHYLENE, Trans 1,2-											
DICHLOROPHENOL, 2,4-											
DICHLOROPROPANE, 1,2-											
DICHLOROPROPENE, 1,3-											
DIELDRIN											
DIETHYLPHTHALATE											
DIMETHYLPHENOL, 2,4-											
DIMETHYLPHTHALATE											
DINITROPHENOL, 2,4-											
DINITROTOLUENE, 2,4-											
1,4 DIOXANE											
DIOXIN (2,3,7,8-TCDD)											
ENDOSULFAN											
ENDRIN											
ETHYLBENZENE	1.4E+02	1.30E-01	1.1E+03	3.0E+01	3.0E+01	2.9E+02	3.0E+02	2.8E-02	2.8E-02	2.7E-01	2.8E-01
#FLUORANTHENE											
FLUORENE											
HEPTACHLOR											
HEPTACHLOR EPOXIDE											
#HEXACHLOROBENZENE											
HEXACHLOROBUTADIENE											
HEXACHLOROXYCLOHEXANE (gamma) LINDANE											
HEXACHLOROETHANE											
#INDENO(1,2,3-cd)PYRENE											
LEAD											
MERCURY											
#METHOXYCHLOR											
METHYL ETHYL KETONE											
METHYL ISOBUTYL KETONE											
METHYL MERCURY											
METHYL TERT BUTYL ETHER											
METHYLENE CHLORIDE	4.3E+00	2.40E-03	1.8E+03	7.0E+03	7.0E+03	1.4E+04	1.4E+04	3.9E+00	3.9E+00	7.8E+00	7.8E+00
METHYLNAPHTHALENE (total 1- & 2-)											
MOLYBDENUM											
NAPHTHALENE											
NICKEL											
PENTACHLOROPHENOL											
PERCHLORATE											
PHENANTHRENE											

TABLE E-2. SOIL ACTION LEVELS FOR LEACHING CONCERNS - RAINFALL >200cm/year

CONTAMINANT	Adjusted 1996 HIDOH RBCA Action Levels For High Rainfall Areas										
	1996 HIDOH RBCA (Rainfall >200 cm/yr)			Target Groundwater Concentrations				Soil Leaching Action Levels			
	Groundwater IS a Drinking Water Source	Soil Leaching Action Level	GAL: SAL	Drinking Water IS Threatened		Drinking Water NOT Threatened		Drinking Water IS Threatened		Drinking Water NOT Threatened	
				Target Groundwater Concentration (Surface Water Within 150m; Table D-1a)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1b)	Target Groundwater Concentration (Surface Water Within 150m; Table D-1c)	Target Groundwater Concentration (Surface Water NOT Within 150m; Table D-1d)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)	Soil Leaching Action Level (Surface Water Within 150m)	Soil Leaching Action Level (Surface Water NOT Within 150m)
(ug/L)	(mg/kg)	ratio	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
PHENOL											
#POLYCHLORINATED BIPHENYLS (PCBs)											
#PYRENE											
SELENIUM											
SILVER											
STYRENE											
tert-BUTYL ALCOHOL											
TETRACHLOROETHANE, 1,1,1,2-											
TETRACHLOROETHANE, 1,1,2,2-											
TETRACHLOROETHYLENE	5.0E+00	4.00E-02	1.3E+02	5.0E+00	5.0E+00	9.9E+01	9.9E+01	4.0E-02	4.0E-02	7.9E-01	7.9E-01
THALLIUM											
TOLUENE	1.0E+03	2.60E+00	3.8E+02	4.0E+01	4.0E+01	1.3E+02	4.0E+02	1.0E-01	1.0E-01	3.4E-01	1.0E+00
TOXAPHENE											
TPH (gasolines)											
TPH (middle distillates)											
TPH (residual fuels)											
TRICHLOROBENZENE, 1,2,4-											
TRICHLOROETHANE, 1,1,1-	2.0E+02	6.00E-02	6.0E+03	6.2E+01	2.0E+02	6.2E+01	6.0E+03	1.0E-02	3.3E-02	1.0E-02	1.0E+00
TRICHLOROETHANE, 1,1,2-											
TRICHLOROETHYLENE	5.0E+00	4.00E-03	7.0E+02	5.0E+00	5.0E+00	7.4E+01	7.4E+01	7.1E-03	7.1E-03	1.1E-01	1.1E-01
TRICHLOROPHENOL, 2,4,5-											
TRICHLOROPHENOL, 2,4,6-											
VANADIUM											
VINYL CHLORIDE											
XYLENES	1.0E+04	8.10E+00	1.0E+04	2.0E+01	2.0E+01	1.0E+02	2.0E+03	2.0E-03	2.0E-03	1.0E-02	2.0E-01
ZINC											

Notes:
 1996 HIDOH groundwater target concentrations and correlative soil leaching action levels in high rainfall areas from Table 1c in Appendix F of 1996 document.
 Adjusted soil leaching levels = Target Groundwater Concentration/1996 GAL: SAL ratio.
 Soil leaching action levels only generated for relatively mobile contaminants modeled in 1996 HIDOH RBCA document

**TABLE F-1. CRITERIA FOR ASSIGNMENT
OF SOIL GROSS CONTAMINATION CEILING LEVELS**

Soil Category	Criteria	Ceiling Level (mg/kg)
Surface Soils		
Residential/Parkland/Agricultural	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	100
	$0.1 \leq$ Odor Index $<$ 100 OR no Odor Index and Vapor Pressure $<$ 1 Torr	500
	Odor Index $<$ 0.1 OR non-odorous chemical	1000
Industrial/Commercial	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	500
	$0.1 \leq$ Odor Index $<$ 100 OR no Odor Index and Vapor Pressure $<$ 1 Torr	1000
	Odor Index $<$ 0.1 OR non-odorous chemical	2500
Subsurface Soils		
Residential/Parkland/Agricultural	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	500
	$0.1 \leq$ Odor Index $<$ 100 OR no Odor Index and Vapor Pressure $<$ 1 Torr	1000
	Odor Index $<$ 0.1 OR non-odorous chemical	2500
Industrial/Commercial	Odor Index \geq 100 OR no Odor Index and Vapor Pressure \geq 1 Torr OR no data	1000
	$0.1 \leq$ Odor Index $<$ 100 OR no Odor Index and Vapor Pressure $<$ 1 Torr	2500
	Odor Index $<$ 0.1 OR non-odorous chemical	5000
Modified from Ontario Ministry of Environment and Energy (MOEE 1996) and Massachusetts Department of Environmental Protection (MADEP 1994).		

**TABLE F-2. COMPONENTS FOR SHALLOW SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
ACENAPHTHENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	4.5E-03	5.13E+02	8.00E-02	5.63E-02
ACENAPHTHYLENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.9E-02	-	-	-
ACETONE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.0E+05	2.70E+02	3.09E+04	1.30E+01	2.08E+01
ALDRIN	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.3E-05	2.63E+02	1.70E-02	1.35E-03
ANTHRACENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.7E-05	-	-	-
ANTIMONY	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
ARSENIC	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
BARIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
BENZENE	5.0E+02	8.7E+02	5.0E+02	1.0E+03	8.7E+02	9.50E+01	4.89E+03	1.50E+00	6.33E+01
BENZO(a)ANTHRACENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.2E-08	-	-	-
BENZO(a)PYRENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.6E-09	-	-	-
BENZO(b)FLUORANTHENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.0E-07	-	-	-
BENZO(g,h,i)PERYLENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.1E-10	-	-	-
BENZO(k)FLUORANTHENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	9.6E-11	-	-	-
BERYLLIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
BIPHENYL, 1,1-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.00E-03	6.00E+01	9.50E-03	5.26E-01
BIS(2-CHLOROETHYL)ETHER	5.0E+02	1.0E+03	5.0E+02	1.0E+03	9.6E+03	7.1E-01	2.87E+02	4.9E-02	1.45E+01
BIS(2-CHLOROISOPROPYL)ETHER	5.0E+02	7.9E+02	5.0E+02	1.0E+03	7.9E+02	8.5E-01	2.24E+03	3.20E-01	2.66E+00
BIS(2-ETHYLHEXYL)PHTHALATE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	6.2E-08	-	-	-
BORON	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	-	-	-	-
BROMODICHLOROMETHANE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	3.0E+03	5.00E+01	1.10E+07	1.68E+03	2.98E-02
BROMOFORM	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.60E+00	1.35E+04	1.30E+00	4.31E+00
BROMOMETHANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	3.1E+03	1.42E+03	8.00E+04	2.00E+01	7.10E+01
CADMIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
CARBON TETRACHLORIDE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.1E+03	1.13E+02	6.30E+04	1.00E+01	1.13E+01
CHLORDANE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.0E-05	8.40E+00	4.92E-04	2.03E-02
CHLOROANILINE, p-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.0E-05	-	-	-
CHLOROBENZENE	5.0E+02	6.8E+02	5.0E+02	1.0E+03	6.8E+02	1.18E+01	1.00E+03	2.20E-01	5.36E+01
CHLOROETHANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.6E+03	1.01E+03	3.80E+05	1.40E+02	7.20E+00
CHLOROFORM	5.0E+02	1.0E+03	5.0E+02	1.0E+03	2.9E+03	1.60E+02	4.22E+05	8.50E+01	1.88E+00
CHLOROMETHANE	1.0E+02	5.0E+02	1.0E+02	5.0E+02	4.1E+03	4.30E+03	-	-	-
CHLOROPHENOL, 2-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	5.5E+04	1.42E+00	1.90E+01	3.60E-03	3.94E+02
CHROMIUM (Total)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
CHROMIUM III	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
CHROMIUM VI	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
CHRYSENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.3E-07	-	-	-
COBALT	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
COPPER	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
CYANIDE (Free)	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	6.20E+02	6.52E+02	5.80E-01	1.07E+03
DIBENZO(a,h)ANTHTRACENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.0E-10	-	-	-

**TABLE F-2. COMPONENTS FOR SHALLOW SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
DIBROMO-3-CHLOROPROPANE, 1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	8.00E-01	-	-	-
DIBROMOCHLOROMETHANE	1.0E+02	5.0E+02	1.0E+02	5.0E+02	1.1E+03	7.60E+01	-	-	-
DIBROMOETHANE, 1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.20E+01	2.00E+05	2.60E+01	4.62E-01
DICHLOROBENZENE, 1,2-	6.0E+02	6.0E+02	1.0E+03	2.5E+03	6.0E+02	1.50E+00	3.05E+05	5.00E+01	3.00E-02
DICHLOROBENZENE, 1,3-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	6.0E+02	2.30E+00	-	-	-
DICHLOROBENZENE, 1,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.80E+00	1.10E+03	1.80E-01	1.00E+01
DICHLOROBENZIDINE, 3,3-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	4.5E-09	-	-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.0E-06	-	-	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	6.5E-06	-	-	-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.5E-06	-	-	-
DICHLOROETHANE, 1,1-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.7E+03	2.34E+02	1.25E+05	3.00E+01	7.80E+00
DICHLOROETHANE, 1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.8E+03	7.90E+01	2.42E+03	5.90E-01	1.34E+02
DICHLOROETHYLENE, 1,1-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.5E+03	5.91E+02	2.00E+06	5.00E+02	1.18E+00
DICHLOROETHYLENE, Cis 1,2-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	1.2E+03	2.15E+02	-	-	-
DICHLOROETHYLENE, Trans 1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	3.1E+03	3.31E+02	6.73E+04	1.70E+01	1.95E+01
DICHLOROPHENOL, 2,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	6.7E-02	1.40E+03	2.10E-01	3.19E-01
DICHLOROPROPANE, 1,2-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	1.1E+03	4.20E+01	1.19E+03	2.50E-01	1.68E+02
DICHLOROPROPENE, 1,3-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.4E+03	4.30E+01	4.16E+03	1.00E+00	4.30E+01
DIELDRIN	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.8E-08	-	-	-
DIETHYLPHTHALATE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	3.5E-04	-	-	-
DIMETHYLPHENOL, 2,4-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	9.8E-02	1.00E+00	1.97E-04	4.97E+02
DIMETHYLPHTHALATE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.7E-03	-	-	-
DINITROPHENOL, 2,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.5E-05	-	-	-
DINITROTOLUENE, 2,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.1E-03	-	-	-
DIOXANE, 1,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	3.70E+01	6.12E+05	1.70E+02	2.18E-01
DIOXIN (2,3,7,8-TCDD)	NA	NA	no criteria	no criteria	NA	-	-	-	-
ENDOSULFAN	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.0E-05	-	-	-
ENDRIN	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.0E-07	-	-	-
ETHYLBENZENE	4.0E+02	4.0E+02	5.0E+02	1.0E+03	4.0E+02	1.00E+01	2.00E+03	4.50E-01	2.22E+01
FLUORANTHENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	5.0E-06	-	-	-
FLUORENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	3.2E-04	-	-	-
HEPTACHLOR	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	3.0E-04	3.00E+02	2.00E-02	1.50E-02
HEPTACHLOR EPOXIDE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.6E-06	3.00E+02	1.90E-02	1.37E-04
HEXACHLOROBENZENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.1E-05	-	-	-
HEXACHLOROBUTADIENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.50E-01	1.20E+04	1.10E+00	1.36E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	9.4E-06	-	-	-
HEXACHLOROETHANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.1E-01	-	-	-
INDENO(1,2,3-cd)PYRENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.0E-06	-	-	-
LEAD	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
MERCURY	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.0E-03	-	-	-

**TABLE F-2. COMPONENTS FOR SHALLOW SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
METHOXYCHLOR	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.4E-06	-	-	-
METHYL ETHYL KETONE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.7E+04	1.00E+02	3.20E+04	1.10E+01	9.09E+00
METHYL ISOBUTYL KETONE	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	1.00E+01	4.20E+02	1.00E-01	1.00E+02
METHYL MERCURY	1.0E+02	5.0E+02	1.0E+02	5.0E+02	2.1E+04	-	-	-	-
METHYL TERT BUTYL ETHER	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	2.45E+02	5.30E+02	1.30E-01	1.88E+03
METHYLENE CHLORIDE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	3.4E+04	4.29E+02	5.60E+05	1.60E+02	2.68E+00
METHYLNAPHTHALENE (total 1- & 2-)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	2.4E+03	6.8E-02	6.80E+01	1.15E-02	5.91E+00
MOLYBDENUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
NAPHTHALENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	8.2E-02	4.40E+02	8.40E-02	9.76E-01
NICKEL	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
PENTACHLOROPHENOL	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.1E-04	-	-	-
PERCHLORATE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
PHENANTHRENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	9.6E-04	5.50E+01	7.42E-03	1.29E-01
PHENOL	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	3.50E-01	1.56E+02	4.00E-02	8.75E+00
POLYCHLORINATED BIPHENYLS (PCBs)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	4.9E-04 to 6.7E-03	-	-	-
PYRENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.5E-06	-	-	-
SELENIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
SILVER	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
STYRENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.5E+03	5.00E+00	1.36E+03	3.00E-01	1.67E+01
tert-BUTYL ALCOHOL	1.0E+02	5.0E+02	1.0E+02	5.0E+02	3.2E+05	4.20E+01	-	-	-
TETRACHLOROETHANE, 1,1,1,2-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	2.0E+03	1.20E+01	-	-	-
TETRACHLOROETHANE, 1,1,2,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	2.0E+03	4.00E+00	1.05E+04	1.50E+00	2.67E+00
TETRACHLOROETHYLENE	2.3E+02	2.3E+02	5.0E+02	1.0E+03	2.3E+02	1.90E+01	3.17E+04	4.68E+00	4.06E+00
THALLIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-
TOLUENE	5.0E+02	6.5E+02	5.0E+02	1.0E+03	6.5E+02	2.80E+01	3.00E+04	8.00E+00	3.50E+00
TOXAPHENE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	4.00E-01	-	-	-
TPH (gasolines)	1.0E+02	5.0E+02	1.0E+02	5.0E+02	-	3.00E+02	1.00E+02	2.22E-02	1.35E+04
TPH (middle distillates)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	-	5.00E+00	1.00E+03	1.41E-01	3.55E+01
TPH (residual fuels)	5.0E+02	2.5E+03	5.0E+02	2.5E+03	-	-	-	-	-
TRICHLOROETHANE, 1,2,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	2.9E-01	2.20E+04	2.96E+00	9.80E-02
TRICHLOROETHANE, 1,1,1-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.2E+03	1.00E+02	6.51E+04	1.20E+01	8.33E+00
TRICHLOROETHANE, 1,1,2-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	1.8E+03	2.25E+01	-	-	-
TRICHLOROETHYLENE	5.0E+02	1.3E+03	5.0E+02	2.5E+03	1.3E+03	7.70E+01	1.36E+06	2.49E+02	3.09E-01
TRICHLOROPHENOL, 2,4,5-	1.0E+02	5.0E+02	1.0E+02	5.0E+02	NA	-	-	-	-
TRICHLOROPHENOL, 2,4,6-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	1.2E-02	3.00E-01	3.60E-05	3.33E+02
VANADIUM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-

**TABLE F-2. COMPONENTS FOR SHALLOW SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
VINYL CHLORIDE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.2E+03	2.58E+03	7.71E+05	2.94E+02	8.78E+00
XYLENES	4.2E+02	4.2E+02	5.0E+02	1.0E+03	4.2E+02	6.00E+00	4.41E+02	1.00E-01	6.00E+01
ZINC	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	-	-	-	-

Notes:
 1. "Residential Land Use" screening levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

Odor Index = VP/ORT in ppm-v

Physio-chemical constants Ontario MOEE (MOEE 1996) except as noted.

Physio-chemical constants for chloroethane and chloromethane from ATSDR Toxicological Profiles (ATSDR 2001).

Odor Recognition Threshold in parts per million - volume (ppm-v = (concentration in mg/m³) x (24/molecular weight)).

TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.

Ceiling Level: Based on comparison of vapor pressure and odor index to Table F-1 or saturation limit, if lower.

Saturation limits calculated using equation in USEPA Region IX PRG guidance (for chemicals that are liquid at ambient temperatures and pressures; refer to Appendix 2).

50% ORT of 0.13 ppm-v for MTBE from information in CaEPA Public Health Goal for MTBE (CaEPA 1999).

TPH VP values from NIOSH (2002); ORT values from ATSDR (2001a).

References for vapor pressure and odor threshold data (in order of use):

1. Ontario Ministry of Environment and Energy (MOEE 1996).
2. Massachusetts Department of Environmental Protection (MADEP 1994).
3. Agency for Toxic Substances and Disease Registry (ATSDR 2001).
4. Vapor Pressure for 1,4 Dioxane from "Solvent Stabilizers - White Paper" (Mohr 2001). Odor Threshold from US Department of Health and Human Services, National Toxicology Program (USDHHS, 2001).

**TABLE F-3. COMPONENTS FOR DEEP SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
ACENAPHTHENE	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	4.50E-03	5.13E+02	8.00E-02	5.63E-02
ACENAPHTHYLENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.90E-02	-	-	-
ACETONE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	1.0E+05	2.70E+02	3.09E+04	1.30E+01	2.08E+01
ALDRIN	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	2.30E-05	2.63E+02	1.70E-02	1.35E-03
ANTHRACENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.70E-05	-	-	-
ANTIMONY	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
ARSENIC	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
BARIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
BENZENE	8.7E+02	8.7E+02	1.0E+03	2.5E+03	8.7E+02	9.50E+01	4.89E+03	1.50E+00	6.33E+01
BENZO(a)ANTHRACENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.20E-08	-	-	-
BENZO(a)PYRENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.60E-09	-	-	-
BENZO(b)FLUORANTHENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.00E-07	-	-	-
BENZO(g,h,i)PERYLENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.10E-10	-	-	-
BENZO(k)FLUORANTHENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	9.60E-11	-	-	-
BERYLLIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
BIPHENYL, 1,1-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.00E-03	6.00E+01	9.50E-03	5.26E-01
BIS(2-CHLOROETHYL)ETHER	1.0E+03	2.5E+03	1.0E+03	2.5E+03	9.6E+03	7.10E-01	2.87E+02	4.9E-02	1.45E+01
BIS(2-CHLOROISOPROPYL)ETHER	7.9E+02	7.9E+02	1.0E+03	2.5E+03	7.9E+02	8.50E-01	2.24E+03	3.20E-01	2.66E+00
BIS(2-ETHYLHEXYL)PHTHALATE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.20E-08	-	-	-
BORON	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	-	-	-	-
BROMODICHLOROMETHANE	2.5E+03	3.0E+03	2.5E+03	5.0E+03	3.0E+03	5.00E+01	1.10E+07	1.68E+03	2.98E-02
BROMOFORM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.60E+00	1.35E+04	1.30E+00	4.31E+00
BROMOMETHANE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	3.1E+03	1.42E+03	8.00E+04	2.00E+01	7.10E+01
CADMIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
CARBON TETRACHLORIDE	1.0E+03	1.1E+03	1.0E+03	2.5E+03	1.1E+03	1.13E+02	6.30E+04	1.00E+01	1.13E+01
CHLORDANE	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	1.00E-05	8.40E+00	4.92E-04	2.03E-02
CHLOROANILINE, p-	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	1.00E-05	-	-	-
CHLOROBENZENE	6.8E+02	6.8E+02	1.0E+03	2.5E+03	6.8E+02	1.18E+01	1.00E+03	2.20E-01	5.36E+01
CHLOROETHANE	1.0E+03	1.6E+03	1.0E+03	2.5E+03	1.6E+03	1.01E+03	3.80E+05	1.40E+02	7.20E+00
CHLOROFORM	1.0E+03	2.5E+03	1.0E+03	2.5E+03	2.9E+03	1.60E+02	4.22E+05	8.50E+01	1.88E+00
CHLOROMETHANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	4.1E+03	4.30E+03	-	-	-
CHLOROPHENOL, 2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	5.5E+04	1.42E+00	1.90E+01	3.60E-03	3.94E+02
CHROMIUM (Total)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
CHROMIUM III	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
CHROMIUM VI	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	6.30E-07	-	-	-
CHRYSENE	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
COBALT	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
COPPER	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	6.20E+02	6.52E+02	5.80E-01	1.07E+03
CYANIDE (Free)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	-	-	-	-
DIBENZO(a,h)ANTHTRACENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.00E-10	-	-	-
DIBROMO-3-CHLOROPROPANE, 1,2-	1.0E+03	1.1E+03	1.0E+03	2.5E+03	1.1E+03	8.00E-01	-	-	-
DIBROMOCHLOROMETHANE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	7.60E+01	-	-	-

**TABLE F-3. COMPONENTS FOR DEEP SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
DIBROMOETHANE, 1,2-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.20E+01	2.00E+05	2.60E+01	4.62E-01
DICHLOROBENZENE, 1,2-	6.0E+02	6.0E+02	2.5E+03	5.0E+03	6.0E+02	1.50E+00	3.05E+05	5.00E+01	3.00E-02
DICHLOROBENZENE, 1,3-	5.0E+02	6.0E+02	5.0E+02	1.0E+03	6.0E+02	2.30E+00	-	-	-
DICHLOROBENZENE, 1,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.80E+00	1.10E+03	1.80E-01	1.00E+01
DICHLOROBENZIDINE, 3,3-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	4.50E-09	-	-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.00E-06	-	-	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.50E-06	-	-	-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	5.50E-06	-	-	-
DICHLOROETHANE, 1,1-	1.0E+03	1.7E+03	1.0E+03	2.5E+03	1.7E+03	2.34E+02	1.25E+05	3.00E+01	7.80E+00
DICHLOROETHANE, 1,2-	1.0E+03	1.8E+03	1.0E+03	2.5E+03	1.8E+03	7.90E+01	2.42E+03	5.90E-01	1.34E+02
DICHLOROETHYLENE, 1,1-	1.0E+03	1.5E+03	1.0E+03	2.5E+03	1.5E+03	5.91E+02	2.00E+06	5.00E+02	1.18E+00
DICHLOROETHYLENE, Cis 1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.2E+03	2.15E+02	-	-	-
DICHLOROETHYLENE, Trans 1,2-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	3.1E+03	3.31E+02	6.73E+04	1.70E+01	1.95E+01
DICHLOROPHENOL, 2,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.70E-02	1.40E+03	2.10E-01	3.19E-01
DICHLOROPROPANE, 1,2-	5.0E+02	5.0E+03	5.0E+02	1.0E+03	1.1E+03	4.20E+01	1.19E+03	2.50E-01	1.68E+02
DICHLOROPROPENE, 1,3-	1.0E+03	1.4E+03	1.0E+03	2.5E+03	1.4E+03	4.30E+01	4.16E+03	1.00E+00	4.30E+01
DIELDRIN	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	1.80E-08	-	-	-
DIETHYLPHTHALATE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	3.50E-04	-	-	-
DIMETHYLPHENOL, 2,4-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	9.80E-02	1.00E+00	1.97E-04	4.97E+02
DIMETHYLPHTHALATE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.70E-03	-	-	-
DINITROPHENOL, 2,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.50E-05	-	-	-
DINITROTOLUENE, 2,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.10E-03	-	-	-
DIOXANE, 1,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	3.70E+01	6.12E+05	1.70E+02	2.18E-01
DIOXIN (2,3,7,8-TCDD)	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	-	-	-	-
ENDOSULFAN	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.00E-05	-	-	-
ENDRIN	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.00E-07	-	-	-
ETHYLBENZENE	4.0E+02	4.0E+02	1.0E+03	2.5E+03	4.0E+02	1.00E+01	2.00E+03	4.50E-01	2.22E+01
FLUORANTHENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	5.00E-06	-	-	-
FLUORENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	3.20E-04	-	-	-
HEPTACHLOR	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	3.00E-04	3.00E+02	2.00E-02	1.50E-02
HEPTACHLOR EPOXIDE	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	2.60E-06	3.00E+02	1.90E-02	1.37E-04
HEXACHLOROBENZENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.10E-05	-	-	-
HEXACHLOROBUTADIENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.50E-01	1.20E+04	1.10E+00	1.36E-01
HEXACHLOROXYCLOHEXANE (gamma) LINDANE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	9.40E-06	-	-	-
HEXACHLOROETHANE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.10E-01	-	-	-
INDENO(1,2,3-cd)PYRENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.00E-06	-	-	-
LEAD	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
MERCURY	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.00E-03	-	-	-
METHOXYCHLOR	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.40E-06	-	-	-
METHYL ETHYL KETONE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	3.4E+04	1.00E+02	3.20E+04	1.10E+01	9.09E+00
METHYL ISOBUTYL KETONE	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.7E+04	1.00E+01	4.20E+02	1.00E-01	1.00E+02

**TABLE F-3. COMPONENTS FOR DEEP SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
METHYL MERCURY	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	-	-	-	-
METHYL TERT BUTYL ETHER	5.0E+02	1.0E+03	5.0E+02	1.0E+03	2.1E+04	2.45E+02	5.30E+02	1.30E-01	1.88E+03
METHYLENE CHLORIDE	1.0E+03	2.4E+03	1.0E+03	2.5E+03	2.4E+03	4.29E+02	5.60E+05	1.60E+02	2.68E+00
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.80E-02	6.80E+01	1.15E-02	5.91E+00
MOLYBDENUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
NAPHTHALENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	8.20E-02	4.40E+02	8.40E-02	9.76E-01
NICKEL	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
PENTACHLOROPHENOL	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.10E-04	-	-	-
PERCHLORATE	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
PHENANTHRENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	9.60E-04	5.50E+01	7.42E-03	1.29E-01
PHENOL	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	3.50E-01	1.56E+02	4.00E-02	8.75E+00
POLYCHLORINATED BIPHENYLS (PCBs)	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	6.70E-03	-	-	-
PYRENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.50E-06	-	-	-
SELENIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
SILVER	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
STYRENE	1.0E+03	1.5E+03	1.0E+03	2.5E+03	1.5E+03	5.00E+00	1.36E+03	3.00E-01	1.67E+01
tert-BUTYL ALCOHOL	5.0E+02	1.0E+03	5.0E+02	1.0E+03	3.2E+05	4.20E+01	-	-	-
TETRACHLOROETHANE, 1,1,1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	2.0E+03	1.20E+01	-	-	-
TETRACHLOROETHANE, 1,1,2,2-	1.0E+03	2.0E+03	1.0E+03	2.5E+03	2.0E+03	4.00E+00	1.05E+04	1.50E+00	2.67E+00
TETRACHLOROETHYLENE	2.3E+02	2.3E+02	1.0E+03	2.5E+03	2.3E+02	1.90E+01	3.17E+04	4.68E+00	4.06E+00
THALLIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-
TOLUENE	6.5E+02	6.5E+02	1.0E+03	2.5E+03	6.5E+02	2.80E+01	3.00E+04	8.00E+00	3.50E+00
TOXAPHENE	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	4.00E-01	-	-	-
TPH (gasolines)	5.0E+03	5.0E+03	5.0E+03	5.0E+03	NA	3.00E+02	1.00E+02	2.22E-02	1.35E+04
TPH (middle distillates)	5.0E+03	5.0E+03	5.0E+03	5.0E+03	NA	5.00E+00	1.00E+03	1.41E-01	3.55E+01
TPH (residual fuels)	5.0E+03	5.0E+03	5.0E+03	5.0E+03	NA	-	-	-	-
TRICHLOROBENZENE, 1,2,4-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	2.90E-01	2.20E+04	2.96E+00	9.80E-02
TRICHLOROETHANE, 1,1,1-	1.0E+03	1.2E+03	1.0E+03	2.5E+03	1.2E+03	1.00E+02	6.51E+04	1.20E+01	8.33E+00
TRICHLOROETHANE, 1,1,2-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	1.8E+03	2.25E+01	-	-	-
TRICHLOROETHYLENE	1.3E+03	1.3E+03	2.5E+03	5.0E+03	1.3E+03	7.70E+01	1.36E+06	2.49E+02	3.09E-01
TRICHLOROPHENOL, 2,4,5-	5.0E+02	1.0E+03	5.0E+02	1.0E+03	NA	-	-	-	-
TRICHLOROPHENOL, 2,4,6-	1.0E+03	2.5E+03	1.0E+03	2.5E+03	NA	1.20E-02	3.00E-01	3.60E-05	3.33E+02
VANADIUM	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-

**TABLE F-3. COMPONENTS FOR DEEP SOIL GROSS CONTAMINATION CEILING LEVELS
(mg/kg)**

CONTAMINANT	¹ Final Residential Ceiling Level	Final Industrial/ Commercial Ceiling Level	¹ Raw Residential Ceiling Level	Raw Industrial/ Commercial Ceiling Level	Soil Saturation Limit (mg/kg)	Vapor Pressure (VP) (Torr @ 20-30 °C)	50 Percentile Odor Recognition Threshold (ORT) (ug/m ³)	50 Percentile Odor Recognition Threshold (ORT) (ppm-v)	Odor Index
VINYL CHLORIDE	1.0E+03	1.2E+03	1.0E+03	2.5E+03	1.2E+03	2.58E+03	7.71E+05	2.94E+02	8.78E+00
XYLENES	4.2E+02	4.2E+02	1.0E+03	2.5E+03	4.2E+02	6.00E+00	4.41E+02	1.00E-01	6.00E+01
ZINC	2.5E+03	5.0E+03	2.5E+03	5.0E+03	NA	-	-	-	-

Notes:
1. "Residential Land Use" screening levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

Odor Index = VP/ORT in ppm-v

Physio-chemical constants Ontario MOEE (MOEE 1996) except as noted.

Physio-chemical constants for chloroethane and chloromethane from ATSDR Toxicological Profiles (ATSDR 2001).

Odor Recognition Threshold in parts per million - volume (ppm-v = (concentration in mg/m³) x (24/molecular weight)).

TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.

Ceiling Level: Based on comparison of vapor pressure and odor index to Table F-1 or saturation limit, if lower.

Saturation limits calculated using equation in USEPA Region IX PRG guidance (for chemicals that are liquid at ambient temperatures and pressures; refer to Appendix 2).

Ceiling Levels for TPH after guidance from Massachusetts Department of Environmental Protection (MADEP 1997a).

References for vapor pressure and odor threshold data (in order of use):

1. Ontario Ministry of Environment and Energy (MOEE 1996).
2. Massachusetts Department of Environmental Protection (MADEP 1994).
3. Agency for Toxic Substances and Disease Registry (ATSDR 2001).
4. National Library of Medicine, Hazardous Substances Data Bank (NLM 2000).
5. U.S. Department of Health and Human Services (NIOSH 2000).

TABLE G-1. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
ACENAPHTHENE	2.0E+01	Taste & Odors	2.1E+03	2.0E+01	Ontario MOEE	5.0E+04
ACENAPHTHYLENE	2.0E+03	Solubility	2.0E+03	-	-	5.0E+04
ACETONE	2.0E+04	Taste & Odors	5.0E+08	2.0E+04	Amoore & Hautala	5.0E+04
ALDRIN	8.5E+00	Solubility	8.5E+00	1.7E+01	Ontario MOEE	5.0E+04
ANTHRACENE	2.2E+01	Solubility	2.2E+01	-	-	5.0E+04
ANTIMONY	5.0E+04	Upper Limit		-	-	5.0E+04
ARSENIC	5.0E+04	Upper Limit		-	-	5.0E+04
BARIUM	5.0E+04	Upper Limit		-	-	5.0E+04
BENZENE	1.7E+02	Taste & Odors	8.8E+05	1.7E+02	Amoore & Hautala	5.0E+04
BENZO(a)ANTHRACENE	5.0E+00	Solubility	5.0E+00	-	-	5.0E+04
BENZO(a)PYRENE	1.9E+00	Solubility	1.9E+00	-	-	5.0E+04
BENZO(b)FLUORANTHENE	7.0E+00	Solubility	7.0E+00	-	-	5.0E+04
BENZO(g,h,i)PERYLENE	1.3E-01	Solubility	1.3E-01	-	-	5.0E+04
BENZO(k)FLUORANTHENE	4.0E-01	Solubility	4.0E-01	-	-	5.0E+04
BERYLLIUM	5.0E+04	Upper Limit		-	-	5.0E+04
BIPHENYL, 1,1-	5.0E-01	Taste & Odors	3.8E+03	5.0E-01	Amoore & Hautala	5.0E+04
BIS(2-CHLOROETHYL)ETHER	3.6E+02	Taste & Odors	8.6E+06	3.6E+02	Amoore & Hautala	5.0E+04
BIS(2-CHLOROISOPROPYL)ETHER	3.2E+02	Taste & Odors	8.5E+05	3.2E+02	Ontario MOEE	5.0E+04
BIS(2-ETHYLHEXYL)PHTHALATE	6.5E+02	Solubility	6.5E+02	-	-	5.0E+04
BORON	5.0E+04	Upper Limit		-	-	5.0E+04
BROMODICHLOROMETHANE	5.0E+04	Upper Limit	3.4E+06	-	-	5.0E+04
BROMOFORM	5.1E+02	Taste & Odors	1.6E+06	5.1E+02	Amoore & Hautala	5.0E+04
BROMOMETHANE	5.0E+04	Upper Limit	7.6E+06	-	-	5.0E+04
CADMIUM	5.0E+04	Upper Limit		-	-	5.0E+04
CARBON TETRACHLORIDE	5.2E+02	Taste & Odors	4.0E+05	5.2E+02	Amoore & Hautala	5.0E+04
CHLORDANE	2.5E+00	Taste & Odors	2.8E+01	2.5E+00	Ontario MOEE	5.0E+04
CHLOROANILINE, p-	5.0E+04	Upper Limit	1.3E+06	-	-	5.0E+04
CHLOROBENZENE	5.0E+01	Taste & Odors	2.4E+05	5.0E+01	Amoore & Hautala	5.0E+04
CHLOROETHANE	1.6E+01	Taste & Odors	2.9E+06	1.6E+01	Amoore & Hautala	5.0E+04
CHLOROFORM	2.4E+03	Taste & Odors	4.0E+06	2.4E+03	Amoore & Hautala	5.0E+04
CHLOROMETHANE	5.0E+04	Upper Limit	4.1E+06	-	-	5.0E+04
CHLOROPHENOL, 2-	1.8E-01	Taste & Odors	1.1E+07	1.8E-01	Ontario MOEE	5.0E+04
CHROMIUM (Total)	5.0E+04	Upper Limit		-	-	5.0E+04
CHROMIUM III	5.0E+04	Upper Limit		-	-	5.0E+04
CHROMIUM VI	5.0E+04	Upper Limit		-	-	5.0E+04
CHRYSENE	8.0E-01	Solubility	8.0E-01	-	-	5.0E+04

TABLE G-1. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
COBALT	5.0E+04	Upper Limit		-	-	5.0E+04
COPPER	1.0E+03	Taste & Odors		1.0E+03	USEPA 2nd MCL	5.0E+04
CYANIDE (Free)	1.7E+02	Taste & Odors	5.0E+08	1.7E+02	Amoore & Hautala	5.0E+04
DIBENZO(a,h)ANTHTRACENE	2.5E-01	Solubility	2.5E-01	-	-	5.0E+04
DIBROMO-3-CHLOROPROPANE, 1,2-	1.0E+01	Taste & Odors	6.0E+05	1.0E+01	Amoore & Hautala	5.0E+04
DIBROMOCHLOROMETHANE	5.0E+04	Upper Limit	2.2E+06	-	-	5.0E+04
DIBROMOETHANE, 1,2-	5.0E+04	Upper Limit	1.7E+06	-	-	5.0E+04
DICHLOROBENZENE, 1,2-	1.0E+01	Taste & Odors	7.8E+04	1.0E+01	USEPA 2nd MCL	5.0E+04
DICHLOROBENZENE, 1,3-	5.0E+04	Upper Limit	7.8E+04	-	-	5.0E+04
DICHLOROBENZENE, 1,4-	5.0E+00	Taste & Odors	3.7E+04	5.0E+00	USEPA 2nd MCL	5.0E+04
DICHLOROBENZIDINE, 3,3-	1.6E+03	Solubility	1.6E+03	-	-	5.0E+04
DICHLORODIPHENYLDICHLOROETHANE (DDD)	8.0E+01	Solubility	8.0E+01	-	-	5.0E+04
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.0E+01	Solubility	2.0E+01	-	-	5.0E+04
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.5E+00	Solubility	1.5E+00	3.5E+02	Ontario MOEE	5.0E+04
DICHLOROETHANE, 1,1-	5.0E+04	Upper Limit	2.5E+06	-	-	5.0E+04
DICHLOROETHANE, 1,2-	7.0E+03	Taste & Odors	4.3E+06	7.0E+03	Amoore & Hautala	5.0E+04
DICHLOROETHYLENE, 1,1-	1.5E+03	Taste & Odors	1.1E+06	1.5E+03	Amoore & Hautala	5.0E+04
DICHLOROETHYLENE, Cis 1,2-	5.0E+04	Upper Limit	1.8E+06	-	-	5.0E+04
DICHLOROETHYLENE, Trans 1,2-	2.6E+02	Taste & Odors	3.2E+06	2.6E+02	Amoore & Hautala	5.0E+04
DICHLOROPHENOL, 2,4-	3.0E-01	Taste & Odors	2.3E+06	3.0E-01	Ontario MOEE	5.0E+04
DICHLOROPROPANE, 1,2-	1.0E+01	Taste & Odors	1.4E+06	1.0E+01	Ontario MOEE	5.0E+04
DICHLOROPROPENE, 1,3-	5.0E+04	Upper Limit	1.4E+06	-	-	5.0E+04
DIELDRIN	4.1E+01	Taste & Odors	9.3E+01	4.1E+01	Ontario MOEE	5.0E+04
DIETHYLPHTHALATE	5.0E+04	Upper Limit	4.5E+05	-	-	5.0E+04
DIMETHYLPHENOL, 2,4-	4.0E+02	Taste & Odors	3.9E+06	4.0E+02	Cal DHS AL	5.0E+04
DIMETHYLPHTHALATE	5.0E+04	Upper Limit	2.5E+06	-	-	5.0E+04
DINITROPHENOL, 2,4-	5.0E+04	Upper Limit	2.8E+06	-	-	5.0E+04
DINITROTOLUENE, 2,4-	5.0E+04	Upper Limit	1.4E+05	-	-	5.0E+04
DIOXANE, 1,4-	5.0E+04	Upper Limit	5.0E+08	2.3E+05	Amoore & Hautala	5.0E+04
DIOXIN (2,3,7,8-TCDD)	7.0E+03	Solubility	7.0E+03	-	-	5.0E+04
ENDOSULFAN	7.5E+01	Solubility	7.5E+01	-	-	5.0E+04
ENDRIN	4.1E+01	Taste & Odors	1.3E+02	4.1E+01	Ontario MOEE	5.0E+04
ETHYLBENZENE	3.0E+01	Taste & Odors	8.5E+04	3.0E+01	USEPA 2nd MCL	5.0E+04
FLUORANTHENE	1.3E+02	Solubility	1.3E+02	-	-	5.0E+04
FLUORENE	9.5E+02	Solubility	9.5E+02	-	-	5.0E+04
HEPTACHLOR	2.0E+01	Taste & Odors	2.8E+01	2.0E+01	Ontario MOEE	5.0E+04

TABLE G-1. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
HEPTACHLOR EPOXIDE	1.8E+02	Solubility	1.8E+02	-	-	5.0E+04
HEXACHLOROBENZENE	5.5E+01	Solubility	5.5E+01	3.0E+03	Ontario MOEE	5.0E+04
HEXACHLOROBUTADIENE	6.0E+00	Taste & Odors	1.0E+03	6.0E+00	Ontario MOEE	5.0E+04
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	3.5E+03	Solubility	3.5E+03	1.2E+04	Ontario MOEE	5.0E+04
HEXACHLOROETHANE	1.0E+01	Taste & Odors	2.5E+04	1.0E+01	Amoore & Hautala	5.0E+04
INDENO(1,2,3-cd)PYRENE	2.7E-01	Solubility	2.7E-01	-	-	5.0E+04
LEAD	5.0E+04	Upper Limit		-	-	5.0E+04
MERCURY	5.0E+04	Upper Limit		-	-	5.0E+04
METHOXYCHLOR	2.0E+01	Solubility	2.0E+01	4.7E+03	Amoore & Hautala	5.0E+04
METHYL ETHYL KETONE	8.4E+03	Taste & Odors	1.3E+08	8.4E+03	Amoore & Hautala	5.0E+04
METHYL ISOBUTYL KETONE	1.3E+03	Taste & Odors	9.5E+06	1.3E+03	Amoore & Hautala	5.0E+04
METHYL MERCURY	5.0E+04	Upper Limit		-	-	5.0E+04
METHYL TERT BUTYL ETHER	5.0E+00	Taste & Odors	7.5E+07	5.0E+00	Cal DHS 2nd MCL	5.0E+04
METHYLENE CHLORIDE	9.1E+03	Taste & Odors	6.6E+06	9.1E+03	Ontario MOEE	5.0E+04
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+01	Taste & Odors	1.3E+04	1.0E+01	Ontario MOEE	5.0E+04
MOLYBDENUM	5.0E+04	Upper Limit		-	-	5.0E+04
NAPHTHALENE	2.1E+01	Taste & Odors	1.6E+04	2.1E+01	Amoore & Hautala	5.0E+04
NICKEL	5.0E+04	Upper Limit		-	-	5.0E+04
PENTACHLOROPHENOL	3.0E+01	Taste & Odors	7.0E+06	3.0E+01	Amoore & Hautala	5.0E+04
PERCHLORATE	5.0E+04	Upper Limit	1.0E+08	-	-	5.0E+04
PHENANTHRENE	4.1E+02	Solubility	4.1E+02	1.0E+03	Ontario MOEE	5.0E+04
PHENOL	5.0E+00	Taste & Odors	4.0E+07	5.0E+00	Cal DHS AL	5.0E+04
POLYCHLORINATED BIPHENYLS (PCBs)	1.6E+01	Solubility	1.6E+01	-	-	5.0E+04
PYRENE	6.8E+01	Solubility	6.8E+01	-	-	5.0E+04
SELENIUM	5.0E+04	Upper Limit		-	-	5.0E+04
SILVER	1.0E+02	Taste & Odors		1.0E+02	USEPA 2nd MCL	5.0E+04
STYRENE	1.0E+01	Taste & Odors	1.6E+05	1.0E+01	USEPA 2nd MCL	5.0E+04
tert-BUTYL ALCOHOL	5.0E+04	Upper Limit	5.0E+08	-	-	5.0E+04
TETRACHLOROETHANE, 1,1,1,2-	5.0E+04	Upper Limit	1.5E+06	-	-	5.0E+04
TETRACHLOROETHANE, 1,1,2,2-	5.0E+02	Taste & Odors	1.5E+06	5.0E+02	Amoore & Hautala	5.0E+04
TETRACHLOROETHYLENE	1.7E+02	Taste & Odors	1.0E+05	1.7E+02	Amoore & Hautala	5.0E+04
THALLIUM	5.0E+04	Upper Limit		-	-	5.0E+04
TOLUENE	4.0E+01	Taste & Odors	2.6E+05	4.0E+01	USEPA 2nd MCL	5.0E+04
TOXAPHENE	1.4E+02	Taste & Odors	1.5E+03	1.4E+02	USEPA 2nd MCL	5.0E+04
TPH (gasolines)	1.0E+02	Taste & Odors	7.5E+04	1.0E+02	USEPA SNARL	5.0E+04
TPH (middle distillates)	1.0E+02	Taste & Odors	2.5E+03	1.0E+02	USEPA SNARL	5.0E+04

TABLE G-1. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Taste And Odor Threshold	Basis	Upper Limit
TPH (residual fuels)	1.0E+02	Taste & Odors	2.5E+03	1.0E+02	USEPA SNARL	5.0E+04
TRICHLOROENZENE, 1,2,4-	3.0E+03	Taste & Odors	1.5E+05	3.0E+03	USEPA (1995)	5.0E+04
TRICHLOROETHANE, 1,1,1-	9.7E+02	Taste & Odors	6.7E+05	9.7E+02	Amoore & Hautala	5.0E+04
TRICHLOROETHANE, 1,1,2-	5.0E+04	Upper Limit	2.2E+06	-	-	5.0E+04
TRICHLOROETHYLENE	3.1E+02	Taste & Odors	5.5E+05	3.1E+02	Amoore & Hautala	5.0E+04
TRICHLOROPHENOL, 2,4,5-	2.0E+02	Taste & Odors	6.0E+05	2.0E+02	Ontario MOEE	5.0E+04
TRICHLOROPHENOL, 2,4,6-	1.0E+02	Taste & Odors	4.0E+05	1.0E+02	Ontario MOEE	5.0E+04
VANADIUM	5.0E+04	Upper Limit		-	-	5.0E+04
VINYL CHLORIDE	3.4E+03	Taste & Odors	1.4E+06	3.4E+03	Amoore & Hautala	5.0E+04
XYLENES	2.0E+01	Taste & Odors	8.1E+04	2.0E+01	USEPA 2nd MCL	5.0E+04
ZINC	5.0E+03	Taste & Odors		5.0E+03	USEPA 2nd MCL	5.0E+04

References:
 Unless otherwise noted, criteria for drinking water taste and odor threshold from summary in *A Compilation of Water Quality Goals* (RWQCBCV 1998) or Ontario MOEE if not available (MOEE 1996).
 Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).
 1/2 solubility based on solubility constants in USEPA Region IX (USEPA 1998) or Ontario MOEE (MOEE 1996) if not available.

Notes:
 Ceiling Level: lowest of 1/2 solubility, taste and odor threshold and 50000 ug/L maximum level
 TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.
 TPH ceiling levels after Massachusetts DEP (MADEP 1997a).
 TPH Taste and Odor Thresholds based on USEPA Suggested-No-Adverse-reaction (SNARL) level for TPH diesel.

TABLE G-2. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS NOT a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Nuisance/Odor Threshold	Basis	Upper Limit
ACENAPHTHENE	2.0E+02	Nuisance/Odors	2.1E+03	2.0E+02	Ontario MOEE	5.0E+04
ACENAPHTHYLENE	2.0E+03	Solubility	2.0E+03	-	-	5.0E+04
ACETONE	5.0E+04	Upper Limit	5.0E+08	2.0E+05	Ontario MOEE	5.0E+04
ALDRIN	8.5E+00	Solubility	8.5E+00	1.7E+02	Ontario MOEE	5.0E+04
ANTHRACENE	2.2E+01	Solubility	2.2E+01	-	-	5.0E+04
ANTIMONY	5.0E+04	Upper Limit		-	-	5.0E+04
ARSENIC	5.0E+04	Upper Limit		-	-	5.0E+04
BARIUM	5.0E+04	Upper Limit		-	-	5.0E+04
BENZENE	2.0E+04	Nuisance/Odors	8.8E+05	2.0E+04	Ontario MOEE	5.0E+04
BENZO(a)ANTHRACENE	5.0E+00	Solubility	5.0E+00	-	-	5.0E+04
BENZO(a)PYRENE	1.9E+00	Solubility	1.9E+00	-	-	5.0E+04
BENZO(b)FLUORANTHENE	7.0E+00	Solubility	7.0E+00	-	-	5.0E+04
BENZO(g,h,i)PERYLENE	1.3E-01	Solubility	1.3E-01	-	-	5.0E+04
BENZO(k)FLUORANTHENE	4.0E-01	Solubility	4.0E-01	-	-	5.0E+04
BERYLLIUM	5.0E+04	Upper Limit		-	-	5.0E+04
BIPHENYL, 1,1-	5.0E+00	Nuisance/Odors	3.8E+03	5.0E+00	Amoore & Hautala	5.0E+04
BIS(2-CHLOROETHYL)ETHER	3.6E+03	Nuisance/Odors	8.6E+06	3.6E+03	Amoore & Hautala	5.0E+04
BIS(2-CHLOROISOPROPYL)ETHER	3.2E+03	Nuisance/Odors	8.5E+05	3.2E+03	Ontario MOEE	5.0E+04
BIS(2-ETHYLHEXYL)PHTHALATE	6.5E+02	Solubility	6.5E+02	-	-	5.0E+04
BORON	5.0E+04	Upper Limit		-	-	5.0E+04
BROMODICHLOROMETHANE	5.0E+04	Upper Limit	3.4E+06	-	-	5.0E+04
BROMOFORM	5.1E+03	Nuisance/Odors	1.6E+06	5.1E+03	Ontario MOEE	5.0E+04
BROMOMETHANE	5.0E+04	Upper Limit	7.6E+06	-	-	5.0E+04
CADMIUM	5.0E+04	Upper Limit		-	-	5.0E+04
CARBON TETRACHLORIDE	5.2E+03	Nuisance/Odors	4.0E+05	5.2E+03	Ontario MOEE	5.0E+04
CHLORDANE	2.5E+01	Nuisance/Odors	2.8E+01	2.5E+01	Ontario MOEE	5.0E+04
CHLOROANILINE, p-	5.0E+04	Upper Limit	1.3E+06	-	-	5.0E+04
CHLOROBENZENE	5.0E+02	Nuisance/Odors	2.4E+05	5.0E+02	Ontario MOEE	5.0E+04
CHLOROETHANE	1.6E+02	Nuisance/Odors	2.9E+06	1.6E+02	Amoore & Hautala	5.0E+04
CHLOROFORM	2.4E+04	Nuisance/Odors	4.0E+06	2.4E+04	Ontario MOEE	5.0E+04
CHLOROMETHANE	5.0E+04	Upper Limit	4.1E+06	-	-	5.0E+04
CHLOROPHENOL, 2-	1.8E+00	Nuisance/Odors	1.1E+07	1.8E+00	Ontario MOEE	5.0E+04
CHROMIUM (Total)	5.0E+04	Upper Limit		-	-	5.0E+04
CHROMIUM III	5.0E+04	Upper Limit		-	-	5.0E+04
CHROMIUM VI	5.0E+04	Upper Limit		-	-	5.0E+04
CHRYSENE	8.0E-01	Solubility	8.0E-01	-	-	5.0E+04
COBALT	5.0E+04	Upper Limit		-	-	5.0E+04

TABLE G-2. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS NOT a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Nuisance/Odor Threshold	Basis	Upper Limit
COPPER	5.0E+04	Upper Limit		-	-	5.0E+04
CYANIDE (Free)	1.7E+03	Nuisance/Odors	5.0E+08	1.7E+03	Ontario MOEE	5.0E+04
DIBENZO(a,h)ANTHTRACENE	2.5E-01	Solubility	2.5E-01	-	-	5.0E+04
DIBROMO-3-CHLOROPROPANE, 1,2-	1.0E+02	Nuisance/Odors	6.0E+05	1.0E+02	Amoore & Hautala	5.0E+04
DIBROMOCHLOROMETHANE	5.0E+04	Upper Limit	2.2E+06	-	-	5.0E+04
DIBROMOETHANE, 1,2-	5.0E+04	Upper Limit	1.7E+06	-	-	5.0E+04
DICHLOROENZENE, 1,2-	1.0E+02	Nuisance/Odors	7.8E+04	1.0E+02	Ontario MOEE	5.0E+04
DICHLOROENZENE, 1,3-	5.0E+04	Upper Limit	7.8E+04	-	-	5.0E+04
DICHLOROENZENE, 1,4-	1.1E+02	Nuisance/Odors	3.7E+04	1.1E+02	Ontario MOEE	5.0E+04
DICHLOROENZIDINE, 3,3-	1.6E+03	Solubility	1.6E+03	-	-	5.0E+04
DICHLORODIPHENYLDICHLOROETHANE (DDD)	8.0E+01	Solubility	8.0E+01	-	-	5.0E+04
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.0E+01	Solubility	2.0E+01	-	-	5.0E+04
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.5E+00	Solubility	1.5E+00	3.5E+03	Ontario MOEE	5.0E+04
DICHLOROETHANE, 1,1-	5.0E+04	Upper Limit	2.5E+06	-	-	5.0E+04
DICHLOROETHANE, 1,2-	5.0E+04	Upper Limit	4.3E+06	2.0E+05	Ontario MOEE	5.0E+04
DICHLOROETHYLENE, 1,1-	1.5E+04	Nuisance/Odors	1.1E+06	1.5E+04	Amoore & Hautala	5.0E+04
DICHLOROETHYLENE, Cis 1,2-	5.0E+04	Upper Limit	1.8E+06	-	-	5.0E+04
DICHLOROETHYLENE, Trans 1,2-	2.6E+03	Nuisance/Odors	3.2E+06	2.6E+03	Ontario MOEE	5.0E+04
DICHLOROPHENOL, 2,4-	3.0E+00	Nuisance/Odors	2.3E+06	3.0E+00	Ontario MOEE	5.0E+04
DICHLOROPROPANE, 1,2-	1.0E+02	Nuisance/Odors	1.4E+06	1.0E+02	Ontario MOEE	5.0E+04
DICHLOROPROPENE, 1,3-	5.0E+04	Upper Limit	1.4E+06	-	-	5.0E+04
DIELDRIN	9.3E+01	Solubility	9.3E+01	4.1E+02	Ontario MOEE	5.0E+04
DIETHYLPHTHALATE	5.0E+04	Upper Limit	4.5E+05	-	-	5.0E+04
DIMETHYLPHENOL, 2,4-	4.0E+03	Nuisance/Odors	3.9E+06	4.0E+03	Ontario MOEE	5.0E+04
DIMETHYLPHTHALATE	5.0E+04	Upper Limit	2.5E+06	-	-	5.0E+04
DINITROPHENOL, 2,4-	5.0E+04	Upper Limit	2.8E+06	-	-	5.0E+04
DINITROTOLUENE, 2,4-	5.0E+04	Upper Limit	1.4E+05	-	-	5.0E+04
DIOXANE, 1,4-	5.0E+04	Upper Limit	5.0E+08	-	-	5.0E+04
DIOXIN (2,3,7,8-TCDD)	7.0E+03	Solubility	7.0E+03	-	-	5.0E+04
ENDOSULFAN	7.5E+01	Solubility	7.5E+01	-	-	5.0E+04
ENDRIN	1.3E+02	Solubility	1.3E+02	4.1E+02	Ontario MOEE	5.0E+04
ETHYLBENZENE	3.0E+02	Nuisance/Odors	8.5E+04	3.0E+02	USEPA 2nd MCL	5.0E+04
FLUORANTHENE	1.3E+02	Solubility	1.3E+02	-	-	5.0E+04
FLUORENE	9.5E+02	Solubility	9.5E+02	-	-	5.0E+04
HEPTACHLOR	2.8E+01	Solubility	2.8E+01	2.0E+02	Ontario MOEE	5.0E+04
HEPTACHLOR EPOXIDE	1.8E+02	Solubility	1.8E+02	-	-	5.0E+04
HEXACHLOROENZENE	5.5E+01	Solubility	5.5E+01	3.0E+04	Ontario MOEE	5.0E+04

TABLE G-2. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS NOT a current or potential source of drinking water)
(ug/L)

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Nuisance/Odor Threshold	Basis	Upper Limit
HEXACHLOROBUTADIENE	6.0E+01	Nuisance/Odors	1.0E+03	6.0E+01	Ontario MOEE	5.0E+04
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	3.5E+03	Solubility	3.5E+03	1.2E+05	Ontario MOEE	5.0E+04
HEXACHLOROETHANE	1.0E+02	Nuisance/Odors	2.5E+04	1.0E+02	Ontario MOEE	5.0E+04
INDENO(1,2,3-cd)PYRENE	2.7E-01	Solubility	2.7E-01	-	-	5.0E+04
LEAD	5.0E+04	Upper Limit		-	-	5.0E+04
MERCURY	5.0E+04	Upper Limit		-	-	5.0E+04
METHOXYCHLOR	2.0E+01	Solubility	2.0E+01	4.7E+04	Ontario MOEE	5.0E+04
METHYL ETHYL KETONE	5.0E+04	Upper Limit	1.3E+08	8.4E+04	Amoore & Hautala	5.0E+04
METHYL ISOBUTYL KETONE	1.3E+04	Nuisance/Odors	9.5E+06	1.3E+04	Amoore & Hautala	5.0E+04
METHYL MERCURY	5.0E+04	Upper Limit		-	-	5.0E+04
METHYL TERT BUTYL ETHER	1.8E+03	Nuisance/Odors	7.5E+07	1.8E+03	CalDHS	5.0E+04
METHYLENE CHLORIDE	5.0E+04	Upper Limit	6.6E+06	9.1E+04	Ontario MOEE	5.0E+04
METHYLNAPHTHALENE (total 1- & 2-)	1.0E+02	Nuisance/Odors	1.3E+04	1.0E+02	Ontario MOEE	5.0E+04
MOLYBDENUM	5.0E+04	Upper Limit		-	-	5.0E+04
NAPHTHALENE	2.1E+02	Nuisance/Odors	1.6E+04	2.1E+02	Ontario MOEE	5.0E+04
NICKEL	5.0E+04	Upper Limit		-	-	5.0E+04
PENTACHLOROPHENOL	5.9E+03	Nuisance/Odors	7.0E+06	5.9E+03	Ontario MOEE	5.0E+04
PERCHLORATE	5.0E+04	Upper Limit	1.0E+08	-	-	5.0E+04
PHENANTHRENE	4.1E+02	Solubility	4.1E+02	1.0E+04	Ontario MOEE	5.0E+04
PHENOL	5.0E+04	Upper Limit	4.0E+07	7.9E+04	Ontario MOEE	5.0E+04
POLYCHLORINATED BIPHENYLS (PCBs)	1.6E+01	Solubility	1.6E+01	-	-	5.0E+04
PYRENE	6.8E+01	Solubility	6.8E+01	-	-	5.0E+04
SELENIUM	5.0E+04	Upper Limit		-	-	5.0E+04
SILVER	5.0E+04	Upper Limit		-	-	5.0E+04
STYRENE	1.1E+02	Nuisance/Odors	1.6E+05	1.1E+02	Ontario MOEE	5.0E+04
tert-BUTYL ALCOHOL	5.0E+04	Upper Limit	5.0E+08	-	-	5.0E+04
TETRACHLOROETHANE, 1,1,1,2-	5.0E+04	Upper Limit	1.5E+06	-	-	5.0E+04
TETRACHLOROETHANE, 1,1,2,2-	5.0E+03	Nuisance/Odors	1.5E+06	5.0E+03	Ontario MOEE	5.0E+04
TETRACHLOROETHYLENE	3.0E+03	Nuisance/Odors	1.0E+05	3.0E+03	Ontario MOEE	5.0E+04
THALLIUM	5.0E+04	Upper Limit		-	-	5.0E+04
TOLUENE	4.0E+02	Nuisance/Odors	2.6E+05	4.0E+02	Ontario MOEE	5.0E+04
TOXAPHENE	1.4E+02	Nuisance/Odors	1.5E+03	1.4E+02	USEPA 2nd MCL	5.0E+04
TPH (gasolines)	5.0E+03	Nuisance/Odors	7.5E+04	5.0E+03	MADEP	5.0E+04
TPH (middle distillates)	2.5E+03	Solubility	2.5E+03	5.0E+03	MADEP	5.0E+04
TPH (residual fuels)	2.5E+03	Solubility	2.5E+03	5.0E+03	MADEP	5.0E+04
TRICHLOROBENZENE, 1,2,4-	3.0E+04	Nuisance/Odors	1.5E+05	3.0E+04	USEPA (1995)	5.0E+04
TRICHLOROETHANE, 1,1,1-	5.0E+04	Upper Limit	6.7E+05	5.0E+05	Ontario MOEE	5.0E+04

**TABLE G-2. GROUNDWATER GROSS CONTAMINATION CEILING LEVELS
(groundwater IS NOT a current or potential source of drinking water)
(ug/L)**

CONTAMINANT	Final Ceiling Level	Basis	Solubility (1/2)	Nuisance/Odor Threshold	Basis	Upper Limit
TRICHLOROETHANE, 1,1,2-	5.0E+04	Upper Limit	2.2E+06	-	-	5.0E+04
TRICHLOROETHYLENE	5.0E+04	Upper Limit	5.5E+05	1.0E+05	Ontario MOEE	5.0E+04
TRICHLOROPHENOL, 2,4,5-	2.0E+03	Nuisance/Odors	6.0E+05	2.0E+03	Ontario MOEE	5.0E+04
TRICHLOROPHENOL, 2,4,6-	1.0E+03	Nuisance/Odors	4.0E+05	1.0E+03	Ontario MOEE	5.0E+04
VANADIUM	5.0E+04	Upper Limit		-	-	5.0E+04
VINYL CHLORIDE	3.4E+04	Nuisance/Odors	1.4E+06	3.4E+04	Ontario MOEE	5.0E+04
XYLENES	5.3E+03	Nuisance/Odors	8.1E+04	5.3E+03	Ontario MOEE	5.0E+04
ZINC	5.0E+04	Upper Limit		-	-	5.0E+04

References:

Unless otherwise noted, criteria for nuisance odor threshold from Ontario MOEE (MOEE 1996) OR data from Amore and Hautala (1983) as presented in *A Compilation of Water Quality Goals* if not available (*RWQCBCV 2000*).

Upper limit of 50000 ug/L intended to limit general groundwater resource degradation (MOEE 1996).

1/2 solubility based on solubility constants in USEPA Region IX (USEPA 2004) or Ontario MOEE (MOEE 1996) if not available.

Odor threshold for MTBE based on average, upper range at which most subjects could smell MTBE in water (CalEPA 1999).

Notes:

Nuisance Odor Thresholds assume ten-fold attenuation/dilution of chemical in groundwater upon discharge to surface water.

Ceiling Level: lowest of 1/2 solubility, odor/taste threshold and 50000 ug/L maximum level (intended to limit general groundwater resource degradation).

TPH -Total Petroleum Hydrocarbons. See text for discussion of different TPH categories.

TPH ceiling level after Massachusetts DEP (MADEP 1997a).

TABLE H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS.

CONTAMINANT	Physical State		Molecular Weight	Organic carbon partition coefficient, K _{oc} (cm ³ /g)	Diffusivity in air, D _a (cm ² /s)	Diffusivity in water, D _w (cm ² /s)	Pure component water solubility, S (mg/L)	Henry's Law constant H (atm·m ³ /mol)	Henry's Law constant H' (unitless)	Skin Absorption Factor ABS (unitless)	Cancer Slope Factor Oral CSFo (mg/kg-d) ⁻¹	Cancer Slope Factor Inhaled CSFi (mg/kg-d) ⁻¹	Reference Dose Oral RfDo (mg/kg-d)	Reference Dose Inhaled RfDi (mg/kg-d)
	V	S												
ACENAPHTHENE	V	S	154	4.90E+03	4.21E-02	7.69E-06	4.24E+00	1.55E-04	6.36E-03				6.0E-02	6.0E-02
ACENAPHTHYLENE	V	S	152	2.50E+03	6.08E-02	7.88E-06	3.93E+00	1.45E-03	5.95E-02				4.0E-02	4.0E-02
ACETONE	V	L	58	5.75E-01	1.24E-01	1.14E-05	1.00E+06	3.88E-05	1.59E-03				9.0E-01	9.0E-01
ALDRIN	NV	S	365	4.90E+04			1.70E-02	4.96E-05	2.03E-03	0.10	1.7E+01	1.7E+01	3.0E-05	3.0E-05
ANTHRACENE	V	S	178	2.35E+04	3.24E-02	7.74E-06	4.34E-02	6.50E-05	2.67E-03				3.0E-01	3.0E-01
ANTIMONY	NV	S	122										4.0E-04	
ARSENIC	NV	S	75							0.0004	1.5E+00	1.5E+01	3.0E-04	
BARIUM	NV	S	137										7.0E-02	1.4E-04
BENZENE	V	L	78	5.89E+01	8.80E-02	9.80E-06	1.75E+03	5.55E-03	2.28E-01		5.5E-02	2.7E-02	4.0E-03	8.6E-03
BENZO(a)ANTHRACENE	NV	S	228	2.00E+05			1.00E-02	1.00E-06	4.10E-05	0.13	7.3E-01	7.3E-01		
BENZO(a)PYRENE	NV	S	252	5.50E+06			3.80E-03	4.90E-07	2.01E-05	0.13	7.30E+00	7.30E+00		
BENZO(b)FLUORANTHENE	NV	S	252	5.50E+05			1.40E-02	1.22E-05	5.00E-04	0.13	7.3E-01	7.3E-01		
BENZO(g,h,i)PERYLENE	NV	S	276	1.60E+06			2.60E-04	1.44E-07	5.90E-06	0.13			4.0E-02	4.0E-02
BENZO(k)FLUORANTHENE	NV	S	252	5.50E+05			8.00E-04	3.87E-05	1.59E-03	0.13	7.3E-02	7.30E-02		
BERYLLIUM	NV	S	9									8.4E+00	2.0E-03	5.7E-06
BIPHENYL, 1,1-	V	S	150	7.76E+03	4.04E-02	8.20E-06	7.50E+00	3.00E-04	1.23E-02				5.0E-02	5.0E-02
BIS(2-CHLOROETHYL)ETHER	V	L	142	7.60E+01	6.92E-02	7.53E-06	1.72E+04	1.80E-05	7.38E-04		1.1E+00	1.2E+00		
BIS(2-CHLOROISOPROPYL)ETHER	V	L	171	6.10E+01	6.31E-02	6.40E-06	1.70E+03	1.13E-04	4.63E-03		7.0E-02	3.5E-02	4.0E-02	4.0E-02
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S	391	1.00E+05			1.30E+00	3.00E-07	1.23E-05	0.10	1.4E-02	1.4E-02	2.0E-02	2.2E-02
BORON	NV	S	11							0.10			2.0E-01	5.7E-03
BROMODICHLOROMETHANE	V	L	164	5.50E+01	2.98E-02	1.06E-05	6.74E+03	1.60E-03	6.56E-02		6.2E-02	6.2E-02	2.0E-02	2.0E-02
BROMOFORM	NV	S	253	1.10E+02			3.20E+03	5.32E-04	2.18E-02	0.10	7.9E-03	3.9E-03	2.0E-02	2.0E-02
BROMOMETHANE	V	G	95	9.00E+00	7.28E-02	1.21E-05	1.52E+04	6.24E-03	2.56E-01				1.4E-03	1.4E-03
CADMIUM	NV	S	112							0.001		6.3E+00	5.0E-04	
CARBON TETRACHLORIDE	V	L	154	1.74E+02	7.80E-02	8.80E-06	7.93E+02	3.04E-02	1.25E+00		1.3E-01	5.3E-02	7.0E-04	7.0E-04
CHLORDANE	NV	S	410	4.40E+04			5.60E-02	4.79E-05	1.96E-03	0.04	3.5E-01	3.5E-01	5.0E-04	2.0E-04
CHLOROANILINE, p-	NV	S	128	6.40E+01			2.60E+03	3.31E-07	1.36E-05	0.10			4.0E-03	4.0E-03
CHLOROBENZENE	V	L	113	2.19E+02	7.30E-02	8.70E-06	4.72E+02	3.70E-03	1.52E-01				2.0E-02	1.7E-02
CHLOROETHANE	V	G	65	1.47E+01	1.04E-01	1.15E-05	5.70E+03	1.10E-02	4.51E-01		2.9E-03	2.9E-03	4.0E-01	2.9E+00
CHLOROFORM	V	L	119	3.98E+01	1.04E-01	1.00E-05	7.92E+03	3.67E-03	1.50E-01			8.1E-02	1.0E-02	1.4E-02
CHLOROMETHANE	V	G	51	3.50E+01	1.10E-01	6.50E-06	8.20E+03	2.40E-02	9.84E-01				2.6E-02	2.6E-02
CHLOROPHENOL, 2-	V	L	132	3.98E+02	5.01E-01	9.46E-06	2.20E+04	3.91E-04	1.60E-02				5.0E-03	5.0E-03
CHROMIUM (Total)	NV	S	52									4.2E+01		
CHROMIUM III	NV	S	52										1.5E+00	
CHROMIUM VI	NV	S	52										3.0E+02	2.2E-06
CHRYSENE	NV	S	228	4.00E+05	2.48E-02	6.21E-06	1.60E-03	9.46E-05	3.88E-03	0.13	7.3E-03	7.3E-03		
COBALT	NV	S	59										9.8E+00	2.0E-02
COPPER	NV	S	64										4.0E-02	5.7E-6
CYANIDE (Free)	NV	S	26	9.20E+00	1.80E-01	1.80E-05	1.00E+06	1.90E+03	7.79E+04	0.10			2.0E-02	
DIBENZO(a,h)ANTHTRACENE	NV	S	278	3.30E+06			5.00E-04	7.30E-08	2.99E-06	0.13	7.3E+00	7.3E+00		
DIBROMO-3-CHLOROPROPANE, 1,2-	V	L	236	1.30E+02	2.12E-02	7.00E-06	1.20E+03	1.47E-04	6.03E-03		1.4E+00	2.4E-03	5.7E-05	5.7E-05
DIBROMOCHLOROMETHANE	V	S	208	4.68E+02	9.60E-02	1.00E-05	4.40E+03	8.50E-04	3.49E-02		8.4E-02	8.4E-02	2.0E-02	2.0E-02
DIBROMOETHANE, 1,2-	V	S	188	4.40E+01	7.33E-02	8.06E-06	3.40E+03	3.20E-04	1.31E-02		2.0E+00	2.0E+00	9.0E-03	2.6E-03
DICHLOROBENZENE, 1,2-	V	L	147	6.17E+02	6.90E-02	7.90E-06	1.56E+02	1.90E-03	7.79E-02				9.0E-02	5.7E-02
DICHLOROBENZENE, 1,3-	V	L	147	6.17E+02	6.90E-02	7.90E-06	1.56E+02	1.90E-03	7.79E-02				3.0E-02	3.0E-02

TABLE H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS.

CONTAMINANT	Physical State		Molecular Weight	Organic carbon partition coefficient, K_{oc} (cm ³ /g)	Diffusivity in air, D_a (cm ² /s)	Diffusivity in water, D_w (cm ² /s)	Pure component water solubility, S (mg/L)	Henry's Law constant H (atm·m ³ /mol)	Henry's Law constant H' (unitless)	Skin Absorption Factor ABS (unitless)	Cancer Slope Factor Oral CSFo (mg/kg-d) ⁻¹	Cancer Slope Factor Inhaled CSFi (mg/kg-d) ⁻¹	Reference Dose Oral RfDo (mg/kg-d)	Reference Dose Inhaled RfDi (mg/kg-d)
	V	S												
DICHLOROENZENE, 1,4-	V	S	147	6.17E+02	6.90E-02	7.90E-06	7.38E+01	2.43E-03	9.96E-02		2.4E-02	2.2E-02	3.0E-02	3.0E-02
DICHLOROBENZIDINE, 3,3-	NV	S	253	1.60E+03			3.11E+00	8.33E-07	3.42E-05	0.10	4.5E-01	4.5E-01		
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S	331	7.80E+05			1.60E-01	7.96E-06	3.26E-04	0.03	2.4E-01	2.4E-01		
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	NV	S	329	4.40E+06			4.00E-02	6.80E-05	2.79E-03	0.03	2.4E-01	2.4E-01		
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S	355	2.40E+05			3.00E-03	3.89E-05	1.59E-03	0.03	3.4E-01	3.4E-01	5.0E-04	5.0E-04
DICHLOROETHANE, 1,1-	V	L	99	3.16E+01	7.42E-02	1.05E-05	5.06E+03	5.62E-03	2.30E-01				1.0E-01	1.4E-01
DICHLOROETHANE, 1,2-	V	L	99	1.74E+01	1.04E-01	9.90E-06	8.52E+03	9.79E-04	4.01E-02		9.1E-02	9.1E-02	3.0E-02	1.4E-03
DICHLOROETHYLENE, 1,1-	V	L	97	5.89E+01	9.00E-02	1.04E-05	2.25E+03	2.61E-02	1.07E+00				5.0E-02	5.7E-02
DICHLOROETHYLENE, Cis 1,2-	V	L	97	3.55E+01	7.36E-02	1.13E-05	3.50E+03	4.08E-03	1.67E-01				1.0E-02	1.0E-02
DICHLOROETHYLENE, Trans 1,2-	V	L	97	5.25E+01	7.07E-02	1.19E-05	6.30E+03	9.38E-03	3.85E-01				2.0E-02	2.0E-02
DICHLOROPHENOL, 2,4-	NV	S	163	6.00E+03			4.50E+03	2.80E-06	1.15E-04	0.10			3.0E-03	3.0E-03
DICHLOROPROPANE, 1,2-	V	L	113	4.37E+01	7.82E-02	8.73E-06	2.80E+03	2.80E-03	1.15E-01		6.8E-02	6.8E-02	1.1E-03	1.1E-03
DICHLOROPROPENE, 1,3-	V	L	111	4.57E+01	6.26E-02	1.00E-05	2.80E+03	1.77E-02	7.26E-01		1.0E-01	1.4E-02	3.0E-02	5.7E-03
DIELDRIN	NV	S	381	7.40E+03			1.86E-01	5.84E-05	2.39E-03	0.10	1.6E+01	1.6E+01	5.0E-05	5.0E-05
DIETHYLPHTHALATE	NV	S	222	1.40E+02			8.96E+02	1.14E-06	4.67E-05	0.10			8.0E-01	8.0E-01
DIMETHYLPHENOL, 2,4-	NV	S	122	4.00E+01			7.87E+03	2.00E-06	8.20E-05	0.10			2.0E-02	2.0E-02
DIMETHYLPHTHALATE	NV	S	194	1.40E+02			5.00E+03	1.05E-07	4.31E-06	0.10			1.0E+01	1.0E+01
DINITROPHENOL, 2,4-	NV	S	184	1.70E+01			5.60E+03	6.45E-10	2.64E-08	0.10			2.0E-03	2.0E-03
DINITROTOLUENE, 2,4-	NV	S	182	4.50E+01			2.70E+02	4.50E-06	1.85E-04	0.10	2.0E-03	2.0E-03	2.0E-03	2.0E-03
DIOXANE, 1,4-	NV	L	88	3.50E+00			1.00E+06	3.00E-06	1.23E-04	0.10	1.1E-02	1.1E-02		
DIOXIN (2,3,7,8-TCDD)	NV	S	322	1.30E+07			1.40E+01	8.10E-05	3.32E-03	0.03	1.5E+05	1.5E+05		
ENDOSULFAN	NV	S	407	3.20E+03			1.50E-01	1.00E-05	4.10E-04	0.10			6.0E-03	6.0E-03
ENDRIN	NV	S	381	1.70E+03			2.60E-01	7.51E-06	3.08E-04	0.10			3.0E-04	3.0E-04
ETHYLBENZENE	V	L	106	3.63E+02	7.50E-02	7.80E-06	1.69E+02	7.88E-03	3.23E-01				1.0E-01	2.9E-01
FLUORANTHENE	NV	S	202	3.80E+04			2.65E-01	6.50E-06	2.67E-04	0.13			4.0E-02	4.0E-02
FLUORENE	V	S	166	1.38E+04	6.08E-02	7.88E-06	1.90E+00	7.70E-05	3.16E-03				4.0E-02	4.0E-02
HEPTACHLOR	NV	S	373	2.20E+04			5.60E-02	1.48E-03	6.07E-02	0.10	4.5E+00	4.6E+00	5.0E-04	5.0E-04
HEPTACHLOR EPOXIDE	NV	S	389	2.30E+04			3.50E-01	3.16E-05	1.30E-03	0.10	9.1E+00	9.1E+00	1.3E-05	1.3E-05
HEXACHLOROBENZENE	NV	S	285	1.20E+06			1.10E-01	1.70E-03	6.97E-02	0.10	1.6E+00	1.6E+00	8.0E-04	8.0E-04
HEXACHLOROBUTADIENE	NV	S	261	2.90E+04			2.00E+00	2.56E-02	1.05E+00	0.10	7.8E-02	7.8E-02	3.0E-04	3.0E-04
HEXACHLOROXYCLOHEXANE (gamma) LINDANE	NV	S	291	3.70E+03			7.00E+00	4.93E-07	2.02E-05	0.04	1.3E+00	1.3E+00	3.0E-04	3.0E-04
HEXACHLOROETHANE	NV	S	237	2.00E+04			5.00E+01	9.85E-03	4.04E-01	0.10	1.4E-02	1.4E-02	1.0E-03	1.0E-03
INDENO(1,2,3-cd)PYRENE	NV	S	276	1.60E+06			5.30E-04	6.95E-08	2.85E-06	0.13	7.3E-01	7.3E-01		
LEAD	NV	S	207										1.6E-04	8.5E-05
MERCURY	NV	S	201										5.0E-03	5.0E-03
METHOXYCHLOR	NV	S	347	7.90E+04			4.00E-02	1.58E-05	6.48E-04	0.10			5.0E-03	5.0E-03
METHYL ETHYL KETONE	V	L	72	4.50E+00	8.95E-02	9.80E-06	2.68E+05	2.74E-05	1.12E-03				6.0E-01	1.4E+00
METHYL ISOBUTYL KETONE	V	L	100	1.34E+02	7.50E-02	7.80E-06	1.90E+04	1.40E-04	5.74E-03				8.0E-02	8.6E-01
METHYL MERCURY	NV	S	216							0.10			1.0E-04	
METHYL TERT BUTYL ETHER	V	L	98	6.00E+00	8.00E-02	1.00E-05	1.50E+05	5.87E-04	2.41E-02		1.8E-03	9.1E-04	8.6E-01	8.6E-01
METHYLENE CHLORIDE	V	L	85	1.11E+01	1.01E-01	1.17E-05	1.32E+04	2.19E-03	8.98E-02		7.5E-03	1.6E-03	6.0E-02	8.6E-01
METHYLNAPHTHALENE (total 1- & 2-)	V	S	142	7.20E+02	5.90E-02	7.50E-06	2.60E+01	2.90E-04	1.19E-02				4.0E-02	4.0E-2
MOLYBDENUM	NV	S	96										5.0E-03	
NAPHTHALENE	V	S	128	1.19E+03	5.90E-02	7.50E-06	3.10E+01	4.83E-04	1.98E-02				2.0E-02	8.6E-04
NICKEL	NV	S	59										2.0E-02	

TABLE H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS.

CONTAMINANT	Physical State		Molecular Weight	Organic carbon partition coefficient, K_{oc} (cm ³ /g)	Diffusivity in air, D_a (cm ² /s)	Diffusivity in water, D_w (cm ² /s)	Pure component water solubility, S (mg/L)	Henry's Law constant H (atm-m ³ /mol)	Henry's Law constant H' (unitless)	Skin Absorption Factor ABS (unitless)	Cancer Slope Factor Oral CSFo (mg/kg-d) ⁻¹	Cancer Slope Factor Inhaled CSFi (mg/kg-d) ⁻¹	Reference Dose Oral RfDo (mg/kg-d)	Reference Dose Inhaled RfDi (mg/kg-d)
	Physical State	State												
PENTACHLOROPHENOL	NV	S	266	3.20E+04			1.40E+04	2.80E-06	1.15E-04	0.25	1.2E-01	1.2E-01	3.0E-02	3.0E-02
PERCHLORATE	NV	S	100				2.00E+05						1.0E-04	
PERCHLORATE													4.0E-02	4.0E-02
PHENANTHRENE	V	S	178	1.40E+04	6.08E-02	7.88E-06	8.16E-01	3.93E-05	1.61E-03				3.0E-01	3.0E-01
PHENOL	NV	S	94	9.10E+01			8.00E+04	1.30E-06	5.33E-05	0.10			3.0E-05	2.0E-05
POLYCHLORINATED BIPHENYLS (PCBs)	NV	S	327 (ave)	3.30E+04			3.20E-02	5.20E-04	2.13E-02	0.14	2.0E+00	2.0E+00	3.0E-02	3.0E-02
PYRENE	V	S	202	1.05E+05	2.72E-02	7.24E-06	1.35E-01	1.10E-05	4.51E-04				5.0E-03	
SELENIUM	NV	S	79										5.0E-03	
SILVER	NV	S	47										2.0E-01	2.9E-01
STYRENE	V	L	104	7.76E+02	7.10E-02	8.00E-06	3.10E+02	2.75E-03	1.13E-01		3.0E-03	3.0E-03		
tert-BUTYL ALCOHOL	V	L	74	3.70E+01	9.00E-02	9.10E-06	1.00E+06	1.17E-05	4.80E-04		2.6E-02	2.6E-02	3.0E-02	3.0E-02
TETRACHLOROETHANE, 1,1,1,2-	V	L	168	9.37E+01	7.10E-02	7.90E-06	2.97E+03	3.45E-04	1.41E-02		2.0E-01	2.0E-01	6.0E-02	6.0E-02
TETRACHLOROETHANE, 1,1,2,2-	V	L	168	9.37E+01	7.10E-02	7.90E-06	2.97E+03	3.45E-04	1.41E-02		2.0E-01	2.0E-01	6.0E-02	6.0E-02
TETRACHLOROETHYLENE	V	L	166	1.55E+02	7.20E-02	8.20E-06	2.00E+02	1.84E-02	7.54E-01		5.4E-01	2.1E-02	1.0E-02	1.0E-02
THALLIUM	NV	S	204										6.6E-05	
THALLIUM													2.0E-01	1.1E-01
TOLUENE	V	L	92	1.82E+02	8.70E-02	8.60E-06	5.26E+02	6.64E-03	2.72E-01					
TOLUENE											1.2E+00	1.2E+00		
TOXAPHENE	NV	S	414	4.90E+03			3.00E+00	2.10E-01	8.61E+00	0.10			3.0E-02	1.4E-02
TPH (gasolines)	V	L	108	5.00E+03	7.00E-02	7.80E-06	1.50E+02	7.20E-04	2.95E-02	0.10			3.0E-02	1.4E-02
TPH (middle distillates)	V	L	170	5.00E+03	7.00E-02	7.80E-06	5.00E+00	7.20E-04	2.95E-02	0.10			3.0E-02	1.4E-02
TPH (residual fuels)	NV	L/S					5.00E+00						1.0E-02	1.0E-03
TRICHLOROBENZENE, 1,2,4-	V	S	180	1.78E+03	3.00E-02	8.23E-06	3.00E+02	1.42E-03	5.82E-02				2.8E-01	6.3E-01
TRICHLOROETHANE, 1,1,1-	V	L	133	1.10E+02	7.80E-02	8.80E-06	1.33E+03	1.72E-02	7.05E-01		5.7E-02	5.6E-02	4.0E-03	4.0E-03
TRICHLOROETHANE, 1,1,2-	V	L	133	5.01E+01	7.80E-02	8.80E-06	4.42E+03	9.13E-04	3.74E-02		4.00E-01	4.0E-01	3.0E-04	1.0E-02
TRICHLOROETHYLENE	V	L	131	1.66E+02	7.90E-02	9.10E-06	1.10E+03	1.03E-02	4.22E-01				1.0E-01	1.0E-01
TRICHLOROPHENOL, 2,4,5-	V	S	198	8.90E+01	2.9E-02	7.0E-06	1.19E+03	2.18E-04	8.94E-03	0.10			1.0E-04	1.0E-04
TRICHLOROPHENOL, 2,4,6-	NV	S	198	2.00E+03			8.00E+02	4.00E-06	1.64E-04	0.10	1.1E-02	1.1E-02	1.0E-04	1.0E-04
VANADIUM	NV	S	51										1.0E-03	

TABLE H. PHYSIO-CHEMICAL AND TOXICITY CONSTANTS USED IN MODELS.

CONTAMINANT	Physical State		Molecular Weight	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Pure component water solubility, S (mg/L)	Henry's Law constant H ($atm\cdot m^3/mol$)	Henry's Law constant H' (unitless)	Skin Absorption Factor ABS (unitless)	Cancer Slope Factor Oral CSFo ($mg/kg\cdot d$) ⁻¹	Cancer Slope Factor Inhaled CSFi ($mg/kg\cdot d$) ⁻¹	Reference Dose Oral RfDo (mg/kg-d)	Reference Dose Inhaled RfDi (mg/kg-d)
	V	G												
VINYL CHLORIDE (nonresidential exposure)	V	G	63	1.86E+01	1.06E-01	1.23E-06	2.76E+03	2.70E-02	1.11E+00		7.5E-01	1.6E-02	3.0E-03	2.9E-02
VINYL CHLORIDE (residential exposure)	V	G	63	1.86E+01	1.06E-01	1.23E-06	2.76E+03	2.70E-02	1.11E+00		1.5E+00	3.1E-02	3.0E-03	2.9E-02
XYLENES	V	L	106	4.07E+02	7.00E-02	7.80E-06	1.61E+02	7.34E-03	3.01E-01				2.0E-01	2.9E-02
ZINC	NV	S	65										3.0E-01	

Notes:

Physical state of chemical at ambient conditions (V - volatile, NV - nonvolatile, S - solid, L - liquid, G - gas).

Chemical considered to be "volatile" if Henry's number ($atm\ m^3/mole$) >0.00001 and molecular weight <200 .

Dibromochloromethane, dibromochloropropane and pyrene considered volatile for purposes of modeling (USEPA 2004). (Molecular weight adjusted to 199 in column E (hidden) to permit generation of volatilization factor in soil direct-exposure models.)

TPH -Total Petroleum Hydrocarbons. RfD values from MADEP 2002. Molecular weights from ATSDR (gasolines) and NIOSH (middle distillates). See text for discussion of different TPH categories.

TPH as gasolines and middle distillates diffusivity constants based on xylenes. (Required for direct exposure models. Does not significantly affect action levels. See Section 5.3)

Physio-chemical constants and ABS values from USEPA Region IX (USEPA 2002) or Ontario MOEE (MOEE 1996) when not available, except as noted.

Physio-chemical constants for dioxin, polychlorinated biphenyls and toxaphene from ATSDR 2001a. PCB solubility from MOEE (1996).

Henry's constant for 2,4 dimethylphenol from Syracuse Research Corporation (SRC 2005).

Physio-chemical constants for 1,4 Dioxane from "Solvent Stabilizers - White Paper" (Mohr 2001).

USEPA Cancer Slope Factors and Reference Doses as presented in Region IX PRGs (USEPA 2004), unless otherwise noted.

Physio-chemical for TBA from *Assessment and Management of MtBE Impacted Sites* (RWQCB 2001). Oral cancer slope factor from California EPA (CalEPA 1999b).

Physio-chemicals and toxicity constants for xylenes based on m-xylene.

Diffusivity constants for methylnaphthalene not available. Constants presented based on naphthalene.

RfDs for acenaphthylene, methylnaphthylene, and phenanthrene based on fluorene; RfDs for benzo(g,h,i)perylene based on fluoranthene (after MADEP 1994). Diffusivities for acenaphthylene, and phenanthrene based on fluorene.

Alternative cancer slope factors and exposure models used for residential exposure to vinyl (refer to USEPA 2004).

**TABLE I-1. DIRECT-EXPOSURE ACTION LEVELS
¹RESIDENTIAL EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
ACENAPHTHENE	3.7E+03	noncarcinogenic effects	-	3.7E+03	NA
ACENAPHTHYLENE	1.3E+03	noncarcinogenic effects	-	1.3E+03	NA
ACETONE	1.4E+04	noncarcinogenic effects	-	1.4E+04	1.0E+05
ALDRIN	2.9E-02	carcinogenic effects	2.9E-02	1.8E+00	NA
ANTHRACENE	2.2E+04	noncarcinogenic effects	-	2.2E+04	NA
ANTIMONY	3.1E+01	noncarcinogenic effects	-	3.1E+01	NA
ARSENIC	4.2E-01	carcinogenic effects	4.2E-01	2.3E+01	NA
BARIUM	5.4E+03	noncarcinogenic effects	-	5.4E+03	NA
BENZENE	6.4E-01	carcinogenic effects	6.4E-01	3.3E+01	8.7E+02
BENZO(a)ANTHRACENE	6.2E+00	carcinogenic effects	6.2E+00	-	NA
BENZO(a)PYRENE	6.2E-01	carcinogenic effects	6.2E-01	-	NA
BENZO(b)FLUORANTHENE	6.2E+00	carcinogenic effects	6.2E+00	-	NA
BENZO(g,h,i)PERYLENE	2.3E+03	noncarcinogenic effects	-	2.3E+03	NA
BENZO(k)FLUORANTHENE	6.2E+01	carcinogenic effects	6.2E+01	-	NA
BERYLLIUM	1.5E+02	noncarcinogenic effects	1.1E+03	1.5E+02	NA
BIPHENYL, 1,1-	3.0E+03	noncarcinogenic effects	-	3.0E+03	NA
BIS(2-CHLOROETHYL)ETHER	2.0E-01	carcinogenic effects	2.0E-01	-	9.6E+03
BIS(2-CHLOROISOPROPYL)ETHER	2.9E+00	carcinogenic effects	2.9E+00	9.5E+02	7.9E+02
BIS(2-ETHYLHEXYL)PHTHALATE	3.5E+01	carcinogenic effects	3.5E+01	1.2E+03	NA
BORON	1.2E+04	noncarcinogenic effects	-	1.2E+04	NA
BROMODICHLOROMETHANE	8.2E-01	carcinogenic effects	8.2E-01	2.2E+02	3.0E+03
BROMOFORM	6.1E+01	carcinogenic effects	6.1E+01	1.2E+03	NA
BROMOMETHANE	3.8E+00	noncarcinogenic effects	-	3.8E+00	3.1E+03
CADMIUM	3.9E+01	noncarcinogenic effects	1.4E+03	3.9E+01	NA
CARBON TETRACHLORIDE	2.5E-01	carcinogenic effects	2.5E-01	2.2E+00	1.1E+03
CHLORDANE	1.6E+00	carcinogenic effects	1.6E+00	3.5E+01	NA
CHLOROANILINE, p-	2.4E+02	noncarcinogenic effects	-	2.4E+02	NA
CHLOROBENZENE	1.5E+02	noncarcinogenic effects	-	1.5E+02	6.8E+02
CHLOROETHANE	3.0E+00	carcinogenic effects	3.0E+00	5.0E+03	1.6E+03
CHLOROFORM	2.2E-01	carcinogenic effects	2.2E-01	5.4E+01	2.9E+03
CHLOROMETHANE	4.6E+01	noncarcinogenic effects	-	4.6E+01	4.1E+03
CHLOROPHENOL, 2-	6.3E+01	noncarcinogenic effects	-	6.3E+01	5.5E+04
CHROMIUM (Total)	2.1E+02	carcinogenic effects	2.1E+02	-	NA
CHROMIUM III	1.2E+05	noncarcinogenic effects	-	1.2E+05	NA
CHROMIUM VI	3.0E+01	carcinogenic effects	3.0E+01	2.2E+02	NA
CHRYSENE	6.2E+02	carcinogenic effects	6.2E+02	-	NA

**TABLE I-1. DIRECT-EXPOSURE ACTION LEVELS
¹RESIDENTIAL EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
COBALT	5.2E+02	trench/construction worker	9.1E+02	1.4E+03	NA
COPPER	3.1E+03	noncarcinogenic effects	-	3.1E+03	NA
CYANIDE (Free)	1.2E+03	noncarcinogenic effects	-	1.2E+03	NA
DIBENZO(a,h)ANTHTRACENE	6.2E-01	carcinogenic effects	6.2E-01	-	NA
DIBROMO-3-CHLOROPROPANE, 1,2-	4.5E-01	carcinogenic effects	4.5E-01	2.1E+00	1.1E+03
DIBROMOCHLOROMETHANE	1.1E+00	carcinogenic effects	1.1E+00	3.8E+02	NA
DIBROMOETHANE, 1,2-	3.2E-02	carcinogenic effects	3.2E-02	4.1E+01	NA
DICHLOROBENZENE, 1,2-	6.0E+02	saturation limit	-	1.1E+03	6.0E+02
DICHLOROBENZENE, 1,3-	5.3E+02	noncarcinogenic effects	-	5.3E+02	6.0E+02
DICHLOROBENZENE, 1,4-	3.4E+00	carcinogenic effects	3.4E+00	4.8E+02	NA
DICHLOROBENZIDINE, 3,3-	1.1E+00	carcinogenic effects	1.1E+00	-	NA
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.4E+00	carcinogenic effects	2.4E+00	-	NA
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.4E+00	carcinogenic effects	2.4E+00	-	NA
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.7E+00	carcinogenic effects	1.7E+00	3.6E+01	NA
DICHLOROETHANE, 1,1-	4.9E+02	noncarcinogenic effects	-	4.9E+02	1.7E+03
DICHLOROETHANE, 1,2-	2.7E-01	carcinogenic effects	2.7E-01	8.4E+00	1.8E+03
DICHLOROETHYLENE, 1,1-	1.2E+02	noncarcinogenic effects	-	1.2E+02	1.5E+03
DICHLOROETHYLENE, Cis 1,2-	4.2E+01	noncarcinogenic effects	-	4.2E+01	1.2E+03
DICHLOROETHYLENE, Trans 1,2-	6.9E+01	noncarcinogenic effects	-	6.9E+01	3.1E+03
DICHLOROPHENOL, 2,4-	1.8E+02	noncarcinogenic effects	-	1.8E+02	NA
DICHLOROPROPANE, 1,2-	3.4E-01	carcinogenic effects	3.4E-01	5.7E+00	1.1E+03
DICHLOROPROPENE, 1,3-	7.7E-01	carcinogenic effects	7.7E-01	1.6E+01	1.4E+03
DIELDRIN	3.0E-02	carcinogenic effects	3.0E-02	3.1E+00	NA
DIETHYLPHTHALATE	4.9E+04	noncarcinogenic effects	-	4.9E+04	NA
DIMETHYLPHENOL, 2,4-	1.2E+03	noncarcinogenic effects	-	1.2E+03	NA
DIMETHYLPHTHALATE	6.1E+05	noncarcinogenic effects	-	6.1E+05	NA
DINITROPHENOL, 2,4-	1.2E+02	noncarcinogenic effects	-	1.2E+02	NA
DINITROTOLUENE, 2,4-	1.2E+02	noncarcinogenic effects	2.4E+02	1.2E+02	NA
DIOXANE, 1,4-	4.4E+01	carcinogenic effects	4.4E+01	-	NA
DIOXIN (2,3,7,8-TCDD)	3.9E-06	carcinogenic effects	3.9E-06	-	NA
ENDOSULFAN	3.7E+02	noncarcinogenic effects	-	3.7E+02	NA
ENDRIN	1.8E+01	noncarcinogenic effects	-	1.8E+01	NA
ETHYLBENZENE	4.0E+02	saturation limit	-	1.8E+03	4.0E+02
FLUORANTHENE	2.3E+03	noncarcinogenic effects	-	2.3E+03	NA
FLUORENE	2.7E+03	noncarcinogenic effects	-	2.7E+03	NA
HEPTACHLOR	1.1E-01	carcinogenic effects	1.1E-01	3.1E+01	NA

**TABLE I-1. DIRECT-EXPOSURE ACTION LEVELS
¹RESIDENTIAL EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
HEPTACHLOR EPOXIDE	5.3E-02	carcinogenic effects	5.3E-02	7.9E-01	NA
HEXACHLOROBENZENE	3.0E-01	carcinogenic effects	3.0E-01	4.9E+01	NA
HEXACHLOROBUTADIENE	6.2E+00	carcinogenic effects	6.2E+00	1.8E+01	NA
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	4.4E-01	carcinogenic effects	4.4E-01	2.1E+01	NA
HEXACHLOROETHANE	3.5E+01	carcinogenic effects	3.5E+01	6.1E+01	NA
INDENO(1,2,3-cd)PYRENE	6.2E+00	carcinogenic effects	6.2E+00	-	NA
LEAD	4.0E+02	USEPA Region IX PRG	-	4.0E+02	NA
MERCURY	1.3E+01	noncarcinogenic effects	-	1.3E+01	NA
METHOXYCHLOR	3.1E+02	noncarcinogenic effects	-	3.1E+02	NA
METHYL ETHYL KETONE	2.2E+04	noncarcinogenic effects	-	2.2E+04	3.4E+04
METHYL ISOBUTYL KETONE	5.3E+03	noncarcinogenic effects	-	5.3E+03	1.7E+04
METHYL MERCURY	6.1E+00	noncarcinogenic effects	-	6.1E+00	NA
METHYL TERT BUTYL ETHER	3.1E+01	carcinogenic effects	3.1E+01	5.7E+03	2.1E+04
METHYLENE CHLORIDE	9.2E+00	carcinogenic effects	9.2E+00	1.9E+03	2.4E+03
METHYLNAPHTHALENE (total 1- & 2-)	1.4E+03	noncarcinogenic effects	-	1.4E+03	NA
MOLYBDENUM	3.9E+02	noncarcinogenic effects	-	3.9E+02	NA
NAPHTHALENE	5.5E+01	noncarcinogenic effects	-	5.5E+01	NA
NICKEL	1.6E+03	noncarcinogenic effects	-	1.6E+03	NA
PENTACHLOROPHENOL	3.0E+00	carcinogenic effects	3.0E+00	1.4E+03	NA
PERCHLORATE	7.8E+00	noncarcinogenic effects	-	7.8E+00	NA
PHENANTHRENE	2.8E+03	noncarcinogenic effects	-	2.8E+03	NA
PHENOL	1.8E+04	noncarcinogenic effects	-	1.8E+04	NA
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+00	noncarcinogenic effects	2.2E+00	1.1E+00	NA
PYRENE	2.3E+03	noncarcinogenic effects	-	2.3E+03	NA
SELENIUM	3.9E+02	noncarcinogenic effects	-	3.9E+02	NA
SILVER	3.9E+02	noncarcinogenic effects	-	3.9E+02	NA
STYRENE	1.5E+03	saturation limit	-	4.3E+03	1.5E+03
tert-BUTYL ALCOHOL	7.0E+01	carcinogenic effects	7.0E+01	-	3.2E+05
TETRACHLOROETHANE, 1,1,1,2-	3.1E+00	carcinogenic effects	3.1E+00	5.1E+02	2.0E+03
TETRACHLOROETHANE, 1,1,2,2-	4.1E-01	carcinogenic effects	4.1E-01	1.0E+03	2.0E+03
TETRACHLOROETHYLENE	4.8E-01	carcinogenic effects	4.8E-01	3.8E+01	2.3E+02
THALLIUM	5.2E+00	noncarcinogenic effects	-	5.2E+00	NA
TOLUENE	6.5E+02	noncarcinogenic effects	-	6.5E+02	6.5E+02
TOXAPHENE	4.0E-01	carcinogenic effects	4.0E-01	-	NA
TPH (gasolines)	8.0E+02	noncarcinogenic effects	-	8.0E+02	NA
TPH (middle distillates)	8.0E+02	noncarcinogenic effects	-	8.0E+02	NA

**TABLE I-1. DIRECT-EXPOSURE ACTION LEVELS
¹RESIDENTIAL EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
TPH (residual fuels)	2.3E+03	noncarcinogenic effects	-	2.3E+03	NA
TRICHLOROBENZENE, 1,2,4-	6.1E+01	noncarcinogenic effects	-	6.1E+01	NA
TRICHLOROETHANE, 1,1,1-	1.2E+03	saturation limit	-	2.0E+03	1.2E+03
TRICHLOROETHANE, 1,1,2-	7.2E-01	carcinogenic effects	7.2E-01	3.6E+01	1.8E+03
TRICHLOROETHYLENE	5.2E-01	carcinogenic effects	5.2E-01	1.6E+01	1.3E+03
TRICHLOROPHENOL, 2,4,5-	2.5E+03	noncarcinogenic effects	-	2.5E+03	NA
TRICHLOROPHENOL, 2,4,6-	6.1E+00	noncarcinogenic effects	4.4E+01	6.1E+00	NA
VANADIUM	7.8E+01	noncarcinogenic effects	-	7.8E+01	NA
VINYL CHLORIDE	1.5E-01	carcinogenic effects	1.5E-01	3.8E+01	1.2E+03
XYLENES	2.7E+02	noncarcinogenic effects	-	2.7E+02	4.2E+02
ZINC	2.3E+04	noncarcinogenic effects	-	2.3E+04	NA

Primary source: USEPA Region IX Preliminary Remediation Goals (PRGs, USEPA 2004), modified as noted below. See text for discussion.

Notes:

1. "Residential" action levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.).

See text for equations and assumptions used in models.

Final action level is lowest of individual action levels for carcinogenic effects and noncarcinogenic effects or action level for construction/trench workers if lower (see Table I-3). Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Carcinogens: Based on target cancer risk of 10⁻⁶ unless otherwise noted.

Noncarcinogens: Based on target hazard quotient of 1.0. Maximum value 1,000,000 mg/kg.

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

Direct-exposure action levels for carcinogenic PAHs, PCBs and TCE based on target excess cancer risk of 10⁻⁶ (see section 3.2.2 in text).

TPH: Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Direct exposure action levels after Massachusetts Department of Environmental Protection (see Section 5.3).

Vinyl Chloride final action level for carcinogenic effects based on alternative model presented in USEPA Region IX PRGs (USEPA 2004).

**TABLE I-2. DIRECT-EXPOSURE ACTION LEVELS
COMMERCIAL/INDUSTRIAL WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
ACENAPHTHENE	2.9E+04	noncarcinogenic effects	-	2.9E+04	NA
ACENAPHTHYLENE	6.1E+03	noncarcinogenic effects	-	6.1E+03	NA
ACETONE	5.4E+04	noncarcinogenic effects	-	5.4E+04	1.0E+05
ALDRIN	1.0E-01	carcinogenic effects	1.0E-01	1.8E+01	NA
ANTHRACENE	2.4E+05	noncarcinogenic effects	-	2.4E+05	NA
ANTIMONY	4.1E+02	noncarcinogenic effects	-	4.1E+02	NA
ARSENIC	1.9E+00	carcinogenic effects	1.9E+00	3.1E+02	NA
BARIUM	1.2E+04	trench/construction worker	-	6.7E+04	NA
BENZENE	1.4E+00	carcinogenic effects	1.4E+00	1.2E+02	8.7E+02
BENZO(a)ANTHRACENE	2.1E+01	carcinogenic effects	2.1E+01	-	NA
BENZO(a)PYRENE	2.1E+00	carcinogenic effects	2.1E+00	-	NA
BENZO(b)FLUORANTHENE	2.1E+01	carcinogenic effects	2.1E+01	-	NA
BENZO(g,h,i)PERYLENE	2.2E+04	noncarcinogenic effects	-	2.2E+04	NA
BENZO(k)FLUORANTHENE	2.1E+02	carcinogenic effects	2.1E+02	-	NA
BERYLLIUM	4.9E+02	trench/construction worker	2.2E+03	1.9E+03	NA
BIPHENYL, 1,1-	2.3E+04	noncarcinogenic effects	-	2.3E+04	NA
BIS(2-CHLOROETHYL)ETHER	5.3E-01	carcinogenic effects	5.3E-01	-	9.6E+03
BIS(2-CHLOROISOPROPYL)ETHER	7.3E+00	carcinogenic effects	7.3E+00	4.0E+03	7.9E+02
BIS(2-ETHYLHEXYL)PHTHALATE	1.2E+02	carcinogenic effects	1.2E+02	1.2E+04	NA
BORON	1.2E+05	noncarcinogenic effects	-	1.2E+05	NA
BROMODICHLOROMETHANE	1.8E+00	carcinogenic effects	1.8E+00	8.0E+02	3.0E+03
BROMOFORM	2.2E+02	carcinogenic effects	2.2E+02	1.2E+04	NA
BROMOMETHANE	1.3E+01	noncarcinogenic effects	-	1.3E+01	3.1E+03
CADMIUM	5.1E+02	noncarcinogenic effects	3.0E+03	5.1E+02	NA
CARBON TETRACHLORIDE	5.4E-01	carcinogenic effects	5.4E-01	7.2E+00	1.1E+03
CHLORDANE	6.5E+00	carcinogenic effects	6.5E+00	4.0E+02	NA
CHLOROANILINE, p-	2.5E+03	noncarcinogenic effects	-	2.5E+03	NA
CHLOROBENZENE	5.2E+02	noncarcinogenic effects	-	5.2E+02	6.8E+02
CHLOROETHANE	6.4E+00	carcinogenic effects	6.4E+00	1.9E+04	1.6E+03
CHLOROFORM	4.6E-01	carcinogenic effects	4.6E-01	1.8E+02	2.9E+03
CHLOROMETHANE	1.5E+02	noncarcinogenic effects	-	1.5E+02	4.1E+03
CHLOROPHENOL, 2-	2.3E+02	noncarcinogenic effects	-	2.3E+02	5.5E+04
CHROMIUM (Total)	2.2E+02	trench/construction worker	4.5E+02	-	NA
CHROMIUM III	1.0E+06	maximum	-	1.0E+06	NA
CHROMIUM VI	3.1E+01	trench/construction worker	6.4E+01	2.5E+03	NA
CHRYSENE	2.1E+03	carcinogenic effects	2.1E+03	-	NA

**TABLE I-2. DIRECT-EXPOSURE ACTION LEVELS
COMMERCIAL/INDUSTRIAL WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
COBALT	5.2E+02	trench/construction worker	1.9E+03	1.3E+04	NA
COPPER	4.1E+04	noncarcinogenic effects	-	4.1E+04	NA
CYANIDE (Free)	1.2E+04	noncarcinogenic effects	-	1.2E+04	NA
DIBENZO(a,h)ANTHTRACENE	2.1E+00	carcinogenic effects	2.1E+00	-	NA
DIBROMO-3-CHLOROPROPANE, 1,2-	2.0E+00	carcinogenic effects	2.0E+00	1.1E+01	1.1E+03
DIBROMOCHLOROMETHANE	2.5E+00	carcinogenic effects	2.5E+00	1.5E+03	NA
DIBROMOETHANE, 1,2-	7.2E-02	carcinogenic effects	7.2E-02	1.4E+02	NA
DICHLOROBENZENE, 1,2-	6.0E+02	saturation limit	-	4.0E+03	6.0E+02
DICHLOROBENZENE, 1,3-	6.0E+02	saturation limit	-	2.1E+03	6.0E+02
DICHLOROBENZENE, 1,4-	7.8E+00	carcinogenic effects	7.8E+00	1.8E+03	NA
DICHLOROBENZIDINE, 3,3-	3.8E+00	carcinogenic effects	3.8E+00	-	NA
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.0E+01	carcinogenic effects	1.0E+01	-	NA
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.0E+01	carcinogenic effects	1.0E+01	-	NA
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	7.0E+00	carcinogenic effects	7.0E+00	4.3E+02	NA
DICHLOROETHANE, 1,1-	1.7E+03	noncarcinogenic effects	-	1.7E+03	1.7E+03
DICHLOROETHANE, 1,2-	6.0E-01	carcinogenic effects	6.0E-01	2.8E+01	1.8E+03
DICHLOROETHYLENE, 1,1-	4.1E+02	noncarcinogenic effects	-	4.1E+02	1.5E+03
DICHLOROETHYLENE, Cis 1,2-	1.4E+02	noncarcinogenic effects	-	1.4E+02	1.2E+03
DICHLOROETHYLENE, Trans 1,2-	2.3E+02	noncarcinogenic effects	-	2.3E+02	3.1E+03
DICHLOROPHENOL, 2,4-	1.8E+03	noncarcinogenic effects	-	1.8E+03	NA
DICHLOROPROPANE, 1,2-	7.3E-01	carcinogenic effects	7.3E-01	2.0E+01	1.1E+03
DICHLOROPROPENE, 1,3-	1.7E+00	carcinogenic effects	1.7E+00	5.3E+01	1.4E+03
DIELDRIN	1.1E-01	carcinogenic effects	1.1E-01	3.1E+01	NA
DIETHYLPHTHALATE	4.9E+05	noncarcinogenic effects	-	4.9E+05	NA
DIMETHYLPHENOL, 2,4-	1.2E+04	noncarcinogenic effects	-	1.2E+04	NA
DIMETHYLPHTHALATE	1.0E+06	maximum	-	1.0E+06	NA
DINITROPHENOL, 2,4-	1.2E+03	noncarcinogenic effects	-	1.2E+03	NA
DINITROTOLUENE, 2,4-	8.6E+02	carcinogenic effects	8.6E+02	1.2E+03	NA
DIOXANE, 1,4-	1.6E+02	carcinogenic effects	1.6E+02	-	NA
DIOXIN (2,3,7,8-TCDD)	1.6E-05	carcinogenic effects	1.6E-05	-	NA
ENDOSULFAN	3.7E+03	noncarcinogenic effects	-	3.7E+03	NA
ENDRIN	1.8E+02	noncarcinogenic effects	-	1.8E+02	NA
ETHYLBENZENE	4.0E+02	saturation limit	-	7.3E+03	4.0E+02
FLUORANTHENE	2.2E+04	noncarcinogenic effects	-	2.2E+04	NA
FLUORENE	2.6E+04	noncarcinogenic effects	-	2.6E+04	NA
HEPTACHLOR	3.8E-01	carcinogenic effects	3.8E-01	3.1E+02	NA

**TABLE I-2. DIRECT-EXPOSURE ACTION LEVELS
COMMERCIAL/INDUSTRIAL WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
HEPTACHLOR EPOXIDE	1.9E-01	carcinogenic effects	1.9E-01	8.0E+00	NA
HEXACHLOROBENZENE	1.1E+00	carcinogenic effects	1.1E+00	4.9E+02	NA
HEXACHLOROBUTADIENE	2.2E+01	carcinogenic effects	2.2E+01	1.8E+02	NA
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	1.7E+00	carcinogenic effects	1.7E+00	2.4E+02	NA
HEXACHLOROETHANE	1.2E+02	carcinogenic effects	1.2E+02	6.2E+02	NA
INDENO(1,2,3-cd)PYRENE	2.1E+01	carcinogenic effects	2.1E+01	-	NA
LEAD	7.5E+02	USEPA Region IX PRG	-	-	NA
MERCURY	1.6E+02	noncarcinogenic effects	-	1.6E+02	NA
METHOXYCHLOR	3.1E+03	noncarcinogenic effects	-	3.1E+03	NA
METHYL ETHYL KETONE	3.4E+04	saturation limit	-	1.1E+05	3.4E+04
METHYL ISOBUTYL KETONE	1.7E+04	saturation limit	-	4.7E+04	1.7E+04
METHYL MERCURY	6.2E+01	noncarcinogenic effects	-	6.2E+01	NA
METHYL TERT BUTYL ETHER	7.0E+01	carcinogenic effects	7.0E+01	2.0E+04	2.1E+04
METHYLENE CHLORIDE	2.1E+01	carcinogenic effects	2.1E+01	9.1E+03	2.4E+03
METHYLNAPHTHALENE (total 1- & 2-)	7.2E+03	noncarcinogenic effects	-	7.2E+03	NA
MOLYBDENUM	5.1E+03	noncarcinogenic effects	-	5.1E+03	NA
NAPHTHALENE	1.9E+02	noncarcinogenic effects	-	1.9E+02	NA
NICKEL	2.0E+04	noncarcinogenic effects	-	2.0E+04	NA
PENTACHLOROPHENOL	9.0E+00	carcinogenic effects	9.0E+00	1.2E+04	NA
PERCHLORATE	1.0E+02	noncarcinogenic effects	-	1.0E+02	NA
PHENANTHRENE	2.9E+04	noncarcinogenic effects	-	2.9E+04	NA
PHENOL	1.8E+05	noncarcinogenic effects	-	1.8E+05	NA
POLYCHLORINATED BIPHENYLS (PCBs)	7.4E+00	carcinogenic effects	7.4E+00	1.1E+01	NA
PYRENE	2.9E+04	noncarcinogenic effects	-	2.9E+04	NA
SELENIUM	5.1E+03	noncarcinogenic effects	-	5.1E+03	NA
SILVER	5.1E+03	noncarcinogenic effects	-	5.1E+03	NA
STYRENE	1.5E+03	saturation limit	-	1.8E+04	1.5E+03
tert-BUTYL ALCOHOL	1.8E+02	carcinogenic effects	1.8E+02	-	3.2E+05
TETRACHLOROETHANE, 1,1,1,2-	7.2E+00	carcinogenic effects	7.2E+00	2.0E+03	2.0E+03
TETRACHLOROETHANE, 1,1,2,2-	9.3E-01	carcinogenic effects	9.3E-01	4.0E+03	2.0E+03
TETRACHLOROETHYLENE	1.3E+00	carcinogenic effects	1.3E+00	1.3E+02	2.3E+02
THALLIUM	6.7E+01	noncarcinogenic effects	-	6.7E+01	NA
TOLUENE	6.5E+02	saturation limit	-	2.2E+03	6.5E+02
TOXAPHENE	1.4E+00	carcinogenic effects	1.4E+00	-	NA
TPH (gasolines)	3.7E+03	noncarcinogenic effects	-	3.7E+03	NA
TPH (middle distillates)	3.7E+03	noncarcinogenic effects	-	3.7E+03	NA

**TABLE I-2. DIRECT-EXPOSURE ACTION LEVELS
COMMERCIAL/INDUSTRIAL WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
TPH (residual fuels)	3.1E+04	noncarcinogenic effects	-	3.1E+04	NA
TRICHLOROBENZENE, 1,2,4-	2.1E+02	noncarcinogenic effects	-	2.1E+02	NA
TRICHLOROETHANE, 1,1,1-	1.2E+03	saturation limit	-	6.9E+03	1.2E+03
TRICHLOROETHANE, 1,1,2-	1.6E+00	carcinogenic effects	1.6E+00	1.3E+02	1.8E+03
TRICHLOROETHYLENE	1.1E+00	carcinogenic effects	1.1E+00	1.1E+02	1.3E+03
TRICHLOROPHENOL, 2,4,5-	1.1E+04	noncarcinogenic effects	-	1.1E+04	NA
TRICHLOROPHENOL, 2,4,6-	6.2E+01	noncarcinogenic effects	1.6E+02	6.2E+01	NA
VANADIUM	1.0E+03	noncarcinogenic effects	-	1.0E+03	NA
VINYL CHLORIDE	7.4E-01	carcinogenic effects	7.4E-01	1.4E+02	1.2E+03
XYLENES	4.2E+02	saturation limit	-	8.9E+02	4.2E+02
ZINC	3.1E+05	noncarcinogenic effects	-	3.1E+05	NA

Primary source: USEPA Region IX Preliminary Remediation Goals (PRGs, USEPA 2004), modified as noted below. See text for discussion.

Notes:

See text for equations and assumptions used in models.

Final action level is lowest of individual action levels for carcinogenic effects and noncarcinogenic effects or action level for construction/trench workers if lower (see Table I-3). Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Carcinogens: Based on target cancer risk of 10^{-6} unless otherwise noted.

Noncarcinogens: Based on target hazard quotient of 1.0. Maximum value 1,000,000 mg/kg.

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

Direct-exposure action levels for carcinogenic PAHs, PCBs and TCE based on target excess cancer risk of 10^{-5} (see section 3.2.2 in text).

TPH: Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Direct exposure action levels after Massachusetts Department of Environmental Protection (see text).

**TABLE I-3. DIRECT-EXPOSURE ACTION LEVELS
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
ACENAPHTHENE	1.7E+05	noncarcinogenic effects	-	1.7E+05	NA
ACENAPHTHYLENE	5.7E+04	noncarcinogenic effects	-	5.7E+04	NA
ACETONE	1.0E+05	saturation limit	-	5.9E+05	1.0E+05
ALDRIN	1.2E+01	carcinogenic effects	1.2E+01	6.0E+01	NA
ANTHRACENE	1.0E+06	maximum	-	1.0E+06	NA
ANTIMONY	1.5E+03	noncarcinogenic effects	-	1.5E+03	NA
ARSENIC	1.8E+02	carcinogenic effects	1.8E+02	1.2E+03	NA
BARIIUM	1.2E+04	noncarcinogenic effects	-	1.2E+04	NA
BENZENE	5.9E+02	carcinogenic effects	5.9E+02	1.4E+03	8.7E+02
BENZO(a)ANTHRACENE	2.4E+02	carcinogenic effects	2.4E+02	-	NA
BENZO(a)PYRENE	2.4E+01	carcinogenic effects	2.4E+01	-	NA
BENZO(b)FLUORANTHENE	2.4E+02	carcinogenic effects	2.4E+02	-	NA
BENZO(g,h,i)PERYLENE	7.0E+04	noncarcinogenic effects	-	7.0E+04	NA
BENZO(k)FLUORANTHENE	2.4E+03	carcinogenic effects	2.4E+03	-	NA
BERYLLIUM	4.9E+02	noncarcinogenic effects	1.1E+03	4.9E+02	NA
BIPHENYL, 1,1-	1.4E+05	noncarcinogenic effects	-	1.4E+05	NA
BIS(2-CHLOROETHYL)ETHER	1.6E+02	carcinogenic effects	1.6E+02	-	9.6E+03
BIS(2-CHLOROISOPROPYL)ETHER	7.9E+02	saturation limit	2.3E+03	4.1E+04	7.9E+02
BIS(2-ETHYLHEXYL)PHTHALATE	1.4E+04	carcinogenic effects	1.4E+04	4.0E+04	NA
BORON	2.3E+05	noncarcinogenic effects	-	2.3E+05	NA
BROMODICHLOROMETHANE	7.4E+02	carcinogenic effects	7.4E+02	9.2E+03	3.0E+03
BROMOFORM	2.6E+04	carcinogenic effects	2.6E+04	4.0E+04	NA
BROMOMETHANE	1.6E+02	noncarcinogenic effects	-	1.6E+02	3.1E+03
CADMIUM	1.5E+03	carcinogenic effects	1.5E+03	1.9E+03	NA
CARBON TETRACHLORIDE	8.8E+01	noncarcinogenic effects	2.3E+02	8.8E+01	1.1E+03
CHLORDANE	7.9E+02	carcinogenic effects	7.9E+02	1.3E+03	NA
CHLOROANILINE, p-	8.0E+03	noncarcinogenic effects	-	8.0E+03	NA
CHLOROBENZENE	6.8E+02	saturation limit	-	6.2E+03	6.8E+02
CHLOROETHANE	1.6E+03	saturation limit	2.8E+03	2.1E+05	1.6E+03
CHLOROFORM	2.1E+02	carcinogenic effects	2.1E+02	2.2E+03	2.9E+03
CHLOROMETHANE	1.9E+03	noncarcinogenic effects	-	1.9E+03	4.1E+03
CHLOROPHENOL, 2-	2.6E+03	noncarcinogenic effects	-	2.6E+03	5.5E+04
CHROMIUM (Total)	2.2E+02	carcinogenic effects	2.2E+02	-	NA
CHROMIUM III	1.0E+06	maximum	-	1.0E+06	NA
CHROMIUM VI	3.1E+01	carcinogenic effects	3.1E+01	2.0E+02	NA
CHRYSENE	2.4E+04	carcinogenic effects	2.4E+04	-	NA

**TABLE I-3. DIRECT-EXPOSURE ACTION LEVELS
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
COBALT	5.2E+02	noncarcinogenic effects	9.4E+02	5.2E+02	NA
COPPER	1.5E+05	noncarcinogenic effects	-	1.5E+05	NA
CYANIDE (Free)	4.1E+04	noncarcinogenic effects	-	4.1E+04	NA
DIBENZO(a,h)ANTHTRACENE	2.4E+01	carcinogenic effects	2.4E+01	-	NA
DIBROMO-3-CHLOROPROPANE, 1,2-	9.4E+01	noncarcinogenic effects	2.8E+02	9.4E+01	1.1E+03
DIBROMOCHLOROMETHANE	9.6E+02	carcinogenic effects	9.6E+02	1.6E+04	NA
DIBROMOETHANE, 1,2-	2.9E+01	carcinogenic effects	2.9E+01	1.7E+03	NA
DICHLOROBENZENE, 1,2-	6.0E+02	saturation limit	-	4.6E+04	6.0E+02
DICHLOROBENZENE, 1,3-	6.0E+02	saturation limit	-	2.2E+04	6.0E+02
DICHLOROBENZENE, 1,4-	3.0E+03	carcinogenic effects	3.0E+03	2.0E+04	NA
DICHLOROBENZIDINE, 3,3-	4.4E+02	carcinogenic effects	4.4E+02	-	NA
DICHLORODIPHENYLDICHLOROETHANE (DDD)	1.2E+03	carcinogenic effects	1.2E+03	-	NA
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	1.2E+03	carcinogenic effects	1.2E+03	-	NA
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	8.7E+02	carcinogenic effects	8.7E+02	1.5E+03	NA
DICHLOROETHANE, 1,1-	1.7E+03	saturation limit	-	2.0E+04	1.7E+03
DICHLOROETHANE, 1,2-	2.6E+02	carcinogenic effects	2.6E+02	3.4E+02	1.8E+03
DICHLOROETHYLENE, 1,1-	1.5E+03	saturation limit	-	5.0E+03	1.5E+03
DICHLOROETHYLENE, Cis 1,2-	1.2E+03	saturation limit	-	1.8E+03	1.2E+03
DICHLOROETHYLENE, Trans 1,2-	2.8E+03	noncarcinogenic effects	-	2.8E+03	3.1E+03
DICHLOROPHENOL, 2,4-	6.0E+03	noncarcinogenic effects	-	6.0E+03	NA
DICHLOROPROPANE, 1,2-	2.4E+02	noncarcinogenic effects	3.1E+02	2.4E+02	1.1E+03
DICHLOROPROPENE, 1,3-	6.6E+02	noncarcinogenic effects	6.8E+02	6.6E+02	1.4E+03
DIELDRIN	1.2E+01	carcinogenic effects	1.2E+01	1.0E+02	NA
DIETHYLPHTHALATE	1.0E+06	maximum	-	1.0E+06	NA
DIMETHYLPHENOL, 2,4-	4.0E+04	noncarcinogenic effects	-	4.0E+04	NA
DIMETHYLPHTHALATE	1.0E+06	maximum	-	1.0E+06	NA
DINITROPHENOL, 2,4-	4.0E+03	noncarcinogenic effects	-	4.0E+03	NA
DINITROTOLUENE, 2,4-	4.0E+03	noncarcinogenic effects	1.0E+05	4.0E+03	NA
DIOXANE, 1,4-	1.8E+04	carcinogenic effects	1.8E+04	-	NA
DIOXIN (2,3,7,8-TCDD)	2.0E-03	carcinogenic effects	2.0E-03	-	NA
ENDOSULFAN	1.2E+04	noncarcinogenic effects	-	1.2E+04	NA
ENDRIN	6.0E+02	noncarcinogenic effects	-	6.0E+02	NA
ETHYLBENZENE	4.0E+02	saturation limit	-	7.9E+04	4.0E+02
FLUORANTHENE	7.0E+04	noncarcinogenic effects	-	7.0E+04	NA
FLUORENE	1.3E+05	noncarcinogenic effects	-	1.3E+05	NA
HEPTACHLOR	4.4E+01	carcinogenic effects	4.4E+01	1.0E+03	NA

**TABLE I-3. DIRECT-EXPOSURE ACTION LEVELS
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
HEPTACHLOR EPOXIDE	2.2E+01	carcinogenic effects	2.2E+01	2.6E+01	NA
HEXACHLOROBENZENE	1.2E+02	carcinogenic effects	1.2E+02	1.6E+03	NA
HEXACHLOROBUTADIENE	6.0E+02	noncarcinogenic effects	2.6E+03	6.0E+02	NA
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.1E+02	carcinogenic effects	2.1E+02	8.3E+02	NA
HEXACHLOROETHANE	2.0E+03	noncarcinogenic effects	1.4E+04	2.0E+03	NA
INDENO(1,2,3-cd)PYRENE	2.4E+02	carcinogenic effects	2.4E+02	-	NA
LEAD	7.5E+02	USEPA Region IX PRG	-	7.5E+02	NA
MERCURY	5.7E+02	noncarcinogenic effects	-	5.7E+02	NA
METHOXYCHLOR	1.0E+04	noncarcinogenic effects	-	1.0E+04	NA
METHYL ETHYL KETONE	3.4E+04	saturation limit	-	9.9E+05	3.4E+04
METHYL ISOBUTYL KETONE	1.7E+04	saturation limit	-	2.5E+05	1.7E+04
METHYL MERCURY	2.0E+02	noncarcinogenic effects	-	2.0E+02	NA
METHYL TERT BUTYL ETHER	2.1E+04	saturation limit	2.8E+04	2.4E+05	2.1E+04
METHYLENE CHLORIDE	2.4E+03	saturation limit	8.2E+03	8.5E+04	2.4E+03
METHYLNAPHTHALENE (total 1- & 2-)	6.4E+04	noncarcinogenic effects	-	6.4E+04	NA
MOLYBDENUM	1.9E+04	noncarcinogenic effects	-	1.9E+04	NA
NAPHTHALENE	2.3E+03	noncarcinogenic effects	-	2.3E+03	NA
NICKEL	7.7E+04	noncarcinogenic effects	-	7.7E+04	NA
PENTACHLOROPHENOL	9.8E+02	carcinogenic effects	9.8E+02	3.5E+04	NA
PERCHLORATE	3.9E+02	noncarcinogenic effects	-	3.9E+02	NA
PHENANTHRENE	1.4E+05	noncarcinogenic effects	-	1.4E+05	NA
PHENOL	6.0E+05	noncarcinogenic effects	-	6.0E+05	NA
POLYCHLORINATED BIPHENYLS (PCBs)	3.4E+01	noncarcinogenic effects	8.4E+01	3.4E+01	NA
PYRENE	1.1E+05	noncarcinogenic effects	-	1.1E+05	NA
SELENIUM	1.9E+04	noncarcinogenic effects	-	1.9E+04	NA
SILVER	1.9E+04	noncarcinogenic effects	-	1.9E+04	NA
STYRENE	1.5E+03	saturation limit	-	1.9E+05	1.5E+03
tert-BUTYL ALCOHOL	5.6E+04	carcinogenic effects	5.6E+04	-	3.2E+05
TETRACHLOROETHANE, 1,1,1,2-	2.0E+03	saturation limit	2.8E+03	2.2E+04	2.0E+03
TETRACHLOROETHANE, 1,1,2,2-	3.6E+02	carcinogenic effects	3.6E+02	4.3E+04	2.0E+03
TETRACHLOROETHYLENE	2.3E+02	saturation limit	3.7E+02	1.5E+03	2.3E+02
THALLIUM	2.6E+02	noncarcinogenic effects	-	2.6E+02	NA
TOLUENE	6.5E+02	saturation limit	-	2.7E+04	6.5E+02
TOXAPHENE	1.7E+02	carcinogenic effects	1.7E+02	-	NA
TPH (gasolines)	3.0E+04	noncarcinogenic effects	-	3.0E+04	NA
TPH (middle distillates)	3.0E+04	noncarcinogenic effects	-	3.0E+04	NA

**TABLE I-3. DIRECT-EXPOSURE ACTION LEVELS
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

CONTAMINANT	Final Action Level (mg/kg)	Basis	Carcinogens (mg/kg)	Noncarcinogens (mg/kg)	Saturation (mg/kg)
TPH (residual fuels)	1.1E+05	noncarcinogenic effects	-	1.1E+05	NA
TRICHLOROBENZENE, 1,2,4-	2.5E+03	noncarcinogenic effects	-	2.5E+03	NA
TRICHLOROETHANE, 1,1,1-	1.2E+03	saturation limit	-	8.1E+04	1.2E+03
TRICHLOROETHANE, 1,1,2-	6.6E+02	carcinogenic effects	6.6E+02	1.5E+03	1.8E+03
TRICHLOROETHYLENE	4.9E+01	carcinogenic effects	4.9E+01	7.4E+02	1.3E+03
TRICHLOROPHENOL, 2,4,5-	9.3E+04	noncarcinogenic effects	-	9.3E+04	NA
TRICHLOROPHENOL, 2,4,6-	2.0E+02	noncarcinogenic effects	1.8E+04	2.0E+02	NA
VANADIUM	3.9E+03	noncarcinogenic effects	-	3.9E+03	NA
VINYL CHLORIDE	2.3E+02	carcinogenic effects	2.3E+02	1.6E+03	1.2E+03
XYLENES	4.2E+02	saturation limit	-	1.1E+04	4.2E+02
ZINC	1.0E+06	maximum	-	1.0E+06	NA

Primary source: USEPA Region IX Preliminary Remediation Goals (PRGs, USEPA 2002), modified as noted below. See text for discussion.

Notes:

See text for equations and assumptions used in models.

Final action level is lowest of individual action levels for carcinogenic effects and noncarcinogenic effects.

Saturation limit used as upper limit for volatile organic compounds that are liquid at ambient conditions (see text).

Carcinogens: Based on target cancer risk of 10^{-5} .

Noncarcinogens: Based on target hazard quotient of 1.0. Maximum value 1,000,000 mg/kg.

Saturation: Theoretical soil saturation level in the absence of free product; calculated for volatile organic compounds that are liquids under ambient conditions (refer to Table H).

TPH: Total Petroleum Hydrocarbons. See text for discussion of different TPH categories. Direct exposure action levels after Massachusetts Department of Environmental Protection (see text).

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS
 (For general reference only. May not be adequately comprehensive for some chemicals.
 Some noted effects may be insignificant. Refer to original documents for additional information.)

CONTAMINANT	Target Organs And Health Effects													Other
	^a Carcinogen	^b Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	^c Skin	
ACENAPHTHENE	NA	5,6						4					4	
ACENAPHTHYLENE	D					5,6	4						4	= Fluorene
ACETONE	D	5,6				3			5,6					
ALDRIN	B2	6								3				
ANTHRACENE	D						4						4	
ANTIMONY	D		4			3,4	5,7				4	1,3,4		hair loss (4)
ARSENIC	A	3,4,6	1,2,4	1,2,3,4		3,4,6				1,2,3,4			1,3,4,6	
BARIUM	D		4			5			6		5			hypertension (6)
BENZENE	A	3		1,2,4		1,2,3,4	3			1,2				
BENZO(a)ANTHRACENE	B2						4						4	No chronic toxicity factors.
BENZO(a)PYRENE	B2						4				3		4	No chronic toxicity factors.
BENZO(b)FLUORANTHENE	B2						4						4	No chronic toxicity factors.
BENZO(g,h,i)PERYLENE	D	5,6				5,6	4		5,6				4	= Fluoranthene
BENZO(k)FLUORANTHENE	B2						4						4	No chronic toxicity factors.
BERYLLIUM	B1	1,6						2	1			1,2,3,4,6	3	
BIPHENYL, 1,1-	D	3							6	3				
BIS(2-CHLOROETHYL)ETHER	B2									4	4			No chronic toxicity factors.
BIS(2-CHLOROISOPROPYL)ETHER	NA						6							
BIS(2-ETHYLHEXYL)PHTHALATE	NA	7,8									8			No chronic toxicity factors.
BORON	D										4,6	5		
BROMODICHLOROMETHANE	B2	4							4,6					
BROMOFORM	B2	3,4,6							4	3,4				
BROMOMETHANE	D	3,5,6	3	1,2					3,4	1,2,3,4		1,2,3,4,5,6		
CADMIUM	B1/D								1,2,3,4,5,6			1,2,3,4		bone loss (1,4)
CARBON TETRACHLORIDE	B2	1,2,4,6		1,2					4	1,2				
CHLORDANE	B2	3,4,6						3,5		4				
CHLOROANILINE, p-	NA	3,6						5	3				3	
CHLOROBENZENE	D	1,2,3,5,6					3		1,2,3,4,5	3	1,2			
CHLOROETHANE	B	1,2		1,2,4										
CHLOROFORM	B2	1,2,3,4,6		1,2					1,2,3,4					
CHLOROMETHANE	C/D			4						3	3,4			
CHLOROPHENOL, 2-	D	1,4		1							1,5,6			
CHROMIUM (Total)	-													
CHROMIUM III	D												3	
CHROMIUM VI	A						1				2	1,6		
CHRYSENE	B2							4					4	No chronic toxicity factors.
COBALT	NA		3										3	hearing (3)
COPPER	D	8											1,4	3
CYANIDE (Free)	D		1,4		1,4,6		4			1,5,6		4		
DIBENZO(a,h)ANTHTRACENE	B2						4						3,4	
DIBROMO-3-CHLOROPROPANE, 1,2-		1		1					3		1,3,4,5,6	1		
DIBROMOCHLOROMETHANE	C	6												

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS
 (For general reference only. May not be adequately comprehensive for some chemicals.
 Some noted effects may be insignificant. Refer to original documents for additional information.)

CONTAMINANT	Target Organs And Health Effects													Other
	^a Carcinogen	^b Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	^c Skin	
DIBROMOETHANE, 1,2-	B2			4						4	1,3			
DICHLOROBENZENE, 1,2-	D	3						3				3		
DICHLOROBENZENE, 1,3-	D	3						3						
DICHLOROBENZENE, 1,4-	C	1,2,3,6						1,2,3	1,2	6	1,2			
DICHLOROBENZIDINE, 3,3-	B2	3											No chronic toxicity factors.	
DICHLORODIPHENYLDICHLOROETHANE (DDD)	B2												No chronic toxicity factors.	
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	B2												No chronic toxicity factors.	
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	B2	3,4,6							3	3				
DICHLOROETHANE, 1,1-	C	3						3,4,5,7						
DICHLOROETHANE, 1,2-	B2	1,2												
DICHLOROETHYLENE, 1,1-	C/D	1,2,3,4,5,6						3	4		4			
DICHLOROETHYLENE, Cis 1,2-	D	4					4,5,7							
DICHLOROETHYLENE, Trans 1,2-	D	4					5,6				4			
DICHLOROPHENOL, 2,4-	E							5						
DICHLOROPROPANE, 1,2-	B2	3						3			5			
DICHLOROPROPENE, 1,3-	B2	6									4			
DIELDRIN	B2	6							3					
DIETHYLPHTHALATE	D			6						4				
DIMETHYLPHENOL, 2,4-	NA						5,6		5,6					
DIMETHYLPHTHALATE	D													
DINITROPHENOL, 2,4-	NA					3,6			3					
DINITROTOLUENE, 2,4-	B2	6	3				3		3,6					
DIOXANE, 1,4-	B2	1,2	1,2					1,2						
DIOXIN (2,3,7,8-TCDD)	NA	1,2,4		1,2,4	1,2,4	1,2	4			1,2,4	1,2,4	4	No chronic toxicity factors.	
ENDOSULFAN	NA	4		4,6		6	4	4,5,6	4,6	4				
ENDRIN	D	5,6		4				6	5					
ETHYLBENZENE	NA	1,2,5,6		1,2,4,6	1,2			1,2,5,6	3	3		3		
FLUORANTHENE	D	5,6					4	5,6				4		
FLUORENE	D						4	5,6				4		
HEPTACHLOR	B2	6							7					
HEPTACHLOR EPOXIDE	B2	6							7					
HEXACHLOROBENZENE	B2	1,3,4,6			4	4	4	4	3,4	3			bones (4)	
HEXACHLOROBUTADIENE	C	4						4				3		
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NA	1,3,6						1,3,6						
HEXACHLOROETHANE	C	3,4						3,4,6						
INDENO(1,2,3-cd)PYRENE	B2							4				4	No chronic toxicity factors.	
LEAD	B2	3,7	7	3,7		3,7	3,7	3,7	3,7	7				
MERCURY	D			4			1	1,3	1,2,3,5,6					
METHOXYCHLOR	D	3		6				3	3	3,5,6				
METHYL ETHYL KETONE	D			6						1,3				
METHYL ISOBUTYL KETONE	NA								7					
METHYL MERCURY	C			6					1,6					

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS
 (For general reference only. May not be adequately comprehensive for some chemicals.
 Some noted effects may be insignificant. Refer to original documents for additional information.)

CONTAMINANT	Target Organs And Health Effects													
	^a Carcinogen	^b Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	^c Skin	Other
METHYL TERT BUTYL ETHER	NA	1,2,6				1,2			1,2,6					
METHYLENE CHLORIDE	B2	3,6	1,2						3	1,2				
METHYLNAPHTHALENE (total 1- & 2-)	C						5,6	4					4	= Fluorene
MOLYBDENUM	D						6							
NAPHTHALENE	C					3	3	4				1,2,6	4	
NICKEL	A/D	1,6					1,2		6			1,2,3	3	
PENTACHLOROPHENOL	B2	1,3,4,6		1,4			4	4	3,6	3,4	1	3,4		
PERCHLORATE					8		3							
PHENANTHRENE	D						5,6	4					4	= Fluorene
PHENOL	D	1,2,3	1,2	4,6					1,2,3	1,2	5			
POLYCHLORINATED BIPHENYLS (PCBs)	B2	1,3,4		1,4	4	6	4	1,4,6			1,3,4		4	
PYRENE	D							4	5,6					
SELENIUM	D	1,2,3,6	1,2				6			1,2		1,3	3,4,6	Selenosis (4,6)
SILVER	D												3,4,6	
STYRENE	C	4,5,6					5,6			1,2,3,5,6		3	3	
tert-BUTYL ALCOHOL														No chronic toxicity factors.
TETRACHLOROETHANE, 1,1,1,2-	C	6							6					
TETRACHLOROETHANE, 1,1,2,2-	C	3,4								3,4				
TETRACHLOROETHYLENE	NA	1,2,3,6							1,2,3					
THALLIUM	D	3	3			3	6			3,4	3,4		3	
TOLUENE	D	5,6		1,2,4					5,6	1,2,3,6	3	1,2,6		
TOXAPHENE	B2	4			4			4	4					
TPH (gasolines)	-													
TPH (middle distillates)	-													
TPH (residual fuels)	-													
TRICHLOROENZENE, 1,2,4-	D				5,6									
TRICHLOROETHANE, 1,1,1-	D	3,7	8							1,2				
TRICHLOROETHANE, 1,1,2-	C	6					7	8					3	
TRICHLOROETHYLENE	B2	3,4,7		4,7		1,2	4	7	3,4,7	1,2,3,4				
TRICHLOROPHENOL, 2,4,5-	NA	1,3,5,6		1					3,5,6		1			
TRICHLOROPHENOL, 2,4,6-	B2	3												
VANADIUM	D	4							4			3,4		

TABLE J. TARGET ORGANS AND CHRONIC HEALTH EFFECTS
(For general reference only. May not be adequately comprehensive for some chemicals.
Some noted effects may be insignificant. Refer to original documents for additional information.)

CONTAMINANT	Target Organs And Health Effects													Other
	^a Carcinogen	^b Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	^c Skin	
VINYL CHLORIDE	A	1,3,4,6		1,4			3,4	4		4	1,4		3	No chronic toxicity factors.
XYLENES	D									1,2,3,4,5,6		1,2		
ZINC	D		1		4		1,2,4,5,6					1		

Notes:
a. Carcinogen type as summarized in RWQCBCV 2001 and ORNL 2001 (see classification below).
b. Includes gastro-intestinal tract, liver, spleen, gall bladder, etc.
c. Includes skin sensitization but not general dermatitis or defatting of skin.
Perchlorate: Chronic effects as summarized in California DHS Perchlorate Action Level supporting document (CalDHS 2001).

Carcinogen Classification
A: Human carcinogen
B: Probable human carcinogen (B1: limited human evidence; B2 Sufficient evidence in animals and inadequate or no evidence in humans)
C: Possible human carcinogen
D: Not classifiable as to human carcinogenicity
E: Evidence of noncarcinogenicity for humans
NA: Carcinogen classification information not available

References:
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7. ORNL, 2003, Risk Assessment Information System (RAIS), Toxicity Profiles: Oak Ridge National Laboratory/U.S. Department of Energy (accessed July 2003), RAGs A Format, especially Critical Effect used for derivation of RfDs, http://risk.lsd.ornl.gov/tox/rap_toxp.shtml.
8. USEPA National Primary Drinking Water Standards (March 2001): U.S. Environmental Protection Agency, Office of Water, EPA 816-F-01-007, www.epa.gov/safewater. (Selectively used.)
For additional online references, see also: Hazardous Substances (On-line) Database: U.S. National Library of Medicine, Toxicology Data Network, <http://toxnet.nlm.nih.gov>.

**TABLE K. SOIL ACTION LEVELS FOR
TERRESTRIAL ECOTOXICITY CONCERNS.**

CONTAMINANT	Urban Area Ecotoxicity Criteria (mg/kg)
ACENAPHTHENE	-
ACENAPHTHYLENE	-
ACETONE	-
ALDRIN	3.5E-01
ANTHRACENE	4.0E+01
ANTIMONY	2.0E+01
ARSENIC	2.0E+01
BARIUM	7.5E+02
BENZENE	2.5E+01
BENZO(a)ANTHRACENE	4.0E+01
BENZO(a)PYRENE	4.0E+01
BENZO(b)FLUORANTHENE	-
BENZO(g,h,i)PERYLENE	4.0E+01
BENZO(k)FLUORANTHENE	4.0E+01
BERYLLIUM	4.0E+00
BIPHENYL, 1,1-	-
BIS(2-CHLOROETHYL)ETHER	-
BIS(2-CHLOROISOPROPYL)ETHER	-
BIS(2-ETHYLHEXYL)PHTHALATE	-
BORON	1.6E+00
BROMODICHLOROMETHANE	-
BROMOFORM	-
BROMOMETHANE	-
CADMIUM	1.2E+01
CARBON TETRACHLORIDE	-
CHLORDANE	-
CHLOROANILINE, p-	-
CHLOROBENZENE	3.0E+01
CHLOROETHANE	-
CHLOROFORM	-
CHLOROMETHANE	-
CHLOROPHENOL, 2-	1.0E+01
CHROMIUM (Total)	-
CHROMIUM III	7.5E+02
CHROMIUM VI	8.0E+00
CHRYSENE	4.0E+01
COBALT	4.0E+01
COPPER	2.3E+02
CYANIDE (Free)	-
DIBENZO(a,h)ANTHRACENE	-
DIBROMO-3-CHLOROPROPANE, 1,2-	-
DIBROMOCHLOROMETHANE	-
DIBROMOETHANE, 1,2-	-
DICHLOROBENZENE, 1,2-	3.0E+01
DICHLOROBENZENE, 1,3-	3.0E+01
DICHLOROBENZENE, 1,4-	3.0E+01
DICHLOROBENZIDINE, 3,3-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	4.0E+00
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	4.0E+00
DICHLOROETHANE, 1,1-	-
DICHLOROETHANE, 1,2-	6.0E+01

**TABLE K. SOIL ACTION LEVELS FOR
TERRESTRIAL ECOTOXICITY CONCERNS.**

CONTAMINANT	Urban Area Ecotoxicity Criteria (mg/kg)
DICHLOROETHYLENE, 1,1-	-
DICHLOROETHYLENE, Cis 1,2-	-
DICHLOROETHYLENE, Trans 1,2-	-
DICHLOROPHENOL, 2,4-	1.0E+01
DICHLOROPROPANE, 1,2-	-
DICHLOROPROPENE, 1,3-	-
DIELDRIN	4.0E+00
DIETHYLPHTHALATE	-
DIMETHYLPHENOL, 2,4-	-
DIMETHYLPHTHALATE	-
DINITROPHENOL, 2,4-	-
DINITROTOLUENE, 2,4-	-
DIOXANE, 1,4-	-
DIOXIN (2,3,7,8-TCDD)	-
ENDOSULFAN	-
ENDRIN	6.0E-02
ETHYLBENZENE	-
FLUORANTHENE	4.0E+01
FLUORENE	-
HEPTACHLOR	-
HEPTACHLOR EPOXIDE	-
HEXACHLOROBENZENE	3.0E+01
HEXACHLOROBUTADIENE	-
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.0E+00
HEXACHLOROETHANE	-
INDENO(1,2,3-cd)PYRENE	4.0E+01
LEAD	2.0E+02
MERCURY	1.0E+01
METHOXYCHLOR	-
METHYL ETHYL KETONE	-
METHYL ISOBUTYL KETONE	-
METHYL MERCURY	1.0E+01
METHYL TERT BUTYL ETHER	-
METHYLENE CHLORIDE	-
METHYLNAPHTHALENE (total 1- & 2-)	-
MOLYBDENUM	4.0E+01
NAPHTHALENE	4.0E+01
NICKEL	1.5E+02
PENTACHLOROPHENOL	5.0E+00
PERCHLORATE	-
PHENANTHRENE	4.0E+01
PHENOL	4.0E+01
POLYCHLORINATED BIPHENYLS (PCBs)	-
PYRENE	-
SELENIUM	1.0E+01
SILVER	2.0E+01
STYRENE	-
tert-BUTYL ALCOHOL	-
TETRACHLOROETHANE, 1,1,1,2-	-
TETRACHLOROETHANE, 1,1,2,2-	-
TETRACHLOROETHYLENE	-
THALLIUM	-

**TABLE K. SOIL ACTION LEVELS FOR
TERRESTRIAL ECOTOXICITY CONCERNS.**

CONTAMINANT	Urban Area Ecotoxicity Criteria (mg/kg)
TOLUENE	-
TOXAPHENE	-
TPH (gasolines)	-
TPH (middle distillates)	-
TPH (residual fuels)	-
TRICHLOROBENZENE, 1,2,4-	3.0E+01
TRICHLOROETHANE, 1,1,1-	-
TRICHLOROETHANE, 1,1,2-	-
TRICHLOROETHYLENE	6.0E+01
TRICHLOROPHENOL, 2,4,5-	1.0E+01
TRICHLOROPHENOL, 2,4,6-	1.0E+01
VANADIUM	2.0E+02
VINYL CHLORIDE	6.0E+01
XYLENES	-
ZINC	6.0E+02
Notes:	
<p>1. Based primarily on phytotoxicity. Included in selection of final soil action levels if less than one-half of the residential soil screening level for human-health, direct-exposure concerns (see Tables A-1, A-2, B-1 and B-2).</p> <p>2. For use in urban areas only. Site-specific studies required for areas where sensitive habitats are present. Refer to Section 3.9.</p>	

Screening For Environmental Concerns At Sites With Contaminated Soil and Groundwater

Volume 2: Background Documentation For The Development of Tier 1 Environmental Screening Levels

Appendices 2 through 10

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DISCLAIMER

This document, *Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater* (Interim Final, May 2005), is a technical report prepared by staff of the Hawai'i Department of Health, Environmental Management Division. It is intended to serve as a update to the 1996 HIDOH document entitled *Risk-Based Corrective Action and Decision Making at Sites With Contaminated Soil and Groundwater*. This document is not intended to establish policy or regulation. The Environmental Action Levels presented in this document and the accompanying text are specifically not intended to serve as: 1) a stand-alone decision making tool, 2) guidance for the preparation of baseline ("Tier 3") environmental assessments, 3) a rule to determine if a waste is hazardous under the state or federal regulations, or 4) a rule to determine when the release of hazardous chemicals must be reported to the overseeing regulatory agency.

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VOLUME 2: BACKGROUND DOCUMENTATION FOR THE DEVELOPMENT OF TIER 1 SOIL AND GROUNDWATER SCREENING LEVELS

APPENDICES

- 1 DEVELOPMENT OF TIER 1 LOOKUP TABLES
- 2 SUMMARY OF HUMAN HEALTH RISK-BASED EQUATIONS AND DEFAULT INPUT PARAMETER VALUES; USEPA REGION IX PRG DOCUMENT (OCTOBER 2004, TEXT ONLY)
- 3 RELEVANT PORTIONS OF *USER'S GUIDE FOR THE JOHNSON AND ETTINGER (1991) MODEL FOR SUBSURFACE VAPOR INTRUSION INTO BUILDINGS; SENSITIVITY ANALYSIS OF JOHNSON AND ETTINGER (1991) MODEL*
- 4 EXAMPLE PRINTOUTS OF INDOOR AIR IMPACT MODELS
- 5 DEVELOPMENT OF SOIL LEACHING SCREENING LEVELS
- 6 RATIONAL FOR MOEE ECOTOXICITY-BASED SOIL CRITERIA
- 7 SUMMARY OF MADEP CARBON RANGE AND TOTAL PETROLEUM HYDROCARBON RISK-BASED SCREENING LEVELS
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GLOSSARY OF TERMS

AWQC: Aquatic Water Quality Criteria
CCC: Criterion for Continuous Concentration
CCM: Criterion for Maximum Concentration
EPA: Environmental Protection Agency
ESL: Environmental Screening Level
FVC: Final Chronic Value
HIDOH: Hawai'i Department of Health
HH: Human Health-consumption of aquatic organisms
LOEL: Lowest-Observed-Effects Level
MADEP: Massachusetts Department of Environmental Protection
MCL: Maximum Concentration Level
MOEE: Ontario Ministry of Environment and Energy
MTBE: Methyl tert-Butyl Ethylene
PCE: Tetrachloroethylene
PRG: Preliminary Remediation Goals
RBSL: Risk-Based Screening Level
RWQCB: Regional Water Quality Control Board
TPH: Total Petroleum Hydrocarbons
USEPA: U.S. Environmental Protection Agency
USDOE: U.S. Department of Energy

APPENDIX 2

SUMMARY OF HUMAN HEALTH RISK-BASED
EQUATIONS AND DEFAULT INPUT PARAMETER
VALUES; USEPA REGION IX PRG DOCUMENT
(OCTOBER 2004, TEXT ONLY)

EQUATIONS FOR DERIVATION OF RISK-BASED SCREENING LEVELS FOR SOIL, INDOOR AIR AND DRINKING WATER

1.0 Introduction

A summary of models and assumptions used to develop for human health, direct-exposure concerns is presented below. For additional information on the models refer to the document *Region IX Preliminary Remediation Goals* ("PRGs", USEPA 2004) and other documents as referenced. A copy of the text of this document is attached.

2.0 SOIL

2.1 Residential and Commercial/Industrial Action Levels

Human exposure assumptions are summarized in Table 1. With the exception of the construction/trench worker exposure scenario, parameter values in Table 1 were taken directly from the USEPA Region IX PRG document. Parameter values for the construction/trench worker exposure scenario are discussed in more detail in Appendix 1. Tables 2 and 3 summarize equations and parameter values used to develop the PRG Volatilization Factors and Particulate Emission Factor.

Age-Adjusted Exposure Factors

Carcinogenic risks under residential exposure scenarios were calculated using the following age-adjusted factors:

1) ingestion [(mg-yr)/kg-day]:

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

2) dermal contact [(mg-yr)/kg-day]:

$$SFS_{adj} = \frac{ED_c \times AF_c \times SA_c}{BW_c} + \frac{(ED_r - ED_c) \times AF_a \times IRS_a}{BW_a}$$

3) inhalation [(m3-yr)/kg-day]:

$$InhF_{adj} = \frac{ED_c \times IRA_c}{BW_c} + \frac{(ED_r - ED_c) \times IRA_a}{BW_a}$$

Definition of terms and default parameter values used in the equations are presented in Tables a through c.

Direct exposure equations for soil are summarized as follows:

Equation 1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{\text{TR} \times \text{AT}_c}{\text{EF}_r \left[\left(\frac{\text{IFS}_{\text{adj}} \times \text{CSF}_o}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{SF}_{\text{adj}} \times \text{ABS} \times \text{CSF}_o}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{InhF}_{\text{adj}} \times \text{CSF}_i}{\text{VF}} \right) \right]}$$

Equation 2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{\text{THQ} \times \text{BW}_c \times \text{AT}_n}{\text{EF}_r \times \text{ED}_c \left[\left(\frac{\text{I}}{\text{RfD}_o} \times \frac{\text{IRS}_c}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{I}}{\text{RfD}_o} \times \frac{\text{SA}_c \times \text{AF}_c \times \text{ABS}}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{I}}{\text{RfD}_i} \times \frac{\text{IRA}_c}{\text{VF}} \right) \right]}$$

Equation 3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{\text{TR} \times \text{BW}_a \times \text{AT}_c}{\text{EF}_o \times \text{ED}_o \left[\left(\frac{\text{IRS}_o \times \text{CSF}_o}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{SA}_a \times \text{AF}_a \times \text{ABS} \times \text{CSF}_o}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{IRA}_a \times \text{CSF}_i}{\text{VF}} \right) \right]}$$

Equation 4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{\text{THQ} \times \text{BW}_a \times \text{AT}_n}{\text{EF}_o \times \text{ED}_o \left[\left(\frac{\text{I}}{\text{RfD}_o} \times \frac{\text{IRS}_o}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{I}}{\text{RfD}_o} \times \frac{\text{SA}_a \times \text{AF}_a \times \text{ABS}}{10^6 \text{ mg/kg}} \right) + \left(\frac{\text{I}}{\text{RfD}_i} \times \frac{\text{IRA}_a}{\text{VF}} \right) \right]}$$

Equation 5: Derivation of the Volatilization Factor

$$\text{VF}(\text{m}^3/\text{kg}) = (Q/C) \times \frac{(3.14 \times D_A \times T)^{1/2}}{(2 \times P_b \times D_A)} \times 10^{-4} (\text{m}^2/\text{cm}^2)$$

$$D_A = \frac{[(\Theta_a^{10/3} D_i H^i + \Theta_w^{10/3} D_w)]/n^2}{P_b K_d + \Theta_w + \Theta_a H'}$$

Equation 6: Derivation of the Soil Saturation Limit

$$\text{sat} = \frac{S}{P_b} (K_d P_b + \Theta_w + H' \Theta_a)$$

Equation 7: Derivation of the Particulate Emission Factor (residential and occupation exposures)

$$\text{PEF}(\text{m}^3/\text{kg}) = \text{Q}/\text{C} \times \frac{3600\text{s}/\text{h}}{0.036 \times (1 - \text{V}) (\text{U}_m / \text{U}_t)^3 \times \text{F}(\text{x})}$$

Volatilization factors (VF) are used for volatile chemicals (defined as having a Henry's Law Constant (atm-m³/mol) greater than 10⁻⁵ and a molecular weight less than 200 grams/mol. The VF term in the soil equations is replaced in the equations with a Particulate Emission Factor (PEF) for non-volatile chemicals.

Use of the Volatilization Factor equation to predict vapor-phase concentrations of a chemical in air is not valid if free-product is present. In cases where a chemicals direct-contact screening level exceeds the chemicals theoretical saturation level, and the chemical is a liquid under ambient conditions, the direct-contact screening level is replaced with the chemicals saturation limit.

2.2 Construction/Trench Workers

Exposure assumptions for the construction/trench worker exposure scenario are summarized in Table 1. The assumed exposed skin area and soil ingestion rate are based on guidance presented in the USEPA *Exposure Factor handbook* (USEPA 1997). The inhalation rate, body weight, averaging time and target hazard quotient are set equal to assumptions used in the USEPA Region IX *Preliminary Remediation Goals* (USEPA 2002) for consistency with screening levels for occupational exposure assumptions. The soil adherence factor is taken from trench-worker exposure scenario assumptions developed by the Massachusetts Department of Environmental Protection for use in calculating screening levels (MADEP 1994).

The Massachusetts Department of Environmental Protection assumes exposure durations of three months for noncarcinogens (plus use of subchronic RfDs) and seven years for carcinogens. A seven-year (versus three month) exposure duration for carcinogens is used in part because shorter exposure durations were considered to be beyond the limits of cancer risk models. For the purposes of this document, a one-time, three month exposure duration to exposed soils at a site was considered to be inadequate. This may be particularly true for utility workers who re-visit a site numerous times over several years for routine maintenance of underground utilities. As noted in Table 1, a total exposure duration of seven years is assumed for both carcinogens and noncarcinogens. An exposure frequency of 20 days (4 weeks) per year for 7 years yields a total of 140 days total exposure. Construction workers may receive 140 days (roughly 6 months) of exposure in a single year and never visit the site again. Using chronic RfDs (generally less stringent than subchronic RfDs) and spreading the total exposure time over seven years is somewhat conservative but is consistent with the utility worker scenario. Due to the short exposure duration, a target risk of 1E-05 was used to calculate soil screening levels for carcinogens. A target hazard quotient of 1.0 was used to calculate soil screening levels for noncarcinogens. This is consistent with assumption used to develop screening levels for residential and industrial/commercial exposure scenarios.

"Particulate Emission Factors (PEF)" are intended to relate the concentration of a chemical in soil to the concentration of the chemical in air-born dust. The PEF used for residential and occupational exposure scenarios (1.316E+09 mg-kg/mg/m³) was taken directly from the USEPA *Region IX Preliminary Remediation Goals* guidance document (USEPA 2000). The PEF reflects a concentration of air-born particulate matter of approximately 0.76 ug/m³. This PEF and associated concentration of air-born dust was not considered to be adequately conservative of conditions that may occur at construction sites. A revised PEF for this exposure scenario was derived through use of a "Dust Emission Factor" for construction sites developed by the USEPA. The Dust Emission Factor of 1.2 tons of dust per month, per

acre is based on USEPA field studies at apartment complex and commercial center developments in semi-arid areas (USEPA 1974, 1985). Derivation of the construction-site PEF is summarized in Table 4. The derived PEF ($1.44E+06 \text{ mg}\cdot\text{kg}/\text{mg}/\text{m}^3$) corresponds to a concentration of air-born dust of approximately $700 \text{ ug}/\text{m}^3$.

3.0 INDOOR AIR

Target levels for indoor air were calculated based on equations incorporated into the Vapor Intrusion spreadsheet published by the USEPA (USEPA 1997). Residential indoor air target levels generated by the spreadsheet were modified by a factor of 0.79 to incorporate the adjusted childhood exposure inhalation factor used in the USEPA Region IX PRGs (see above):

$$\text{Childhood Exposure Adj. Factor} = \frac{\text{Vapor Intrusion Spreadsheet Inhalation Factor}}{\text{PRG Adjusted Inhalation Factor}}$$

$$\text{Childhood Exposure Adj. Factor} = \left(\frac{ED_a \times IRA_a}{BW_a} \right) / \left(\frac{ED_c \times IRA_c}{BW_c} + \frac{(ED_r - ED_c) \times IRA_a}{BW_a} \right) = 0.79$$

Equation 8: Residential Exposures to Carcinogenic Contaminants in Indoor Air

$$C_{\text{air}}(\text{ug} / \text{m}^3) = \frac{TR \times AT_c}{EF_{\text{res}} \times ED_{\text{res}} \times URF}$$

Equation 9: Occupational Exposures to Carcinogenic Contaminants in Indoor Air

$$C_{\text{air}}(\text{ug} / \text{m}^3) = \frac{TR \times AT_c}{EF_{\text{occ}} \times ED_{\text{occ}} \times URF}$$

Equation 10: Residential Exposures to Noncarcinogenic Contaminants in Indoor Air

$$C_{\text{air}}(\text{ug} / \text{m}^3) = \frac{THQ \times AT_{\text{nc}} \times \text{RfC}}{EF_{\text{res}} \times ED_{\text{res}}}$$

Equation 11: Occupational Exposures to Noncarcinogenic Contaminants in Indoor Air

$$C_{\text{air}}(\text{ug} / \text{m}^3) = \frac{THQ \times AT_{\text{nc}} \times \text{RfC}}{EF_{\text{occ}} \times ED_{\text{occ}}}$$

where URF is the unit risk factor carcinogens (ug/m^3)⁻¹ for and RfC carcinogens (ug/m^3) is the reference concentration for noncarcinogens. A summary of URFs and RfCs for specific chemicals is provided in Table E-3 of Appendix 1.

4.0 DRINKING WATER

USEPA Region IX PRGs equations for calculation of risk-based goals for tapwater are noted below (USEPA 2002). Default parameter values are noted in Table 1. Unlike most promulgated Primary Maximum Contaminant Levels (MCLs) for drinking water, the PRG tapwater goals for volatile chemicals that take into account inhalation of vapors during showering and other activities:

Equation 12: Ingestion and Inhalation of Carcinogenic Contaminants in Tapwater

$$C(\text{ug/L}) = \frac{\text{TR} \times \text{ATc}}{\text{Efr}[(\text{IFWadj} \times \text{CSFo}) + (\text{VFw} \times \text{InhFadj} \times \text{CSFi})]} \times 1000 \text{ug/mg}$$

Equation 13: Ingestion and Inhalation of Noncarcinogenic Contaminants in Tapwater

$$C(\text{ug/L}) = \frac{\text{THQ} \times \text{BWa} \times \text{ATn}}{\text{Efr} \times \text{EDr} \left[\left(\frac{\text{IRWa}}{\text{RfDo}} \right) + \left(\frac{\text{VFw} + \text{IRAA}}{\text{RfDi}} \right) \right]} \times 1000 \text{ug/mg}$$

where VFw is the Volatilization Factor of water to air, assumed to be 0.5 L/m³. A summary of screening levels developed through use of this model is provided in the Table F series of Appendix 1.

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**TABLE 1. HUMAN EXPOSURE PARAMETER DEFINITIONS
AND DEFAULT VALUES**

Symbol	Definition (units)	Default	References (refer to USEPA 2002 for full references)
CSFo	Cancer slope factor oral (mg/kg-d) ⁻¹	--	Chemical specific - Appendix 1, Table J
CSFi	Cancer slope factor inhaled (mg/kg-d) ⁻¹	--	Chemical specific - Appendix 1, Table J
RfDo	Reference dose oral (mg/kg-d)	--	Chemical specific - Appendix 1, Table J
RfDi	Reference dose inhaled (mg/kg-d)	--	Chemical specific - Appendix 1, Table J
TRr/o	Target cancer risk - residential, occupational/ industrial exposure scenario	10 ⁻⁶	USEPA 2004. See Appendix 1, Section 3.2 for exceptions
*TRctw	Target cancer risk - construction/trench worker exposure scenario	10 ⁻⁵	HIDOH 2003
THQ	Target hazard quotient	1.0	USEPA 2004
BWa	Body weight, adult (kg)	70	RAGS (Part A), USEPA 1989 (EPA/540/1-89/002) Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
BWc	Body weight, child (kg)	15	
ATc	Average time – carcinogens (days)	25,550	RAGS (Page A), USEPA 1989 (EPA/540/1-89/002)
ATn	Average time – noncarcinogens (days)	ED*365	USEPA 2004
SAar	Exposed surface area, adult res. (cm ² /day)	5,700	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
SAaw	Exposed surface area, adult occ. (cm ² /day)	3,300	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
SAC	Exposed surface area, child (cm ² /day)	2,800	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
*SAac/tw	Exposed surface area, construction/trench worker (cm ² /day)	5,800	Exposure Factors, USEPA 1997 (EPA/600/P-95/002Fa)
AFar	Adherence factor, adult res. (mg/cm ²)	0.07	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
AFaw	Adherence factor, occupational (mg/cm ²)	0.20	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
*AFctw	Adherence factor, construction/trench worker (mg/cm ²)	0.51	Massachusetts DEP (1994)
AFc	Adherence factor, child (mg/cm ²)	0.20	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
ABS	Skin absorption (unitless): chemical specific	--	Dermal Assessment, USEPA 2004 (EPA/540/R-99/005)
IRAA	Inhalation rate – adult (m ³ /day)	20	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
IRAc	Inhalation rate – child (m ³ /day)	10	Exposure Factors, USEPA 1997 (EPA/600/P-95/002Fa)
*IRActw	Inhalation rate – construction/trench worker (m ³ /day)	20	Exposure Factors, USEPA 1997 (EPA/600/P-95/002Fa)
IRWa	Drinking water ingestion – adult (L/day)	2	RAGS (Part A), USEPA 1989 (EPA/540/1-89/002)
IRWc	Drinking water ingestion – child (L/day)	1	PEA Cal-EPA (DTSC, 1994)
IRSa	Soil ingestion – adult (mg/day)	100	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
IRSc	Soil ingestion – child (mg/day)	200	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
IRSo	Soil ingestion – occupational (mg/day)	50	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
*IRSctw	Soil ingestion – construction/trench worker (mg/day)	330	USEPA 2001
EFr	Exposure frequency – residential (d/y)	350	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
EFo	Exposure frequency – occupational (d/y)	250	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
*EFctw	Exposure frequency – construction/trench worker (d/y)	20	Massachusetts DEP (1994)
EDr	Exposure duration – residential (years)	30	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
EDc	Exposure duration – child (years)	6 ^a	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
EDo	Exposure duration – occupational (years)	25	Exposure Factors, USEPA 1991 (OSWER No. 9285.6-03)
*EDctw	Exposure duration – construction/trench worker (years)	7	modified from Massachusetts DEP (1994)
IFSadj	Ingestion factor, soils ([mg-yr]/[kg-d])	114	RAGS (Part B, v 1991 (OSWER No. 9285.7-01B)
SFSadj	Skin contact factor, soils ([mg-yr]/[kg-d])	361	By analogy to RAGS (Part B)
InhFadj	Inhalation factor ([m ³ -yr]/[kg-d])	11	By analogy to RAGS (Part B)
IFWadj	Ingestion factor, water ([1-yr]/[kg-d])	1.1	By analogy to RAGS (Part B)
VFW	Volatilization factor for water (L/m ³)	0.5	RAGS (Part B), USEPA 1991 (OSWER No. 9285.7-01B)
PEFres/oc	Particulate emission factor (m ³ /kg) - residential/occupational exposure scenarios	1.32E+09	Soil Screening Guidance (USEPA 1996a)
*PEFctw	Particulate emission factor (m ³ /kg) - construction/trench worker exposure scenarios	1.44E+06	Based on Construction Site Dust Emission Factors (USEPA 1974, 1985). See attached table.
VFs	Volatilization factor for soil (m ³ /kg)	-	Chemical specific; Soil Screening Guidance (USEPA 1996a,b)
sat	Soil saturation concentration (mg/kg)	-	Chemical specific; Soil Screening Guidance (USEPA 1996a,b)

Primary Reference: USEPA, 2004, *Preliminary Remediation Goals*: U.S. Environmental Protection Agency, Region IX, October 2004,

a Exposure duration for lifetime residents is assumed to be 30 years total (vinyl chloride – 70 yrs). For carcinogens, exposures are combined for children (6 years) and adults (24 years). A residential ED of 70 years and total adult exposure 64 years is assumed for vinyl chloride.

* This document only. Not presented in USEPA Region IX PRGs.

**TABLE 2. VOLATILIZATION FACTOR PARAMETER DEFINITIONS
AND DEFAULT VALUES**

Parameter	Definition (units)	Default
VF _S	Volatilization factor M ³ /kg)	--
D _A	Apparent diffusivity (cm ² /s)	--
Q/C	Inverse of the mean conc. at the center of a 0.5-acre square source (g/m ² -s per kg/m ³)	68.81
T	Exposure interval (s)	9.5 x 10 ⁸
rho _b	Dry soil bulk density (g/cm ³)	1.5
theta _a	Air filled soil porosity (L _{air} /L _{soil})	0.28 or n-w
n	Total soil porosity (L _{pore} /L _{soil})	0.43 or 1 - (b/s)
theta _w	Water-filled soil porosity (L _{water} /L _{soil})	0.15
rho _s	Soil particle density (g/cm ³)	2.65
D _i	Diffusivity in air (cm ² /s)	Chemical-specific
H	Henry's Law constant (atm-m ³ /mol)	Chemical-specific
H'	Dimensionless Henry's Law constant	Calculated from H by multiplying by 41 (USEPA 1991a)
D _w	Diffusivity in water (cm ² /s)	Chemical-specific
K _d	Soil-water partition coefficient (cm ³ /g) = K _{oc} x f _{oc}	Chemical-specific
K _{oc}	Soil organic carbon-water partition coefficient (cm ³ /g)	Chemical-specific
f _{oc}	Fraction organic carbon in soil (g/g)	0.006 (0.6%)

**TABLE 3. PARTICULATE EMISSION FACTOR PARAMETER DEFINITIONS AND
DEFAULT VALUES - RESIDENTIAL/OCCUPATIONAL SCENARIOS**

Parameter	Definition (units)	Default
PEF	Particulate emission factor (m ³ /kg)	1.316 x 10 ⁹
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source (g/m ² -s per kg/m ³)	90.80
V	Fraction of vegetative cover (unitless)	0.5
Um	Mean annual windspeed (m/s)	4.69
Ut	Equivalent threshold value of windspeed at 7 m (m/s) 11.32	11.32
F(x)	Function dependent on Um/Ut derived using Cowherd (1985) (unitless)	0.194

**TABLE 4. PARTICULATE EMISSION FACTOR FOR
CONSTRUCTION/TRENCH WORKER EXPOSURE SCENARIO**

Dust Generated (moderate to heavy construction) (M_{dust}):			
Dust Emission Factor (EF):	1.2 2400 1089	tons/mo-acre lbs/mo-acre kgs/mo-acre	USEPA 1974, 1985 conversion conversion
Volume Air Passing Over Site Per Month Per Acre (V_{air}):			
Length Perpendicular To Wind (L):	1 43560 4047 64	acre ft ² m ² m	Default EF area conversion conversion $L=Area^{0.5}$
Air Mixing Zone Height (MZ):	2	m	model assumption
Ave Wind Speed (V):	4.69	m/s	USEPA 2004 (default PRG value)
Seconds per 30.4 Day Month (S):	2.63E+06	sec/month	conversion
Volume Air (Volume-air):	1.57E+09	m ³	$Volume-air=L \times MZ \times V \times S$
Average Concentration Dust in Air ($C_{dust-air}$):			
Concentration Dust ($C_{dust-air}$):	6.95E-07 0.695	kg/m ³ mg/m ³	$(C_{air} = M_{dust}/Volume-air)$ conversion
Particulate Emission Factor (PEF):			
Concentration soil in dust ($C_{dust-soil}$):	1,000,000	mg/kg	Model assumption - 100% (1000000 mg/kg) of dust is derived from on-site soil.
PEF:	1.44E+06	(mg/kg)/ (mg/m ³)	$PEF=C_{dust-soil}/C_{dust-air}$

Attachment

Text of USEPA Region IX Preliminary Remediation Goals Document (October 2004)

**USERS' GUIDE AND BACKGROUND TECHNICAL DOCUMENT
FOR
USEPA REGION 9'S PRELIMINARY REMEDIATION GOALS (PRG) TABLE**

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DISCLAIMER

Preliminary remediation goals (PRGs) focus on common exposure pathways and may not consider all exposure pathways encountered at CERCLA / RCRA sites (Exhibit 1-1). PRGs do not consider impact to groundwater or address ecological concerns. The PRG Table is specifically not intended as a (1) stand-alone decision-making tool, (2) as a substitute for EPA guidance for preparing baseline risk assessments, (3) a rule to determine if a waste is hazardous under RCRA, or (4) set of final cleanup or action levels to be applied at contaminated sites.

The guidance set out in this document is not final Agency action. It is not intended, nor can it be relied upon to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided herein, or act at variance with the guidance, based on an analysis of specific circumstances. The Agency also reserves the right to change this guidance at any time without public notice.

1.0 INTRODUCTION

Region 9 Preliminary Remediation Goals (PRGs) are risk-based tools for evaluating and cleaning up contaminated sites. They are being used to streamline and standardize all stages of the risk decision-making process.

The Region 9 PRG Table combines current human health toxicity values with standard exposure factors to estimate contaminant concentrations in environmental media (soil, air, and water) that are considered by the Agency to be health protective of human exposures (including sensitive groups), over a lifetime. Chemical concentrations above these levels would not automatically designate a site as "dirty" or trigger a response action. However, exceeding a PRG suggests that further evaluation of the potential risks that may be posed by site contaminants is appropriate. Further evaluation may include additional sampling, consideration of ambient levels in the environment, or a reassessment of the assumptions contained in these screening-level estimates (e.g. appropriateness of route-to-route extrapolations, appropriateness of using chronic toxicity values to evaluate childhood exposures, appropriateness of generic exposure factors for a specific site etc.).

The risk-based concentrations presented in the Table may be used as screening goals or initial cleanup goals if applicable. Generally a screening goal is intended to provide health protection without knowledge of the specific exposure conditions at a site. PRGs may also be used as initial cleanup goals when the exposure assumptions based on site-specific data match up with the default exposure assumptions in the PRG Table. When considering PRGs as cleanup goals, it is EPA's preference to assume maximum beneficial use of a property (that is, residential use) unless a non-residential number (for example, industrial soil PRG) can be justified.

Before applying PRGs at a particular site, the Table user should consider whether the exposure pathways and exposure scenarios at the site are fully accounted for in the PRG calculations. Region 9 PRG concentrations are based on direct contact pathways for which generally accepted methods, models, and assumptions have been developed (i.e. ingestion, dermal contact, and inhalation) for specific land-use conditions and do not consider impact to groundwater or ecological receptors (see Developing a Conceptual Site Model below).

**EXHIBIT 1-1
TYPICAL EXPOSURE PATHWAYS BY MEDIUM
FOR RESIDENTIAL AND INDUSTRIAL LAND USES^a**

EXPOSURE PATHWAYS, ASSUMING:		
MEDIUM	RESIDENTIAL LAND USE	INDUSTRIAL LAND USE
Ground Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
Surface Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
	Ingestion during swimming	
	Ingestion of contaminated fish	
Soil	<i>Ingestion</i>	<i>Ingestion</i>
	<i>Inhalation of particulates</i>	<i>Inhalation of particulates</i>
	<i>Inhalation of volatiles</i>	<i>Inhalation of volatiles</i>
	Exposure to indoor air from soil gas	Exposure to indoor air from soil gas
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant, meat, or dairy products	Inhalation of particulates from trucks and heavy equipment
	<i>Dermal absorption</i>	<i>Dermal absorption</i>

Footnote:

^aExposure pathways considered in the PRG calculations are indicated in boldface italics.

2.0 READING THE PRG TABLE

2.1 General Considerations

With the exceptions described below, PRGs are chemical concentrations that correspond to fixed levels of risk (i.e. either a one-in-one million [10^{-6}] cancer risk or a noncarcinogenic hazard quotient of 1) in soil, air, and water. In most cases, where a substance causes both cancer and noncancer (systemic) effects, the 10^{-6} cancer risk will result in a more stringent criteria and consequently this value is presented in the printed copy of the Table. PRG concentrations that equate to a 10^{-6} cancer risk are indicated by "ca". PRG concentrations that equate to a hazard quotient of 1 for noncarcinogenic concerns are indicated by "nc".

If the risk-based concentrations are to be used for site screening, it is recommended that both cancer and noncancer-based PRGs be used. Both carcinogenic and noncarcinogenic values may be obtained at the Region 9 PRG homepage at:

<http://www.epa.gov/region09/waste/sfund/prg/>

It has come to my attention that some users have been multiplying the cancer PRG concentrations by 10 or 100 to set "action levels" for triggering remediation or to set less stringent cleanup levels for a specific site after considering non-risk-based factors such as ambient levels, detection limits, or technological feasibility. This risk management practice recognizes that there may be a range of values that may be "acceptable" for carcinogenic risk (EPA's risk management range is one-in-a-million [10^{-6}] to one-in-ten thousand [10^{-4}]). However, this practice could lead one to overlook serious noncancer health threats and it is strongly recommended that the user consult with a toxicologist or regional risk assessor before doing this. For carcinogens, I have indicated by asterisk ("ca*") in the PRG Table where the noncancer PRGs would be exceeded if the cancer value that is displayed is multiplied by 100. Two stars ("ca**") indicate that the noncancer values would be exceeded if the cancer PRG were multiplied by 10. There is no range of "acceptable" noncarcinogenic "risk" so that under no circumstances should noncancer PRGs be multiplied by 10 or 100, when setting final cleanup criteria. In the rare case where noncancer PRGs are more stringent than cancer PRGs set at one-in-one-million risk, a similar approach has been applied (e.g. "nc**").

In general, PRG concentrations in the printed Table are risk-based but for soil there are two important exceptions: (1) for several volatile chemicals, PRGs are based on the soil saturation equation ("sat") and (2) for relatively less toxic inorganic and semivolatile contaminants, a non-risk based "ceiling limit" concentration is given as 10^{+5} mg/kg ("max"). At the Region 9 PRG website, the risk-based calculations for these same chemicals are also available in the "InterCalc Tables" if the user wants to view the risk-based concentrations prior to the application of "sat" or "max". For more information on why the "sat" value and not a risk-based value is presented for several volatile chemicals in the PRG Table, please see the discussion in Section 4.6.

With respect to applying a "ceiling limit" for chemicals other than volatiles, it is recognized that

this is not a universally accepted approach. Some within the agency argue that all values should be risk-based to allow for scaling (for example, if the risk-based PRG is set at a hazard quotient = 1.0, and the user would like to set the hazard quotient to 0.1 to take into account multiple chemicals, then this is as simple as multiplying the risk-based PRG by 1/10th). If scaling is necessary, PRG users can do this simply by referring to the “InterCalc Tables” at our website where risk-based soil concentrations are presented for all chemicals (see soil calculations, “combined” pathways column).

In spite of the fact that applying a ceiling limit is not a universally accepted approach, we have opted to continue applying a “max” soil concentration to the PRG Table for the following reasons:

- Risk-based PRGs for some chemicals in soil exceed unity (>1,000,000 mg/kg) which is not possible.
- The ceiling limit of 10^{+5} mg/kg is equivalent to a chemical representing 10% by weight of the soil sample. At this contaminant concentration (and higher), the assumptions for soil contact may be violated (for example, soil adherence and windborne dispersion assumptions) due to the presence of the foreign substance itself.
- PRGs currently do not address short-term exposures (e.g. pica children and construction workers). Although extremely high soil PRGs are likely to represent relatively non-toxic chemicals, such high values may not be justified if in fact more toxicological data were available for evaluating short-term and/or acute exposures.

In addition to Region 9 PRG values, the PRG Table also includes California EPA PRGs ("CAL-Modified PRGs") for specific chemicals where CAL-EPA screening values may deviate significantly from the federal values (see Section 2.4) and EPA OSWER soil screening levels (SSLs) for protection of groundwater (see Section 2.5).

2.2 Toxicity Values

Hierarchy of Toxicity Values

There is a new hierarchy of human health toxicity values that replaces earlier guidance. This is important because human toxicity values known as cancer slope factors (SF) or non-cancer reference doses (RfDs) form the basis of the PRG values listed in the table. As noted in OSWER Directive 9285.7-53 (dated December 5, 2003), the updated EPA hierarchy is as follows: Tier 1 - EPA’s Integrated IRIS, Tier 2 - EPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs), and Tier 3 - Other Toxicity Values. Tier 3 includes additional EPA sources (e.g. historic HEAST and NCEA provisional values) and non-EPA sources of toxicity information (e.g. California EPA toxicity values).

The PRG Table lists Tier 1 toxicity values from IRIS as “i” and Tier 2 toxicity values known as PPRTVs as “p”. Tier 3 toxicity values were obtained from various sources including California EPA databases “c”, historic HEAST tables “h” and NCEA provisional values “n”.

Inhalation Conversion Factors

As of January 1991, IRIS and NCEA databases no longer present RfDs or SFs for the inhalation route. These criteria have been replaced with reference concentrations (RfC) for noncarcinogenic effects and unit risk factors (URF) for carcinogenic effects. However, for purposes of estimating risk and calculating risk-based concentrations, inhalation reference doses (RfDi) and inhalation slope factors (SF_i) are preferred. This is not a problem for most chemicals because the inhalation toxicity criteria are easily converted. To calculate an RfDi from an RfC, the following equation and assumptions may be used for most chemicals:

$$\text{RfDi} \frac{\text{mg}}{(\text{kg} \cdot \text{day})} = \text{RfC} (\text{mg} / \text{m}^3) \times \frac{20\text{m}^3}{\text{day}} \times \frac{1}{70\text{kg}}$$

Likewise, to calculate an SF_i from an inhalation URF, the following equation and assumptions may be used:

$$\text{SF}_i \frac{(\text{kg} \cdot \text{day})}{(\text{mg})} = \text{URF} (\text{m}^3 / \text{ug}) \times \frac{\text{day}}{20\text{m}^3} \times 70\text{kg} \times \frac{10^3 \text{ ug}}{\text{mg}}$$

Route-to-Route Methods

Route-to-route extrapolations (“r”) were frequently used when there were no toxicity values available for a given route of exposure. Oral cancer slope factors (“SF_o”) and reference doses (“RfD_o”) were used for both oral and inhaled exposures for organic compounds lacking inhalation values. Inhalation slope factors (“SF_i”) and inhalation reference doses (“RfD_i”) were used for both inhaled and oral exposures for organic compounds lacking oral values. Route extrapolations were not performed for inorganics due to portal of entry effects and known differences in absorption efficiency for the two routes of exposure.

An additional route extrapolation is the use of oral toxicity values for evaluating dermal exposures. In general, dermal toxicity values are not listed in EPA databases and consequently must be estimated from oral toxicity information. However, a scientifically defensible data base often does not exist for making an adjustment to the oral slope factor/RfD so that the oral toxicity value is often applied without adjustment to estimate a dermal toxicity value. For more information please refer to recent Agency guidance (USEPA 2004) entitled *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* available on the web at:

<http://www.epa.gov/superfund/programs/risk/ragse/index.htm>

Please note that whenever route-extrapolated values are used to calculate risk-based PRGs, additional uncertainties are introduced in the calculation.

2.3 PRGs Derived with Special Considerations

Most of the Region 9 PRGs are readily derived by referring to Equations 4-1 thru 4-8 contained in this “User’s Guide/Technical Background Document” to the Region 9 PRGs. However, there are some chemicals for which the standard equations do not apply and/or adjustments to the toxicity values are recommended. These special case chemicals are discussed below.

Cadmium The PRGs for Cadmium are based on the oral RfD for water which is slightly more conservative (by a factor of 2) than the RfD for food. Because the PRGs are considered screening values, we elected to use the more conservative RfD for cadmium. However, reasonable arguments could be made for applying an RfD for food (instead of the oral RfD for water) for some media such as soils.

The water RfD for cadmium assumes a 5% oral absorption factor. The assumption of an oral absorption efficiency of 5% for Cadmium leads to an estimated dermal RfD of 2.5E-05. The PRG calculations incorporate these adjustments per recent guidance (USEPA 2004).

Chromium 6 For Chromium 6 (Cr6), IRIS shows an air unit risk of 1.2E-2 per (ug/cu.m) or expressed as an inhalation cancer slope factor (adjusting for inhalation/body weight) of 42 (mg/kg-day)⁻¹. However, the supporting documentation in the IRIS file states that these toxicity values are based on an assumed 1:6 ratio of Cr6:Cr3. Because of this assumption, we in Region 9 prefer to present PRGs based on these cancer toxicity values as “total chromium” numbers.

In the PRG Table, we also include a Cr6 specific value (assuming 100% Cr6) that is derived by multiplying the “total chromium” value by 7, yielding a cancer potency factor of 290 (mg/kg-day)⁻¹. This is considered to be an overly conservative assumption by some within the Agency. However, this calculation is also consistent with the State of California's interpretation of the Mancuso study that forms the basis of Cr6's toxicity values.

If you are working on a project outside of California (and outside of Region 9), you may want to contact the appropriate regulatory officials to determine what their position is on this issue. As mentioned, Region 9 also includes PRGs for “total chromium” which is based on the same ratio (1:6 ratio Cr6:Cr3) that forms the basis of the cancer slope factor of 42 (mg/kg-day)⁻¹ presented in IRIS.

Dioxin Dioxins, furans, and some polychlorinated biphenyls are members of the same family and exhibit similar toxicological properties. Before using the dioxin PRG at an individual site, these dioxin-related compounds must be summed together. However, they differ in the degree of toxicity so that a toxicity equivalence factor (TEF) must first be applied to adjust the measured concentrations to a toxicity equivalent concentration. EPA Region 9 has adopted the 1997 World Health Organization (WHO) TEFs. For more on this, please refer to the following article (in Environmental Health Perspectives, Vol. 6, No. 12, Dec. 1998) online at: <http://ehp.niehs.nih.gov/members/1998/106p775-792vandenberg/vandenberg-full.html>

Lead Residential PRGs for Lead (Region 9 EPA and California EPA) are derived based on pharmacokinetic models. Both EPA's Integrated Exposure Uptake Biokinetic (IEUBK) Model and California's LeadSpread model are designed to predict the probable blood lead concentrations for children between six months and seven years of age who have been exposed to lead through various sources (air, water, soil, dust, diet and *in utero* contributions from the mother). Run in the reverse, these models also allow the user to calculate lead PRGs that are considered "acceptable" by EPA or the State of California.

EPA uses a second Adult Lead Model to estimate PRGs for an industrial setting. This PRG is intended to protect a fetus that may be carried by a pregnant female worker. It is assumed that a cleanup goal that is protective of a fetus will also afford protection for male or female adult workers. The model equations were developed to calculate cleanup goals such that there would be no more than a 5% probability that fetuses exposed to lead would exceed a blood lead (PbB) of 10 Fg/dL. An updated screening level for soil lead at commercial/industrial (i.e., non-residential) sites of 800 ppm is based on a recent analysis of the combined phases of NHANES III that chooses a cleanup goal protective of all subpopulations.

For more information on EPA's lead models and other lead-related topics, please go to:
<http://www.epa.gov/oerrpage/superfund/programs/lead/>

For more information on California's LeadSpread Model and Cal-Modified PRGs for lead, please go to:
<http://www.dtsc.ca.gov/ScienceTechnology/ledspred.html>

Manganese The IRIS RfD (0.14 mg/kg-day) includes manganese from all sources, including diet. The author of the IRIS assessment for manganese recommends that the dietary contribution from the normal U.S. diet (an upper limit of 5 mg/day) be subtracted when evaluating non-food (e.g. drinking water or soil) exposures to manganese, leading to a RfD of 0.071 mg/kg-day for non-food items. The explanatory text in IRIS further recommends using a modifying factor of 3 when calculating risks associated with non-food sources due to a number of uncertainties that are discussed in the IRIS file for manganese, leading to a RfD of 0.024 mg/kg-day. This modified RfD is applied in the derivation of the Region 9 PRGs for soil and water. For more information regarding the Manganese RfD, you may want to contact Dr. Bob Benson at (303) 312-7070.

Nitrates/Nitrites Tap water PRGs for Nitrates/Nitrites are based on the MCL as there is no available RfD for these compounds. For more information, please see IRIS at:
<http://www.epa.gov/iriswebp/iris/index.html>

Thallium IRIS has many values for the different salts of thallium. However, our analytical data packages typically report "thallium". Therefore, as a practical matter it makes more sense to report a PRG for plain thallium. We have done this by making the adjustment contained in the IRIS file for thallium sulfate based on the molecular weight of the thallium in the thallium salt. The adjusted oral RfD for plain thallium is 6.6 E-05 mg/kg-day which we use to calculate a thallium PRG.

Vinyl Chloride In EPA's recent reassessment of vinyl chloride toxicity, IRIS presents two cancer slope factors for vinyl chloride (VC): one that is intended to be applied towards evaluating adult risks and a second more protective slope factor that takes into account the unique susceptibility of developing infants and young children. For residential PRGs, the Region 9 PRG Table applies the more conservative cancer potency factor that addresses exposures to both children and adults whereas for the industrial soils PRG, the adult only cancer slope factor is applied.

Because of the age-dependent vulnerability associated with vinyl chloride exposures, and due to the method that is applied in deriving the cancer slope factor for VC, an assumption of a 70 year exposure over the lifetime is assumed, consistent with the way that the toxicity value for VC was derived. Therefore, instead of the usual exposure assumption of 6 years as a child and 24 years as an adult that is assumed for carcinogenic substances, we have revised the exposure assumption for VC to 6 years as a child and 64 years as adult. Since most of the cancer risk is associated with the first 30 years of exposure to VC, there is actually little difference between a 30 year exposure assumption (typically assumed for Superfund risk assessments) and the 70 year exposure assumption that is assumed in calculating the PRG for VC.

2.4 Cal-Modified PRGs

When EPA Region 9 first came out with a Draft of the PRG Table in 1992, there was concern expressed by California EPA's Department of Toxic Substances and Control (DTSC) that for some chemicals, the risk-based concentrations that are calculated using Cal-EPA toxicity values are "significantly" more protective than the risk-based concentrations that are calculated using EPA toxicity values. Because the risk-based PRGs are order-of-magnitude estimates at best, it was agreed by both Agencies that a difference of approximately 4 or greater would be regarded as a significant difference. For chemicals with California and EPA values that differ by a factor of 4 or more, both the EPA PRGs and the "Cal-Modified PRGs" are listed in the Table.

Please note that in the State of California, Cal-Modified PRGs should be used as screening levels for contaminated sites if they are more stringent than the Federal numbers.

2.5 Soil Screening Levels

Generic, soil screening levels (SSLs) for the protection of groundwater have been included in the PRG Table for 100 of the most common contaminants at Superfund sites. Generic SSLs are derived using default values in standardized equations presented in EPA OSWER's *Soil Screening Guidance* series, available on the web at <http://www.epa.gov/superfund/resources/soil/index.htm>.

The SSLs were developed using a default dilution-attenuation factor (DAF) of 20 to account for natural processes that reduce contaminant concentrations in the subsurface. Also included are generic SSLs that assume no dilution or attenuation between the source and the receptor well (i.e., a DAF of 1). These values can be used at sites where little or no dilution or attenuation of soil leachate concentrations is expected at a site (e.g., sites with shallow water tables, fractured media, karst topography, or source size greater than 30 acres).

In general, if an SSL is not exceeded for the migration to groundwater pathway, the user may eliminate this pathway from further investigation.

It should be noted that in the State of California, the California Regional Water Quality Control Board has derived “California SSLs” for a number of pathways including migration to groundwater. These are not included in the Region 9 PRG Table, but may be accessed at the following website:

<http://www.swrcb.ca.gov/rwqcb2/rbsl.htm>

Or, for more information on the “California SSLs”, please contact Dr Roger Brewer at: (510) 622-2374.

2.6 Miscellaneous

Volatile organic compounds (VOCs) are indicated by "y" in the VOC column of the Table and in general, are defined as those chemicals having a Henry's Law constant greater than 10^{-5} (atm-m³/mol) and a molecular weight less than 200 g/mole). Three borderline chemicals (dibromochloromethane, 1,2-dibromochloropropane, and pyrene) which do not strictly meet these criteria of volatility have also been included based upon discussions with other state and federal agencies and after a consideration of vapor pressure characteristics etc. Volatile organic chemicals are evaluated for potential volatilization from soil/water to air using volatilization factors (see Section 4.4).

Chemical-specific dermal absorption values for contaminants in soil and dust are presented for arsenic, cadmium, chlordane, 2,4-D, DDT, lindane, TCDD, PAHs, PCBs, and pentachlorophenols as recommended in the *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Interim Guidance* (USEPA 2004). Otherwise, default skin absorption fractions are assumed to be 0.10 for nonvolatile organics. Please note that previous defaults of 0.01 and 0.10 for inorganics and VOCs respectively, have been withdrawn per new guidance.

3.0 USE OF PRGS AT SITES

The decision to use PRGs at a site will be driven by the potential benefits of having generic risk-based concentrations in the absence of site-specific risk assessments. The original intended use of PRGs was to provide initial cleanup goals for individual chemicals given specific medium and land-use combinations (see RAGS Part B, 1991), however risk-based concentrations have several applications. They can also be used for:

- □ Setting health-based detection limits for chemicals of potential concern
- □ Screening sites to determine whether further evaluation is appropriate
- □ Calculating cumulative risks associated with multiple contaminants

A few basic procedures are recommended for using PRGs properly. These are briefly described below. Potential problems with the use of PRGs are also identified.

3.1 Conceptual Site Model

The primary condition for use of PRGs is that exposure pathways of concern and conditions at the site match those taken into account by the PRG framework. Thus, it is always necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of PRGs at the site and the need for additional information. For those pathways not covered by PRGs, a risk assessment specific to these additional pathways may be necessary. Nonetheless, the PRG lookup values will still be useful in such situations for focusing further investigative efforts on the exposure pathways not addressed.

To develop a site-specific CSM, perform an extensive records search and compile existing data (e.g. available site sampling data, historical records, aerial photographs, and hydrogeologic information). Once this information is obtained, CSM worksheets such as those provided in ASTM's *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (1995) can be used to tailor the generic worksheet model to a site-specific CSM. The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways and routes and receptors. It summarizes our understanding of the contamination problem.

As a final check, the CSM should answer the following questions:

- ☐ Are there potential ecological concerns?
- ☐ Is there potential for land use other than those covered by the PRGs (that is, residential and industrial)?
- ☐ Are there other likely human exposure pathways that were not considered in development of the PRGs (e.g. impact to groundwater, local fish consumption, raising beef, dairy, or other livestock)?
- ☐ Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?

If any of these four conditions exist, the PRG may need to be adjusted to reflect this new information. Suggested websites for the evaluation of pathways not currently addressed by Region 9 PRG's are presented in Exhibit 3-1.

EXHIBIT 3-1
SUGGESTED WEBSITES FOR EVALUATING EXPOSURE
PATHWAYS NOT CURRENTLY ADDRESSED BY REGION 9 PRGs

EXPOSURE PATHWAY	WEBSITE
Migration of contaminants to an underlying potable aquifer	EPA Soil Screening Guidance: http://www.epa.gov/superfund/resources/soil/index.htm California Water Board Guidance: http://www.swrcb.ca.gov/rwqcb2/rbsl.htm
Ingestion via plant uptake	EPA Soil Screening Guidance: http://www.epa.gov/superfund/resources/soil/index.htm EPA Fertilizer Risk Assessment: http://www.epa.gov/epaoswer/hazwaste/recycle/fertiliz/risk/
Ingestion via meat, dairy products, human milk	EPA Protocol for Combustion Facilities: http://www.epa.gov/epaoswer/hazwaste/combust/riskvol.htm#volume1 California “Hot Spots” Risk Guidelines: http://www.oehha.ca.gov/air/hot_spots/HRSguide.html
Inhalation of volatiles that have migrated into basements or other enclosed spaces.	EPA’s draft Subsurface Vapor Intrusion Guidance: http://www.epa.gov/correctiveaction/eis/vapor.htm EPA’s Version of Johnson & Ettinger Model: http://www.epa.gov/oerrpage/superfund/programs/risk/airmodel/johnson_ettinger.htm
Ecological pathways	EPA Ecological Soil Screening Guidance: http://www.epa.gov/superfund/programs/risk/ecorisk/ecossl.htm NOAA Sediment Screening Table: http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html

3.2 Background Levels Evaluation

A necessary step in determining the applicability of Region 9 risk-based PRGs is the consideration of background contaminant concentrations. There is new EPA guidance on determining background at sites. *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites* (USEPA 2001b) is available on the web at:
<http://www.epa.gov/superfund/programs/risk/background.pdf> .

EPA may be concerned with two types of background at sites: naturally occurring and

anthropogenic. Natural background is usually limited to metals whereas anthropogenic (i.e. human-made) “background” includes both organic and inorganic contaminants. Before embarking on an extensive sampling and analysis program to determine local background concentrations in the area, one should first compile existing data on the subject. Far too often there is pertinent information in the literature that gets ignored, resulting in needless expenditures of time and money.

Generally EPA does not clean up below natural background. In some cases, the predictive risk-based models generate PRG concentrations that lie within or even below typical background concentrations for the same element or compound. If natural background concentrations are higher than the risk-based PRG concentrations, then background concentrations should also be considered in determining whether further evaluation and/or remediation is necessary at a particular site. Exhibit 3-2 presents summary statistics for selected elements in soils that have background levels that may exceed risk-based PRGs.

Where anthropogenic “background” levels exceed PRGs and EPA has determined that a response action is necessary and feasible, EPA's goal will be to develop a comprehensive response to the widespread contamination. This will often require coordination with different authorities that have jurisdiction over the sources of contamination in the area.

**EXHIBIT 3-2
BACKGROUND CONCENTRATIONS OF SELECTED ELEMENTS IN SOILS**

TRACE ELEMENT	U.S. STUDY DATA ¹			CALIFORNIA DATA ²		
	Range	GeoMean	ArMean	Range	GeoMean	ArMean
Arsenic	<.1-97	5.2 mg/kg	7.2 mg/kg	0.59-11	2.75 mg/kg	3.54 mg/kg
Beryllium	<1-15	0.63 “	0.92 “	0.10-2.7	1.14 “	1.28 “
Cadmium	<1-10	--	<1	0.05-1.7	0.26	0.36
Chromium	1-2000	37	54	23-1579	76.25	122.08
Nickel	<5-700	13	19	9.0-509	35.75	56.60

¹Shacklette and Hansford, “Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States”, USGS Professional Paper 1270, 1984.

²Bradford et. al, “Background Concentrations of Trace and Major Elements in California Soils”, Kearney Foundation Special Report, UC-Riverside and CAL-EPA DTSC, March 1996.

3.3 Screening Sites with Multiple Pollutants

A suggested stepwise approach for PRG-screening of sites with multiple pollutants is as follows:

- Perform an extensive records search and compile existing data.

- Identify site contaminants in the PRG Table. Record the PRG concentrations for various media and note whether PRG is based on cancer risk (indicated by "ca") or noncancer hazard (indicated by "nc"). Segregate cancer PRGs from non-cancer PRGs and exclude (but don't eliminate) non-risk based PRGs ("sat" or "max").
- For cancer risk estimates, take the site-specific concentration (maximum or 95 UCL) and divide by the PRG concentrations that are designated for cancer evaluation ("ca"). Multiply this ratio by 10⁻⁶ to estimate chemical-specific risk for a reasonable maximum exposure (RME). For multiple pollutants, simply add the risk for each chemical:

$$Risk = \left[\left(\frac{CONC_x}{PRG_x} \right) \% \left(\frac{CONC_y}{PRG_y} \right) \% \left(\frac{CONC_z}{PRG_z} \right) \right] \times 10^{&6}$$

- For non-cancer hazard estimates. Divide the concentration term by its respective non-cancer PRG designated as "nc" and sum the ratios for multiple contaminants. The cumulative ratio represents a non-carcinogenic hazard index (HI). A hazard index of 1 or less is generally considered "safe". A ratio greater than 1 suggests further evaluation. **[Note that carcinogens may also have an associated non-cancer PRG that is not listed in the PRG Table. To obtain these values, the user should view or download the InterCalc Tables at the PRG website and display the appropriate sections.]**

$$Hazard\ Index = \left[\left(\frac{conc_x}{PRG_x} \right) \% \left(\frac{conc_y}{PRG_y} \right) \% \left(\frac{conc_z}{PRG_z} \right) \right]$$

For more information on screening site risks, the reader should contact EPA Region 9's Technical Support Section.

3.4 Potential Problems

As with any risk-based tool, the potential exists for misapplication. In most cases the root cause will be a lack of understanding of the intended use of Region 9 PRGs. In order to prevent misuse of PRGs, the following should be avoided:

- Applying PRGs to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios,
- Not considering background concentrations when choosing PRGs as cleanup goals,
- Use of PRGs as cleanup levels without the nine-criteria analysis specified in the National Contingency Plan (or, comparable analysis for programs outside of Superfund),
- Use of PRGs as cleanup levels without verifying numbers with a toxicologist or regional risk assessor,

- □ Use of antiquated PRG Tables that have been superseded by more recent publications,
- □ Not considering the effects of additivity when screening multiple chemicals, and
- □ Adjusting PRGs upward by factors of 10 or 100 without consulting a toxicologist or regional risk assessor.

4.0 TECHNICAL SUPPORT DOCUMENTATION

Region 9 PRGs consider human exposure hazards to chemicals from contact with contaminated soils, air, and water. The emphasis of the PRG equations and technical discussion are aimed at developing screening criteria for soils, since this is an area where few standards exist. For air and water, additional reference concentrations or standards are available for many chemicals (e.g. MCLs, non-zero MCLGs, AWQC, and NAAQS) and consequently the discussion of these media are brief.

4.1 Ambient Air and the Vapor Intrusion Pathway

The ambient air PRG is applicable to both indoor and outdoors and is based on a residential exposure scenario using standard Superfund exposure factors (see Exhibit 4-1 below).

The air PRG may also be used as a health-protective indoor air target for determining soil gas and groundwater screening levels for the evaluation of the subsurface vapor intrusion pathway. The “vapor intrusion pathway” refers to the migration of volatile chemicals from the subsurface into overlying buildings. Volatile chemicals in buried wastes and/or contaminated groundwater can emit vapors that may migrate through subsurface soils and into indoor air spaces of overlying buildings in ways similar to that of radon gas seeping into homes.

To derive a soil gas and/or groundwater screening level that targets the air PRG, it is necessary to divide the air PRG by an appropriate attenuation factor. The attenuation factor represents the factor by which subsurface vapor concentrations migrating into indoor air spaces are reduced due to diffusive, advective, and/or other attenuating mechanisms. The attenuation factor can be empirically determined and/or calculated using an appropriate vapor intrusion model such as the Johnson and Ettinger model available at: http://www.epa.gov/oerrpage/superfund/programs/risk/airmodel/johnson_ettinger.htm . Once the appropriate attenuation factor is determined, the following equation can be used to derive a screening level that would be protective of indoor air assuming residential land use.

For Soil Gas, the relationship is as follows:

$$C_{\text{soil-gas}}[\text{ug}/\text{m}^3] = \text{Air PRG} [\text{ug}/\text{m}^3]/\text{AF}$$

where

$C_{\text{soil-gas}}$ = soil gas screening level

AF = attenuation factor (ratio of indoor air concentration to soil gas concentration)

For Groundwater, the relationship is as follows:

$$C_{gw}[\text{ug/L}] = \text{Air PRG} [\text{ug/m}^3] \times 10^{-3} \text{ m}^3/\text{L} \times 1/\text{H} \times 1/\text{AF}$$

where

C_{gw} = groundwater screening level

H = dimensionless Henry's Law Constant at 25C [(mg/L - vapor)/(mg/L - water)]

AF = attenuation factor (ratio of indoor air concentration to soil gas concentration)

For more information on EPA's current understanding of this emerging exposure pathway, please refer to EPA's recent draft guidance *Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)* (USEPA 2002) available on the web at:

<http://www.epa.gov/correctiveaction/eis/vapor.htm>

4.2 Soils - Direct Ingestion

Calculation of risk-based PRGs for direct ingestion of soil is based on methods presented in RAGS HHEM, Part B (USEPA 1991a) and *Soil Screening Guidance* (USEPA 1996a,b, USEPA 2001a). Briefly, these methods backcalculate a soil concentration level from a target risk (for carcinogens) or hazard quotient (for noncarcinogens).

Residential Soil PRGs

A number of studies have shown that inadvertent ingestion of soil is common among children 6 years old and younger (Calabrese et al. 1989, Davis et al. 1990, Van Wijnen et al. 1990). To take into account the higher soil intake rate for children, two different approaches are used to estimate PRGs, depending on whether the adverse health effect is cancer or some effect other than cancer.

For carcinogens, the method for calculating PRGs uses an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates, body weights, and exposure duration for children from 1 to 6 years old and others from 7 to 31 years old. This health-protective approach is chosen to take into account the higher daily rates of soil ingestion in children as well as the longer duration of exposure that is anticipated for a long-term resident. For more on this method, see USEPA RAGs Part B (1991a).

For noncarcinogenic concerns, the more protective method of calculating a soil PRG is to evaluate childhood exposures separately from adult exposures. In other words, an age-adjustment factor is not applied as was done for carcinogens. This approach is considered conservative because it combines the higher 6-year exposure for children with chronic toxicity criteria. In their analysis of the method, the Science Advisory Board (SAB) indicated that, for most chemicals, the approach may be overly protective. However, they noted that there are specific instances when the chronic RfD may be based on endpoints of toxicity that are specific to children (e.g. fluoride and nitrates) or when the dose-response is steep (i.e., the dosage difference between the no-observed-adverse-effects level [NOAEL] and an adverse effects level is small). Thus, for the purposes of screening, EPA Region 9 has adopted this approach for calculating soil PRGs for noncarcinogenic health concerns.

Industrial Soil PRGs

In the *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (Supplemental SSL Guidance, EPA 2001a), two different soil ingestion rates are assumed for non-construction workers: 100 mg/day is assumed for outdoor workers whereas 50 mg/day is assumed for indoor workers. The default value of 100 mg/day for outdoor workers is also recommended by EPA's Technical Review Workgroup for Lead (TRW), and it reflects increased exposures to soils for outdoor workers relative to their indoor counterparts. For more on this, please see the Supplemental SSL Guidance available at the following website:

<http://www.epa.gov/superfund/resources/soil/index.htm>

Because the Region 9 PRGs are generic and intended for screening sites early in the investigation process (often before site-specific information is available), we have chosen to use the 100 mg/day soil ingestion (i.e. outdoor worker) assumption to calculate industrial soil PRGs. The appropriateness of this assumption for a particular site may be evaluated when additional information becomes available regarding site conditions or site development.

4.3 Soils - Dermal Contact

Dermal Contact Assumptions

Exposure factors for dermal contact with soil are based on recommendations in *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Interim Guidance* (USEPA 2004). Recommended RME (reasonable maximum exposure) defaults for adult workers' skin surface areas (3300 cm²/day) and soil adherence factors (0.2 mg/cm²) now differ from the defaults recommended for adult residents (5700 cm²/day, 0.07 mg/cm²) as noted in Exhibit 4-1. This is due to differences in the range of activities experienced by workers versus residents.

Dermal Absorption

Chemical-specific skin absorption values recommended by the Superfund Dermal Workgroup were applied when available. Chemical-specific values are included for the following chemicals: arsenic, cadmium, chlordane, 2,4-D, DDT, lindane, TCDD, PAHs, PCBs, and pentachlorophenols.

The *Supplemental Guidance for Dermal Risk Assessment* (USEPA 2004) recommends a default dermal absorption factor for semivolatile organic compounds of 10% as a screening method for the majority of SVOCs without dermal absorption factors. Default dermal absorption values for other chemicals (VOCs and inorganics) are not recommended in this new guidance. Therefore, the assumption of 1% for inorganics and 10% for volatiles is no longer included in the PRG Table. This change has minimal impact on the final risk-based calculations because human exposure to VOCs and inorganics in soils is generally driven by other pathways of exposure.

4.4 Soils - Vapor and Particulate Inhalation

Agency toxicity criteria indicate that risks from exposure to some chemicals via inhalation far outweigh the risk via ingestion; therefore soil PRGs have been designed to address this pathway

as well. The models used to calculate PRGs for inhalation of volatiles/particulates are based on updates to risk assessment methods presented in RAGS Part B (USEPA 1991a) and are identical to the *Soil Screening Guidance: User's Guide and Technical Background Document* (USEPA 1996a,b).

It should be noted that the soil-to-air pathway that is evaluated in the PRGs calculations is based on inhalation exposures that result from the volatilization or particulate emissions of chemicals from soil to outdoor air. **The soil PRG calculations do not evaluate potential for volatile contaminants in soil to migrate indoors. For more on the subsurface vapor intrusion pathway please see Section 4.1.**

To address the soil-to-outdoor air pathways, the PRG calculations incorporate volatilization factors (VF_s) for volatile contaminants and particulate emission factors (PEF) for nonvolatile contaminants. These factors relate soil contaminant concentrations to air contaminant concentrations that may be inhaled on-site. The VF_s and PEF equations can be broken into two separate models: an emission model to estimate emissions of the contaminant from the soil and a dispersion model to simulate the dispersion of the contaminant in the atmosphere.

The box model in RAGS Part B has been replaced with a dispersion term (Q/C) derived from a modeling exercise using meteorological data from 29 locations across the United States because the box model may not be applicable to a broad range of site types and meteorology and does not utilize state-of-the-art techniques developed for regulatory dispersion modeling. The dispersion model for both volatiles and particulates is the AREA-ST, an updated version of the Office of Air Quality Planning and Standards, Industrial Source Complex Model, ISC2. However, different Q/C terms are used in the VF and PEF equations. Los Angeles was selected as the 90th percentile data set for volatiles and Minneapolis was selected as the 90th percentile data set for fugitive dusts (USEPA 1996 a,b). A default source size of 0.5 acres was chosen for the PRG calculations. This is consistent with the default exposure area over which Region 9 typically averages contaminant concentrations in soils. If unusual site conditions exist such that the area source is substantially larger than the default source size assumed here, an alternative Q/C could be applied (see USEPA 1996a,b).

Volatilization Factor for Soils

Volatile chemicals, defined as those chemicals having a Henry's Law constant greater than 10^{-5} (atm-m³/mol) and a molecular weight less than 200 g/mole, were screened for inhalation exposures using a volatilization factor for soils (VF_s). Please note that VF_s 's and other physical-chemical data for VOCs are contained in the InterCalc Tables at the EPA Region 9 PRG website.

The emission terms used in the VF_s are chemical-specific and were calculated from physical-chemical information obtained from several sources. The priority of these sources were as follows: *Soil Screening Guidance* (USEPA 1996a,b), *Superfund Chemical Data Matrix* (USEPA 1996c), *Fate and Exposure Data* (Howard 1991), *Subsurface Contamination Reference Guide* (EPA 1990a), and *Superfund Exposure Assessment Manual* (SEAM, EPA 1988). When there was a choice between a measured or a modeled value (e.g. Koc), our default was to use modeled values. In those cases where Diffusivity Coefficients (D_i) were not provided in existing literature, D_i 's were calculated using Fuller's Method described in SEAM. A surrogate term was required for some chemicals that lacked physico-chemical information. In these cases, a proxy chemical of similar structure was used that may over- or under-estimate the PRG for soils.

Equation 4-9 forms the basis for deriving generic soil PRGs for the inhalation pathway. The following parameters in the standardized equation can be replaced with specific site data to develop a simple site-specific PRG

- □ Source area
- □ Average soil moisture content
- □ Average fraction organic carbon content
- □ Dry soil bulk density

The basic principle of the VF_s model (Henry's law) is applicable only if the soil contaminant concentration is at or below soil saturation "sat". Above the soil saturation limit, the model cannot predict an accurate VF-based PRG. How these particular cases are handled, depends on whether the contaminant is liquid or solid at ambient soil temperatures (see Section 4.6).

Particulate Emission Factor for Soils

Inhalation of chemicals adsorbed to respirable particles (PM_{10}) were assessed using a default PEF equal to $1.316 \times 10^9 \text{ m}^3/\text{kg}$ that relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils. The generic PEF was derived using default values in Equation 4-11, which corresponds to a receptor point concentration of approximately $0.76 \text{ ug}/\text{m}^3$. The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g. years). This represents an annual average emission rate based on wind erosion that should be compared with chronic health criteria; it is not appropriate for evaluating the potential for more acute exposures.

The impact of the PEF on the resultant PRG concentration (that combines soil exposure pathways for ingestion, skin contact, and inhalation) can be assessed by accessing the Region 9 PRG website and viewing the pathway-specific soil concentrations listed in the InterCalc Tables. Equation 4-11 forms the basis for deriving a generic PEF for the inhalation pathway. For more details regarding specific parameters used in the PEF model, the reader is referred to *Soil Screening Guidance: Technical Background Document* (USEPA 1996a).

Note: the generic PEF evaluates windborne emissions and does not consider dust emissions from traffic or other forms of mechanical disturbance that could lead to greater emissions than assumed here.

4.5 Soils - Migration to Groundwater

The methodology for calculating SSLs for the migration to groundwater was developed to identify chemical concentrations in soil that have the potential to contaminate groundwater. Migration of contaminants from soil to groundwater can be envisioned as a two-stage process: (1) release of contaminant in soil leachate and (2) transport of the contaminant through the underlying soil and aquifer to a receptor well. The SSL methodology considers both of these fate and transport mechanisms.

SSLs are backcalculated from acceptable ground water concentrations (i.e. nonzero MCLGs, MCLs, or risk-based PRGs). First, the acceptable groundwater concentration is multiplied by a

dilution factor to obtain a target leachate concentration. For example, if the dilution factor is 10 and the acceptable ground water concentration is 0.05 mg/L, the target soil leachate concentration would be 0.5 mg/L. The partition equation (presented in the *Soil Screening Guidance* document) is then used to calculate the total soil concentration (i.e. SSL) corresponding to this soil leachate concentration.

The SSL methodology was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited. Because of this constraint, the methodology is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface. For more on SSLs, and how to calculate site-specific SSLs versus generic SSLs presented in the PRG Table, the reader is referred to the *Soil Screening Guidance* document (USEPA 1996a,b).

4.6 Soil Saturation Limit

The soil saturation concentration “sat” corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil pore air have been reached. Above this concentration, the soil contaminant may be present in free phase, i.e., nonaqueous phase liquids (NAPLs) for contaminants that are liquid at ambient soil temperatures and pure solid phases for compounds that are solid at ambient soil temperatures.

Equation 4-10 is used to calculate “sat” for each volatile contaminant. As an update to RAGS HHEM, Part B (USEPA 1991a), this equation takes into account the amount of contaminant that is in the vapor phase in soil in addition to the amount dissolved in the soil’s pore water and sorbed to soil particles.

Chemical-specific “sat” concentrations must be compared with each VF-based PRG because a basic principle of the PRG volatilization model is not applicable when free-phase contaminants are present. How these cases are handled depends on whether the contaminant is liquid or solid at ambient temperatures. Liquid contaminant that have a VF-based PRG that exceeds the “sat” concentration are set equal to “sat” whereas for solids (e.g., PAHs), soil screening decisions are based on the appropriate PRGs for other pathways of concern at the site (e.g., ingestion).

4.7 Tap Water - Ingestion and Inhalation

Calculation of PRGs for ingestion and inhalation of contaminants in domestic water is based on the methodology presented in RAGS HHEM, Part B (USEPA 1991a). Ingestion of drinking water is an appropriate pathway for all chemicals. For the purposes of this guidance, however, inhalation of volatile chemicals from water is considered routinely only for chemicals with a Henry’s Law constant of 1×10^{-5} atm-m³/mole or greater and with a molecular weight of less than 200 g/mole.

For volatile chemicals, an upperbound volatilization constant (VF_w) is used that is based on all uses of household water (e.g. showering, laundering, and dish washing). Certain assumptions were made. For example, it is assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L and the air exchange rate is 0.25 air changes/hour (Andelman in RAGS Part B). Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent (i.e. half of the concentration of each

chemical in water will be transferred into air by all water uses). Note: the range of transfer efficiencies extends from 30% for toilets to 90% for dishwashers.

4.8 Default Exposure Factors

Default exposure factors were obtained primarily from RAGS Supplemental Guidance Standard Default *Exposure Factors* (OSWER Directive, 9285.6-03) dated March 25, 1991 and more recent information from U.S. EPA's Office of Solid Waste and Emergency Response, U.S. EPA's Office of Research and Development, and California EPA's Department of Toxic Substances Control (see Exhibit 4-1).

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors ("adj"). Use of age-adjusted factors are especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposures across pathways, additional age-adjusted factors are used for inhalation and dermal exposures. These factors approximate the integrated exposure from birth until age 30 combining contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors were obtained from RAGS PART B or developed by analogy (see derivations next page).

For soils only, noncarcinogenic contaminants are evaluated in children separately from adults. No age-adjustment factor is used in this case. The focus on children is considered protective of the higher daily intake rates of soil by children and their lower body weight. For maintaining consistency when evaluating soils, dermal and inhalation exposures are also based on childhood contact rates.

(1) ingestion([mg-yr]/[kg-d]):

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} \% \frac{(ED_r \& ED_c) \times IRS_a}{BW_a}$$

(2) skin contact([mg-yr]/[kg-d]):

$$SFS_{adj} = \frac{ED_c \times AF \times SA_c}{BW_c} \% \frac{(ED_r \& ED_c) \times AF \times SA_a}{BW_a}$$

(3) inhalation ([m³-yr]/[kg-d]):

$$InhF_{adj} = \frac{ED_c \times IRA_c}{BW_c} \% \frac{(ED_r \& ED_c) \times IRA_a}{BW_a}$$

EXHIBIT 4-1 STANDARD DEFAULT FACTORS

<u>Symbol</u>	<u>Definition (units)</u>	<u>Default</u>	<u>Reference</u>
CSFo	Cancer slope factor oral (mg/kg-d)-1	--	IRIS, PPRTV, HEAST, NCEA, or California
CSFi	Cancer slope factor inhaled (mg/kg-d)-1	--	IRIS, PPRTV, HEAST, NCEA, or California
RfDo	Reference dose oral (mg/kg-d)	--	IRIS, PPRTV, HEAST, NCEA, or California
RfDi	Reference dose inhaled (mg/kg-d)	--	IRIS, PPRTV, HEAST, NCEA, or California
TR	Target cancer risk	10 ⁻⁶	--
THQ	Target hazard quotient	1	--
BWa	Body weight, adult (kg)	70	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
BWc	Body weight, child (kg)	15	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
ATc	Averaging time - carcinogens (days)	25550	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
ATn	Averaging time - noncarcinogens (days)	ED*365	
SAa	Exposed surface area for soil/dust (cm ² /day) – adult resident	5700	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
	– adult worker	3300	
SAC	Exposed surface area, child in soil (cm ² /day)	2800	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
AFa	Adherence factor, soils (mg/cm ²) – adult resident	0.07	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
	– adult worker	0.2	
AFc	Adherence factor, child (mg/cm ²)	0.2	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
ABS	Skin absorption defaults (unitless): – semi-volatile organics	0.1	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
	– volatile organics	--	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
	– inorganics	--	Dermal Assessment, EPA 2004 (EPA/540/R-99/005)
IRAA	Inhalation rate - adult (m ³ /day)	20	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRAc	Inhalation rate - child (m ³ /day)	10	Exposure Factors, EPA 1997 (EPA/600/P-95/002Fa)
IRWa	Drinking water ingestion - adult (L/day)	2	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
IRWc	Drinking water ingestion - child (L/day)	1	PEA, Cal-EPA (DTSC, 1994)
IRSa	Soil ingestion - adult (mg/day)	100	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRSc	Soil ingestion - child (mg/day),	200	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRSo	Soil ingestion - occupational (mg/day)	100	Soil Screening Guidance (EPA 2001a)
EFr	Exposure frequency - residential (d/y)	350	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EFo	Exposure frequency - occupational (d/y)	250	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDr	Exposure duration - residential (years)	30 ^a	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDc	Exposure duration - child (years)	6	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDO	Exposure duration - occupational (years)	25	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IFSadj	Age-adjusted factors for carcinogens: Ingestion factor, soils ([mg-yr]/[kg-d])	114	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
SFSadj	Dermal factor, soils ([mg-yr]/[kg-d])	361	By analogy to RAGS (Part B)
InhFadj	Inhalation factor, air ([m ³ -yr]/[kg-d])	11	By analogy to RAGS (Part B)
IFWadj	Ingestion factor, water ([L-yr]/[kg-d])	1.1	By analogy to RAGS (Part B)
VFw	Volatilization factor for water (L/m ³)	0.5	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
PEF	Particulate emission factor (m ³ /kg)	See below	Soil Screening Guidance (EPA 1996a,b)
VF _s	Volatilization factor for soil (m ³ /kg)	See below	Soil Screening Guidance (EPA 1996a,b)
sat	Soil saturation concentration (mg/kg)	See below	Soil Screening Guidance (EPA 1996a,b)

Footnote:

^aExposure duration for lifetime residents is assumed to be 30 years total. For carcinogens, exposures are combined for children (6 years) and adults (24 years).

4.9 Standardized Equations

The equations used to calculate the PRGs for carcinogenic and noncarcinogenic contaminants are presented in Equations 4-1 through 4-8. The PRG equations update RAGS Part B equations. The methodology backcalculates a soil, air, or water concentration level from a target risk (for carcinogens) or hazard quotient (for noncarcinogens). For completeness, the soil equations combine risks from ingestion, skin contact, and inhalation simultaneously. **Note: the InterCalc Tables available at the EPA Region 9 PRG website also includes pathway-specific concentrations, should the user decide against combining specific exposure pathways; or, the user wants to identify the relative contribution of each pathway to exposure.**

To calculate PRGs for volatile chemicals in soil, a chemical-specific volatilization factor is calculated per Equation 4-9. Because of its reliance on Henry's law, the VF_s model is applicable only when the contaminant concentration in soil is at or below saturation (i.e. there is no free-phase contaminant present). Soil saturation ("sat") corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above this point, pure liquid-phase contaminant is expected in the soil. If the PRG calculated using VF_s was greater than the calculated sat, the PRG was set equal to sat, in accordance with *Soil Screening Guidance* (USEPA 1996 a,b). The equation for deriving sat is presented in Equation 4-10.

PRG EQUATIONS

Soil Equations: For soils, equations were based on three exposure routes (ingestion, skin contact, and inhalation).

Equation 4-1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{TR \times AT_c}{EF_r \left[\left(\frac{IFS_{adj} \times CSF_o}{10^6 \text{mg/kg}} \right) \% \left(\frac{SFS_{adj} \times ABS \times CSF_o}{10^6 \text{mg/kg}} \right) \% \left(\frac{InhF_{adj} \times CSF_i}{VF_s^a} \right) \right]}$$

Equation 4-2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{THQ \times BW_c \times AT_n}{EF_r \times ED_o \left[\left(\frac{1}{RfD_o} \times \frac{IRS_c}{10^6 \text{mg/kg}} \right) \% \left(\frac{1}{RfD_o} \times \frac{SA_c \times AF \times ABS}{10^6 \text{mg/kg}} \right) \% \left(\frac{1}{RfD_i} \times \frac{IRA_c}{VF_s^a} \right) \right]}$$

Equation 4-3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{TR \times BW_a \times AT_c}{EF_o \times ED_o \left[\left(\frac{IRS_o \times CSF_o}{10^6 \text{mg/kg}} \right) \% \left(\frac{SA_a \times AF \times ABS \times CSF_o}{10^6 \text{mg/kg}} \right) \% \left(\frac{IRA_a \times CSF_i}{VF_s^a} \right) \right]}$$

Footnote:

^aUse VF_s for volatile chemicals (defined as having a Henry's Law Constant [atm-m³/mol] greater than 10⁻⁵ and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.

Equation 4-4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{THQ \times BW_a \times AT_n}{EF_o \times ED_o \left[\left(\frac{1}{RfD_o} \times \frac{IRS_o}{10^6 \text{mg/kg}} \right) \% \left(\frac{1}{RfD_o} \times \frac{SA_a \times AF \times ABS}{10^6 \text{mg/kg}} \right) \% \left(\frac{1}{RfD_i} \times \frac{IRA_a}{VF_s^a} \right) \right]}$$

Tap Water Equations:

Equation 4-5: Ingestion and Inhalation Exposures to Carcinogenic Contaminants in Water

$$C(\text{ug/L}) = \frac{TR \times AT_c \times 1000 \text{ug/mg}}{EF_r \left[(IFW_{adj} \times CSF_o) \% (VF_w \times InhF_{adj} \times CSF_i) \right]}$$

Equation 4-6: Ingestion and Inhalation Exposures to Noncarcinogenic Contaminants in Water

$$C(\text{ug/L}) = \frac{THQ \times BW_a \times AT_n \times 1000 \text{ug/mg}}{EF_r \times ED_r \left[\left(\frac{IRW_a}{RfD_o} \right) \% \left(\frac{VF_w \times IRA_a}{RfD_i} \right) \right]}$$

Air Equations:

Equation 4-7: Inhalation Exposures to Carcinogenic Contaminants in Air

$$C(\text{ug/m}^3) = \frac{TR \times AT_c \times 1000 \text{ug/mg}}{EF_r \times InhF_{adj} \times CSF_i}$$

Equation 4-8: Inhalation Exposures to Noncarcinogenic Contaminants in Air

$$C(\text{ug/m}^3) = \frac{THQ \times RfD_i \times BW_a \times AT_n \times 1000 \text{ug/mg}}{EF_r \times ED_r \times IRA_a}$$

Footnote:

^aUse VF_s for volatile chemicals (defined as having a Henry's Law Constant [atm-m³/mol] greater than 10⁻⁵ and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.

SOIL-TO-AIR VOLATILIZATION FACTOR (VF_s)

Equation 4-9: Derivation of the Volatilization Factor

$$VF_s (m^3/kg) = (Q/C) \times \frac{(3.14 \times D_A \times T)^{1/2}}{(2 \times \rho_b \times D_A)} \times 10^8 (m^2/cm^2)$$

where:

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

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
VF _s	Volatilization factor (m ³ /kg)	--
D _A	Apparent diffusivity (cm ² /s)	--
Q/C	Inverse of the mean conc. at the center of a 0.5-acre square source (g/M ² -s per kg/m ³)	68.81
T	Exposure interval (s)	9.5 x 10 ⁸
ρ _b	Dry soil bulk density (g/cm ³)	1.5
Θ _a	Air filled soil porosity (L _{air} /L _{soil})	0.28 or n-Θ _w
n	Total soil porosity (L _{pore} /L _{soil})	0.43 or 1 - (ρ _b /ρ _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
H	Henry's Law constant (atm-m ³ /mol)	Chemical-specific
H'	Dimensionless Henry's Law constant	Calculated from H by multiplying by 41 (USEPA 1991a)
D _w	Diffusivity in water (cm ² /s)	Chemical-specific
K _d	Soil-water partition coefficient (cm ³ /g) = K _{oc} f _{oc}	Chemical-specific
K _{oc}	Soil organic carbon-water partition coefficient (cm ³ /g)	Chemical-specific
f _{oc}	Fraction organic carbon in soil (g/g)	0.006 (0.6%)

SOIL SATURATION CONCENTRATION (sat)

Equation 4-10: Derivation of the Soil Saturation Limit

$$sat = \frac{S}{\rho_b} (K_d \rho_b \% \Theta_w \% H)^{\Theta_a}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
sat	Soil saturation concentration (mg/kg)	--
S	Solubility in water (mg/L-water)	Chemical-specific
ρ_b	Dry soil bulk density (kg/L)	1.5
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or $1 - (\rho_b/\rho_s)$
ρ_s	Soil particle density (kg/L)	2.65
K_d	Soil-water partition coefficient (L/kg)	$K_{oc} \times f_{oc}$ (chemical-specific)
k_{oc}	Soil organic carbon/water partition coefficient (L/kg)	Chemical-specific
f_{oc}	Fraction organic carbon content of soil (g/g)	0.006 or site-specific
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
Θ_a	Air filled soil porosity (L_{air}/L_{soil})	0.28 or $n - \Theta_w$
w	Average soil moisture content (kg_{water}/kg_{soil} or L_{water}/kg_{soil})	0.1
H	Henry's Law constant ($atm \cdot m^3/mol$)	Chemical-specific
H'	Dimensionless Henry's Law constant	$H \times 41$, where 41 is a units conversion factor

SOIL-TO-AIR PARTICULATE EMISSION FACTOR (PEF)

Equation 4-11: Derivation of the Particulate Emission Factor

$$PEF (m^3/kg) = Q/C \times \frac{3600s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
PEF	Particulate emission factor (m ³ /kg)	1.316 x 10 ⁹
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source (g/M ² -s per kg/m ³)	90.80
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 7 m (m/s)	11.32
F(x)	Function dependent on U _m /U _t derived using Cowherd (1985) (unitless)	0.194

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APPENDIX 3

RELEVANT PORTIONS OF
*USER'S GUIDE FOR THE JOHNSON AND
ETTINGER (1991) MODEL FOR SUBSURFACE
VAPOR INTRUSION INTO BUILDINGS*

SENSITIVITY ANALYSIS OF *JOHNSON AND
ETTINGER (1991) MODEL*

**USER'S GUIDE FOR
EVALUATING SUBSURFACE VAPOR INTRUSION
INTO BUILDINGS**

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DISCLAIMER

This document presents technical and policy recommendations based on current understanding of the phenomenon of subsurface vapor intrusion. This guidance does not impose any requirements or obligations on the U.S. Environmental Protection Agency (EPA) or on the owner/operators of sites that may be contaminated with volatile and toxic compounds. The sources of authority and requirements for addressing subsurface vapor intrusion are the applicable and relevant statutes and regulations. This guidance addresses the assumptions and limitations that need to be considered in the evaluation of the vapor intrusion pathway. This guidance provides instructions on the use of the vapor transport model that originally was developed by P. Johnson and R. Ettinger in 1991 and subsequently modified by EPA in 1998, 2001, and again in November 2002. On November 29, 2002 EPA published Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Federal Register: November 29, 2002 Volume 67, Number 230 Page 71169-71172). This document is intended to be a companion for that guidance. Users of this guidance are reminded that the science and policies concerning vapor intrusion are complex and evolving.

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WHAT'S NEW IN THIS VERSION!

This revised version of the User's Guide corresponds with the release of Version 3.1 of the Johnson and Ettinger (1991) model (J&E) spreadsheets for estimating subsurface vapor intrusion into buildings. Several things have changed within the models since Version 2 was released in December 2000 and since the original version was released in September 1998. The following represent the major changes in Version 3.1 to be consistent with Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Quality from Groundwater and Soils dated November 25, 2002 as referenced below:

1. Table 1 lists the chemicals that are commonly found at contaminated sites. This list has been expanded from the list of chemicals included in Version 2 of the model. We have also applied certain criteria to determine whether it is appropriate to run the model for these contaminants. Only those contaminants for which all of the toxicological or physical chemical properties needed to make an assessment of the indoor inhalation risk are included in the spreadsheets. A chemical is considered to be sufficiently toxic if the vapor concentration of the pure component poses an incremental life time cancer risk greater than 1×10^{-6} or the noncancer hazard index is greater than 1. A chemical is considered to be sufficiently volatile if its Henry's law constant is 1×10^{-5} atm-m³/mole or greater. The final chemical list for Version 3 includes 108 chemicals.
2. **Chemical Property Data** - The source of chemical data used in the calculation is primarily EPA's Superfund Chemical Data Matrix (SCDM) database. EPA's WATER9 database is used for chemicals not included in the SCDM database. Appendix B contains other data sources. Henry's Law value for cumene is incorrect in the above listed reference. The correct value was determined by using EPA's system performs automated reasoning in chemistry algorithms found in "Prediction of Chemical Reactivity Parameters and Physical Properties of Organic Compounds from Molecular Structure Using SPARE." EPA-2003.
3. **Toxicity Values** – EPA's Integrated Risk Information System (IRIS) is the generally preferred source of carcinogenic unit risks and non-carcinogenic reference concentrations (RfCs) for inhalation exposure.¹ The following two sources were consulted, in order of preference, when IRIS values were not available: provisional toxicity values recommended by EPA's National Center for Environmental Assessment (NCEA) and EPA's Health Effects Assessment Summary Tables (HEAST). If no inhalation toxicity data could be obtained from IRIS, NCEA, or HEAST, extrapolated unit risks and/or RfCs using toxicity data for oral exposure (cancer slope factors and/or reference doses, respectively) from these same sources

¹ U.S. EPA. 2002. Integrated Risk Information System (IRIS). <http://www.epa.gov/iriswebp/iris/index.html>. November.

using the same preference order were used.² Note that for most compounds, extrapolation from oral data introduces considerable uncertainty into the resulting inhalation value. Values obtained from inhalation studies or from pharmacokinetic modeling applied to oral doses will be less uncertain than those calculated using the equations noted in footnote 2.

IRIS currently does not include carcinogenicity data for trichloroethylene (TCE), a volatile contaminant frequently encountered at hazardous waste sites. The original carcinogenicity assessment for TCE, which was based on a health risk assessment conducted in the late 1980's, was withdrawn from IRIS in 1994. The Superfund Technical Support Center has continued to recommend use of the cancer slope factor from the withdrawn assessment, until a reassessment of the carcinogenicity of TCE is completed. In 2001, the Agency published a draft of the TCE toxicity assessment for public comment.³ Using this guidance, TCE target concentrations for the draft vapor intrusion guidance were calculated using a cancer slope factor identified in that document, which is available on the NCEA web site. This slope factor was selected because it is based on state-of-the-art methodology. However, because this document is still undergoing review, the slope factor and the target concentrations calculated for TCE are subject to change and should be considered "provisional" values.

Toxicity databases such as IRIS are routinely updated as new information becomes available; the data included in the lookup tables are current as of December 2003. Users of these models are strongly encouraged to research the latest toxicity values for contaminants of interest from the sources noted above. In the next year, IRIS reassessments are expected for several contaminants commonly found in subsurface contamination whose inhalation toxicity values are currently based on extrapolation.

4. Assumption and Limitations

The Johnson and Ettinger (J&E) Model was developed for use as a screening level model and, consequently, is based on a number of simplifying assumptions regarding contaminant distribution and occurrence, subsurface characteristics, transport mechanisms, and building construction. The assumptions of the J&E Model as implemented in EPA's spreadsheet version are listed in Section 2.11, Section 5, and

² The oral-to-inhalation extrapolations assume an adult inhalation rate (IR) of 20 m³/day and an adult body weight (BW) of 70 kg. Unit risks (URs) were extrapolated from cancer slope factors (CSFs) using the following equation:

$$\text{UR } (\mu\text{g}/\text{m}^3)^{-1} = \text{CSF } (\text{mg}/\text{kg}/\text{d})^{-1} * \text{IR } (\text{m}^3/\text{d}) * (1/\text{BW})(\text{kg}^{-1}) * (10^{-3} \text{ mg}/\mu\text{g})$$

Reference concentrations (RfCs) were extrapolated from reference doses (RfDs) using the following equation:

$$\text{RfC } (\text{mg}/\text{m}^3) = \text{RfD } (\text{mg}/\text{kg}/\text{d}) * (1/\text{IR}) (\text{m}^3/\text{d})^{-1} (\text{BW } (\text{kg})$$

³ US EPA, Trichloroethylene Health Risk Assessment: Synthesis and Characterization – External Review Draft, Office of Research and Development, EPA/600/P-01-002A, August, 2001.

Table 12 along with an assessment of the likelihood that the assumptions can be verified through field evaluation.

5. Soil Parameters

A list of generally reasonable, yet conservative, model input parameters for selected soil and sampling related parameters are provided in Tables 7 and 8. These tables also provide the practical range, typical or mean value (if applicable), and most conservative value for these parameters. For building parameters with low uncertainty and sensitivity, only a single “fixed” value corresponding to the mean or typical value is provided in Table 9. Soil-dependent properties are provided in Table 10 for soils classified according to the US Soil Conservation Soil (SCS) system. If site soils are not classified according to the US SCS, Table 11 can be used to assist in selecting an appropriate SCS soil type corresponding to the available site lithologic information. Note that the selection of the soil texture class should be biased towards the coarsest soil type of significance, as determined by the site characterization program. These input parameters were developed considering soil-physics science, available studies of building characteristics, and expert opinion. Consequently, the input parameters listed in Tables 7 and 8 are considered default parameters for a first-tier assessment, which should in most cases provide a reasonably (but not overly) conservative estimate of the vapor intrusion attenuation factor for a site. The soil water filled porosity (θ_w) is dependent on the soil type and the default value was removed from the model set up. Users must define soil type or input a value for the porosity.

6. Building Parameters

Building Air Exchange Rate (Default Value = 0.25 hr⁻¹)

Results from 22 studies for which building air exchange data are available were summarized in Hers et al. (2001). When all the data were analyzed, the 10th, 50th, and 90th percentile values were 0.21, 0.51, and 1.48 air exchanges per hour (AEH). Air exchange rates varied depending on season and climatic region. For example, for the winter season and coldest climatic area (Region 1, Great Lakes area and extreme northeast US), the 10th, 50th, and 90th percentile values were 0.11, 0.27, and 0.71 AEH. In contrast, for the winter season and warmest climatic area [Region 4 (southern California, Texas, Florida, Georgia)], the 10th, 50th, and 90th percentile values were 0.24, 0.48, and 1.13 AEH. For this guidance, a default value of 0.25 for air exchange rate was selected to represent the lower end of these distributions. The previous version of the guidance included a default value of 0.45 exchanges per hour.

Building Area and Subsurface Foundation Area (Default Value = 10 m by 10 m)

A Michigan study indicates that a 111.5 m² area approximately corresponds to the 10th percentile floor space area for residential single family dwellings, based on statistics compiled by the U.S. Department of Commerce (DOC) and U.S. Housing and Urban Development (HUD). The previous median value was 9.61 m x 9.61 m.

Building Mixing Height (Default Value = 2.44 m for slab-on-grade scenario; = 3.66 m for basement scenario)

The J&E Model assumes that subsurface volatiles migrating into the building are completely mixed within the building volume, which is determined by the building area and mixing height. The building mixing height will depend on a number of factors including the building height, the heating, ventilation and air conditioning (HVAC) system operation, environmental factors such as indoor-outdoor pressure differentials and wind loading, and seasonal factors. For a single-story house, the variation in mixing height can be approximated by the room height. For a multi-story house or apartment building, the mixing height will be greatest for houses with HVAC systems that result in significant air circulation (e.g., forced-air heating systems). Mixing heights will be less for houses using electrical baseboard heaters. It is likely that mixing height is, to some degree, correlated to the building air exchange rate.

There are little data available that provide for direct inference of mixing height. There are few sites, with a small number of houses where indoor air concentrations were above background, and where both measurements at ground level and the second floor were made (CDOT, Redfields, Eau Claire). Persons familiar with the data sets for these sites indicate that in most cases a fairly significant reduction in concentrations (factor of two or greater) was observed, although at one site (Eau Claire, "S" residence), the indoor TCE concentrations were similar in both the basement and second floor of the house. For the CDOT site apartments, there was an approximate five-fold reduction between the concentrations measured for the first floor and second floor units. Less mixing would be expected for an apartment because there are less cross-floor connections than for a house. The default value chosen for a basement house scenario (3.66 m) would be representative of a two-fold reduction or attenuation in vapor concentrations between floors.

Crack Width (0.1 cm) and Crack Ratio (Default Value = 0.0002 for basement house; = 0.0038 for slab-on-grade house)

The crack width and crack ratio are related. Assuming a square house and that the only crack is a continuous edge crack between the foundation slab and wall ("perimeter crack"), the crack ratio and crack width are related as follows:

$$\text{Crack Ratio} = \frac{4(\text{Crack Width} / \sqrt{\text{Subsurface Foundation Area}})}{\text{Subsurface Foundation Area}}$$

There is little information available on crack width or crack ratio. One approach used by radon researchers is to back calculate crack ratios using a model for soil gas flow through cracks and the results of measured soil gas flow rates into a building. For example, the back-calculated values for a slab/wall edge crack based on soil gas-entry rates reported in Nazaroff (1992), Revzan et al. (1991), and Nazaroff et al. (1985) range from approximately 0.0001 to 0.001. Another possible approach is to measure crack openings although this, in practice, is difficult to do. Figley and Snodgrass (1992) present data from ten houses where edge crack measurements were made. At the eight houses where cracks were observed, the cracks' widths ranged from hairline cracks up to 5 mm wide, while the total crack length per house ranged from 2.5 m to 17.3 m. Most crack widths were less than 1 mm. The suggested defaults for crack ratio is regulatory guidance, literature and models also vary. In ASTM E1739-95, a default crack ratio of 0.01 is used. The crack ratios suggested in the VOLASOIL model (developed by the Dutch Ministry of Environment) range from 0.0001 to 0.0000001. The VOLASOIL model values correspond to values for a "good" and "bad" foundation, respectively. The crack ratio used by J&E (1991) for illustrative purposes ranged from 0.001 to 0.01. The selected default values fall within the ranges observed.

Q_{soil} (Default Value = 5 L/min)

The method used to estimate the vapor flowrate into a building (Q_{soil}) is an analytical solution for two-dimensional soil gas flow to a small horizontal drain (Nazaroff 1992) ("Perimeter Crack Model"). Use of this model can be problematic in that Q_{soil} values are sensitive to soil-air permeability and consequently a wide range in flows can be predicted.

An alternate empirical approach was selected to determine the Q_{soil} value. This new approach is based on trace tests (i.e., mass balance approach). When soil gas advection is the primary mechanism for tracer intrusion into a building, the Q_{soil} value is estimated by measuring the concentrations of a chemical tracer in indoor air, outdoor air, and in soil vapor below a building, and measuring the building ventilation rate (Hers et al. 2000a; Fischer et al. 1996; Garbesi et al. 1993; Rezvan et al. 1991; Barbesi and Sectro 1989). The Q_{soil} values measured using this technique were compared to predicted rates using the Perimeter Crack model, for sites with coarse-grained soils. The Perimeter Crack model predictions are both higher and lower than the measured values, but overall are within one order of magnitude of the measured values. Although the Q_{soil} predicted by the models and measured using field tracer tests are uncertain, the results suggest that a "typical" range for houses on coarse-grained soils is on the order of 1 to 10 L/min. A disadvantage with the tracer

test approach is that there are only limited data, and there do not appear to be any tracer studies for field sites with fine-grained soils.

Because the advective flow zone is relatively limited in extent, the soil type adjacent to the building foundation is of importance. In many cases, coarse-grained imported fill is placed below foundations, and either coarse-grained fill, or disturbed, loose fill is placed adjacent to the foundation walls. Therefore, a conservative approach for the purposes of this guidance is to assume that soil gas flow will be controlled by coarse-grained soil, and not to rely on the possible reduction in flow that would be caused by fine-grained soils near the house foundation. For these reasons, a soil gas flow rate of 5 L/min (midpoint between 1 and 10 L/min) was chosen as the input value.

7. Convenience Changes

- Default values for soil bulk densities have been added to the lookup tables for the various soil types.
- Default values for soil water-filled porosity have been updated within the lookup tables for soil properties for the various soil types.
- The chemical data list has been expanded to include 108 chemicals. Chemical physical properties were reviewed and updated where applicable to provide the user with more accurate values.
- All of the lookup functions within the models were modified to include an exact match parameter, rather than a closest match. The models would previously return data for CAS Numbers not in the lookup tables. Although the DATENTER sheet informed the user that this CAS Number was not found, it would return values on the CHEMPROPS sheet that was the closest match. This caused some confusion and therefore was changed.
- CAS number and soil type pick lists were added to the cells within the models where the user is required to provide data in a specific format. The pick lists were added to assist the user from entering data that are not an acceptable parameter.
- All models were modified to require the user to specify the soil type of each stratum. In addition, a button was added that allows the user to automatically retrieve the default values for the soil type selected. These additions were added as a convenience to the user and soil selection can be ignored should site-specific data be available.
- All models were modified to include an input for the average vapor flow rate into the building (Q_{soil}) in liters/minute (L/min). This value can be left blank and the model will calculate the value of Q_{soil} as was done in previous versions.

- All models were also modified to include a button that will reset the default value on the DATENTER sheet. This button will allow the user to clear all values and reset the default values or reset only those values that have a default value. The user is also allowed to specify whether the values should be reset for the basement or slab-on-grade scenario.

SECTION 1

INTRODUCTION TO THE VAPOR INTRUSION MODEL THEORY AND APPLICATION

Volatilization of contaminants located in subsurface soils or in groundwater, and the subsequent mass transport of these vapors into indoor spaces constitutes a potential inhalation exposure pathway, which may need to be evaluated when preparing risk assessments. Likewise, this potential indoor inhalation exposure pathway may need evaluation when estimating a risk-based soil or groundwater concentration below which associated adverse health effects are unlikely.

Johnson and Ettinger (J&E) (1991) introduced a screening-level model that incorporates both convective and diffusive mechanisms for estimating the transport of contaminant vapors emanating from either subsurface soils or groundwater into indoor spaces located directly above the source of contamination. In their article, J&E reported that the results of the model were in qualitative agreement with published experimental case histories and in good qualitative and quantitative agreement with detailed three-dimensional numerical modeling of radon transport into houses.

The J&E Model is a one-dimensional analytical solution to convective and diffusive vapor transport into indoor spaces and provides an estimated attenuation coefficient that relates the vapor concentration in the indoor space to the vapor concentration at the source of contamination. The model is constructed as both a steady-state solution to vapor transport (infinite or non-diminishing source) and as a quasi-steady-state solution (finite or diminishing source). Inputs to the model include chemical properties of the contaminant, saturated and unsaturated zone soil properties, and structural properties of the building.

This manual provides documentation and instructions for using the vapor intrusion model as provided in the accompanying spreadsheets.

Model results (both screening and advanced) are provided as either a risk-based soil or groundwater concentration, or as an estimate of the actual incremental risks associated with a user-defined initial concentration. That is to say that the model will reverse-calculate an “acceptable” soil or groundwater concentration given a user-defined risk level (i.e., target risk level or target hazard quotient), or the model may be used to forward-calculate an incremental cancer risk or hazard quotient based on an initial soil or groundwater concentration.

The infinite source models for soil contamination and groundwater contamination should be used as first-tier screening tools. In these models, all but the most sensitive model parameters have

been set equal to central tendency or upper bound values. Values for the most sensitive parameters may be user-defined.

More rigorous estimates may be obtained using site-specific data and the finite source model for soil contamination. Because the source of groundwater contamination may be located upgradient of the enclosed structure for which the indoor inhalation pathway is to be assessed, the advanced model for contaminated groundwater is based on an infinite source of contamination, however, site-specific values for all other model parameters may be user-defined.

In addition to the finite and infinite source models referred to above, two models that allow the user to input empirical soil gas concentration and sampling depth information directly into the spreadsheets. These models will subsequently estimate the resulting steady-state indoor air concentrations and associated health risks.

Because of the paucity of empirical data available for either bench-scale or field-scale verification of the accuracy of these models, as well as for other vapor intrusion models, the user is advised to consider the variation in input parameters and to explore and quantify the impacts of assumptions on the uncertainty of model results. At a minimum, a range of results should be generated based on variation of the most sensitive model parameters.

SECTION 2

MODEL THEORY

Chemical fate and transport within soils and between the soil column and enclosed spaces are determined by a number of physical and chemical processes. This section presents the theoretical framework on which the J&E Model is based, taking into account the most significant of these processes. In addition, this section also presents the theoretical basis for estimating values for some of the most sensitive model parameters when empirical field data are lacking. The fundamental theoretical development of this model was performed by J&E (1991).

2.1 MODEL SETTING

Consider a contaminant vapor source (C_{source}) located some distance (L_T) below the floor of an enclosed building constructed with a basement or constructed slab-on-grade. The source of contamination is either a soil-incorporated volatile contaminant or a volatile contaminant in solution with groundwater below the top of the water table.

Figure 1 is a simplified conceptual diagram of the scenario where the source of contamination is incorporated in soil and buried some distance below the enclosed space floor. At the top boundary of contamination, molecular diffusion moves the volatilized contaminant toward the soil surface until it reaches the zone of influence of the building. Here convective air movement within the soil column transports the vapors through cracks between the foundation and the basement slab floor. This convective sweep effect is induced by a negative pressure within the structure caused by a combination of wind effects and stack effects due to building heating and mechanical ventilation.

Figure 2 illustrates the scenario where the source of contamination is below the top of the water table. Here the contaminant must diffuse through a capillary zone immediately above the water table and through the subsequent unsaturated or vadose zone before convection transports the vapors into the structure.

The suggested minimum site characterization information for a first-tier evaluation of the vapor intrusion pathway includes: site conceptual model, nature and extent of contamination distribution, soil lithologic descriptions, groundwater concentrations, and/or possibly near source soil vapor concentrations. The number of samples and measurements needed to establish this information varies by site, and it is not possible to provide a hard and fast rule.

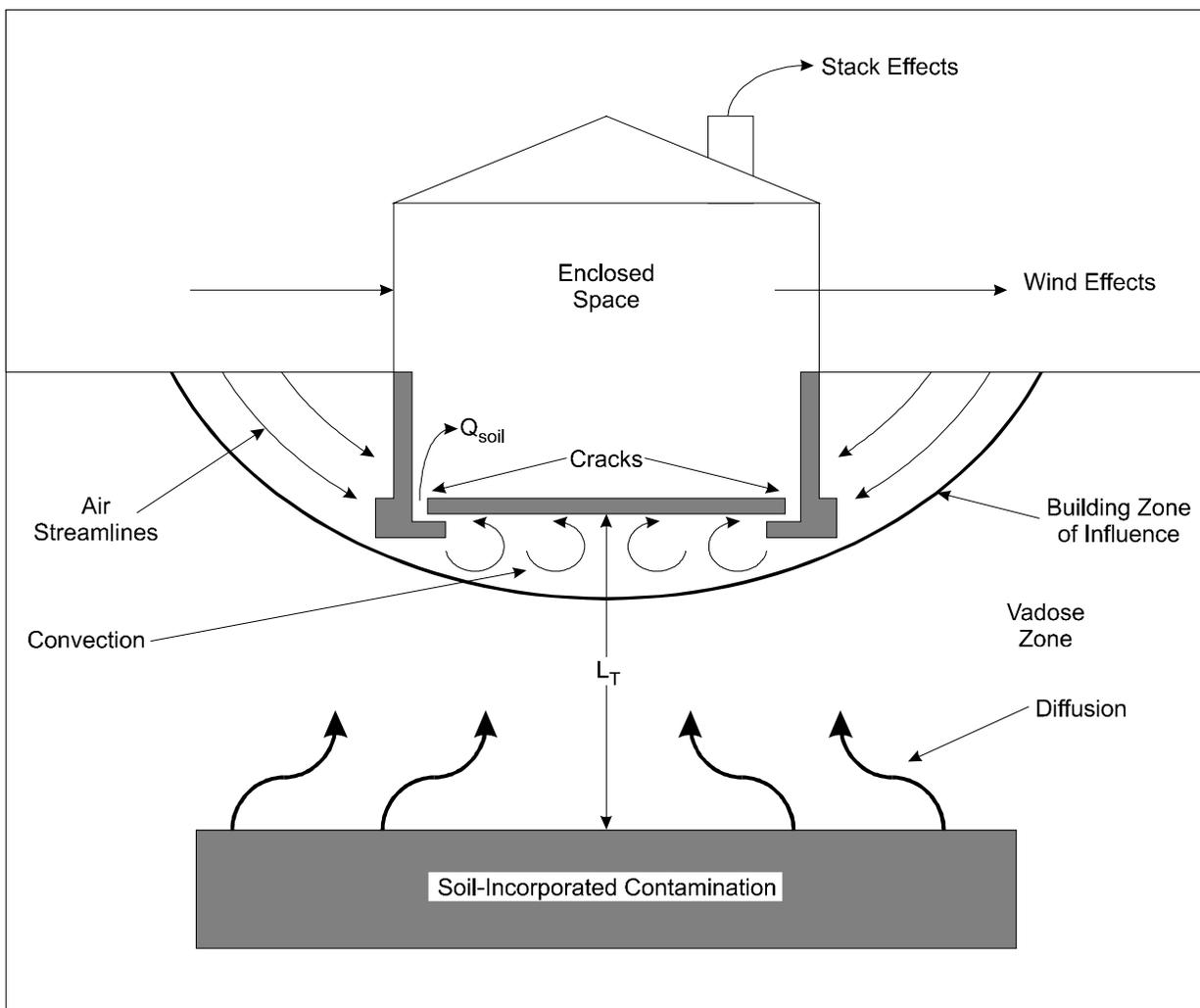


Figure 1. Pathway for Subsurface Vapor Intrusion into Indoor Air

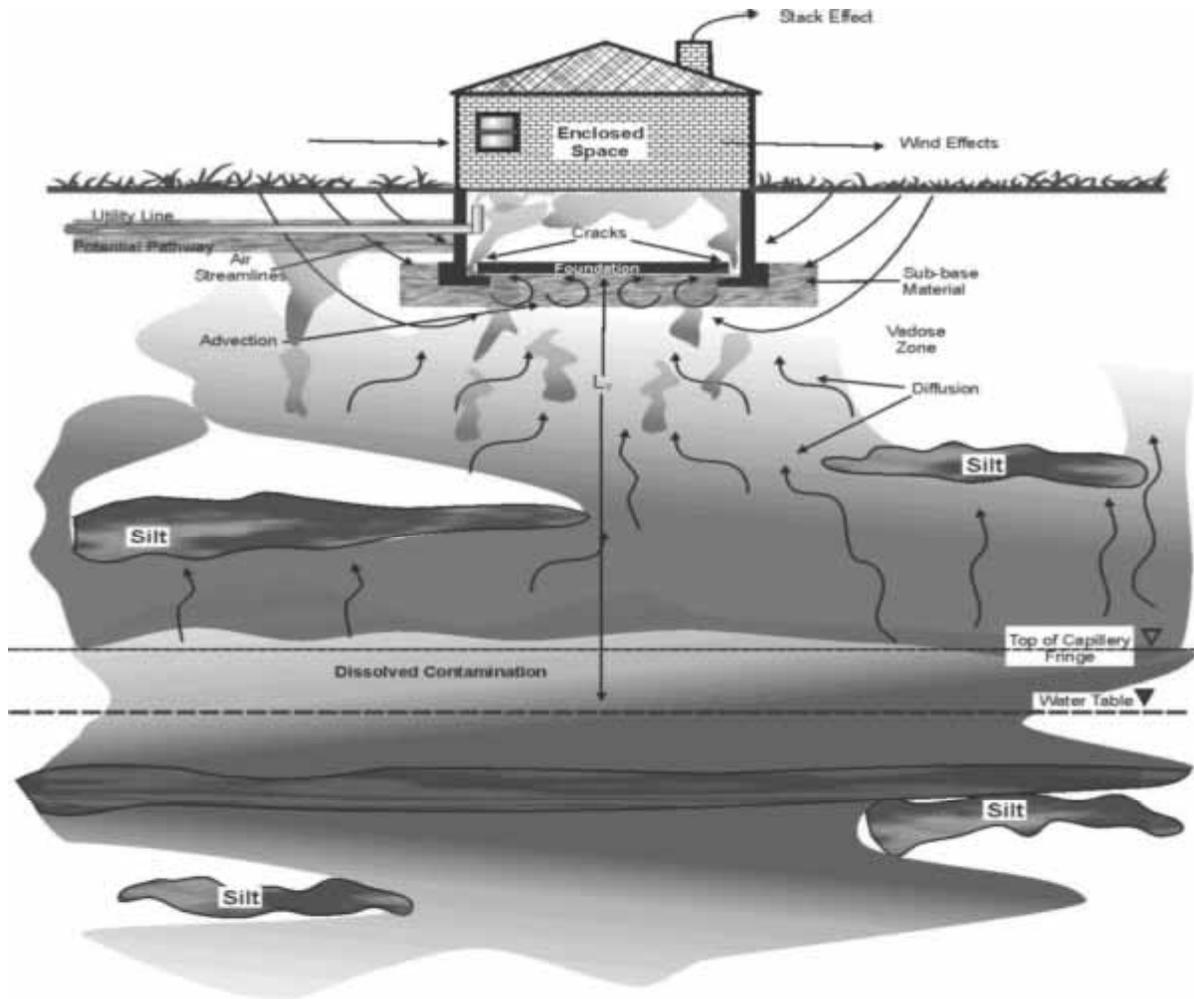


Figure 2. Vapor Pathway into Buildings

Based on the conceptual site model, the user can select the appropriate spreadsheet corresponding to the vapor source at the site and determine whether to use the screening level spreadsheet (which accommodates only one soil type above the capillary fringe) or the more advanced version (which allows up to three layers above the capillary fringe). As most of the inputs to the J&E Model are not collected during a typical site characterization, conservative inputs are typically estimated or inferred from available data and other non-site specific sources of information.

Table 1 lists 114 chemicals that may be found at hazardous waste sites and it indicates whether the chemical is sufficiently toxic and volatile to result in a potentially unacceptable indoor inhalation risk. It also provides a column for checking off the chemicals found or reasonably suspected to be present in the subsurface at a site. Under this approach, a chemical is considered sufficiently toxic if the vapor concentration of the pure component poses an incremental lifetime cancer risk greater than 10^{-6} or results in a non-cancer hazard index greater than one. A chemical is considered sufficiently volatile if its Henry's Law Constant is 1×10^{-5} atm-m³/mol or greater (EPA, 1991). It is assumed that if a chemical does not meet both of these criteria, it need not be further considered as part of the evaluation. Table 1 also identifies six chemicals that meet the toxicity and volatility criteria but are not included in the vapor intrusion models because one or more of the needed physical or chemical properties has not been found in the literature.

The rate of soil gas entry (Q_{soil}) or average vapor flow rate into the building is a function solely of convection; however, the vapor concentration entering the structure may be limited by either convection or diffusion depending upon the magnitude of the source-building separation (L_T).

2.2 VAPOR CONCENTRATION AT THE SOURCE OF CONTAMINATION

With a general concept of the problem under consideration, the solution begins with an estimate of the vapor concentration at the source of contamination.

In the case of soil contamination, the initial concentration (C_R) does not contain a residual-phase (e.g., nonaqueous-phase liquid or solid); and in the case of contaminated groundwater, the initial contaminant concentration (C_W) is less than the aqueous solubility limit (i.e., in solution with water).

Given these initial conditions, C_{source} for soil contamination may be estimated from Johnson et al. (1990) as:

$$C_{source} = \frac{H'_{TS} C_R \rho_b}{\theta_w + K_d \rho_b + H'_{TS} \theta_a} \quad (1)$$

where C_{source} = Vapor concentration at the source of contamination, g/cm³-v

H'_{TS} = Henry's law constant at the system (soil) temperature, dimensionless

TABLE 1. SCREENING LIST OF CHEMICALS

CAS No.	Chemical	Is Chemical Sufficiently Toxic? ¹	Is Chemical Sufficiently Volatile? ²	Check Here if Known or Reasonably Suspected to be Present ³
83329	Acenaphthene	YES	YES	
75070	Acetaldehyde	YES	YES	
67641	Acetone	YES	YES	
75058	Acetronitrile	YES	YES	
98862	Acetophenone	YES	YES	
107028	Acrolein	YES	YES	
107131	Acrylonitrile	YES	YES	
309002	Aldrin	YES	YES	
319846	Alpha-HCH (alpha-BHC)	YES	YES	
62533	Aniline	YES	NO	NA
120127	Anthracene	NO	YES	NA
56553	Benz(a)anthracene	YES	NO	NA
100527	Benzaldehyde	YES	YES	
71432	Benzene	YES	YES	
50328	Benzo(a)pyrene	YES	NO	NA
205992	Benzo(b)fluoranthene	YES	YES	
207089	Benzo(k)fluoranthene	NO	NO	NA
65850	Benzoic Acid	NO	NO	NA
100516	Benzyl alcohol	YES	NO	NA
100447	Benzylchloride	YES	YES	
91587	Beta-Chloronaphthalene ³	YES	YES	
319857	Beta-HCH(beta-BHC)	YES	NO	NA
92524	Biphenyl	YES	YES	
111444	Bis(2-chloroethyl)ether	YES	YES	
108601	Bis(2-chloroisopropyl)ether ³	YES	YES	
117817	Bis(2-ethylhexyl)phthalate	NO	NO	NA
542881	Bis(chloromethyl)ether ³	YES	YES	
75274	Bromodichloromethane	YES	YES	
75252	Bromoform	YES	YES	
106990	1,3-Butadiene	YES	YES	
71363	Butanol	YES	NO	NA
85687	Butyl benzyl phthalate	NO	NO	NA
86748	Carbazole	YES	NO	NA
75150	Carbon disulfide	YES	YES	
56235	Carbon tetrachloride	YES	YES	
57749	Chlordane	YES	YES	

(continued)

CAS No.	Chemical	Is Chemical Sufficiently Toxic? ¹	Is Chemical Sufficiently Volatile? ²	Check Here if Known or Reasonably Suspected to be Present ³
126998	2-Chloro-1,3-butadiene(chloroprene)	YES	YES	
108907	Chlorobenzend	YES	YES	
109693	1-Chlorobutane	YES	YES	
124481	Chlorodibromomethane	YES	YES	
75456	Chlorodifluoromethane	YES	YES	
75003	Chloroethane (ethyl chloride)	YES	YES	
67663	Chloroform	YES	YES	
95578	2-Chlorophenol	YES	YES	
75296	2-Chloropropane	YES	YES	
218019	Chrysene	YES	YES	
156592	Cis-1,2-Dichloroethylene	YES	YES	
123739	Crotonaldehyde(2-butenal)	YES	YES	
998828	Cumene	YES	YES	
72548	DDD	YES	NO	NA
72559	DDE	YES	YES	
50293	DDT	YES	NO	NA
53703	Dibenz(a,h)anthracene	YES	NO	NA
132649	Dibenzofuran	YES	YES	
96128	1,2-Dibromo-3-chloropropane ³	YES	YES	
106934	1,2-Dibromoethane(ethylene dibromide)	YES	YES	
541731	1,3-Dichlorobenzene	YES	YES	
95501	1,2-Dichlorobenzene	YES	YES	
106467	1,4-Dichlorobenzene	YES	YES	
91941	3,3-Dichlorobenzidine	YES	NO	NA
75718	Dichlorodifluoromethane	YES	YES	
75343	1,1-Dichloroethane	YES	YES	
107062	1,2-dichloroethane	YES	YES	
75354	1,1-Dichloroethylene	YES	YES	
120832	2,4-Dichloroephenol	YES	NO	NA
78875	1,2-Dichloropropane	YES	YES	
542756	1,3-Dichloropropene	YES	YES	
60571	Dieldrin	YES	YES	
84662	Diethylphthalate	YES	NO	NA
105679	2,4-Dimethylphenol	YES	NO	NA
131113	Dimethylphthalate	NA	NO	NA
84742	Di-n-butyl phthalate	NO	NO	NA

(continued)

CAS No.	Chemical	Is Chemical Sufficiently Toxic? ¹	Is Chemical Sufficiently Volatile? ²	Check Here if Known or Reasonably Suspected to be Present ³
534521	4,6 Dinitro-2methylphenol (4, 6-dinitro-o-cresol)	YES	NO	NA
51285	2,4-Dinitrophenol	YES	NO	NA
121142	2,4-Dinitrotoluene	YES	NO	NA
606202	2,6-Dinitrotoluene	YES	NO	NA
117840	Di-n-octyl phthalate	NO	YES	NA
115297	Endosulfan	YES	YES	
72208	Endrin	YES	NO	NA
106898	Epichlorohydrin ³	YES	YES	
60297	Ethyl ether	YES	YES	
141786	Ethylacetate	YES	YES	
100414	Ethylbenzene	YES	YES	
75218	Ethylene oxide	YES	YES	
97632	Ethylmethacrylate	YES	YES	
206440	Fluoranthene	NO	YES	NA
86737	Fluorene	YES	YES	
110009	Furane	YES	YES	
58899	Gamma-HCH(Lindane)	YES	YES	
76448	Heptachlor	YES	YES	
1024573	Heptachlor epoxide	YES	NO	NA
87683	Hexachloro-1,3-butadiene	YES	YES	
118741	Hexachlorobenzene	YES	YES	
77474	Hexachlorocyclopentadiene	YES	YES	
67721	Hexachloroethane	YES	YES	
110543	Hexane	YES	YES	
74908	Hydrogene cyanide	YES	YES	
193395	Indeno (1,2,3-cd)pyrene	NO	NO	NA
78831	Isobutanol	YES	YES	
78591	Isophorone	YES	NO	NA
7439976	Mercury (elemental)	YES	YES	
126987	Methacrylonitrile	YES	YES	
72435	Methoxychlor	YES	YES	
79209	Methy acetate	YES	YES	
96333	Methyl acrylate	YES	YES	
74839	Methyl bromide	YES	YES	
74873	Methyl chloride (chloromethane)	YES	YES	
108872	Methylcyclohexane	YES	YES	

(continued)

CAS No.	Chemical	Is Chemical Sufficiently Toxic? ¹	Is Chemical Sufficiently Volatile? ²	Check Here if Known or Reasonably Suspected to be Present ³
74953	Methylene bromide	YES	YES	
75092	Methylene chloride	YES	YES	
78933	Methylethylketone (2-butanone)	YES	YES	
108101	Methylisobutylketone (4-methyl-2-pentanone)	YES	YES	
80626	Methylmethacrylate	YES	YES	
91576	2-Methylnaphthalene	YES	YES	
108394	3-Methylphenol(m-cresol)	YES	NO	NA
95487	2-Methylphenol(o-cresol)	YES	NO	NA
106455	4-Methylphenol (p-cresol)	YES	NO	NA
99081	m-Nitrotoluene	YES	NO	NA
1634044	MTBE	YES	YES	
108383	m-Xylene	YES	YES	
91203	Naphthalene	YES	YES	
104518	n-Butylbenzene	YES	YES	
98953	Nitrobenzene	YES	YES	
100027	4-Nitrophenol	YES	NO	NA
79469	2-Nitropropane	YES	YES	
924163	N-nitroso-di-n-butylamine ³	YES	YES	
621647	N-Nitroso-di-n-propylamine	YES	NO	NA
86306	N-Nitrosodiphenylamine	YES	NO	NA
103651	n-Propylbenzene	YES	YES	
88722	o-Nitrotoluene	YES	YES	
95476	o-Xylene	YES	YES	
106478	p-Chloroaniline	YES	NO	NA
87865	Pentachlorophenol	YES	NO	NA
108952	Phenol	YES	NO	NA
99990	p-Nitrotoluene	YES	NO	NA
106423	p-Xylene	YES	YES	
129000	Pyrene	YES	YES	
110861	Pyridine	YES	NO	NA
135988	Sec-Butylbenzene	YES	YES	
100425	Styrene	YES	YES	
98066	Tert-Butylbenzene	YES	YES	
630206	1,1,1,2-Tetrachloroethane	YES	YES	
79345	1,1,2,2,-Tetrachloroethane	YES	YES	
127184	Tetrachloroethylene	YES	YES	

(continued)

CAS No.	Chemical	Is Chemical Sufficiently Toxic? ¹	Is Chemical Sufficiently Volatile? ²	Check Here if Known or Reasonably Suspected to be Present ³
108883	Toluene	YES	YES	
8001352	Toxaphen	YES	NO	NA
156605	Trans-1,2-Dichloroethylene	YES	YES	
76131	1,1,2-Trichloro-1,2,2-trifluoroethane	YES	YES	
120821	1,2,4-Trichlorobenzene	YES	YES	
79005	1,1,2-Trichloroethane	YES	YES	
71556	1,1,1-Trichloroethane	YES	YES	
79016	Trichloroethylene	YES	YES	
75694	Trichlorofluoromethane	YES	YES	
95954	2,4,5-Trichlorophenol	YES	NO	NA
88062	2,4,6-Trichlorophenol	YES	NO	NA
96184	1,2,3-Trichloropropane	YES	YES	
95636	1,2,4-Trimethylbenzene	YES	YES	
108678	1,3,5-Trimethylbenzene	YES	YES	
108054	Vinyl acetate	YES	YES	
75014	Vinyl chloride (chloroethene)	YES	YES	

¹ A chemical is considered sufficiently toxic if the vapor concentration of the pure component poses an incremental lifetime cancer risk greater than 10^{-6} or a non-cancer hazard index greater than 1.

² A chemical is considered sufficiently volatile if its Henry's law constant is 1×10^{-5} atm-m³/mol or greater.

³ One or more of the physical chemical properties required to run the indoor air vapor intrusion models was not found during a literature search conducted March 2003.

- C_R = Initial soil concentration, g/g
 ρ_b = Soil dry bulk density, g/cm³
 θ_w = Soil water-filled porosity, cm³/cm³
 K_d = Soil-water partition coefficient, cm³/g (= K_{oc} x f_{oc})
 θ_a = Soil air-filled porosity, cm³/cm³
 K_{oc} = Soil organic carbon partition coefficient, cm³/g
 f_{oc} = Soil organic carbon weight fraction.

If the initial soil concentration includes a residual phase, the user is referred to the NAPL-SCREEN or NAPL-ADV models as discussed in Appendix A. These models estimate indoor air concentrations and associated risks for up to 10 user-defined contaminants that comprise a residual phase mixture in soils.

C_{source} for groundwater contamination is estimated assuming that the vapor and aqueous-phases are in local equilibrium according to Henry's law such that:

$$C_{source} = H'_{TS} C_w \quad (2)$$

where C_{source} = Vapor concentration at the source of contamination, g/cm³-v

H'_{TS} = Henry's law constant at the system (groundwater) temperature, dimensionless

C_w = Groundwater concentration, g/cm³-w.

The dimensionless form of the Henry's law constant at the system temperature (i.e., at the average soil/groundwater temperature) may be estimated using the Clapeyron equation by:

$$H'_{TS} = \frac{\exp\left[-\frac{\Delta H_{v,TS}}{R_c} \left(\frac{1}{T_S} - \frac{1}{T_R}\right)\right] H_R}{RT_S} \quad (3)$$

where H'_{TS} = Henry's law constant at the system temperature, dimensionless

$\Delta H_{v,TS}$ = Enthalpy of vaporization at the system temperature, cal/mol

- T_S = System temperature, °K
 T_R = Henry's law constant reference temperature, °K
 H_R = Henry's law constant at the reference temperature, atm-m³/mol
 R_C = Gas constant (= 1.9872 cal/mol - °K)
 R = Gas constant (= 8.205 E-05 atm-m³/mol-°K).

The enthalpy of vaporization at the system temperature can be calculated from Lyman et al. (1990) as:

$$\Delta H_{v,TS} = \Delta H_{v,b} \left[\frac{(1-T_S/T_C)}{(1-T_B/T_C)} \right]^n \quad (4)$$

- where
- $\Delta H_{v,TS}$ = Enthalpy of vaporization at the system temperature, cal/mol
 - $\Delta H_{v,b}$ = Enthalpy of vaporization at the normal boiling point, cal/mol
 - T_S = System temperature, °K
 - T_C = Critical temperature, °K
 - T_B = Normal boiling point, °K
 - n = Constant, unitless.

Table 2 gives the value of n as a function of the ratio T_B/T_C .

TABLE 2. VALUES OF EXPONENT n AS A FUNCTION OF T_B/T_C

T_B/T_C	n
< 0.57	0.30
0.57 - 0.71	0.74 (T_B/T_C) - 0.116
> 0.71	0.41

2.3 DIFFUSION THROUGH THE CAPILLARY ZONE

Directly above the water table, a saturated capillary zone exists whereby groundwater is held within the soil pores at less than atmospheric pressure (Freeze and Cherry, 1979). Between drainage and wetting conditions, the saturated water content varies but is always less than the fully saturated water content which is equal to the soil total porosity. This is the result of air entrapment in the pores during the wetting process (Gillham, 1984). Upon rewetting, the air content of the capillary zone will be higher than after main drainage. Therefore, the air content will vary as a function of groundwater recharge and discharge. At the saturated water content, Freijer (1994) found that the relative vapor-phase diffusion coefficient was almost zero. This implies that all remaining air-filled soil pores are disconnected and thus blocked for gas diffusion. As the air-filled porosity increased, however, the relative diffusion coefficient indicated the presence of connected air-filled pores that corresponded to the air-entry pressure head. The air-entry pressure head corresponds with the top of the saturated capillary zone. Therefore, to allow for the calculation of the effective diffusion coefficient by lumping the gas-phase and aqueous-phase together, the water-filled soil porosity in the capillary zone ($\theta_{w,cz}$) is calculated at the air-entry pressure head (h) according to the procedures of Waitz et al. (1996) and the van Genuchten equation (van Genuchten, 1980) for the water retention curve:

$$\theta_{w,cz} = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha_1 h)^N\right]^M} \quad (5)$$

- where
- $\theta_{w,cz}$ = Water-filled porosity in the capillary zone, cm^3/cm^3
 - θ_r = Residual soil water content, cm^3/cm^3
 - θ_s = Saturated soil water content, cm^3/cm^3
 - α_1 = Point of inflection in the water retention curve where $d\theta_w/dh$ is maximal, cm^{-1}
 - h = Air-entry pressure head, cm (= $1/\alpha_1$ and assumed to be positive)
 - N = van Genuchten curve shape parameter, dimensionless
 - M = $1 - (1/N)$.

With a calculated value of $\theta_{w,cz}$ within the capillary zone at the air-entry pressure head, the air-filled porosity within the capillary zone ($\theta_{a,cz}$) corresponding to the minimum value at which gas diffusion is relevant is calculated as the total porosity (n) minus $\theta_{w,cz}$.

Hers (2002) computed the SCS class average values of the water filled porosity and the height of the capillary zone SCS soil textural classifications. Table 3 provides the class average values for each of the SCS soil types. These data replace the mean values developed by Schaap and

Leij (1998) included in the previous U.S. Environmental Protection Agency (EPA) version of the J&E Models. With the class average values presented in Table 3, a general estimate can be made of the values of $\theta_{w,cz}$ and $\theta_{a,cz}$ for each soil textural classification.

The total concentration effective diffusion coefficient across the capillary zone (D_{cz}^{eff}) may then be calculated using the Millington and Quirk (1961) model as:

$$D_{cz}^{eff} = D_a \left(\theta_{a,cz}^{3.33} / n_{cz}^2 \right) + \left(D_w / H'_{TS} \right) \left(\theta_{w,cz}^{3.33} / n_{cz}^2 \right) \quad (6)$$

where

D_{cz}^{eff} = Effective diffusion coefficient across the capillary zone, cm^2/s

D_a = Diffusivity in air, cm^2/s

$\theta_{a,cz}$ = Soil air-filled porosity in the capillary zone, cm^3/cm^3

n_{cz} = Soil total porosity in the capillary zone, cm^3/cm^3

D_w = Diffusivity in water, cm^2/s

H'_{TS} = Henry's law constant at the system temperature, dimensionless

$\theta_{w,cz}$ = Soil water-filled porosity in the capillary zone, cm^3/cm^3 .

According to Fick's law of diffusion, the rate of mass transfer across the capillary zone can be approximated by the expression:

$$E = A(C_{source} - C_{g0})D_{cz}^{eff} / L_{cz} \quad (7)$$

where

E = Rate of mass transfer, g/s

A = Cross-sectional area through which vapors pass, cm^2

C_{source} = Vapor concentration within the capillary zone, g/cm^3-v

C_{g0} = A known vapor concentration at the top of the capillary zone, g/cm^3-v (C_{g0} is assumed to be zero as diffusion proceeds upward)

D_{cz}^{eff} = Effective diffusion coefficient across the capillary zone, cm^2/s

L_{cz} = Thickness of capillary zone, cm .

TABLE 3. CLASS AVERAGE VALUES OF THE VAN GENUCHTEN SOIL WATER RETENTION PARAMETERS FOR THE 12 SCS SOIL TEXTURAL CLASSIFICATIONS

Soil texture (USDA)	Saturated water content, θ_s	Residual water Content, θ_r	van Genuchten parameters		
			α_1 (1/cm)	N	M
Clay	0.459	0.098	0.01496	1.253	0.2019
Clay loam	0.442	0.079	0.01581	1.416	0.2938
Loam	0.399	0.061	0.01112	1.472	0.3207
Loamy sand	0.390	0.049	0.03475	1.746	0.4273
Silt	0.489	0.050	0.00658	1.679	0.4044
Silty loam	0.439	0.065	0.00506	1.663	0.3987
Silty clay	0.481	0.111	0.01622	1.321	0.2430
Silty clay loam	0.482	0.090	0.00839	1.521	0.3425
Sand	0.375	0.053	0.03524	3.177	0.6852
Sandy clay	0.385	0.117	0.03342	1.208	0.1722
Sandy clay loam	0.384	0.063	0.02109	1.330	0.2481
Sandy loam	0.387	0.039	0.02667	1.449	0.3099

The value of C_{source} is calculated using Equation 2; the value of A is assumed to be 1 cm^2 ; and the value of $D_{\text{cz}}^{\text{eff}}$ is calculated by Equation 6. What remains is a way to estimate a value for L_{cz} .

Lohman (1972) and Fetter (1994) estimated the rise of the capillary zone above the water table using the phenomenon of capillary such that water molecules are subject to an upward attractive force due to surface tension at the air-water interface and the molecular attraction of the liquid and solid phases. The rise of the capillary zone can thus be estimated using the equation for the height of capillary rise in a bundle of tubes of various diameters equivalent to the diameters between varying soil grain sizes. Fetter (1994) estimated the mean rise of the capillary zone as:

$$L_{\text{cz}} = \frac{2 \alpha_2 \text{COS } \lambda}{\rho_w g R} \quad (8)$$

where

- L_{cz} = Mean rise of the capillary zone, cm
- α_2 = Surface tension of water, g/s (= 73)
- λ = Angle of the water meniscus with the capillary tube, degrees (assumed to be zero)
- ρ_w = Density of water, g/cm³ (= 0.999)
- g = Acceleration due to gravity, cm/s² (= 980)
- R = Mean interparticle pore radius, cm

and;

$$R = 0.2D \quad (9)$$

where

- R = Mean interparticle pore radius, cm
- D = Mean particle diameter, cm.

Assuming that the default values of the parameters given in Equation 8 are for groundwater between 5° and 25°C , Equation 8 reduces to:

$$L_{\text{cz}} = \frac{0.15}{R} \quad (10)$$

Nielson and Rogers (1990) estimated the arithmetic mean particle diameter for each of the 12 SCS soil textural classifications at the mathematical centroid calculated from its classification area (Figure 3). Table 4 shows the centroid compositions and mean particle sizes of the 12 SCS soil textural classes.

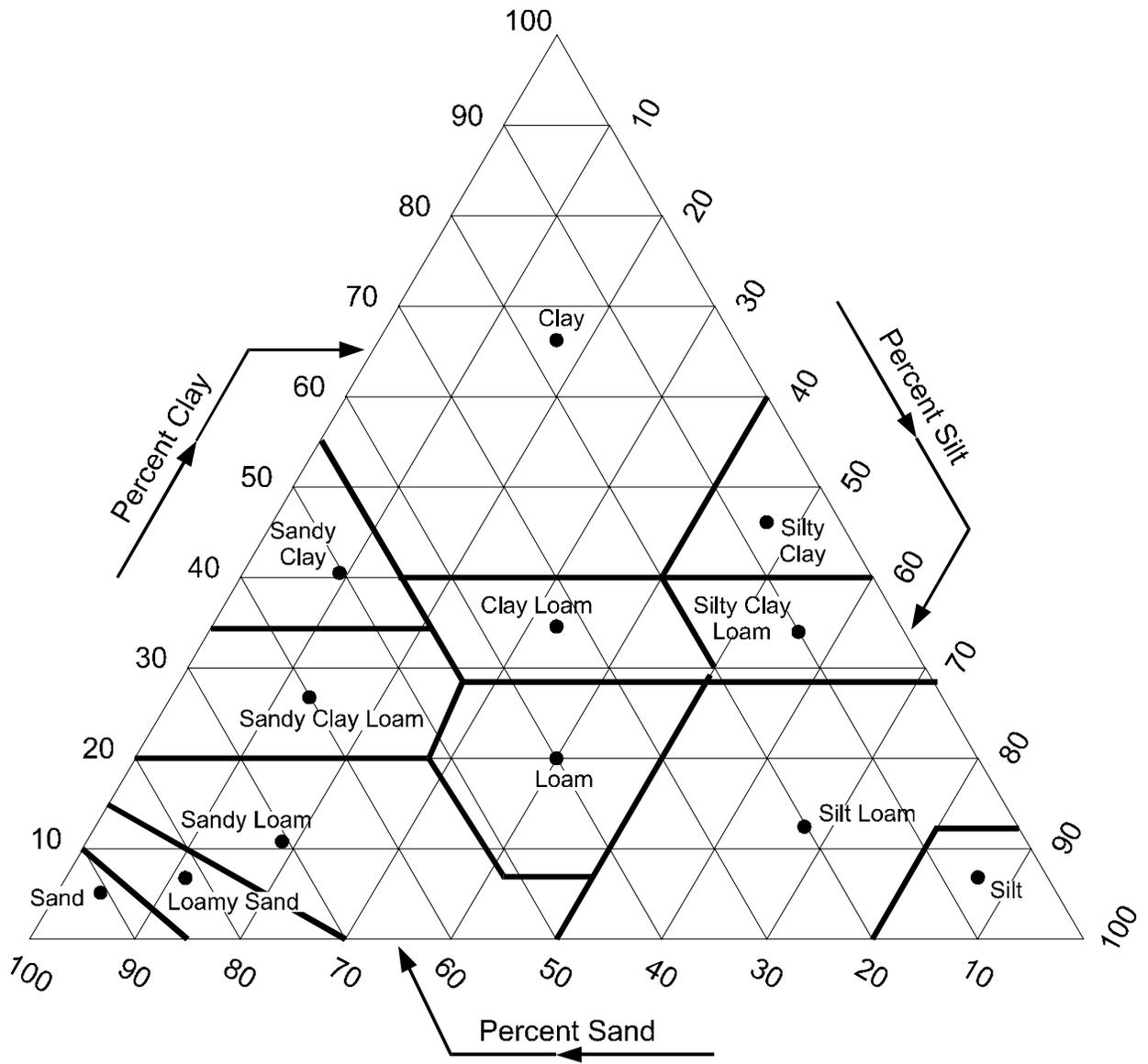


Figure 3. U.S. Soil Conservation Service Classification Chart Showing Centroid Compositions (Solid Circles)

TABLE 4. CENTROID COMPOSITIONS, MEAN PARTICLE DIAMETERS AND DRY BULK DENSITY OF THE 12 SCS SOIL TEXTURAL CLASSIFICATIONS

Textural class	% clay	% silt	% sand	Arithmetic mean particle diameter, cm	Dry Bulk Density g/cm ³
Sand	3.33	5.00	91.67	0.044	1.66
Loamy sand	6.25	11.25	82.50	0.040	1.62
Sandy loam	10.81	27.22	61.97	0.030	1.62
Sandy clay loam	26.73	12.56	60.71	0.029	1.63
Sandy clay	41.67	6.67	51.66	0.025	1.63
Loam	18.83	41.01	40.16	0.020	1.59
Clay loam	33.50	34.00	32.50	0.016	1.48
Silt loam	12.57	65.69	21.74	0.011	1.49
Clay	64.83	16.55	18.62	0.0092	1.43
Silty clay loam	33.50	56.50	10.00	0.0056	1.63
Silt	6.00	87.00	7.00	0.0046	1.35
Silty clay	46.67	46.67	6.66	0.0039	1.38

Given the mean particle diameter data in Table 4, the mean thickness of the capillary zone may then be estimated using Equations 9 and 10.

2.4 DIFFUSION THROUGH THE UNSATURATED ZONE

The effective diffusion coefficient within the unsaturated zone may also be estimated using the same form as Equation 6:

$$D_i^{eff} = D_a \left(\theta_{a,i}^{3.33} / n_i^2 \right) + (D_w / H'_{TS}) \left(\theta_{w,i}^{3.33} / n_i^2 \right) \quad (11)$$

where

- D_i^{eff} = Effective diffusion coefficient across soil layer i, cm^2/s
- D_a = Diffusivity in air, cm^2/s
- $\theta_{a,i}$ = Soil air-filled porosity of layer i, cm^3/cm^3
- n_i = Soil total porosity of layer i, cm^3/cm^3
- D_w = Diffusivity in water, cm^2/s
- $\theta_{w,i}$ = Soil water-filled porosity of layer i, cm^3/cm^3
- H'_{TS} = Henry's law constant at the system temperature, dimensionless

The overall effective diffusion coefficient for systems composed of n distinct soil layers between the source of contamination and the enclosed space floor is:

$$D_T^{eff} = \frac{L_T}{\sum_{i=0}^n L_i / D_i^{eff}} \quad (12)$$

where

- D_T^{eff} = Total overall effective diffusion coefficient, cm^2/s
- L_i = Thickness of soil layer i, cm
- D_i^{eff} = Effective diffusion coefficient across soil layer i, cm^2/s
- L_T = Distance between the source of contamination and the bottom of the enclosed space floor, cm.

Note that in the case of cracks in the floor of the enclosed space, the value of L_T does not include the thickness of the floor, nor does the denominator of Equation 12 include the thickness of the floor and the associated effective diffusion coefficient across the crack(s). An unlimited number of soil layers, including the capillary zone, may be included in Equation 12, but all layers must be located between the source of contamination and the enclosed space floor.

2.5 THE INFINITE SOURCE SOLUTION TO CONVECTIVE AND DIFFUSIVE TRANSPORT

Under the assumption that mass transfer is steady-state, J&E (1991) give the solution for the attenuation coefficient (α) as:

$$\alpha = \frac{\left[\left(\frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right) x \exp\left(\frac{Q_{\text{soil}} L_{\text{crack}}}{D^{\text{crack}} A_{\text{crack}}} \right) \right]}{\left[\exp\left(\frac{Q_{\text{soil}} L_{\text{crack}}}{D^{\text{crack}} A_{\text{crack}}} \right) + \left(\frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right) + \left(\frac{D_T^{\text{eff}} A_B}{Q_{\text{soil}} L_T} \right) \left[\exp\left(\frac{Q_{\text{soil}} L_{\text{crack}}}{D^{\text{crack}} A_{\text{crack}}} \right) - 1 \right] \right]} \quad (13)$$

where	α	= Steady-state attenuation coefficient, unitless
	D_T^{eff}	= Total overall effective diffusion coefficient, cm^2/s
	A_B	= Area of the enclosed space below grade, cm^2
	Q_{building}	= Building ventilation rate, cm^3/s
	L_T	= Source-building separation, cm
	Q_{soil}	= Volumetric flow rate of soil gas into the enclosed space, cm^3/s
	L_{crack}	= Enclosed space foundation or slab thickness, cm
	A_{crack}	= Area of total cracks, cm^2
	D_{crack}	= Effective diffusion coefficient through the cracks, cm^2/s (assumed equivalent to D_i^{eff} of soil layer i in contact with the floor).

The total overall effective diffusion coefficient is calculated by Equation 12. The value of A_B includes the area of the floor in contact with the underlying soil and the total wall area below grade. The building ventilation rate (Q_{building}) may be calculated as:

$$Q_{\text{building}} = (L_B W_B H_B ER) / 3,600 \text{ s} / h \quad (14)$$

where	Q_{building}	= Building ventilation rate, cm^3/s
	L_B	= Length of building, cm
	W_B	= Width of building, cm
	H_B	= Height of building, cm

ER = Air exchange rate, (1/h).

The building dimensions in Equation 14 are those dimensions representing the total "living" space of the building; this assumes that the total air volume within the structure is well mixed and that any vapor contaminant entering the structure is instantaneously and homogeneously distributed.

The volumetric flow rate of soil gas entering the building (Q_{soil}) is calculated by the analytical solution of Nazaroff (1988) such that:

$$Q_{soil} = \frac{2 \pi \Delta P k_v X_{crack}}{\mu \ln(2 Z_{crack} / r_{crack})} \quad (15)$$

where Q_{soil} = Volumetric flow rate of soil gas entering the building, cm^3/s

π = 3.14159

ΔP = Pressure differential between the soil surface and the enclosed space, $g/cm-s^2$

k_v = Soil vapor permeability, cm^2

X_{crack} = Floor-wall seam perimeter, cm

μ = Viscosity of air, $g/cm-s$

Z_{crack} = Crack depth below grade, cm

r_{crack} = Equivalent crack radius, cm.

Equation 15 is an analytical solution to vapor transport solely by pressure-driven air flow to an idealized cylinder buried some distance (Z_{crack}) below grade; the length of the cylinder is taken to be equal to the building floor-wall seam perimeter (X_{crack}). The cylinder, therefore, represents that portion of the building below grade through which vapors pass. The equivalent radius of the floor-wall seam crack (r_{crack}) is given in J&E (1991) as:

$$r_{crack} = \eta (A_B / X_{crack}) \quad (16)$$

where r_{crack} = Equivalent crack radius, cm

η = A_{crack}/A_B , ($0 \leq \eta \leq 1$)

A_B = Area of the enclosed space below grade, cm^2

X_{crack} = Floor-wall seam perimeter, cm.

The variable r_{crack} is actually the product of the fixed crack-to-total area ratio (η) and the hydraulic radius of the idealized cylinder, which is equal to the total area (A_B) divided by that portion of the cylinder perimeter in contact with the soil gas (X_{crack}). Therefore, if the dimensions of the enclosed space below grade (A_B) and/or the floor-wall seam perimeter (X_{crack}) vary, and the crack-to-total area ratio (η) remains constant, the value of r_{crack} must also vary. The total area of cracks (A_{crack}) is the product of η and A_B .

Equation 15 requires that the soil column properties within the zone of influence of the building (e.g., porosities, bulk density, etc.) be homogeneous, that the soil be isotropic with respect to vapor permeability, and that the pressure within the building be less than atmospheric.

Equation 13 contains the exponent of the following dimensionless group:

$$\left(\frac{Q_{\text{soil}} L_{\text{crack}}}{D_{\text{crack}} A_{\text{crack}}} \right) \cdot \quad (17)$$

This dimensionless group represents the equivalent Peclet number for transport through the building foundation. As the value of this group approaches infinity, the value of α approaches:

$$\frac{\left(\frac{D_T^{\text{eff}} A_B}{Q_{\text{building}} L_T} \right)}{\left(\frac{D_T^{\text{eff}} A_B}{Q_{\text{soil}} L_T} \right) + 1} \cdot \quad (18)$$

In the accompanying spreadsheets, if the exponent of Equation 17 is too great to be calculated, the value of α is set equal to Equation 18.

With a calculated value of α , the steady-state vapor-phase concentration of the contaminant in the building (C_{building}) is calculated as:

$$C_{\text{building}} = \alpha C_{\text{source}} \cdot \quad (19)$$

2.6 THE FINITE SOURCE SOLUTION TO CONVECTIVE AND DIFFUSIVE TRANSPORT

If the thickness of soil contamination is known, the finite source solution of J&E (1991) can be employed such that the time-averaged attenuation coefficient ($\langle\alpha\rangle$) may be calculated as:

$$\langle\alpha\rangle = \frac{\rho_b C_R \Delta H_c A_B}{Q_{building} C_{source} \tau} \left(\frac{L_T^0}{\Delta H_c} \right) \left[(\beta^2 + 2 \Psi \tau)^{1/2} - \beta \right] \quad (20)$$

where	$\langle\alpha\rangle$	= Time-averaged finite source attenuation coefficient, unitless
	ρ_b	= Soil dry bulk density at the source of contamination, g/cm ³
	C_R	= Initial soil concentration, g/g
	ΔH_c	= Initial thickness of contamination, cm
	A_B	= Area of enclosed space below grade, cm ²
	$Q_{building}$	= Building ventilation rate, cm ³ /s
	C_{source}	= Vapor concentration at the source of contamination, g/cm ³ -v
	τ	= Exposure interval, s
	L_T^0	= Source-building separation at time = 0, cm

and;

$$\beta = \left(\frac{D_T^{eff} A_B}{L_T^0 Q_{soil}} \right) \left[1 - \exp \left(- \frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}} \right) \right] + 1 \quad (21)$$

and;

$$\Psi = \frac{D_T^{eff} C_{source}}{(L_T^0)^2 \rho_b C_R} \quad (22)$$

Implicit in Equation 20 is the assumption that source depletion occurs from the top boundary of the contaminated zone as contaminant volatilizes and moves upward toward the soil surface. This creates a hypothetical "dry zone" (δ) that grows with time; conversely, the "wet zone" of contamination retreats proportionally. When the thickness of the depletion zone (δ) is equal to the initial thickness of contamination (ΔH_c), the source is totally depleted. The unitless expression $(L_T^0/\Delta H_c)[(\beta^2 + 2\Psi\tau)^{1/2} - \beta]$ in Equation 20 represents the cumulative fraction of the depletion zone at the end of the exposure interval τ . Multiplying this expression by the remainder of Equation 20 results in the time-averaged finite source attenuation coefficient ($\langle\alpha\rangle$).

With a calculated value for $\langle\alpha\rangle$, the time-averaged vapor concentration in the building ($C_{building}$) is:

$$C_{building} = \langle\alpha\rangle C_{source} \quad (23)$$

For extended exposure intervals (e.g., 30 years), the time for source depletion may be less than the exposure interval. The time for source depletion (τ_D) may be calculated by:

$$\tau_D = \frac{[\Delta H_c / L_T^0 + \beta]^2 - \beta^2}{2\Psi} \quad (24)$$

If the exposure interval (τ) is greater than the time for source depletion (τ_D), the time-averaged building vapor concentration may be calculated by a mass balance such that:

$$C_{building} = \frac{\rho_b C_R \Delta H_c A_B}{Q_{building} \tau} \quad (25)$$

where $C_{building}$ = Time-averaged vapor concentration in the building, g/cm³-v

ρ_b = Soil dry bulk density at the source of contamination, g/cm³

C_R = Initial soil concentration, g/g

ΔH_c = Initial thickness of contamination, cm

A_B = Area of enclosed space below grade, cm²

$Q_{building}$ = Building ventilation rate, cm³/s

τ = Exposure interval, s.

2.7 THE SOIL GAS MODELS

Use of the J&E Model has typically relied on a theoretical partitioning of the total volume soil concentration into the sorbed, aqueous, and vapor phases. The model has also relied on a theoretical approximation of vapor transport by diffusion and convection from the source of emissions to the building floor in contact with the soil. Use of measured soil gas concentrations directly beneath the building floor instead of theoretical vapor concentrations and vapor transport has obvious advantages that would help to reduce the uncertainty in the indoor air concentration estimates made by the model.

The soil gas models (SG-SCREEN and SG-ADV) are designed to allow the user to input measured soil gas concentration and sampling depth information directly into the spreadsheets. In the new models, the value of the user-defined soil gas concentration is assigned as the value of C_{source} in Equation 19. The steady-state (infinite source) attenuation coefficient (α) in Equation 19 is calculated using Equation 13. The steady-state solution for the attenuation coefficient is used because no evaluation has been made regarding the size and total mass of the source of emissions. The source of emissions, therefore, cannot be depleted over time. The soil gas models estimate the steady-state indoor air concentration over the exposure duration. For a detailed discussion of using the soil gas models as well as soil gas sampling, see Section 4 of this document.

2.8 SOIL VAPOR PERMEABILITY

Soil vapor permeability (k_v) is one of the most sensitive model parameters associated with convective transport of vapors within the zone of influence of the building. Soil vapor permeability is typically measured from field pneumatic tests. If field data are lacking, however, an estimate of the value of k_v can be made with limited data.

Soil intrinsic permeability is a property of the medium alone that varies with the size and shape of connected soil pore openings. Intrinsic permeability (k_i) can be estimated from the soil saturated hydraulic conductivity:

$$k_i = \frac{K_s \mu_w}{\rho_w g} \quad (26)$$

where

- k_i = Soil intrinsic permeability, cm^2
- K_s = Soil saturated hydraulic conductivity, cm/s
- μ_w = Dynamic viscosity of water, g/cm-s (= 0.01307 at 10°C)
- ρ_w = Density of water, g/cm^3 (= 0.999)

g = Acceleration due to gravity, cm/s^2 (= 980.665).

Schaap and Leij (1998) computed the SCS class average values of the saturated hydraulic conductivity (K_s) for each of the 12 SCS soil textural classifications (Table 5). With these values, a general estimate of the value of k_i can be made by soil type. As an alternative, in situ measurements of the site-specific saturated hydraulic conductivity can be made and the results input into Equation 26 to compute the value of the soil intrinsic permeability.

Effective permeability is the permeability of the porous medium to a fluid when more than one fluid is present; it is a function of the degree of saturation. The relative air permeability of soil (k_{rg}) is the effective air permeability divided by the intrinsic permeability and therefore takes into account the effects of the degree of water saturation on air permeability.

TABLE 5. CLASS AVERAGE VALUES OF SATURATED HYDRAULIC CONDUCTIVITY FOR THE 12 SCS SOIL TEXTURAL CLASSIFICATIONS

Soil texture , USDA	Class average saturated hydraulic conductivity, cm/h
Sand	26.78
Loamy sand	4.38
Sandy loam	1.60
Sandy clay loam	0.55
Sandy clay	0.47
Loam	0.50
Clay loam	0.34
Silt loam	0.76
Clay	0.61
Silty clay loam	0.46
Silt	1.82
Silty clay	0.40

Parker et al. (1987) extended the relative air permeability model of van Genuchten (1980) to allow estimation of the relative permeabilities of air and water in a two- or three-phase system:

$$k_{rg} = (1 - S_{te})^{1/2} (1 - S_{te}^{1/M})^{2M} \quad (27)$$

where k_{rg} = Relative air permeability, unitless ($0 \leq k_{rg} \leq 1$)

S_{te} = Effective total fluid saturation, unitless

M = van Genuchten shape parameter, unitless.

Given a two-phase system (i.e., air and water), the effective total fluid saturation (S_{te}) is calculated as:

$$S_{te} = \frac{(\theta_w - \theta_r)}{(n - \theta_r)} \quad (28)$$

where S_{te} = Effective total fluid saturation, unitless

θ_w = Soil water-filled porosity, cm^3/cm^3

θ_r = Residual soil water content, cm^3/cm^3

n = Soil total porosity, cm^3/cm^3 .

Class average values for the parameters θ_r and M by SCS soil type may be obtained from Table 3.

The effective air permeability (k_v) is then the product of the intrinsic permeability (k_i) and the relative air permeability (k_{rg}) at the soil water-filled porosity θ_w .

2.9 CALCULATION OF A RISK-BASED SOIL OR GROUNDWATER CONCENTRATION

Both the infinite source model estimate of the steady-state building concentration and the finite source model estimate of the time-averaged building concentration represent the exposure point concentration used to assess potential risks. Calculation of a risk-based media concentration for a carcinogenic contaminant takes the form:

$$C_c = \frac{TR \times AT_c \times 365 \text{ days / yr}}{URF \times EF \times ED \times C_{building}} \quad (29)$$

where C_c = Risk-based media concentration for carcinogens, $\mu\text{g}/\text{kg}$ -soil, or $\mu\text{g}/\text{L}$ -water

TR = Target risk level, unitless

AT_c = Averaging time for carcinogens, yr

URF = Unit risk factor, $(\mu\text{g}/\text{m}^3)^{-1}$

EF = Exposure frequency, days/yr

ED = Exposure duration, yr

C_{building} = Vapor concentration in the building, $\mu\text{g}/\text{m}^3$ per $\mu\text{g}/\text{kg}$ -soil,
or $\mu\text{g}/\text{m}^3$ per $\mu\text{g}/\text{L}$ -water.

In the case of a noncarcinogenic contaminant, the risk-based media concentration is calculated by:

$$C_{\text{NC}} = \frac{\text{THQ} \times \text{AT}_{\text{NC}} \times 365 \text{ days/yr}}{\text{EF} \times \text{ED} \times \frac{1}{\text{RfC}} \times C_{\text{building}}} \quad (30)$$

where

C_{NC}	= Risk-based media concentration for noncarcinogens, $\mu\text{g}/\text{kg}$ -soil, or $\mu\text{g}/\text{L}$ -water
THQ	= Target hazard quotient, unitless
AT_{NC}	= Averaging time for noncarcinogens, yr
EF	= Exposure frequency, days/yr
ED	= Exposure duration, yr
RfC	= Reference concentration, mg/m^3
C_{building}	= Vapor concentration in the building, mg/m^3 per $\mu\text{g}/\text{kg}$ -soil, or mg/m^3 per $\mu\text{g}/\text{L}$ -water.

The spreadsheets calculate risk-based media concentrations based on a unity initial concentration. That is, soil risk-based concentrations are calculated with an initial hypothetical soil concentration of 1 $\mu\text{g}/\text{kg}$ -soil, while for groundwater the initial hypothetical concentration is 1 $\mu\text{g}/\text{L}$ -water.

For this reason, the values of C_{source} and C_{building} shown on the INTERCALCS worksheet when reverse-calculating a risk-based media concentration do not represent actual values. For these calculations, the following message will appear on the RESULTS worksheet:

"MESSAGE: The values of C_{source} and C_{building} on the INTERCALCS worksheet are based on unity and do not represent actual values."

When forward-calculating risks from a user-defined initial soil or groundwater concentration, the values of C_{source} and C_{building} on the INTERCALCS worksheet are correct.

2.10 CALCULATION OF INCREMENTAL RISKS

Forward-calculation of incremental risks begins with an actual initial media concentration (i.e., $\mu\text{g}/\text{kg}$ -soil or $\mu\text{g}/\text{L}$ -water). For carcinogenic contaminants, the risk level is calculated as:

$$Risk = \frac{URF \times EF \times ED \times C_{building}}{AT_C \times 365 \text{ days} / \text{yr}} \quad (31)$$

For noncarcinogenic contaminants, the hazard quotient (HQ) is calculated as:

$$HQ = \frac{EF \times ED \times \frac{1}{RfC} \times C_{building}}{AT_{NC} \times 365 \text{ days} / \text{yr}} \quad (32)$$

2.11 MAJOR MODEL ASSUMPTIONS/LIMITATIONS

The following represent the major assumptions/limitations of the J&E Model.

1. Contaminant vapors enter the structure primarily through cracks and openings in the walls and foundation.
2. Convective transport occurs primarily within the building zone of influence and vapor velocities decrease rapidly with increasing distance from the structure.
3. Diffusion dominates vapor transport between the source of contamination and the building zone of influence.
4. All vapors originating from below the building will enter the building unless the floors and walls are perfect vapor barriers.
5. All soil properties in any horizontal plane are homogeneous.
6. The contaminant is homogeneously distributed within the zone of contamination.
7. The areal extent of contamination is greater than that of the building floor in contact with the soil.
8. Vapor transport occurs in the absence of convective water movement within the soil column (i.e., evaporation or infiltration), and in the absence of mechanical dispersion.
9. The model does not account for transformation processes (e.g., biodegradation, hydrolysis, etc.).

10. The soil layer in contact with the structure floor and walls is isotropic with respect to permeability.
11. Both the building ventilation rate and the difference in dynamic pressure between the interior of the structure and the soil surface are constant values.

Use of the J&E Model as a first-tier screening tool to identify sites needing further assessment requires careful evaluation of the assumptions listed in the previous section to determine whether any conditions exist that would render the J&E Model inappropriate for the site. If the model is deemed applicable at the site, care must be taken to ensure reasonably conservative and self-consistent model parameters are used as input to the model. Considering the limited site data typically available in preliminary site assessments, the J&E Model can be expected to predict only whether or not a risk-based exposure level will be exceeded at the site. Precise prediction of concentration levels is not possible with this approach.

The suggested minimum site characterization information for a first tier evaluation of the vapor intrusion pathway includes: site conceptual model, nature and extent of contamination distribution, soil lithologic descriptions, groundwater concentrations, and/or possibly near source soil vapor concentrations. The number of samples and measurements needed to establish this information varies by site and it's not possible to provide a hard and fast rule. Bulk soil concentrations should not be used unless appropriately preserved during sampling.

Based on the conceptual site model (CSM), the user can select the appropriate spreadsheet corresponding to the vapor source at the site and determine whether to use the screening level spreadsheet (which allows only one soil type above the capillary fringe) or the more advanced version (which allows up to three layers above the capillary fringe). Because most of the inputs to the J&E Model are not collected during a typical site characterization, conservative inputs have to be estimated or inferred from available data and other non-site-specific sources of information.

The uncertainty in determining key model parameters and sensitivity of the J&E Model to those key model parameters is qualitatively described in Table 6. As shown in the table, building-related parameters will moderate to high uncertainty and model sensitivity include: Q_{soil} , building crack ratio, building air-exchange rate, and building mixing height. Building-related parameters with low uncertainty and sensitivity include: foundation area, depth to base of foundation, and foundation slab thickness. Of the soil-dependent properties, the soil moisture parameters clearly are of critical importance for the attenuation value calculations.

TABLE 6. UNCERTAINTY AND SENSITIVITY OF KEY PARAMETERS FOR THE VAPOR INTRUSION MODEL

Input Parameter	Parameter Uncertainty Or Variability	Shallower Contamination Building Underpressurized	Parameter Sensitivity		Deeper Contamination Building Not Underpressurized
			Deeper Contamination Building Underpressurized	Shallower Contamination Building Not Underpressurized	
Soil Total Porosity (n)	Low	Low	Low	Low	Low
Soil Water-filled Porosity (θ_w)	Moderate to High	Low to Moderate	Moderate to High	Moderate to High	Moderate to High
Capillary Zone Water-filled Porosity ($\theta_{n,cz}$)	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High
Thickness of Capillary Zone (L_{cz})	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High
Soft Dry Bulk Density (ρ_b)	Low	Low	Low	Low	Low
Average Vapor Flowrate into a Building (Q_{soil})	High	Moderate to High	Low to Moderate	N/A	N/A
Soil Vapor Permeability(K_v)	High	Moderate to High	Low to Moderate	N/A	N/A
Soil to Building Pressure Differential (ΔP)	Moderate	Moderate	Low to Moderate	N/A	N/A
Henry's Law Constant (for single chemical) (H)	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Diffusivity in Air (D_A)	Low	Low	Low	Low	Low
Indoor Air Exchange Rate (ER)	Moderate	Moderate	Moderate	Moderate	Moderate
Enclosed Space Height (H_B)	Moderate	Moderate	Moderate	Moderate	Moderate
Area of Enclosed Space Below Grade (A_B)	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Depth Below Grade to Bottom of Enclosed Space (L_F)	Low	Low	Low	Low	Low
Crack-to-Total Area Ratio (η)	High	Low	Low	Moderate to High	Low to Moderate
Enclosed Space Floor Thickness (L_{crack})	Low	Low	Low	Low	Low

SECTION 3

SOIL AND GROUNDWATER MODEL APPLICATION

This section provides step-by-step instructions on how to implement the soil and groundwater contamination versions of the J&E Model using the spreadsheets. This section also discusses application of the soil gas versions of the model. The user provides data and selects certain input options, and views model results via a series of worksheets. Error messages are provided within both the data entry worksheet and the results worksheet to warn the user that entered data are missing or outside of permitted limits.

The J&E Model as constructed within the accompanying spreadsheets requires a range of input variables depending on whether a screening-level or advanced model is chosen. Table 7 provides a list of all major input variables, the range of practical values for each variable, the default value for each variable, and the relative model sensitivity and uncertainty of each variable. Table 7 also includes references for each value or range of values.

Table 8 indicates the results of an increase in the value of each input parameter. The results are shown as either an increase or a decrease in the building concentration (C_{building}) of the pollutant. An increase in the building concentration will result in an increase in the risk when forward-calculating from an initial soil or groundwater concentration. When reverse-calculating to a risk-based “acceptable” soil or groundwater concentration, an increase in the hypothetical unit building concentration will result in a lower “acceptable” soil or groundwater concentration.

A list of reasonably conservative model input parameters for building-related parameters is provided in Table 9, which also provides the practical range, typical or mean value (if applicable), and most conservative value for these parameters. For building parameters with low uncertainty and sensitivity, only a single “fixed” value corresponding to the mean or typical value is provided in Table 9. Soil-dependent properties are provided in Table 10 for soils classified according to the US SCS system. If site soils are not classified according to the US SCS, Table 11 can be used to assist in selecting an appropriate SCS soil type corresponding to the available site lithologic information. Note that the selection of the soil texture class should be biased towards the coarsest soil type of significance, as determined by the site characterization program.

TABLE 7. RANGE OF VALUES FOR SELECTED INPUT PARAMETERS

Input parameter	Practical range of values	Default value
Soil water-filled porosity (θ_w)	0.04 – 0.33 cm ³ /cm ^{3a}	Soil dependent see Table 10
Soil vapor permeability (k_v)	10 ⁻⁶ – 10 ⁻¹² cm ^{2b,c}	10 ⁻⁸ cm ^{2d}
Soil-building pressure differential (ΔP)	0 – 20 Pa ³	4 Pa ^f
Media initial concentration (C_R, C_w)	User-defined	NA
Depth to bottom of soil contamination (L_b)	User-defined	NA
Depth to top of concentration (L_T)	User-defined	NA
Floor-wall seam gap (w)	0.05 – 1.0 cm ^e	0.1 cm ^e
Soil organic carbon fraction (f_{oc})	0.001 – 0.006 ^a	0.002 ^a
Indoor air exchange rate (ER)	0.18 – 1.26 (H ⁻¹) ^g	0.25 (h ⁻¹) ^{g,h}
Soil total porosity (n)	0.34 – 0.53 cm ³ /cm ^{3a}	0.43 cm ³ /cm ^{3a}
Soil dry bulk density (ρ_b)	1.25 – 1.75 g/cm ^{3a}	1.5 g/cm ^{3a}

^aU.S. EPA (1996a and b).

^bJohnson and Ettinger (1991).

^cNazaroff (1988).

^dBased on transition point between diffusion and convection dominated transport from Johnson and Ettinger (1991).

^eEaton and Scott (1984); Loureiro et al. (1990).

^fLoureiro et al. (1990); Grimsrud et al. (1983).

^gKoontz and Rector (1995).

^hParker et al. (1990).

ⁱU.S. DOE (1995).

TABLE 8. EFFECT ON BUILDING CONCENTRATION FROM AN INCREASE IN INPUT PARAMETER VALUES

Input parameter	Change in parameter value	Effect on building concentration
Soil water-filled porosity (θ_w)	Increase	Decrease
Soil vapor permeability (k_v)	Increase	Increase
Soil-building pressure differential (ΔP)	Increase	Increase
Media initial concentration (C_R, C_w) ^a	Increase	Increase
Depth to bottom of soil contamination (L_b) ^b	Increase	Increase
Depth to top of concentration (L_T)	Increase	Decrease
Floor-wall seam gap (w)	Increase	Increase
Soil organic carbon fraction (f_{oc})	Increase	Decrease
Indoor air exchange rate (ER)	Increase	Decrease
Building volume ^c ($L_B \times W_B \times H_B$)	Increase	Decrease
Soil total porosity (n)	Increase	Increase
Soil dry bulk density (ρ_b)	Increase	Decrease

^a This parameter is applicable only when forward-calculating risk.

^b Applicable only to advanced model for soil contamination.

^c Used with building air exchange rate to calculate building ventilation rate.

TABLE 9. BUILDING-RELATED PARAMETERS FOR THE VAPOR INTRUSION MODEL

Input Parameter	Units	Fixed or Variable	Typical or Mean Value	Range	Conservative Value	Default Value
Total Porosity	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Unsaturated Zone Water-filled Porosity	cm ³ /cm ³	Variable	Specific to soil texture, see Table 10			
Capillary Transition zone Water-filled Porosity	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Capillary Transition Zone height	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Q _{soil}	L/min	Variable	Specific to soil texture, see Table 10			
Soil air permeability	m ²	Variable	Specific to soil texture, see Table 10			
Building Depressurization	Pa	Variable	4	0-15	15	N/A
Henry's law constant (for single chemical)	-	Fixed	Specific to chemical, see Appendix B			
Free-Air Diffusion Coefficient (single chemical)	-	Fixed	Specific to chemical, see Appendix B			
Building Air exchange Rate	hr ⁻¹	Variable	0.5	0.1-1.5	0.1	0.25
Building Mixing height – Basement scenario	m	Variable	3.66	2.44-4.88	2.44	3.66
Building Mixing height – Slab-on-grade scenario	m	Variable	2.44	2.13-3.05	2.13	2.44
Building Footprint Area – Basement Scenario	m ²	Variable	120	80-200+	80	100
Building Footprint Area – Slab-on-Grade Scenario	m ²	Variable	120	80-200+	80	100
Subsurface Foundation area – Basement Scenario	m ²	Variable	208	152-313+	152	180
Subsurface Foundation area – Slab-on-Grade Scenario	m ²	Fixed	127	85-208+	85	106
Depth to Base of Foundation – Basement Scenario	m	Fixed	2	N/A	N/A	2
Depth to Base of Foundation – Slab-on-Grade Scenario	m	Fixed	0.15	N/A	N/A	0.15
Perimeter Crack Width	mm	Variable	1	0.5-5	5	1
Building Crack ratio – Slab-on-Grade Scenario	dimensionless	Variable	0.00038	0.00019-0.0019	0.0019	3.77 x 10 ⁻⁴
Building Crack ratio – Basement Scenario	dimensionless	Variable	0.0002	0.0001-0.001	0.001	2.2 x 10 ⁻⁴
Crack Dust Water-Filled Porosity	cm ³ /cm ³	Fixed	Dry	N/A	N/A	Dry
Building Foundation Slab Thickness	m	Fixed	0.1	N/A	N/A	0.1

TABLE 10. SOIL-DEPENDENT PROPERTIES FOR THE VAPOR INTRUSION MODEL - FIRST TIER ASSESSMENT

U.S. Soil Conservation Service (SCS) Soil Texture	Saturated		Unsaturated Zone				Capillary Transition Zone		
	Water Content Total Porosity θ_s (cm ³ /cm ³)	Residual Water Content θ_r (cm ³ /cm ³)	Water-Filled Porosity				Saturated Water Content Total Porosity θ_s (cm ³ /cm ³)	$\theta_{w, cap}$ @ air-entry	Height Cap Zone Fetter (94) (cm)
			Mean or Typical ($FC_{1/3bar} + \theta_r$)/2 $\theta_{w, unsat}$ (cm ³ /cm ³)	Range $\theta_{w, unsat}$ (cm ³ /cm ³)	Conservative $\theta_{w, unsat}$ (cm ³ /cm ³)	Modeled $\theta_{w, unsat}$ (cm ³ /cm ³)			
Clay	0.459	0.098	0.215	0.098-0.33	0.098	0.215	0.459	0.412	81.5
Clay Loam	0.442	0.079	0.168	0.079-0.26	0.079	0.168	0.442	0.375	46.9
Loam	0.399	0.061	0.148	0.061-0.24	0.061	0.148	0.399	0.332	37.5
Loamy Sand	0.39	0.049	0.076	0.049-0.1	0.049	0.076	0.39	0.303	18.8
Silt	0.489	0.05	0.167	0.05-0.28	0.050	0.167	0.489	0.382	163.0
Silt Loam	0.439	0.065	0.180	0.065-0.3	0.065	0.180	0.439	0.349	68.2
Silty Clay	0.481	0.111	0.216	0.11-0.32	0.111	0.216	0.481	0.424	192.0
Silty Clay Loam	0.482	0.09	0.198	0.09-0.31	0.090	0.198	0.482	0.399	133.9
Sand	0.375	0.053	0.054	0.053-0.055	0.053	0.054	0.375	0.253	17.0
Sandy Clay	0.385	0.117	0.197	0.117-0.28	0.117	0.197	0.385	0.355	30.0
Sandy Clay Loam	0.384	0.063	0.146	0.063-0.23	0.063	0.146	0.384	0.333	25.9
Sandy Loam	0.387	0.039	0.103	0.039-0.17	0.039	0.103	0.387	0.320	25.0
Loamy Sand	0.39	0.049	0.076	0.049-0.1	0.049	0.076	0.39	0.303	18.8

TABLE 11. GUIDANCE FOR SELECTION OF SOIL TYPE

If your boring log indicates that the following materials are the predominant soil types ...	Then you should use the following texture classification when obtaining the attenuation factor
Sand or Gravel or Sand and Gravel, with less than about 12 % fines, where “fines” are smaller than 0.075 mm in size.	Sand
Sand or Silty Sand, with about 12 % to 25 % fines	Loamy Sand
Silty Sand, with about 20 % to 50 % fines	Sandy Loam
Silt and Sand or Silty Sand or Clayey, Silty Sand or Sandy Silt or Clayey, Sandy Silt, with about 45 to 75 % fines	Loam
Sandy Silt or Silt, with about 50 to 85 % fines	Silt Loam

These input parameters were developed from the best available soil-physics science, available studies of building characteristics, and international-expert opinion. Consequently, the input parameters listed in Tables 9 and 10 are considered default parameters for a first-tier assessment, which should in most cases provide a reasonably (but not overly) conservative estimate of the vapor intrusion attenuation factor for a site. Justification for the building-related and soil-dependent parameters values selected as default values for the J&E Model is described below.

3.1 JUSTIFICATION OF DEFAULT SOIL-DEPENDENT PROPERTIES

The default soil-dependent parameters recommended for a first tier assessment (Table 10) represent mean or typical values, rather than the most conservative value, in order to avoid overly conservative estimates of attenuation factors. Note, however, that the range of values for some

soil properties can be very large, particularly in the case of moisture content and hydraulic conductivity. Consequently, selecting a soil type and corresponding typical soil property value may not accurately or conservatively represent a given site. Note also that Table 9 does not provide estimates of soil properties for very coarse soil types, such as gravel, gravelly sand, and sandy gravel, etc., which also may be present in the vadose zone. Consequently, in cases where the vadose zone is characterized by very coarse materials, the J&E Model may not provide a conservative estimate of attenuation factor.

As discussed above, the J&E Model is sensitive to the value of soil moisture content. Unfortunately, there is little information available on measured moisture contents below buildings. Therefore, the typical approach is to use a water retention model (e.g., van Genuchten model) to approximate moisture contents. For the unsaturated zone, the selected default value for soil moisture is a value equal to halfway between the residual saturation value and field capacity, using the van Genuchten model-predicted values for U.S. SCS soil types. For the capillary transition zone, a moisture content corresponding to the air entry pressure head is calculated by using the van Genuchten model. When compared to other available water retention models, the van Genuchten model yields somewhat lower water contents, which results in more conservative estimates of attenuation factor. The soil moisture contents listed in Table 10 are based on agricultural samples, which are likely to have higher water contents than soils below building foundations and, consequently result in less-conservative estimates of the attenuation factor.

3.2 JUSTIFICATION OF DEFAULT BUILDING-RELATED PROPERTIES

Building Air Exchange Rate (Default Value = 0.25 AEH)

The results of 22 studies for which building air exchange rates are reported in Hers et al. (2001). Ventilation rates vary widely from approximately 0.1 AEH for energy efficient “air-tight” houses (built in cold climates) (Fellin and Otson, 1996) to over 2 AEH (AHRAE (1985); upper range). In general, ventilation rates will be higher in summer months when natural ventilation rates are highest. Murray and Burmaster (1995) conducted one of the most comprehensive studies of U.S. residential air exchange rates (sample size of 2844 houses). The data set was analyzed on a seasonal basis and according to climatic region. When all the data were analyzed, the 10th, 50th and 90th percentile values were 0.21, 0.51 and 1.48 AEH. Air exchange rates varied depending on season and climatic region. For example, for the winter season and coldest climatic area (Region 1, e.g., Great Lakes area and extreme northeast U.S.), the 10th, 50th, and 90th percentile values were 0.11, 0.27 and 0.71 AEH, respectively.. In contrast, for the winter season and warmest climatic area [Region 4 (southern California, Texas, Florida, Georgia)], the 10th, 50th, and 90th percentile values were 0.24, 0.48 and 1.13 AEH, respectively. Although building air exchange rates would be higher during the summer months, vapor intrusion during winter months (when house depressurization is expected to be most significant) would be of greatest concern. For this guidance, a default value of 0.25 for air exchange rate was selected to represent the lower end of these distributions.

Crack Width and Crack Ratio (Default Value = 0.0002 for basement house; = 0.0038 for slab-on-grade house)

The crack width and crack ratio are related. Assuming a square house and that the only crack is a continuous edge crack between the foundation slab and wall (“perimeter crack”), the crack ratio and crack width are related as follows:

$$\text{Crack Ratio} = \text{Crack Width} \times 4 \times (\text{Subsurface Foundation Area})^{0.5} / \text{Subsurface Foundation Area}$$

Little information is available on crack width or crack ratio. One approach used by radon researchers is to back-calculate crack ratios using a model for soil gas flow through cracks and the results of measured soil gas flow rates into a building. For example, the back-calculated values for a slab/wall edge crack based on soil gas-entry rates reported in Nazaroff (1992), Revzan *et al.* (1991), and Nazaroff *et al.* (1985) range from about 0.0001 to 0.001. Another possible approach is to measure crack openings although this, in practice, is difficult to do. Figley and Snodgrass (1992) present data from 10 houses where edge crack measurements were made. At the eight houses where cracks were observed, the crack widths ranged from hairline cracks up to 5 mm wide, while the total crack length per house ranged from 2.5 m to 17.3 m. Most crack widths were less than 1 mm. The suggested defaults for crack ratio in regulatory guidance, literature, and models also vary. In ASTM E1739-95, a default crack ratio of 0.01 is used. The crack ratios suggested in the VOLASOIL model (developed by the Dutch Ministry of Environment) range from 0.0001 to 0.000001. The VOLASOIL model values correspond to values for a “good” and “bad” foundation, respectively. The crack ratio used by J&E (1991) for illustrative purposes ranged from 0.001 to 0.01. The selected default values fall within the ranges observed.

Building Area and Subsurface Foundation Area (Default Value = 10 m by 10 m)

The default building area is based on the following information:

- Default values used in the Superfund User’s Guide (9.61 m by 9.61 m or 92.4 m²)
- Default values used by the State of Michigan, as documented in Part 201, Generic Groundwater and Soil Volatilization to Indoor Air Inhalation Criteria: Technical Support Document (10.5 m by 10.5 m of 111.5 m²).

The Michigan guidance document indicates that the 111.5 m² area approximately corresponds to the 10th percentile floor space area for a residential single-family dwelling, based on statistics compiled by the U.S. Department of Commerce (DOC) and U.S. Housing and Urban Development (HUD). The typical, upper, and lower ranges presented in Table 9 are subjectively chosen values. The subsurface foundation area is a function of the building area, and depth to the base of the foundation, which is fixed.

Building Mixing Height (Default Value = 2.44 m for slab-on-grade scenario; = 3.66 m for basement scenario)

The J&E Model assumes that subsurface volatiles migrating into the building are completely mixed within the building volume, which is determined by the building area and mixing height. The building mixing height will depend on a number of factors including building height; heating, ventilation, and air conditioning (HVAC) system operation, environmental factors such as indoor-outdoor pressure differentials and wind loading, and seasonal factors. For a single-story house, the variation in mixing height can be approximated by using the room height. For a multi-story house or apartment building, the mixing height will be greatest for houses with HVAC systems that result in significant air circulation (e.g., forced-air heating systems). Mixing heights would likely be less for houses with electrical baseboard heaters. It is likely that mixing height is, to some degree, correlated to the building air exchange rate.

Little data are available that provides for direct inference of mixing height. There are few sites, with a small number of houses where indoor air concentrations were above background, and where both measurements at ground level and the second floor were made Colorado Department of Transportation (CDOT), Redfields, Eau Claire). Persons familiar with the data sets for these sites indicate that in most cases a fairly significant reduction in concentrations (factor of two or greater) was observed, although at one site (Eau Claire, “S” residence), the indoor trichloroethylene (TCE) concentrations were similar in both the basement and second floor of the house. For the CDOT site apartments, there was an approximate five-fold reduction between the concentrations measured for the first floor and second floor units (Mr. Jeff Kurtz, EMSI, personal communication, June 2002). Less mixing would be expected for an apartment because there are less cross-floor connections than for a house. The value chosen for a basement house scenario (3.66 m) would be representative of a two-fold reduction or attenuation in vapor concentrations between floors.

Q_{soil} (Default Value = 5 L/min)

The method often used with the J&E Model for estimating the soil gas advection rate (Q_{soil}) through the building envelope is an analytical solution for two-dimensional soil gas flow to a small horizontal drain (Nazaroff 1992) (“Perimeter Crack Model”). Use of this model can be problematic in that Q_{soil} values are sensitive to soil-air permeability and consequently a wide range in flows can be predicted.

An alternate empirical approach is to select a Q_{soil} value on the basis of tracer tests (i.e., mass balance approach). When soil gas advection is the primary mechanism for tracer intrusion into a building, the Q_{soil} can be estimated by measuring the concentrations of a chemical tracer in indoor air, in outdoor air, and in soil vapor below a building, and by measuring the building ventilation rate (Hers et al. 2000a; Fischer et al. 1996; Garbesi et al. 1993; Rezvan et al. 1991; Garbesi and Sextro, 1989). For sites with coarse-grained soils (Table 10). The Q_{soil} values measured using this technique are compared to predicted rates using the Perimeter Crack model. The Perimeter Crack model predictions are both higher and lower than the measured values, but overall are within one order of magnitude of the measured values. Although the Q_{soil} values predicted by the models and measured

using field tracer tests are uncertain, the results suggest that a “typical” range for houses on coarse-grained soils is on the order of 1 to 10 L/min. A disadvantage with the tracer test approach is that only limited data are available and there do not appear to be any tracer studies for field sites with fine-grained soils.

It is also important to recognize that the advective zone of influence for soil gas flow is limited to soil immediately adjacent to the building foundation. Some data on pressure coupling provide insight on the extent of the advective flow zone. For example, Garbesi *et al.* (1993) report a pressure coupling between the soil and experimental basement (*i.e.*, relative to that between the basement and atmosphere) equal to 96 percent directly below the slab, between 29 percent and 44 percent at 1 m below the basement floor slab, and between 0.7 percent and 27 percent at a horizontal distance of 2 m from the basement wall. At the Chatterton site (research site investigated by the author), the pressure coupling immediately below the building floor slab ranged from 90 to 95 percent and at a depth of 0.5 m was on the order of 50 percent. These results indicate that the advective zone of influence will likely be limited to a zone within 1 to 2 m of the building foundation.

Because the advective flow zone is relatively limited in extent, the soil type adjacent to the building foundation is of importance. In many cases, coarse-grained imported fill is placed below foundations, and either coarse-grained fill, or disturbed, loose fill is placed adjacent to the foundation walls. Therefore, a conservative approach for the purposes of this guidance is to assume that soil gas flow will be controlled by coarse-grained soil, and not rely on the possible reduction in flow that would be caused by fine-grained soils near to the house foundation. For these reasons, a soil gas flow rate of 5 L/min (midpoint between 1 and 10 L/min) was chosen as the input value.

3.3 RUNNING THE MODELS

Eight different models are provided in MICROSOFT EXCEL formats.

1. Models for Soil Contamination:
SL-SCREEN-Feb 04.XLS
SL-ADV-Feb 04.XLS
2. Models for Groundwater Contamination:
GW-SCREEN-Feb 04.XLS
GW-ADV-Feb 04.XLS
3. Model for Soil Gas Contamination
SG-SCREEN-Feb 04.xls
SG-ADV-Feb 04.xls
4. Models for Non Aqueous Phase Liquids
NAPL-SCREEN-Feb 04.xls

Both the screening-level models and the advanced models allow the user to calculate a risk-based media concentration or incremental risks from an actual starting concentration in soil or in groundwater. Data entry within the screening-level models is limited to the most sensitive model parameters and incorporates only one soil stratum above the contamination. The advanced models provide the user with the ability to enter data for all of the model parameters and also incorporate up to three individual soil strata above the contamination for which soil properties may be varied.

To run any of the models, simply open the appropriate model file within MICROSOFT EXCEL. Each model is constructed of the following worksheets:

1. DATENTER (Data Entry Sheet)
2. CHEMPROPS (Chemical Properties Sheet)
3. INTERCALCS (Intermediate Calculations Sheet)
4. RESULTS (Results Sheet)
5. VLOOKUP (Lookup Tables).

The following is an explanation of what is contained in each worksheet, how to enter data, how to interpret model results, and how to add/revise the chemical properties data found in the VLOOKUP Tables. As examples, Appendix C contains all the worksheets for the advanced soil contamination model SL-ADV.

3.4 THE DATA ENTRY SHEET (DATENTER)

Figure 4 is an example of a data entry sheet. In this case, it shows the data entry sheet for the screening-level model for contaminated groundwater (GW-SCREEN). Figure 5 is an example of an advanced model data entry sheet (GW-ADV). Note that the screening-level model sheet requires entry of considerably less data than does the advanced sheet. To enter data, simply position the cursor within the appropriate box and type the value; all other cells are protected.

Error Messages

In the case of the screening-level models, all error messages will appear in red type below the applicable row of data entry boxes. For the advanced models, error messages may appear on the data entry sheet or in the lower portion of the results sheet. Error messages will occur if required entry data are missing or if data are out of range or do not conform to model conventions. The error message will tell the user what kind of error has occurred.

GW-SCREEN
Version 3.1; 02/04

Reset to
Defaults

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES X
OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION
(enter "X" in "YES" box and initial groundwater conc. below)

YES

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_w ($\mu\text{g/L}$)	Chemical
56235		Carbon tetrachloride

MORE
↓

ENTER Depth below grade to bottom of enclosed space floor, L_f (cm)	ENTER Depth below grade to water table, L_{WT} (cm)	ENTER SCS soil type directly above water table	ENTER Average soil/ groundwater temperature, T_s ($^{\circ}\text{C}$)	ENTER Average vapor flow rate into bldg. (Leave blank to calculate) Q_{soil} (L/m)
200	400	SC	10	5

MORE
↓

ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vadose zone soil vapor permeability, k_v (cm^2)	ENTER Vadose zone SCS soil type Lookup Soil Parameters	ENTER Vadose zone soil dry bulk density, ρ_b^v (g/cm^3)	ENTER Vadose zone soil total porosity, n^v (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^v (cm^3/cm^3)
SC			SC	1.63	0.385	0.197

MORE
↓

ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)	ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
1.0E-06	1	70	30	30	350
Used to calculate risk-based groundwater concentration.					

Figure 4. GW-SCREEN Data Entry Sheet

Figure 6 is an example of an error message appearing on the data entry sheet. Figure 7 illustrates error messages appearing within the message and error summary section on the results sheet (advanced models only).

Entering Data

Each data entry sheet requires the user to input values for model variables. Data required for the soil contamination scenario will differ from that required for the groundwater contamination scenario. In addition, data required for the screening-level models will differ from that required for the advanced models.

Model Variables--

The following is a list of all data entry variables required for evaluating either a risk-based media concentration or the incremental risks due to actual contamination. A description for which model(s) the variable is appropriate is given in parenthesis after the name of the variable. In addition, notes on how the variable is used in the calculations and how to determine appropriate values of the variable are given below the variable name. A quick determination of which variables are required for a specific model can be made by reviewing the data entry sheet for the model chosen. Example data entry sheets for each model can be found in Appendix D.

1. *Calculate Risk-Based Concentration or Calculate Incremental Risks from Actual Concentration* (All Soil and Groundwater Models)

The model will calculate either a risk-based soil or groundwater concentration or incremental risks but cannot calculate both simultaneously. Enter an "X" in only one box.

2. *Chemical CAS No.* (All Models)

Enter the appropriate CAS number for the chemical you wish to evaluate; do not enter dashes. The CAS number entered must exactly match that of the chemical, or the error message "CAS No. not found" will appear in the "Chemical" box. Once the correct CAS number is entered, the name of the chemical will automatically appear in the "Chemical" box. A total of 108 chemicals and their associated properties are included with each model; see Section 3.7 for instructions on adding/revising chemicals.

GW-SCREEN
Version 3.1; 02/04

Reset to
Defaults

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION
(enter "X" in "YES" box and initial groundwater conc. below)

YES

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C_w ($\mu\text{g/L}$)	Cannot calculate risk-based concentration and incremental risk simultaneously.
56235		Carbon tetrachloride

Figure 6. Example Error Message on Data Entry Sheet

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

INCREMENTAL RISK CALCULATIONS:

Indoor exposure soil conc., carcinogen ($\mu\text{g/kg}$)	Indoor exposure soil conc., noncarcinogen ($\mu\text{g/kg}$)	Risk-based indoor exposure soil conc., ($\mu\text{g/kg}$)	Soil saturation conc., C_{sat} ($\mu\text{g/kg}$)	Final indoor exposure soil conc., ($\mu\text{g/kg}$)	Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA	NA	3.09E+05	NA	8.0E-08	7.9E-04

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL
DOWN
TO "END"

ERROR: Combined thickness of strata A + B + C must be = depth below grade to top of contamination.

Figure 7. Example Error Message on Results Sheet

3. *Initial Soil or Groundwater Concentration* (All Soil and Groundwater Models) (L_w)

Enter a value only if incremental risks are to be calculated. Be sure to enter the concentration in units of $\mu\text{g}/\text{kg}$ (wet weight basis soil) or $\mu\text{g}/\text{L}$ (groundwater). Typically, this value represents the average concentration within the zone of contamination. If descriptive statistics are not available to quantify the uncertainty in the average value, the maximum value may be used as an upper bound estimate.

4. *Average Soil/Groundwater Temperature* (All Models) (T_s)

The soil/groundwater temperature is used to correct the Henry's law constant to the specified temperature. Figure 8 from U.S. EPA (1995) shows the average temperature of shallow groundwater in the continental United States. Shallow groundwater temperatures may be used to approximate subsurface soil temperatures greater than 1 to 2 meters below the ground surface. Another source of information may be your State groundwater protection regulatory agency.

5. *Depth Below Grade to Bottom of Enclosed Space Floor* (All Models) (L_F)

Enter the depth to the bottom of the floor in contact with the soil. The default value for slab-on-grade and basement construction is 15 cm and 200 cm, respectively.

6. *Depth Below Grade to Top of Contamination* (Soil Models Only) (L_T)

Enter the depth to the top of soil contamination. If the contamination begins at the soil surface, enter the depth below grade to the bottom of the enclosed space floor. The depth to the top of contamination must be greater than or equal to the depth to the bottom of the floor.

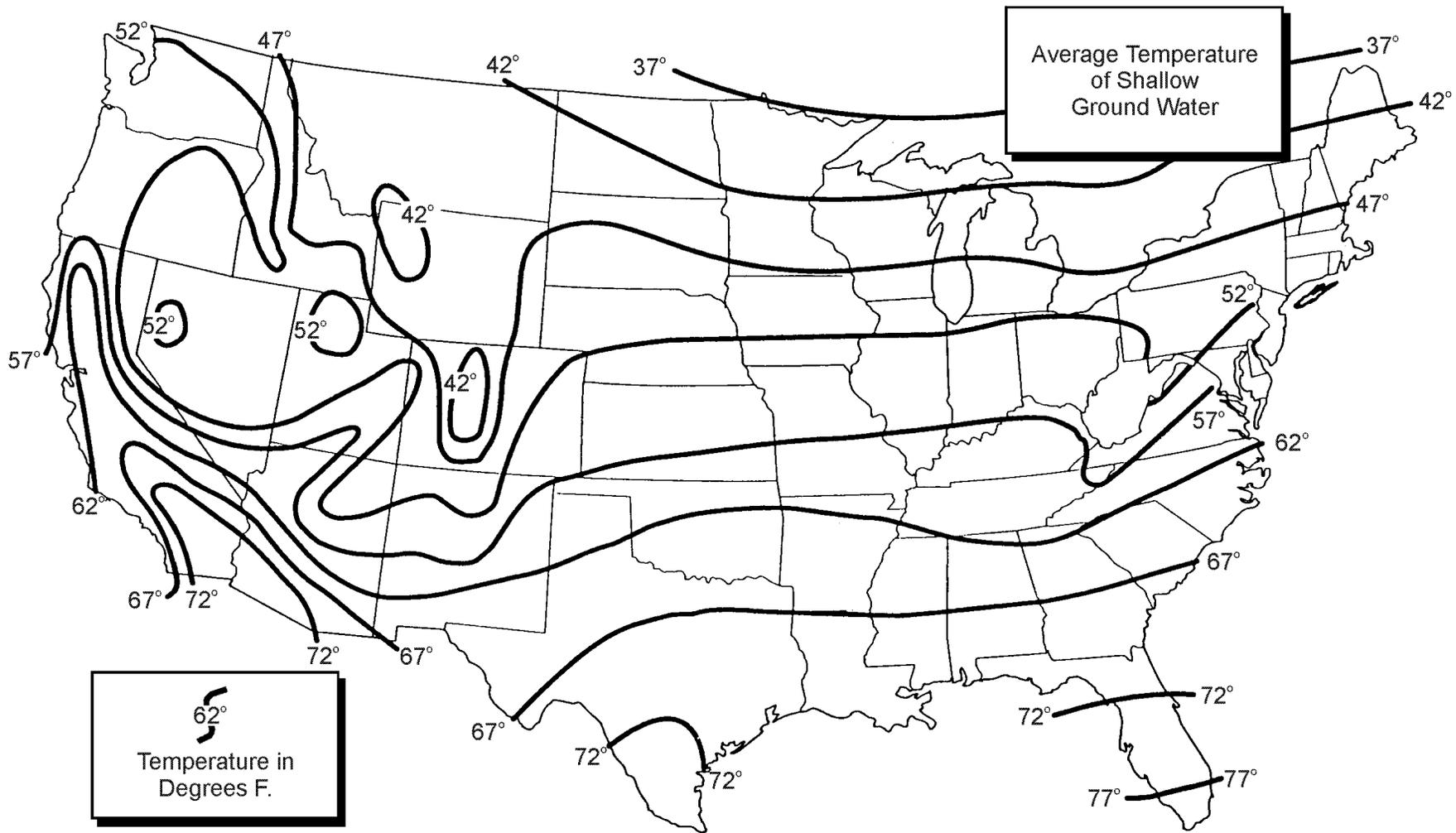


Figure 8. Average Shallow Groundwater Temperature in the United States

7. *Depth Below Grade to Water Table (Groundwater Models Only) (L_{wt})*

Enter the depth to the top of the water table (i.e., where the pressure head is equal to zero and the pressure is atmospheric).

Note: The thickness of the capillary zone is calculated based on the SCS soil textural classification above the top of the water table. The depth below grade to the top of the water table minus the thickness of the capillary zone must be greater than the depth below grade to the bottom of the enclosed space floor. This means that the top of the capillary zone is always below the floor.

8. *Depth Below Grade to Bottom of Contamination (Advanced Soil Model Only) (L_B)*

This value is used to calculate the thickness of soil contamination. A value greater than zero and greater than the depth to the top of contamination will automatically invoke the finite source model. If the thickness of contamination is unknown, two options are available:

1. Entering a value of zero will automatically invoke the infinite source model.
2. Enter the depth to the top of the water table. This will invoke the finite source model under the assumption that contamination extends from the top of contamination previously entered down to the top of the water table.

9. *Thickness of Soil Stratum "X" (Advanced Models Only) (h_x , $x = A, B, \text{ or } C$)*

In the advanced models, the user can define up to three soil strata between the soil surface and the top of contamination or to the soil gas sampling depth, as appropriate. These strata are listed as A, B, and C. Stratum A extends down from the soil surface, Stratum B is below Stratum A, and Stratum C is the deepest stratum. The thickness of Stratum A must be at least as thick as the depth below grade to the bottom of the enclosed space floor. The combined thickness of all strata must be equal to the depth to the top of contamination, or to the soil gas sampling depth, as appropriate. If soil strata B and/or C are not to be considered, a value of zero must be entered for each stratum not included in the analysis.

10. *Soil Stratum A SCS Soil Type (Advanced Models Only) (SES – soil)*

Enter one of the following SCS soil type abbreviations:

<u>Abbreviation</u>	<u>SCS Soil Type</u>
C	Clay
CL	Clay loam
L	Loam
LS	Loamy sand
S	Sand
SC	Sandy clay
SCL	Sandy clay loam
SI	Silt
SIC	Silty clay
SICL	Silty clay loam
SIL	Silty loam
SL	Sandy loam

The SCS soil textural classification can be determined by using either the ATSM Standard Test Method for Particle-Size Analysis of Soils (D422-63) or by using the analytical procedures found in the U.S. Natural Resources Conservation Service (NRCS) Soil Survey Laboratory Methods Manual, Soil Survey Laboratory Investigations Report No. 42. After determining the particle size distribution of a soil sample, the SCS soil textural classification can be determined using the SCS classification chart in Figure 7.

The SCS soil type along with the Stratum A soil water-filled porosity is used to estimate the soil vapor permeability of Stratum A which is in contact with the floor and walls of the enclosed space below grade. Alternatively, the user may define a soil vapor permeability (see Variable No. 11).

11. *User-Defined Stratum A Soil Vapor Permeability (Advanced Models Only)(K_v)*

As an alternative to estimating the soil vapor permeability of soil Stratum A, the user may define the soil vapor permeability. As a general guide, the following represent the practical range of vapor permeabilities:

<u>Soil type</u>	<u>Soil vapor permeability, cm²</u>
Medium sand	1.0 x 10 ⁻⁷ to 1.0 x 10 ⁻⁶
Fine sand	1.0 x 10 ⁻⁸ to 1.0 x 10 ⁻⁷
Silty sand	1.0 x 10 ⁻⁹ to 1.0 x 10 ⁻⁸
Clayey silts	1.0 x 10 ⁻¹⁰ to 1.0 x 10 ⁻⁹

12. *Vadose Zone SCS Soil Type (Screening Models Only) (SCS – soil)*

Because the screening-level models accommodate only one soil stratum above the top of contamination or soil gas sampling depth, enter the SCS soil type from the list given in Variable No. 10.

13. *User-Defined Vadose Zone Soil Vapor Permeability (Screening Models Only) (K_v)*

For the same reason cited in No. 12 above, the user may alternatively define a soil vapor permeability. Use the list of values given in Variable No. 11 as a general guide.

14. *Soil Stratum Directly Above the Water Table (Advanced Groundwater Models Only) (A, B, or C)*

Enter either A, B, or C as the soil stratum directly above the water table. This value must be the letter of the deepest stratum for which a thickness value has been specified under Variable No. 9.

15. *SCS Soil Type Directly Above Water Table (Groundwater Models Only) (SCS – soil)*

Enter the correct SCS soil type from the list given in Variable No. 10 for the soil type directly above the water table. The soil type entered is used to estimate the rise (thickness) of the capillary zone.

16. *Stratum "X" Soil Dry Bulk Density* (Advanced Models Only) (P_x , $x = A, B, \text{ or } C$)

Identify the soil type for each strata and accept the default value or enter a site-specific value for the average soil dry bulk density. Dry bulk density is used in a number of intermediate calculations and is normally determined by field measurements (ASTM D 2937 Method).

17. *Stratum "X" Soil Total Porosity* (Advanced Models Only) (n^x , $x = A, B, \text{ or } C$)

Total soil porosity (n) is determined as:

$$n = 1 - \rho_b / \rho_s$$

where ρ_b is the soil dry bulk density (g/cm^3) and ρ_s is the soil particle density (usually 2.65 g/cm^3).

18. *Stratum "X" Soil Water-Filled Porosity* (Advanced Models Only) (θ_w^x , $X = a, b, \text{ or } c$)

Enter the average long-term volumetric soil moisture content; this is typically a depth-averaged value for the appropriate soil stratum. A long-term average value is typically not readily available. Do not use values based on episodic measurements unless they are representative of long-term conditions. Table 10 provides a soil-specific range of typical value for specified soils. The user must define soil type or input site-specific values.

One option is to use a model to estimate the long-term average soil water-filled porosities of each soil stratum between the enclosed space floor and the top of contamination. The HYDRUS model version 5.0 (Vogel et al., 1996) is a public domain code for simulating one-dimensional water flow, solute transport, and heat movement in variably-saturated soils. The water flow simulation module of HYDRUS will generate soil water content as a function of depth and time given actual daily precipitation data. Model input requirements include either the soil hydraulic properties of van Genuchten (1980) or those of Brooks and Corey (1966). The van Genuchten soil hydraulic properties required are the same as those given in Tables 3 and 4 (i.e., θ_s , θ_r , N , α_1 , and K_s). The HYDRUS model is available from the U.S. Department of Agriculture (USDA) - Agricultural Research Service in Riverside, California via their internet website at <http://www.ussl.ars.usda.gov/MODELS/HYDRUS.HTM>. One and two-dimensional commercial versions of HYDRUS (Windows versions) are available at the International Ground Water Modeling Center website at <http://www.mines.edu/research/igwmc/software/>. Schaap and Leij (1998) have recently developed a Windows program entitled ROSETTA for estimating the van Genuchten soil hydraulic properties based on a limited or more extended set of input

data. The ROSETTA program can be found at the USDA website: <http://www.ussl.ars.usda.gov/MODELS/rosetta/rosetta.htm>. The van Genuchten hydraulic properties can then be input into HYDRUS to estimate soil moisture content.

19. *Stratum "X" Soil Organic Carbon Fraction* (Advanced Soil Models Only) (f_{oc}^X , X = A, B, or c)

Enter the depth-averaged soil organic carbon fraction for the stratum specified. Soil organic carbon is measured by burning off soil carbon in a controlled-temperature oven. This parameter, along with the chemical's organic carbon partition coefficient (K_{oc}), is used to determine the soil-water partition coefficient (K_d).

20. *Vadose Zone Soil Dry Bulk Density* (Screening Models Only) (ρ^A)

Because the screening-level models accommodate only one soil stratum above the top of contamination, identify the soil type and accept the default values or enter the depth-averaged soil dry bulk density. The universal default value is 1.5 g/cm³, which is consistent with U.S. EPA (1996a and b) for subsurface soils.

21. *Vadose Zone Soil Total Porosity* (Screening Models Only) (m^A)

Because the screening-level models accommodate only one soil stratum above the top of contamination, enter the depth-averaged soil total porosity. The default value is 0.43, which is consistent with U.S. EPA (1996a and b) for subsurface soils.

22. *Vadose Zone Soil Water-Filled Porosity* (Screening Models Only) (θ_w^A)

Because the screening-level models accommodate only one soil stratum above the top of contamination, enter the depth-averaged soil water-filled porosity. The default value is 0.30, which is consistent with U.S. EPA (1996a and b) for subsurface soils.

23. *Vadose Zone Soil Organic Carbon Fraction* (Soil Screening Model Only) (f_{oc}^A)

Because the screening-level models accommodate only one soil stratum above the top of contamination, enter the depth-averaged soil organic carbon fraction. The default value is 0.002, which is consistent with U.S. EPA (1996a and b) for subsurface soils.

24. *Enclosed Space Floor Thickness* (Advanced Models Only) (L_{crack})

Enter the thickness of the floor slab. All models operate under the assumption that the floor in contact with the underlying soil is composed of impermeable concrete

whether constructed as a basement floor or slab-on-grade. The default value is 10 cm, which is consistent with J&E (1991).

25. *Soil-Building Pressure Differential* (Advanced Models Only) (ΔP)

Because of wind effects on the structure, stack effects due to heating of the interior air, and unbalanced mechanical ventilation, a negative pressure with respect to the soil surface is generated within the structure. This pressure differential (ΔP) induces a flow of soil gas through the soil matrix and into the structure through cracks, gaps, and openings in the foundation. The effective range of values of ΔP is 0-20 pascals (Pa) (Loureiro et al., 1990; Eaton and Scott, 1984). Individual average values for wind effects and stack effects are approximately 2 Pa (Nazaroff et al., 1985; Put and Meijer, 1989). Typical values for the combined effects of wind pressures and heating are 4 to 5 Pa (Loureiro et al., 1990; Grimsrud et al., 1983). A conservative default value of ΔP was therefore chosen to be 4 Pa (40 g/cm-s²).

For more information on estimating site-specific values of ΔP , the user is referred to Nazaroff et al. (1987) and Grimsrud et al. (1983).

26. *Enclosed Space Floor Length* (Advanced Models Only) (L_B)

The default value is 1000 cm (see Variable No. 28).

27. *Enclosed Space Floor Width* (Advanced Models Only) (W_B)

The default value is 1000 cm (see Variable No. 28).

28. *Enclosed Space Height* (Advanced Models Only) (H_B)

For a single story home, the variation in mixing height will be the greatest for houses with HVAC systems that result in significant air circulation (e.g., forced air heat pump). Mixing heights would be less for houses with electrical baseboard heaters.

The mixing height is approximated by the room height. The default value is 2.44 meters for a single story house without a basement.

For a single story house with a basement less mixing would be expected because of the cross floor connections. The default values for a house with a basement is 3.66 m. This value represents a two-fold reduction in vapor concentrations between the floors.

29. *Floor-Wall Seam Crack Width* (Advanced Models Only) (W)

The conceptual model used in the spreadsheets follows that of Loureiro et al. (1990) and Nazaroff (1988) and is illustrated in Figure 9. The model is based on a single-

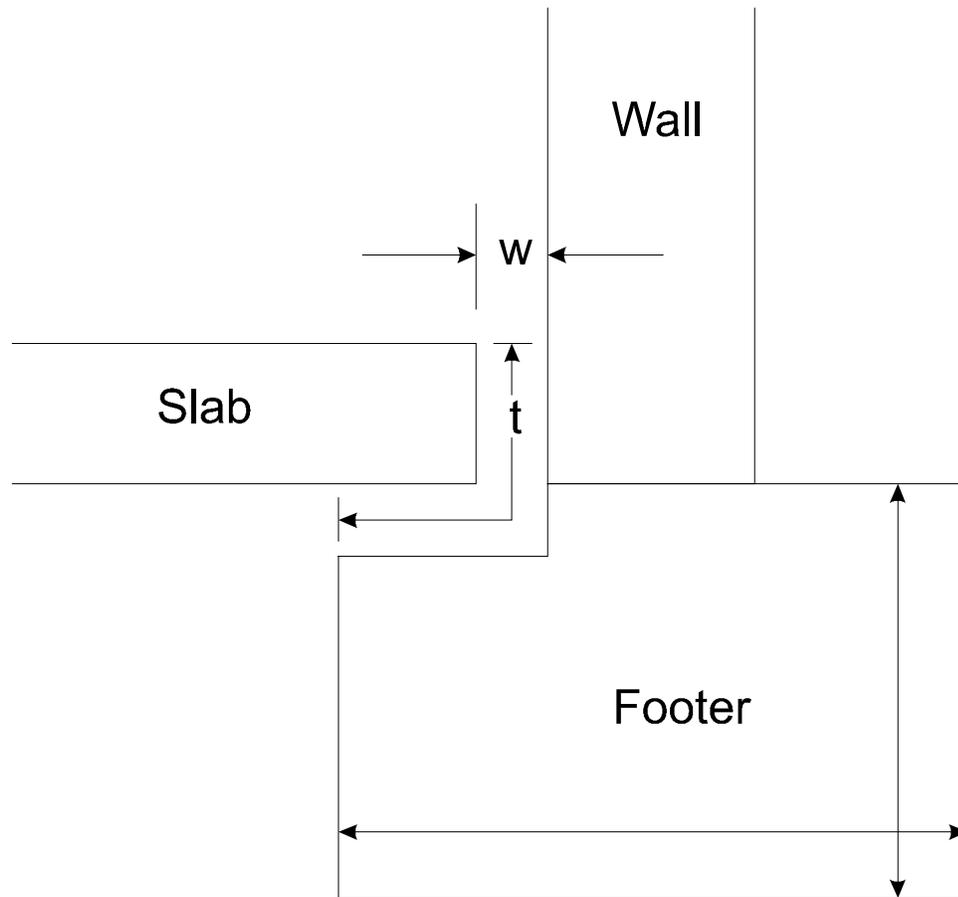


Figure 9. Floor Slab and Foundation

family house with a poured concrete basement floor and wall foundations, or constructed slab-on-grade in similar fashion. A gap is assumed to exist at the junction between the floor and the foundation along the perimeter of the floor. The gap exists as a result of building design or concrete shrinkage. This gap is assumed to be the only opening in the understructure of the house and therefore the only route for soil gas entry.

Eaton and Scott (1984) reported typical open areas of approximately 300 cm^2 for the joints between walls and floor slabs of residential structures in Canada. Therefore, given the default floor length and width of 1000 cm , a gap width (w) of 0.1 cm equates to a total gap area of 900 cm^2 , which is reasonable given the findings of Eaton and Scott. This value of the gap width is also consistent with the typical value reported in Loureiro et al. (1990). The default value of the floor-wall seam crack width was therefore set equal to 0.1 cm .

30. *Indoor Air Exchange Rate (Advanced Models Only) (ER)*

The indoor air exchange rate is used along with the building dimensions to calculate the building ventilation rate. The default value of the indoor air exchange rate is 0.25/h. This value is consistent with the 10th percentile of houses in all regions of the U.S., as reported in Koontz and Rector (1995). This value is also consistent with the range of the control group of 331 houses in a study conducted by Parker et al. (1990) to compare data with that of 292 houses with energy-efficient features in the Pacific Northwest.

31. *Averaging Time for Carcinogens (All Models) (AT_c)*

Enter the averaging time in units of years. The default value is 70 years.

32. *Averaging Time for Noncarcinogens (All Models) (AT_{nc})*

Enter the averaging time in units of years. The averaging time for noncarcinogens is set equal to the exposure duration. The default value for residential exposure from U.S. EPA (1996a and b) is 30 years.

33. *Exposure Duration (All Models) (ED)*

Enter the exposure duration in units of years. The default value for residential exposure from U.S. EPA (1996a and b) is 30 years.

34. *Exposure Frequency (All Models) (EF)*

Enter the exposure frequency in units of days/yr. The default value for residential exposure from U.S. EPA (1996a and b) is 350 days/yr.

35. *Target Risk for Carcinogens (All Soil and Groundwater Models) (TR)*

If a risk-based media concentration is to be calculated, enter the target risk-level. The default value is 1×10^{-6} .

36. *Target Hazard quotient for Noncarcinogens (All Soil and Groundwater Models) (THQ)*

If a risk-based media concentration is to be calculated, enter the target hazard quotient. The default value is 1.

The remaining four worksheets include the results sheet (RESULTS) and three ancillary sheets. The ancillary sheets include the chemical properties sheet (CHEMPROPS), the intermediate calculations sheet (INTERCALCS), and the lookup tables (VLOOKUP).

3.5 THE RESULTS SHEET (RESULTS)

Once all data are entered in the data entry sheet, the model results may be viewed on the RESULTS sheet. For the soil and groundwater models, calculations are presented as either a risk-based soil or groundwater concentration, or the incremental risks associated with an initial soil or groundwater concentration. In the case of the advanced models, the user should check the message and error summary below the results section to ensure that no error messages appear. If one or more error messages appear, re-enter the appropriate data.

The RESULTS worksheet shows the indoor exposure soil or groundwater concentration for either a carcinogen or noncarcinogen as appropriate. When a contaminant is both a carcinogen and a noncarcinogen, the risk-based indoor exposure concentration is set equal to the lower of these two values. In addition, the soil saturation concentration (C_{sat}) or the aqueous solubility limit (S) is also displayed for the soil and groundwater models, respectively.

The equilibrium vapor concentration at the source of contamination is limited by the value of C_{sat} for soil contamination and by the value of S for groundwater contamination, as appropriate. For a single contaminant, the vapor concentration directly above the source of soil contamination cannot be greater than that associated with the soil saturation concentration; for groundwater contamination, the vapor concentration cannot be greater than that associated with the solubility limit. As a result, subsurface soil concentrations greater than C_{sat} and groundwater concentrations greater than S will not produce higher vapor concentrations. Therefore, if the indoor vapor concentration predicted from a soil concentration greater than or equal to the value of C_{sat} and it does not exceed the health-based limit in indoor air (target risk or target hazard quotient), the vapor intrusion pathway will not be of concern for that particular chemical. The same is true for an indoor vapor concentration predicted from a groundwater concentration greater than or equal to the value of S. That does not necessarily mean, however, that the subsurface contamination will not be of concern from a groundwater protection standpoint, (ingestion) and the potential for free-phase contamination (e.g., NAPL) must also be addressed.

For subsurface soils, the physical state of a contaminant at the soil temperature plays a significant role. When a contaminant is a liquid (or gas) at the soil temperature, the upper limit of the soil screening level is set at C_{sat} . This tends to reduce the potential for NAPL to exist within the vadose zone. The case is different for a subsurface contaminant that is a solid at the soil temperature. In this case, the screening level is not limited by C_{sat} because of the reduced possibility of leaching to the water table. If the model estimates a risk-based screening level greater than C_{sat} for a solid in soils, the model will display the final soil concentration as "NOC" or Not of Concern for the vapor intrusion pathway.

In the case of groundwater contamination, the physical state of the contaminant is not an issue in that the contamination has already reached the water table. Because the equilibrium vapor concentration at the source of emissions cannot be higher than that associated with the solubility limit, the vapor concentration is calculated at the solubility limit if the user enters a groundwater concentration greater than the value of S when forward-calculating risk. When reverse-calculating a risk-based groundwater concentration, the model will display the final groundwater concentration as "NOC" for the vapor intrusion pathway if the model calculates a risk-based level greater than or equal to the value of S. It should be noted, however, that if the soil properties or other conditions specified in the DATENTER worksheet are changed, the final risk-based soil or groundwater concentration must be remodeled.

It should also be understood that if a contaminant is labeled "Not of Concern" for the vapor intrusion pathway, all other relevant exposure pathways must be considered for both contaminated soils and groundwater.

3.6 THE CHEMICAL PROPERTIES SHEET (CHEMPROPS)

The chemical properties sheet provides a summary of the chemical and toxicological properties of the chemical selected for analysis. These data are retrieved from the VLOOKUP sheet by CAS number. All data in the chemical properties sheet are protected.

3.7 THE INTERMEDIATE CALCULATIONS SHEET (INTERCALS)

The intermediate calculations sheet provides solutions to intermediate variables. Review of the values of the intermediate variables may be helpful in an analysis of the cause-and-effect relationships between input values and model results. All data in the intermediate calculations sheet are protected.

3.8 THE LOOKUP TABLES (VLOOKUP)

The VLOOKUP sheet contains two lookup tables from which individual data are retrieved for a number of model calculations. The first table is the Soil Properties Lookup Table. This table contains the average soil water retention curve data of Hers (2002) and Schaap and Leij (1998) and the mean grain diameter data of Nielson and Rogers (1990) by SCS soil type, and the mean dry bulk density from Leij, Stevens, et al (1994).

3.9 ADDING, DELETING, OR REVISING CHEMICALS

Data for any chemical may be edited, new chemicals added, or existing chemicals deleted from the Chemical Properties Lookup Table within the VLOOKUP worksheet. To begin an editing

session, the user must unprotect (unseal) the worksheet (the password is "ABC" in capital letters); editing of individual elements or addition and deletion of chemicals may then proceed. Space has been allocated for up to 260 chemicals in the lookup table. Row number 284 is the last row that may be used to add new chemicals. After the editing session is complete, the user must sort all the data in the lookup table (except the column headers) in ascending order by CAS number. After sorting is complete, the worksheet should again be protected (sealed).

SECTION 4

SOIL GAS MODEL APPLICATION

Two additional models have been added to allow the user to input measured soil gas concentration and sampling depth data directly into the spreadsheet. These models eliminate the need for theoretical partitioning of a total volume soil concentration or a groundwater concentration into discrete phases. This section provides instructions for using the soil gas models.

4.1 RUNNING THE MODELS

Two models are provided as MICROSOFT EXCEL spreadsheets. The screening-level model is titled SG-SCREEN.xls (EXCEL). The advanced model is titled SG-ADV.xls.

Both the screening-level and advanced models allow the user to calculate steady-state indoor air concentrations and incremental risks from user-defined soil gas concentration data. The models do not allow for reverse-calculation of a risk-based soil or groundwater concentration. As with the soil and groundwater screening-level models, the SG-SCREEN model operates under the assumption that the soil column properties are homogeneous and isotropic from the soil surface to an infinite depth. In addition, the SG-SCREEN model uses the same default values for the building properties as the SL-SCREEN and GW-SCREEN models. The advanced model allows the user to specify up to three different soil strata from the bottom of the building floor in contact with the soil to the soil gas sampling depth. Finally, the advanced model allows the user to specify values for all of the model variables.

To run the models, simply open the appropriate file within either MICROSOFT EXCEL worksheet. Each model is constructed of the following worksheets:

1. DATENTER (Data Entry Sheet)
2. CHEMPROPS (Chemical Properties Sheet)
3. INTERCALCS (Intermediate Calculations Sheet)
4. RESULTS (Results Sheet)
5. VLOOKUP (Lookup Tables)

Each worksheet follows the form of the worksheets in the soil and groundwater models. See Section 4.2 for a description of each worksheet.

The DATENTER worksheet of each of the soil gas models is different than those of the soil and groundwater models. Figure 10 shows the DATA ENTER worksheet of the SG-ADV model. Note that there is no option for running the model to calculate a risk-based media concentration. As with the other models, the user enters the CAS number of the chemical of interest. This automatically retrieves the chemical and toxicological data for that chemical. The CAS number must match one of the chemicals listed in the VLOOKUP worksheet, or the message "CAS No. not found" will appear in the "Chemical" box. The user also has the opportunity to add new chemicals to the data base. Next, the user must enter a value for the soil gas concentration of the chemical of interest. The user may enter this value in units of $\mu\text{g}/\text{m}^3$ or parts-per-million by volume (ppmv). If the soil gas concentration is entered in units of ppmv, the concentration is converted to units of $\mu\text{g}/\text{m}^3$ by:

$$C_g' = \frac{C_g \times MW}{R \times T_S} \quad (33)$$

where

- C_g' = Soil gas concentration, $\mu\text{g}/\text{m}^3$
- C_g = Soil gas concentration, ppmv
- MW = Molecular weight, g/mol
- R = Gas constant (= $8.205 \text{ E-}05 \text{ atm}\cdot\text{m}^3/\text{mol}\cdot^\circ\text{K}$)
- T_S = System (soil) temperature, $^\circ\text{K}$.

In the soil gas models, the steady-state indoor air concentration is calculated by Equation 19 (i.e., $C_{\text{building}} = \alpha C_{\text{source}}$). The value of the vapor concentration at the source of emissions (C_{source}) is assigned the value of the user-defined soil gas concentration. The value of the steady-state attenuation coefficient (α) in Equation 19 is calculated by Equation 13. Because no evaluation has been made of the extent of the source of emissions, steady-state conditions (i.e., a non-diminishing source) must be assumed.

The SG-SCREEN model operates under the assumption of homogeneously distributed soil properties and isotropic conditions with respect to soil vapor permeability from the soil surface to an infinite depth. The SG-ADV model, on the other hand, allows the user to specify up to three different soil strata between the building floor in contact with the soil and the soil gas sampling depth. Soil properties within these three strata may be varied to allow for different diffusion resistances to vapor transport.

4.2 SOIL GAS SAMPLING

In order to use the soil gas models, soil gas concentrations must be measured at one or more depths below ground surface (bgs). The user is advised to take samples directly under building slabs

SG-ADV
Version 3.1: 02/04

Reset to
Defaults

Soil Gas Concentration Data	
ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C _g (ppmv)
	OR
	ENTER Soil gas conc., C _g (µg/m ³)
71432	2.00E+01
	Chemical
	Benzene

MORE
↓

ENTER Depth below grade to bottom of enclosed space floor, L _f (cm)	ENTER Soil gas sampling depth below grade, L _s (cm)	ENTER Average soil temperature, T _s (°C)	ENTER Thickness of soil stratum A, h _A (cm) (Enter value or 0)	ENTER Thickness of soil stratum B, h _B (cm) (Enter value or 0)	ENTER Thickness of soil stratum C, h _C (cm) (Enter value or 0)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	ENTER User-defined stratum A soil vapor permeability, k _v (cm ²)
200	400	10	100	100	100	L	

MORE
↓

ENTER Stratum A SCS soil type Lookup Soil Parameters	ENTER Stratum A soil total porosity, n ^A (unitless)	ENTER Stratum A soil dry bulk density, ρ _d ^A (g/cm ³)	ENTER Stratum A soil water-filled porosity, g _w ^A (cm ³ /cm ³)	ENTER Stratum B SCS soil type Lookup Soil Parameters	ENTER Stratum B soil dry bulk density, ρ _d ^B (g/cm ³)	ENTER Stratum B soil total porosity, n ^B (unitless)	ENTER Stratum B soil water-filled porosity, g _w ^B (cm ³ /cm ³)	ENTER Stratum C SCS soil type Lookup Soil Parameters	ENTER Stratum C soil dry bulk density, ρ _d ^C (g/cm ³)	ENTER Stratum C soil total porosity, n ^C (unitless)	ENTER Stratum C soil water-filled porosity, g _w ^C (cm ³ /cm ³)
	1.5	0.43	0.15		1.5	0.43	0.25		1.7	0.38	0.3

MORE
↓

ENTER Enclosed space floor thickness, L _{enc} (cm)	ENTER Soil-bldg pressure differential, ΔP (g/cm-s ²)	ENTER Enclosed space floor length, L _e (cm)	ENTER Enclosed space width, W _e (cm)	ENTER Enclosed space height, H _b (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg, Q _{av} (L/m) Leave blank to calculate
10	40	1000	1000	366	0.1	0.25	5

END

ENTER Averaging time for carcinogens, AT _c (yrs)	ENTER Averaging time for noncarcinogens, AT _{nc} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

Figure 10. SG-ADV Data Entry Worksheet

or basement floors when possible. This can be accomplished by drilling through the floor and sampling through the drilled hole. Alternatively, an angle-boring rig can be used to sample beneath the floor from outside the footprint of the building. When sampling directly beneath the floor is not possible, enough samples adjacent to the structure should be taken to adequately estimate an average concentration based on reasonable spatial and temporal scales.

Soil gas measurements can be made using several techniques; however, active whole-air sampling methods and active or passive sorbent sampling methods are usually employed. Typically, a whole-air sampling method is used whereby a non-reactive sampling probe is inserted into the soil to a prescribed depth. This can be accomplished manually using a "slam bar," or a percussion power drill, or the probe can be inserted into the ground using a device such as a Geoprobe.[®] The Geoprobe[®] device is attached to the rear of a specially customized vehicle. In the field, the rear of the vehicle is placed over the sample location and hydraulically raised on its base. The weight of the vehicle is then used to push the sampling probe into the soil. A built-in hammer mechanism allows the probe to be driven to predetermined depths up to 50 feet depending on the type of soil encountered. Soil gas samples can be withdrawn directly from the probe rods, or flexible tubing can be connected to the probe tips at depth for sample withdrawal.

Whole-air sampling is typically accomplished using an evacuated Summa or equivalent canister, or by evacuation to a Tedlar bag. Normal operation includes the use of an in-line flow controller and a sintered stainless steel filter to minimize particles becoming entrained in the sample atmosphere. For a 6-liter Summa canister, a normal sampling flow rate for a 24-hr integrated sample might be on the order of 1.5 ml/min; however, higher sampling rates can be used for grab samples. The sampling rate chosen, however, must not be so high as to allow for ambient air leakage between the annulus of the probe and the surrounding soils. Depending on the target compounds, excessive air leakage can dilute the sample (in some cases below the analytical detection limits).

One way to check for leakage is to test an aliquot of the sample gas for either nitrogen or oxygen content before the sample is routed to the canister or Tedlar bag. To test for nitrogen in real- or near real-time requires a portable gas chromatograph/mass spectrometer (GC/MS). A portable oxygen meter, however, can be used to test for sample oxygen content in real-time with a typical accuracy of one-half of one percent. If air leakage is detected by the presence of excessive nitrogen or oxygen, the seal around the sample probe at the soil surface as well as all sampling equipment connections and fittings should be checked. Finally, the flow rate may need to be reduced to decrease or eliminate the air leakage.

The collection and concentration of soil gas contaminants can be greatly affected by the components of the sampling system. It is imperative to use materials that are inert to the contaminants of concern. Areas of sample collection that need particular attention are:

- The seal at the soil surface around the sample probe
- Use of a probe constructed of stainless steel or other inert material
- Minimization of the use of porous or synthetic materials (i.e., PTFE, rubber, or most plastics) that may adsorb soil gas and cause cross-contamination

- Purging of the sample probe and collection system before sampling
- Leak-check of sampling equipment to reduce air infiltration
- Keeping the length of all sample transfer lines as short as possible to minimize condensation of extracted gas in the lines.

The choice of analytical methods for whole-air soil gas sampling depends on the contaminants of concern. Concentrations of volatile organic compounds (VOCs) in the soil gas are typically determined using EPA Method TO-14 or TO-15. In the case of semi-volatile compounds, an active sorbent sampling methodology can be used. In this case, a low-volume sampling pump is normally used to withdraw the soil gas, which is then routed to a polyurethane foam (PUF) plug. Vapor concentrations of semi-volatile contaminants sorbed to the PUF are then determined using EPA Method TO-10. The active soil gas sampling equipment can be assembled to allow for both canister sampling for volatiles and PUF sampling for semi-volatiles.

Passive sorbent sampling involves burial of solid sorbent sampling devices called cartridges or cassettes to a depth of normally 5 feet or less. The cassettes may be configured with one or more sorbents depending on the list of target analytes, and are typically left in-ground for 72 to 120 hours or longer. During this time period, the vapor-phase soil gas contaminants pass through the cassette and are adsorbed as the soil gas moves toward the soil surface by diffusion and/or convection. Analytical methods for sorbent sampling depend on the target analytes and the sorbent used and may include EPA Method TO-10 or a modified EPA Method TO-1. Vapor-phase concentrations for some solid sorbent sampling systems are determined using the total mass of each contaminant recovered, the time in-ground, the cross-sectional area of the cassette, the diffusivity of the compound in air, and a quasi-empirical adsorption rate constant.

Recent EPA technology verification reports produced by the EPA National Exposure Research Laboratory (EPA 1998, 1998a) concluded, at least for two such systems, that the sorbent methodologies accurately accounted for the presence of most of the soil gas contaminants in the studies. Further, the reports concluded that the sorbent systems showed detection of contaminants at low concentrations not reported using an active whole-air sampling system. For one system, however, it was noted that as the vapor concentrations reported for the whole-air sampling system increased by 1 to 4 orders-of-magnitude, the associated concentrations reported for the sorbent system increased only marginally. Perhaps the best use of such passive sorbent sampling methods is to help confirm which contaminants are present in the soil gas and not necessarily contaminant concentrations.

An excellent discussion of soil gas measurement methods and limitations can be found in the ASTM Standard Guide for Soil Gas Monitoring in the Vadose Zone D5314-92e1. ASTM Standard Guides are available from the ASTM website at:

<http://www.astm.org>.

In addition, soil gas measurement method summaries can be found in the EPA Standard Operating Procedures for Soil Gas Sampling (SOP No. 2042) developed by the EPA Environmental Response

Team (ERT) in Edison, New Jersey. This document can be downloaded from the ERT Compendium of Standard Operating Procedures at the following website:

http://www.ert.org/media_resrcs/media_resrcs.asp.

Data Quality and Data Quality Objectives

The results of soil gas sampling must meet the applicable requirements for data quality and satisfy the data quality objectives of the study for which they are intended. Data quality objectives are qualitative and quantitative statements derived from the data quality objectives process that clarify study objectives, define the appropriate type of data, and specify the tolerable levels of potential decision errors that will be used to support site decisions. Data quality objectives are formulated in the first phase of a sampling project.

In the second phase of the project, a Quality Assurance Project Plan (QAPP) translates these requirements into measurement performance specifications and quality assurance/quality control procedures to provide the data necessary to satisfy the user's needs. The QAPP is the critical planning document for any environmental data collection operation because it documents how quality assurance and quality control activities will be implemented during the life of the project. Development of the data quality objectives and the QAPP for soil gas sampling should follow the guidance provided by EPA's Quality Assurance Division of the Office of Research and Development. Guidance documents concerning the development and integration of the data quality objectives and the QAPP can be obtained from the EPA website at:

http://epa.gov/ncercqa/qa/qa_docs.html.

In addition to the above guidance, the EPA Regional Office and/or other appropriate regulatory agency should be consulted concerning specific sampling requirements.

4.3 ASSUMPTIONS AND LIMITATIONS OF THE SOIL GAS MODEL

As discussed previously, the soil gas models operate under the assumption of steady-state conditions. This means that enough time has passed for the vapor plume to have reached the building of interest directly above the source of contamination and that the vapor concentrations have reached their maximum values. Depending on the depth at which the soil gas is sampled, diffusion of the soil gas toward the building is a function of the soil properties between the building floor in contact with the soil and the sampling depth. Convection of the soil gas into the structure is a function of the building properties and the effective soil vapor permeability. Assumptions and limitations of the soil gas models are the same as those in Section 2.11 with the exception of the source vapor concentration that is determined empirically through soil gas sampling.

The user should also recognize the inherent limitations of soil gas sampling. First, the geologic variability of the subsurface may be considerable. This may be especially problematic for

shallow soil gas sampling because soil moisture content can vary widely as a function of precipitation events and surface runoff. The soil moisture content has an exponential effect on the rate of vapor diffusion. Transformation processes such as biodegradation can also occur in shallow subsurface soils. In some cases, only a relatively thin stratum of bioactive soil can greatly reduce the emission flux toward the soil surface. Finally, subsurface phase equilibria is a dynamic process resulting in varying vapor-phase concentrations over time at the same sampling location and depth. These factors can result in significant differences in measured soil gas concentrations over relatively small spatial and temporal scales.

For these reasons, the planning phase of the soil gas-sampling program should carefully consider the inherent uncertainties in site-specific sampling and analytical data. In the final analysis, the extent of soil gas sampling is a trade-off between sampling costs and the degree of certainty required in the soil gas concentration data.

SECTION 5

ASSUMPTIONS AND LIMITATIONS OF THE J&E MODEL

The J&E Model is a one-dimensional analytical solution to diffusive and convective transport of vapors into indoor spaces. The model is formulated as an attenuation factor that relates the vapor concentration in the indoor space to the vapor concentration at the source. It was developed for use as a screening level model and consequently is based on a number of simplifying assumptions regarding contaminant distribution and occurrence, subsurface characteristics, transport mechanisms, and building construction.

EPA is suggesting that the J&E Model be used at Resource Conservation and Recovery Act (RCRA) Corrective Action Sites, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)/Superfund Sites, and voluntary cleanup sites. EPA is not recommending that the J&E Model be used for sites contaminated with petroleum products if the products were derived from Underground Storage Tanks. The J&E Model does not account for contaminant attenuation (biodegradation, hydrolysis, sorption, and oxidation/reduction). Attenuation is potentially a significant concern for these type of sites. EPA is recommending that investigators use OSWER Directive 9610.17: Use of Risk Based Decision-Making in UST Corrective Action Programs to evaluate these types of sites.

The J&E Model as implemented by EPA assumes homogeneous soil layers with isotropic properties that characterize the subsurface. The first tier spreadsheet versions allow only one layer; the advanced spreadsheet versions allow up to three layers. Sources of contaminants that can be modeled include dissolved, sorbed, or vapor sources where the concentrations are below the aqueous solubility limit, the soil saturation concentration, and/or the pure component vapor concentration. The contaminants are assumed to be homogeneously distributed at the source. All but one of the spreadsheets assumes an infinite source. The exception is the advanced model for a bulk soil source, which allows for a finite source. For the groundwater and bulk soil models, the vapor concentration at the source is calculated assuming equilibrium partitioning. Vapor from the source is assumed to diffuse directly upward (one-dimensional transport) through uncontaminated soil (including an uncontaminated capillary fringe if groundwater is the vapor source) to the base of a building foundation, where convection carries the vapor through cracks and openings in the foundation into the building. Both diffusive and convective transport processes are assumed to be at steady state. Neither sorption nor biodegradation is accounted for in the transport of vapor from the source to the base of the building.

The assumptions described above and in Table 12 suggest a number of conditions that preclude the use of the Non-NAPL Models as implemented by EPA. These conditions include:

TABLE 12. ASSUMPTIONS AND LIMITATIONS OF THE VAPOR INTRUSION MODEL

Assumption	Implication	Field Evaluation
Contaminant		
No contaminant free-liquid/precipitate phase present	J&E Model not representative of NAPL partitioning from source	NAPL or not at site—easier to evaluation for floating product or soil contamination sites. Most DNAPL sites with DNAPL below the water table defy easy characterization.
Contaminant is homogeneously distributed within the zone of contamination		
No contaminant sources or sinks in the building.	Indoor sources of contaminants and/or sorption of vapors on materials may confound interpretation of results.	Survey building for sources, assessment of sinks unlikely
Equilibrium partitioning at contaminant source.	Groundwater flow rates are low enough so that there are no mass transfer limitations at the source.	Not likely
Chemical or biological transformations are not significant (model will predict more intrusion)	Tendency to over predict vapor intrusion for degradable compounds	From literature
Subsurface Characteristics		
Soil is homogeneous within any horizontal plane	Stratigraphy can be described by horizontal layers (not tilted layers)	Observe pattern of layers and unconformities Note: In simplified J&E Model layering is not considered
All soil properties in any horizontal plane are homogeneous		
The top of the capillary fringe must be below the bottom of the building floor in contact with the soil.		
EPA version of JE Model assumes the capillary fringe is uncontaminated.		
Transport Mechanisms		
One-dimensional transport	Source is directly below building, stratigraphy does not influence flow direction, no effect of two- or three-dimensional flow patterns.	Observe location of source, observe stratigraphy, pipeline conduits, not likely to assess two- and three-dimensional pattern.
Two separate flow zones, one diffusive one convective.	No diffusion (dispersion) in the convective flow zone. Plug flow in convective zone	Not likely
Vapor-phase diffusion is the dominant mechanism for transporting contaminant vapors from contaminant sources located away from the foundation to the soil region near the foundation	Neglects atmospheric pressure variation effects, others?	Not likely

(continued)

Assumption	Implication	Field Evaluation
Straight-line gradient in diffusive flow zone.	Inaccuracy in flux estimate at match point between diffusive and convective sections of the model.	Not likely
Diffusion through soil moisture will be insignificant (except for compounds with very low Henry's Law Constant	Transport through air phase only. Good for volatiles. Only low volatility compounds would fail this and they are probably not the compounds of concern for vapor intrusion	From literature value of Henry's Law Constant.
Convective transport is likely to be most significant in the region very close to a basement, or a foundation, and vapor velocities decrease rapidly with increasing distance from a structure		Not likely
Vapor flow described by Darcy's law	Porous media flow assumption.	Observations of fractured rock, fractured clay, karst, macropores, preferential flow channels.
Steady State convection	Flow not affected by barometric pressure, infiltration, etc.	Not likely
Uniform convective flow near the foundation	Flow rate does not vary by location	Not likely
Uniform convective velocity through crack or porous medium	No variation within cracks and openings and constant pressure field between interior spaces and the soil surface	Not likely
Significant convective transport only occurs in the vapor phase	Movement of soil water not included in vapor impact	Not likely
All contaminant vapors originating from directly below the basement will enter the basement, unless the floor and walls are perfect vapor barriers. (Makes model over est. vapors as none can flow around the building)	Model does not allow vapors to flow around the structure and not enter the building	Not likely
Contaminant vapors enter structures primarily through cracks and openings in the walls and foundation	Flow through the wall and foundation material itself neglected	Observe numbers of cracks and openings. Assessment of contribution from construction materials themselves not likely

- The presence or suspected presence of residual or free-product non-aqueous phase liquids (LNAPL, DNAPL, fuels, solvents, etc.) in the subsurface.
- The presence of heterogeneous geologic materials (other than the three layers allowed in the advanced spreadsheets) between the vapor source and building. The J&E Model does not apply to geologic materials that are fractured, contain macropores or other preferential pathways, or are composed of karst.

- Sites where significant lateral flow of vapors occurs. These can include geologic layers that deflect contaminants from a strictly upward motion and buried pipelines or conduits that form preferential paths. Significantly different permeability contrasts between layers are likely to cause lateral flow of vapors. The model assumes the source of contaminants is directly below the potential receptors.
- Very shallow groundwater where the building foundation is wetted by the groundwater.
- Very small building air exchange rates (e.g., $< 0.25/h$)
- Buildings with crawlspace structures or other significant openings to the subsurface (e.g., earthen floors, stone buildings, etc.). The EPA spreadsheet only allows for either slab on grade or basement construction.
- Contaminated groundwater sites with large fluctuations in the water table elevation. In these cases, the capillary fringe is likely to be contaminated; whereas in the groundwater source spreadsheets, the capillary fringe is assumed to be uncontaminated.

In theory the above limitations are readily conceptualized, but in practice the presence of these limiting conditions may be difficult to verify even when extensive site characterization data are available. Conditions that are particularly difficult to verify in the field include the presence of residual non-aqueous phase liquids (NAPLs) in the unsaturated zone and the presence and influence of macropores, fractures and other preferential pathways in the subsurface. Additionally, in the initial stages of evaluation, especially at the screening level, information about building construction and water table fluctuations may not be available. Even the conceptually simple assumptions (e.g., one-dimensional flow, lack of preferential pathways) may be difficult to assess when there are little site data available.

The vapor equilibrium models employed to estimate the vapor concentration at the source of soil contamination is applicable only if "low" concentrations of the compound(s) are sorbed to organic carbon in the soil, dissolved in soil moisture, and present as vapor within the air-filled soil pores (i.e., a three-phase system). The vapor equilibrium models do not account for a residual phase NAPLs. If residual phase contaminants are present in the soil column, the user is referred to either the NAPL-SCREEN or NAPL-ADV model (Appendix A), as appropriate.

In the case of contaminated groundwater, the vapor equilibrium model operates under the assumption that the contaminant is present at levels below the water solubility limit. If the user-defined soil concentration is greater than the soil saturation concentration (C_{sat}) or if the groundwater concentration is greater than the solubility limit (S), the equilibrium vapor concentration will be calculated at the value of C_{sat} or S as appropriate.

The user is also reminded that when estimating a risk-based soil concentration, the model will compare the calculated soil concentration with the soil saturation concentration above which a residual phase is likely to occur. The soil saturation concentration (C_{sat}) is calculated as in U.S. EPA (1996a and b). If the risk-based concentration is greater than the saturation concentration and the contaminant is a liquid or gas at the soil temperature, the final soil concentration will be set equal to the soil saturation concentration. This tends to eliminate the possibility of allowing a liquid residual phase to exist within the soil column, which may leach to the water table. If the risk-based soil concentration is greater than C_{sat} and the contaminant is a solid, the contaminant is not of concern for the vapor intrusion pathway.

Likewise, the groundwater models will compare the calculated risk-based groundwater concentration to the aqueous solubility limit of the compound. If the risk-based groundwater concentration is greater than the solubility limit, the contaminant is not of concern for the vapor intrusion pathway.

Finally, it should be recognized that the procedures used to estimate both the soil saturation concentration and the aqueous solubility limit do not consider the effects of multiple contaminants. The estimated values, therefore, may be artificially high such that a residual phase may actually exist at somewhat lower concentrations.

The procedures used to estimate the soil vapor permeability of the soil stratum in contact with the building floor and walls assume isotropic soils and steady-state soil moisture content. In addition, the calculations do not account for preferential vapor pathways due to soil fractures, vegetation root pathways, or the effects of a gravel layer below the floor slab or backfill. These items may act to increase the vapor permeability of in situ soils.

If in situ pneumatic tests are used to measure site vapor permeability, care must be taken to ensure adequate sampling to reduce the possibility of missing important soil structure effects due to anisotropy.

Single-point in situ pneumatic tests are typically conducted by measuring the pressure in a probe as a metered flow of air is passed through the probe and into the soil. Garbesi et al. (1996), however, demonstrated that soil vapor permeability increases with the sampling length scale. Using a dual-probe dynamic pressure sampling apparatus, Garbesi et al. (1996) demonstrated that the average soil vapor permeability typically increases up to a constant value as the distance between the source probe and detector probe increases. On a length scale typical of a house (3 to 10 m), use of the dual-probe sampling technique found that the soil permeability was approximately 10 to 20 times higher than that measured by the single-point method. Although arguably the most accurate means of determining in situ soil vapor permeability, the techniques of Garbesi et al. (1996) are complex and require specialized equipment.

Another method for determining the intrinsic permeability of soil is to conduct empirical measurements of the saturated hydraulic conductivity (K_s). These data are then input into Equation

26. The resulting value of k_i is then multiplied by the relative air permeability (k_{rg}) calculated by Equation 27 to yield the effective air permeability of the soil.

Estimation of the rise of the capillary zone is based on the equation for the rise of a liquid in a capillary tube. The procedure assumes that the interstitial space between the soil particles is equivalent to the capillary tube diameter and that the resulting rise of water occurs under steady-state soil column drainage conditions. In actuality, the height of the capillary zone is uneven or fingered due to the variation in the actual in situ particle size distribution. In addition, the groundwater models do not account for the episodic rise and fall of the water table or the capillary zone due to aquifer recharge and discharge. As constructed, the groundwater models do not allow the top of the capillary zone to be above the bottom of the building floor in contact with the soil. The user should be aware, however, that in reality the top of the capillary zone may rise to levels above the floor in some cases.

Diffusion across the capillary zone is estimated based on lumping vapor and aqueous-phase diffusion together within the calculation of the effective diffusion coefficient. To allow for vapor-phase diffusion within the capillary zone, the air-filled soil pores must be connected. In reality, the capillary zone may be comprised of a tension-saturated zone immediately above the water table and the deep portion of the vadose zone within which the soil water content is strongly dependent on the pressure head. Diffusion across the tension-saturated zone is dominated by liquid-phase diffusion, which is typically four orders of magnitude less than vapor-phase diffusion. Therefore, a large concentration gradient may exist between the top of the water table and the top of the tension-saturated zone (McCarthy and Johnson, 1993).

Lumping vapor and aqueous-phase diffusion together is a less-intensive, although less-rigorous, method for estimating the effective diffusion coefficient. The result is typically a higher effective diffusion coefficient relative to separate solutions for aqueous diffusion across the tension-saturated zone and both vapor and aqueous diffusion across the unsaturated portion of the vadose zone.

To minimize the possible overestimation of the effective diffusion coefficient, the soil air-filled porosity within the capillary zone is estimated based on the air-entry pressure head, which corresponds with the water-filled porosity at which the interstitial air-filled pores first become connected. The user should be aware that this procedure is inherently conservative if a significant concentration gradient exists across the tension-saturated zone. This conservatism may be somewhat offset in that the model does not consider any episodic rise in the level of the water table. During such events, water that had previously been part of the saturated zone (and hence contain higher contaminant concentrations) is redistributed in the vadose zone resulting in temporary elevations in soil gas concentrations.

The model assumes that all vapors from underlying soils will enter the building through gaps and openings in the walls, floor, and foundation. This implies that a constant pressure field is generated between the interior spaces and the soil surface and that the vapors are intercepted within the pressure field and transported into the building. This assumption is inherently conservative in

that it neglects periods of near zero pressure differentials (e.g., during mild weather when windows are left open).

As with the estimation procedure for soil vapor permeability, the model assumes isotropic soils in the horizontal direction; vertical anisotropy is accounted for by a series of isotropic soil strata above the top of contamination. Soil properties within the zone of soil contamination are assumed to be identical to those of the soil stratum directly above the contamination and extend downward to an infinite depth. Solute transports by convection (e.g., water infiltration) and by mechanical dispersion are neglected. Transformation processes (e.g., biodegradation, hydrolysis, etc.) are also neglected.

The J&E Model treats the entire building as a single chamber with instantaneous and homogeneous vapor dispersion. It therefore neglects contaminant sinks and the room-to-room variation in vapor concentration due to unbalanced mechanical and/or natural ventilation.

5.1 SOURCE VAPOR CONCENTRATION

As applied in the accompanying spreadsheets, the vapor equilibrium model employed to estimate the vapor concentration at the source of soil contamination is applicable in the limit of "low" concentrations where compounds are sorbed to organic carbon in the soil, dissolved in soil moisture, and present as vapor within the air-filled soil pores (i.e., a three-phase system). The model does not account for a residual phase (e.g., NAPL). If residual phase contaminants are present in the soil column, the user is referred to either the NAPL-SCREEN or NAPL-ADV model, as appropriate.

In the case of contaminated groundwater, the vapor equilibrium model operates under the assumption that the contaminant is present at levels below the water solubility limit. If the user-defined soil concentration is greater than the soil saturation concentration (C_{sat}) or if the groundwater concentration is greater than the solubility limit (S), the equilibrium vapor concentration will be calculated at the value of C_{sat} or S as appropriate.

The user is also reminded that when estimating a risk-based soil concentration, the model will compare the calculated soil concentration with the soil saturation concentration above which a residual phase is likely to occur. The soil saturation concentration (C_{sat}) is calculated as in U.S. EPA (1996a and b). If the risk-based concentration is greater than the saturation concentration and the contaminant is a liquid or gas at the soil temperature, the final soil concentration will be set equal to the soil saturation concentration. This tends to eliminate the possibility of allowing a liquid residual phase to exist within the soil column, which may leach to the water table. If the risk-based soil concentration is greater than C_{sat} and the contaminant is a solid, the contaminant is not of concern for the vapor intrusion pathway.

Likewise, the groundwater models will compare the calculated risk-based groundwater concentration to the aqueous solubility limit of the compound. If the risk-based groundwater

concentration is greater than the solubility limit, the contaminant is not of concern for the vapor intrusion pathway.

Finally, it should be recognized that the procedures used to estimate both the soil saturation concentration and the aqueous solubility limit do not consider the effects of multiple contaminants. The estimated values, therefore, may be artificially high such that a residual phase may actually exist at somewhat lower concentrations.

5.2 SOIL VAPOR PERMEABILITY

The procedures used to estimate the soil vapor permeability of the soil stratum in contact with the building floor and walls assumes isotropic soils and steady-state soil moisture content. In addition, the calculations do not account for preferential vapor pathways due to soil fractures, vegetation root pathways, or the effects of a gravel layer below the floor slab or backfill which may act to increase the vapor permeability with respect to in situ soils.

If in situ pneumatic tests are used to measure site vapor permeability, care must be taken to ensure adequate sampling to reduce the possibility of missing important soil structure effects due to anisotropy.

Single point in situ pneumatic tests are typically conducted by measuring the pressure in a probe as a metered flow of air is passed through the probe and into the soil. Garbesi et al. (1996), however, demonstrated that soil vapor permeability increases with the sampling length scale. Using a dual-probe dynamic pressure sampling apparatus, Garbesi et al. (1996) demonstrated that the average soil vapor permeability typically increases up to a constant value as the distance between the source probe and detector probe increases. On a length scale typical of a house (3 to 10 m) use of the dual-probe sampling technique found that the soil permeability was approximately 10 to 20 times higher than that measured by the single point method. Although arguably the most accurate means of determining in situ soil vapor permeability, the techniques of Garbesi et al. (1996) are complex and require specialized equipment.

Another method for determining the intrinsic permeability of soil is to conduct empirical measurements of the saturated hydraulic conductivity (K_s). These data are then input into Equation 26. The resulting value of k_i is then multiplied by the relative air permeability (k_{rg}) calculated by Equation 27 to yield the effective air permeability of the soil.

5.3 RISE OF AND DIFFUSION ACROSS THE CAPILLARY ZONE

Estimation of the rise of the capillary zone is based on the equation for the rise of a liquid in a capillary tube. The procedure assumes that the interstitial space between the soil particles is equivalent to the capillary tube diameter and that the resulting rise of water occurs under steady-state soil column drainage conditions. In actuality, the height of the capillary zone is uneven or fingered due to the variation in the actual in situ particle size distribution. In addition, the groundwater

models do not account for the episodic rise and fall of the water table or the capillary zone due to aquifer recharge and discharge. As constructed, the groundwater models do not allow the top of the capillary zone to be above the bottom of the building floor in contact with the soil. The user should be aware, however, that in reality the top of the capillary zone might rise to levels above the floor in some cases.

Diffusion across the capillary zone is estimated based on lumping vapor and aqueous-phase diffusion together within the calculation of the effective diffusion coefficient. To allow for vapor-phase diffusion within the capillary zone, the air-filled soil pores must be connected. In reality, the capillary zone may be comprised of a tension-saturated zone immediately above the water table and the deep portion of the vadose zone within which the soil water content is a strongly dependent on the pressure head. Diffusion across the tension-saturated zone is dominated by liquid-phase diffusion which is typically four orders of magnitude less than vapor-phase diffusion. Therefore, a large concentration gradient may exist between the top of the water table and the top of the tension-saturated zone (McCarthy and Johnson, 1993).

Lumping vapor and aqueous-phase diffusion together is a less intensive, although less rigorous, method for estimating the effective diffusion coefficient. The result is typically a higher effective diffusion coefficient relative to separate solutions for aqueous diffusion across the tension-saturated zone and both vapor and aqueous diffusion across the unsaturated portion of the vadose zone.

To minimize the possible over estimation of the effective diffusion coefficient, the soil air-filled porosity within the capillary zone is estimated based on the air-entry pressure head, which corresponds with the water-filled porosity at which the interstitial air-filled pores first become connected. The user should be aware that this procedure is inherently conservative if a significant concentration gradient exists across the tension-saturated zone. This conservatism may be somewhat offset in that the model does not consider any episodic rise in the level of the water table. During such events, water which had previously been part of the saturated zone (and hence contain higher contaminant concentrations) is redistributed in the vadose zone resulting in temporary elevations in soil gas concentrations.

5.4 DIFFUSIVE AND CONVECTIVE TRANSPORT INTO THE STRUCTURE

The following is a discussion of the major assumptions and limitations of the J&E Model for diffusive and convective vapor transport into buildings.

The model assumes that all vapors from underlying soils will enter the building through gaps and openings in the walls, floor, and foundation. This implies that a constant pressure field is generated between the interior spaces and the soil surface and that the vapors are intercepted within the pressure field and transported into the building. This assumption is inherently conservative in that it neglects periods of near zero pressure differentials (e.g., during mild weather when windows are left open).

As with the estimation procedure for soil vapor permeability, the model assumes isotropic soils in the horizontal direction; vertical anisotropy is accounted for by a series of isotropic soil strata above the top of contamination. Soil properties within the zone of soil contamination are assumed to be identical to those of the soil stratum directly above the contamination and extend downward to an infinite depth. Solute transports by convection (e.g., water infiltration) and by mechanical dispersion are neglected. Transformation processes (e.g., biodegradation, hydrolysis, etc.) are also neglected.

An empirical field study (Fitzpatrick and Fitzgerald, 1997) indicated that the model may be overly conservative for nonchlorinated species (e.g., benzene, toluene, ethylbenzene and xylene) but in some cases, may underpredict indoor concentrations for chlorinated species. The authors contribute the likely cause for this discrepancy to the significant biodegradation of the nonchlorinated compounds.

The J&E Model treats the entire building as a single chamber with instantaneous and homogeneous vapor dispersion. It therefore neglects contaminant sinks and the room-to-room variation in vapor concentration due to unbalanced mechanical and/or natural ventilation.

Finally, convective vapor flow from the soil matrix into the building is represented as an idealized cylinder buried below grade. This cylinder represents the total area of the structure below the soil surface (walls and floor). The total crack or gap area is assumed to be a fixed fraction of this area. Because of the presence of basement walls, the actual vapor entry rate is expected to be 50 to 100 percent of that provided by the idealized geometry (Johnson and Ettinger, 1991).

SECTION 6

INTERPRETATION OF RESULTS

The models described herein are theoretical approximations of complex physical and chemical processes and as such should not be used in a deterministic fashion (i.e., to generate a single outcome). At the least, a range of outcomes should be explored focusing on the most sensitive model input variables. In general, using the default values for input variables will result in higher indoor air concentrations and thus higher incremental risks or lower risk-based media concentrations. With a realistic range of outcomes, the risk manager may assess the uncertainty in the model predictions.

From a conceptual point of view, the vapor intrusion model provides a theoretical description of the processes involved in vapor intrusion from subsurface soils or groundwater into indoor structures. A combination of modeling and sampling methods is also possible to reduce the uncertainty of the calculated indoor air concentrations. Typically this involves field methods for measuring soil gas very near or below an actual structure. It should be understood, however, that soil gas sampling results outside the footprint of the building may or may not be representative of the soil gas concentrations directly below the structure. For solid building floors in contact with the soil (e.g., concrete slabs), the soil gas directly beneath the floor may be considerably higher than that adjacent to the structure. This is typically due to a vapor pooling effect underneath the near impermeable floor. Once a representative average concentration is determined, all vapor directly below the areal extent of the building is presumed to enter the structure. The soil gas concentration, along with the building ventilation rate and the soil gas flow rate into the building, will determine the indoor concentration. When using the soil gas models, it must be remembered that no analysis has been made concerning the source of contamination. Therefore, the calculated indoor concentration is assumed to be steady-state. The procedures described in API (1998) can be used to calibrate the diffusion transport considerations of the J&E Model as well as for calibrating the Model for transformation processes (e.g., biodegradation). The reader is also referred to U.S. EPA (1992) for a more detailed discussion of applying soil gas measurements to indoor vapor intrusion.

Finally, calibration and verification of the model have been limited due to the paucity of suitable data. Research is needed to provide spatially and temporally correlated measurements during different seasons, at different locations, with different buildings, and over a range of different contaminants such that the accuracy of the model may be determined. Appendix E contains bibliography and references.

Evaluation of the Johnson and Ettinger Model for Prediction of Indoor Air Quality

by Ian Hers, Reidar Zapf-Gilje, Paul C. Johnson, and Loretta Li

Abstract

Screening level models are now commonly used to estimate vapor intrusion for subsurface volatile organic compounds (VOCs). Significant uncertainty is associated with processes and models and, to date, there has been only limited field-based evaluation of models for this pathway. To address these limitations, a comprehensive evaluation of the Johnson and Ettinger (J&E) model is provided through sensitivity analysis, comparisons of model-predicted to measured vapor intrusion for 11 petroleum hydrocarbon and chlorinated solvent sites, and review of radon and flux chamber studies. Significant intrusion was measured at five of 12 sites with measured vapor attenuation ratios (α_m 's) (indoor air/source vapor) ranging from $\sim 1 \times 10^{-6}$ to 1×10^{-4} . Higher attenuation ratios were measured for studies using radon, inert tracers, and flux chambers; however, these ratios are conservative owing to boundary conditions and tracer properties that are different than those at most VOC-contaminated sites. Reasonable predictions were obtained using the J&E model with comparisons indicating that model-predicted vapor attenuation ratios (α_p 's) were on the same order, or less than the α_m 's. For several sites, the α_m were approximately two orders of magnitude less than the α_p 's indicating that the J&E model is conservative in these cases. The model comparisons highlight the importance in using appropriate input parameters for the J&E model. The regulatory implications associated with use of the J&E model to derive screening criteria are also discussed.

Introduction

The use of models to predict indoor air quality associated with volatile organic compound (VOC) contamination in soil and ground water is now commonplace (ASTM 1995; Johnson et al. 1998, Hers et al. 2002). Screening models typically used for this pathway are the Johnson and Ettinger (1991) model (henceforth referred to as the J&E model), or variants thereof. Processes controlling the intrusion of VOC vapors into buildings are not well understood, the accuracy of the J&E model is uncertain, and there have been only limited comparisons of model predictions to field data. There are also substantial differences in the way in which the J&E model is used for regulatory purposes.

To address these limitations, this paper presents a comprehensive evaluation of the J&E model based on theoretical considerations and field data from petroleum hydrocarbon and chlorinated solvent sites, and radon and flux chamber studies. Data sources are published studies, consultant or agency reports, and a field-based research program conducted by the authors. Included in the data sets analyzed are several recent groundbreaking investigations at chlorinated solvent sites.

The paper begins with an analysis of methods for estimating input parameters for the J&E model and their effect on model sensitivity and uncertainty. This analysis provides the needed context for the methods employed to interpret the field data used for this study. It is also important because it is

essential that model attributes and potential limitations be understood before using field data to evaluate the predictive capabilities of a model. Field-based methods for the evaluation of vapor attenuation ratio (α), defined as the indoor air concentration divided by the source vapor concentration, are evaluated next. The primary focus is measured vapor attenuation ratios (α_m) from 11 sites with petroleum hydrocarbon and chlorinated solvent contamination. Information from tracer studies using radon or an injected tracer such as sulphur hexafluoride (SF_6), and flux chamber studies are also reviewed. The measured α_m from field studies are compared to model-predicted vapor attenuation ratios (α_p) using the J&E model. Trends in the data are qualitatively evaluated and possible factors affecting vapor intrusion are considered. The paper also comments on the use of the J&E model to derive regulatory screening criteria.

J&E Model Input Parameters, Sensitivity, and Uncertainty

The basic form of the J&E model couples one-dimensional steady-state diffusion through soil, and diffusion and advection through a building envelope (i.e., foundation). A simple "box" model, which assumes uniform and instantaneous mixing of chemicals within the building enclosure, is used to estimate the indoor air concentration. Model sensitivity and uncertainty analysis and input needed for comparisons of

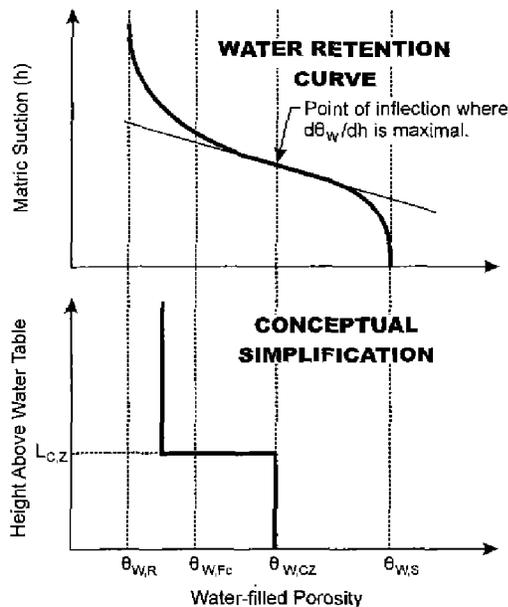


Figure 1. Conceptual simplification of water retention curve for purposes of estimating moisture contents and capillary rise ($\theta_{w,r}$, $\theta_{w,fc}$, $\theta_{w,cz}$, $\theta_{w,s}$ are the residual, field capacity, capillary zone, and saturated water contents).

model predictions to field data all require estimation of effective diffusion coefficient and soil gas advection rate. Because the available data varied, different methods were used to estimate these input parameters and interpret field data. The estimation methods subsequently used in this paper are discussed in the following sections.

Estimation of Effective Diffusion Coefficient (Air-Filled and Total Porosity)

The J&E model uses the Millington and Quirk (1961) relationship to estimate the effective diffusion coefficient (D_T^{eff}), as follows:

$$D_T^{eff} = (\theta_a^{10/3} / \theta^2) * D_{air} + 1/H^2 * (\theta_w^{10/3} / \theta^2) * D_{water}$$

where θ_a , θ_w , and θ are the air-filled, water-filled, and total porosity; D_{air} and D_{water} are free-air and free-water diffusion coefficients (L^2T^{-1}); and H^2 is the dimensionless Henry's law constant.

A common method for estimating air-filled and total porosity directly uses the measured soil moisture content and bulk density. A potential disadvantage is that soil disturbance during sampling can lead to inaccurate moisture, density, and hence, porosity estimates. Samples obtained adjacent to buildings may not be representative of conditions below buildings owing to the drying of soil that can occur.

A second method involves the use of the van Genuchten (VG) model (van Genuchten 1980) to predict the water retention parameters for U.S. Soil Conservation Service (SCS) soil types, based on VG model curve-fit parameters computed by Schaap and Leij (1998) (Simplified VG method). This method, developed by Environmental Quality Management Inc. (EQM 2000), is incorporated in U.S. EPA guidance for this

pathway. The VG model parameters are, in turn, used to develop a simplified step function for water-filled porosity (Figure 1). The capillary zone ($\theta_{w,cz}$) water-filled porosity is equal to the moisture content at the inflection point in the water retention curve where $d\theta_w/dh$ is maximal, as suggested by Waitz et al. (1996) (where θ_w and h equal the water-filled porosity and matric suction, respectively). Vapor-phase diffusion becomes negligible once the water-filled porosity exceeds the $\theta_{w,cz}$. The height of the capillary zone is estimated using an equation for capillary rise in a tube (Fetter 1994), and mean particle size for the SCS soil textural classifications (Nielson and Rogers 1990). The water-filled porosity above the capillary zone is user defined; we suggest a practical range below a building is between the residual water content and field capacity.

The simplified VG model likely predicts lower than actual water-filled porosity in soil, for the capillary transition zone (Figure 1). Because diffusion rates are much higher in air than water, this simplification likely results in conservative (high) diffusion estimates through the capillary transition zone. However, this conservatism may be counterbalanced by nonrepresentative assumptions for the ground water contamination source. The common paradigm for prediction of cross-media VOC transport is that dissolved chemicals are present below a static water table, and that transport through the capillary transition zone is limited to vapor- and aqueous-phase diffusion. In reality, there will be some lateral ground water flow and dispersive mixing of chemicals in the tension-saturated zone, and vertical movement of chemicals as a result of water-table fluctuations. There is limited information on VOC migration in the capillary transition zone. One study, involving a large chamber, showed that the pore-water concentrations in the tension-saturated zone were similar to those below the water table, and showed a sharp decline in concentrations near the top of the tension-saturated zone (McCarthy and Johnson 1993). The implication is that a more representative top boundary for dissolved ground water contaminants may be some distance above the water table.

Estimation of Soil Gas Advection Rate (Q_{soil})

The method often used with the J&E model for estimating the soil gas advection rate (Q_{soil}) through the building envelope is an analytical solution for two-dimensional soil gas flow to a small horizontal drain (Nazaroff 1992). This model is used to simulate gas flow to an edge crack located at the perimeter of a building (perimeter crack model). The Q_{soil} (L^3T^{-1}) is estimated as follows:

$$Q_{soil} = \frac{2 \pi k_a \Delta P X_{crack}}{\mu \ln \left(\frac{2 z_{crack}}{r_{crack}} \right)} \quad (2)$$

where k_a is the soil-air permeability (L^2), ΔP is the pressure difference between the building and ambient air, X_{crack} is the perimeter crack length (L), μ is the gas viscosity ($ML^{-1}T^{-1}$), z_{crack} is the depth to edge crack (L), and r_{crack} is the crack radius (L). The ratio of cracks to total subsurface foundation area (i.e., base and walls) (η) can be expressed as

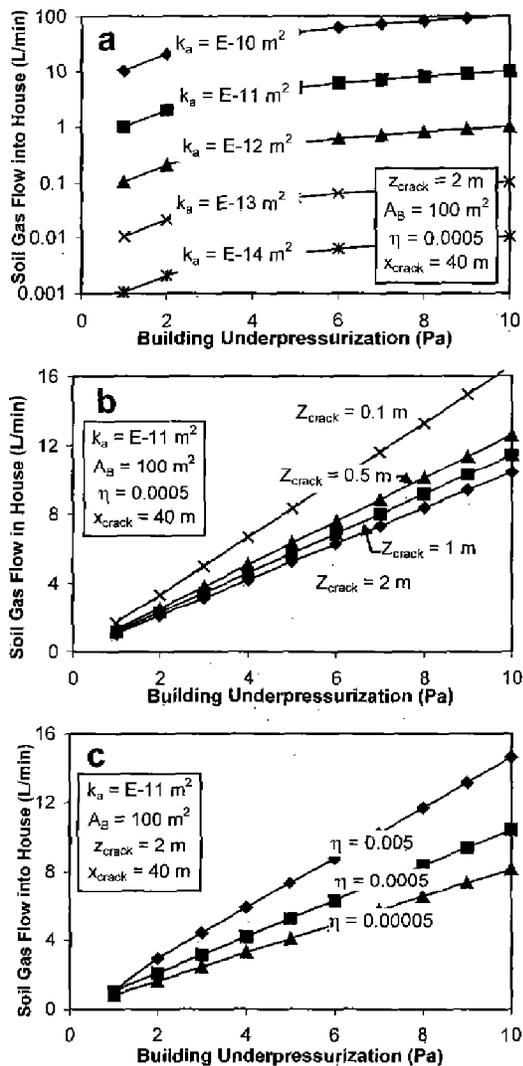


Figure 2. Sensitivity of soil gas flow to perimeter crack model (used in J&E model) to (a) soil-air permeability (k_a), (b) depth to perimeter crack (z_{crack}), and (c) crack ratio (η). X_{crack} = perimeter crack length, A_B = subsurface foundation area.

$$\eta = \frac{r_{crack} X_{crack}}{A_B} \quad (3)$$

where A_B is the subsurface foundation area (L^2). The perimeter crack model accounts for both soil gas flow through soil and the foundation, but is most sensitive to the soil-air permeability based on the analysis presented in Figure 2. For the range of values chosen for k_a , η , ΔP , and z_{crack} , by far the greatest variation is obtained for k_a with the predicted Q_{soil} ranging between ~ 0.001 and 100 L/min.

One method of estimating soil-air permeability is to use published values for saturated hydraulic conductivity and water retention parameters for a particular soil type (EQM 2000). This method involves the following steps: (1) obtain saturated hydraulic conductivity for soil texture type (Schaap and Leij 1998); (2) estimate intrinsic permeability from saturated hydraulic conductivity; (3) estimate effective total fluid saturation at field capacity;

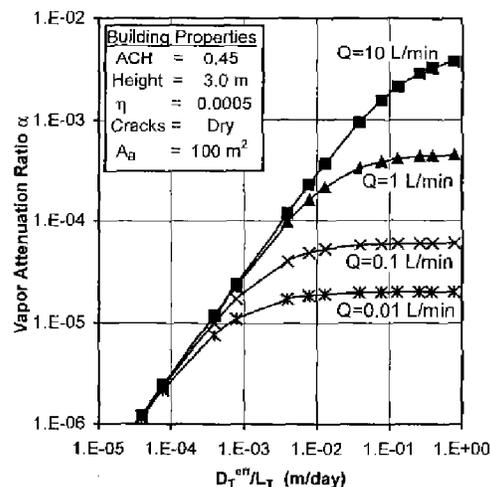


Figure 3. Sensitivity of vapor attenuation ratio (benzene) to soil-gas flow rate (Q) into building using perimeter crack model with dry dust-filled concrete cracks with total porosity = 0.3 Height = building height, $Q = Q_{soil}$, ACH = air exchanges per hour (other symbols previously defined).

(4) estimate relative air permeability using the relationship proposed by Parker et al. (1987); and (5) calculate effective soil-air permeability (relative air permeability multiplied by intrinsic permeability). The soil-air permeability can also be measured in the field (Garbesi and Sextro 1995; Hers and Zapf-Gilje 1998); however, this type of testing is rarely performed.

The Q_{soil} can also be estimated from a tracer test mass balance. When soil-gas advection is the primary mechanism for tracer intrusion into a building, the Q_{soil} can be estimated by measuring the concentrations of a chemical tracer in indoor air, outdoor air, and in soil vapor below a building, and measuring the building ventilation rate (Hers et al. 2002; Fischer et al. 1996; Garbesi et al. 1993; Rezvan et al. 1991; Garbesi and Sextro, 1989). The Q_{soil} values measured using this technique are compared to predicted rates using the perimeter crack model, for sites with coarse-grained soils (Table 1). The perimeter crack model predictions are both higher and lower than the measured values, but overall are within one order of magnitude of the measured values. Although the Q_{soil} predicted by models and measured using field tracer tests are uncertain, the results suggest that a "typical" range for houses on coarse-grained soils is on the order of 1 to 10 L/min.

J&E Model Sensitivity for Key Input Parameters

The sensitivity of the benzene α_p predicted by the J&E model is evaluated as a function of soil gas flow (Q_{soil}), the effective diffusion coefficient (D_T^{eff}), and contamination depth (L_T) (Figure 3). The D_T^{eff}/L_T ratio captures the influence of soil properties and depth to contamination source on α_p . For BTEX and most chlorinated solvent compounds, chemical-specific variation in the D_T^{eff}/L_T ratio is not significant because the free-air diffusion coefficients vary by only a factor of two, and the Henry's law constants vary by a factor of 10 (D_T^{eff}/L_T is less sensitive to H' than D_{air}). Because the effective diffusion coefficient is calculated using the Millington and Quirk (1961) relationship, the soil properties of relevance are the air-filled and total porosity. A high D_T^{eff}/L_T ratio is asso-

Table 1
Comparison of Measured and Model-Predicted Soil Gas Flow Rates Into Buildings

Site	Foundation Type	ΔP (Pa)	Subsurface Foundation Area (m ²)	Crack Ratio η	Depth to Perimeter Crack (m)	$k_{\text{soil-air}}$ (Darcy)	Soil Gas Flow Rates	
							Measured	Predicted
							Tracer (L/min)	PCM (L/min)
Chatterton Site (Hers et al. 2000)	Slab-on-grade	30	57	0.00033	0.3	10	2.7	29
	Slab-on-grade	10	57	0.00033	0.3	10	4.2	9.6
	Slab-on-grade	10	57	0.0001	0.3	10	2.9	8.2
Alameda Site Fischer et al. (1996)	Slab-on-grade	3	50	0.0001	0.2	10	1.4	2.4
Central California Site Garbese & Sextro (1989)	Filled hollow block basement w/coating	30	128	0.0001	2.5	3	67	8.3
Ben Lomond Garbesi et al. (1993)	Experimental basement	10	26	0.00075	1.8	6	9.7	2.3
Spokane Valley Houses Revzan et al. (1991)	Poured concrete basements	5	220	0.0001	2	200	102	110

Notes: Bold print values assumed, all other values measured, ΔP = building underpressurization, PCM = Perimeter Crack model.

Table 2
Qualitative Summary of Sensitive Parameters for the J&E Model

	Building Depressurized (Advection and Diffusion)	Building Not Depressurized (Diffusion Only)
High D_T^{eff}/L_T (shallow and/or dry soil)	Q_{soil} (advection controlled)	Building foundation cracks
Moderate D_T^{eff}/L_T	Q_{soil} and moisture content (MC)	Building foundation cracks and MC
Low D_T^{eff}/L_T (deep and/or wet soil)	Moisture content (diffusion controlled)	Moisture content (MC)

Note: Indoor air concentrations are directly proportional to source concentrations, building mixing height and ventilation rate.

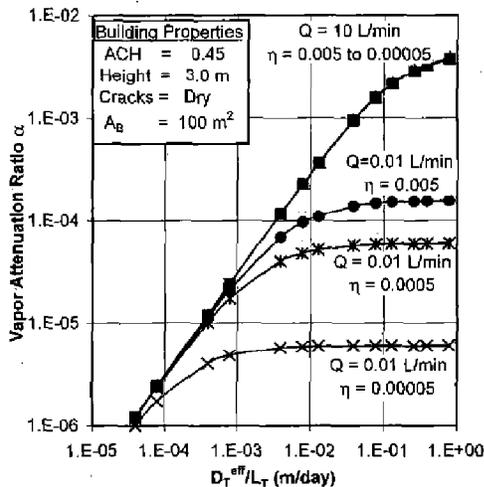


Figure 4. Sensitivity of vapor attenuation ratio (benzene) to soil-gas flow rate (Q) using perimeter crack model and foundation crack ratio (η) (other symbols previously defined).

ciated with dry soils and/or shallow contamination, whereas a low D_T^{eff}/L_T ratio is associated with wet soils and/or deep contamination. Based on the analysis in the sections that follow, sensitive parameters for the J&E model are also qualitatively summarized in Table 2.

Sensitivity of α_p to Q_{soil}

For sensitivity analysis purposes, a Q_{soil} range of 0.01 to 10 L/min was chosen because it is considered representative of most houses or small buildings. The results indicate that Q_{soil} begins to have a significant influence on α_p when D_T^{eff}/L_T values are moderate to relatively large (>0.001 m/day) (Figure 3). The J&E model is described to be advection controlled for this scenario. When D_T^{eff}/L_T is relatively small (<0.001 m/day), α_p is not sensitive to Q_{soil} . The J&E model is described to be diffusion controlled for this scenario. The D_T^{eff}/L_T for case studies subsequently evaluated in this paper ranged from ~ 0.002 to 0.1 m/day. For these D_T^{eff}/L_T values, the maximum error in prediction caused by a four order of magnitude variation in Q_{soil} ranges from 3X to 100X.

Sensitivity of α_p to Crack Ratio

The influence of crack ratio (η) on α_p was evaluated for two different Q_{soil} values (Figure 4). For $Q_{\text{soil}} = 10$ L/min, α_p is not sensitive to η . When $Q_{\text{soil}} = 0.01$ L/min, a two order of magnitude change in η causes up to 25X change in α_p . The sensitivity of α_p to η increases as Q_{soil} decreases, with sensitivity highest for the diffusion-only case (i.e., $Q_{\text{soil}} = 0$). The crack ratio is of little importance for smaller D_T^{eff}/L_T or $Q_{\text{soil}} > 1$ L/min, which means that for the majority of sites crack ratio will not be important.

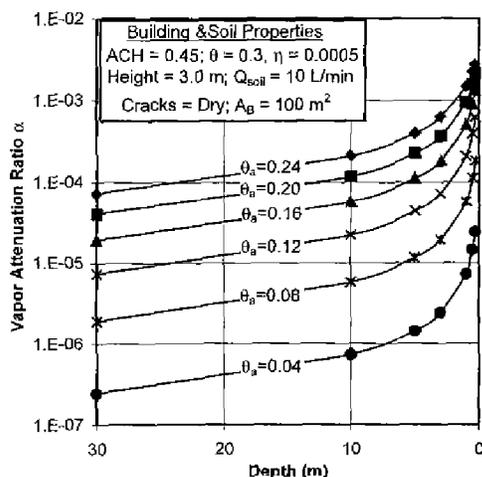


Figure 5. Sensitivity of vapor attenuation ratio (benzene) to water-filled porosity (θ_a). Other symbols previously defined.

Sensitivity of α_p to Air-Filled Porosity (Moisture Content)

The effect of air-filled porosity and depth to contamination was evaluated for a soil with moisture contents ranging from 3.6% to 15.6% (dry weight) and a constant total porosity of 0.3 (Figure 5). This variation in moisture content is potentially representative of the difference between a dry soil below a building compared to a wet soil within the capillary transition zone. The corresponding air-filled porosities are between 0.04 and 0.26. A Q_{soil} value of 10 L/min was assumed. For a constant depth to contamination, a 4X change in moisture content causes approximately or more than two orders of magnitude change in α_p . For a constant moisture content, α_p becomes sensitive to depth to contamination, at shallow depths. It is clear that soil layers with high moisture content will have a significant effect on the diffusive flux and vapor intrusion.

J&E Model Uncertainty for Range of Values

Vapor attenuation ratios predicted by the J&E model are provided for a range of soil gas advection rates and building properties, as a function of D_T^{eff}/L_T (Figure 6). For illustrative purposes, upper and lower soil-gas advection rates were estimated for four U.S. SCS soil textures (sand, loamy sand, sandy loam, and silt) using published values for saturated hydraulic conductivity and the perimeter crack model. The soil type only applies to soil immediately adjacent to the building, because the radius-of-influence for soil-gas advection is relatively limited. The estimated Q_{soil} values are highly uncertain; however, we note that the predicted values for sand (1 to 10 L/min) are consistent with the results of tracer tests for coarse-grained soils. The uncertainty in Q_{soil} increases for finer-grained soils because the influence of permeable soil layers and preferential pathways (e.g., utility back-fill) becomes more important. It is suggested that the Q_{soil} for sand be used when near the foundation soil is not well characterized.

The building properties input to the model are the crack ratio, dust-filled crack moisture content, building height, building air exchanges, and building foundation size. The upper and lower building properties given are subjectively considered to represent the range of values that would be encountered at most

sites, based on available information and the author's experience (Hers and Zapf-Gilje 1998; Hers et al. 2001). The subsurface foundation area is for a house with a shallow basement or slab-on-grade foundation. Slightly lower α_p 's would be predicted for a deep basement with larger foundation area.

The graphs in Figure 6 illustrate the effect of variation in Q_{soil} and building properties on vapor attenuation ratio, but do not address uncertainty in D_T^{eff}/L_T , which is primarily caused by soil moisture content. To gain insight into uncertainty in model predictions owing to moisture content, a possible range in D_T^{eff}/L_T was evaluated for two hypothetical scenarios. The first scenario (Site 1) assumes a shallow soil vapor source (1.5 m depth) situated well above the water table. The second scenario (Site 2) assumes a relatively deep water table (6 m depth) and contamination that is limited to a dissolved ground water plume. Both sites were assumed to have uniform SCS loamy sand soil. The approach taken was to first obtain a plausible best estimate, and upper and lower range for D_T^{eff}/L_T . For Site 1, a constant air-filled porosity halfway between the residual water content and field capacity was assumed. For Site 2, the simplified VG method was used to estimate the air-filled and total porosity for the capillary zone. As shown in Table 3, the resulting porosities are expressed as relative water saturation values where $S = \theta_w/\theta$ and $\theta_a = \theta(1-S)$. The reason for using relative saturation values in the uncertainty analysis is that the air-filled and total porosity are expected to be strongly correlated. Therefore, uncertainty would be overestimated if these parameters are allowed to vary independently. This is prevented through the use of the relative saturation values. The uncertainty ranges given for total porosity and relative saturation are considered reasonable values for a well-characterized site.

Using the best estimate values and uncertainty ranges, the best estimate, lower and upper ranges are provided for the normalized effective diffusion coefficient (D_T^{eff}/L_T) (Table 3 and Figure 6). For Site 1, the upper and lower D_T^{eff}/L_T values vary by a factor of 2.4. For Site 2, the uncertainty is greater (factor of 23) because the sensitivity of D_T^{eff}/L_T to air-filled porosity within the capillary zone is high because moisture content is also high.

The overall uncertainty in the vapor attenuation ratio will be dependent on the available data. If there is information only on the contamination depth, the range in α_p can vary three to four orders of magnitude. When information on soil properties is also available, the uncertainty in D_T^{eff}/L_T and Q_{soil} is reduced resulting in α_p that vary over two orders of magnitude (Figure 6). When good quality site-specific data is available for both soil properties (e.g., moisture content) and building properties (e.g., ventilation rate, mixing height), it may be possible to reduce the uncertainty in α_p to approximately one order of magnitude.

Field-Based Methods for Evaluation of Vapor Intrusion

Three field-based approaches or methods are used to evaluate vapor intrusion: the indoor VOC method, the tracer method, and the flux chamber method. The *indoor VOC method* involves measurement of VOC concentrations in indoor air and at the contamination source. The α_m will vary depending on the contamination scenario. For sites with dissolved ground water plumes, the α_m is calculated using a

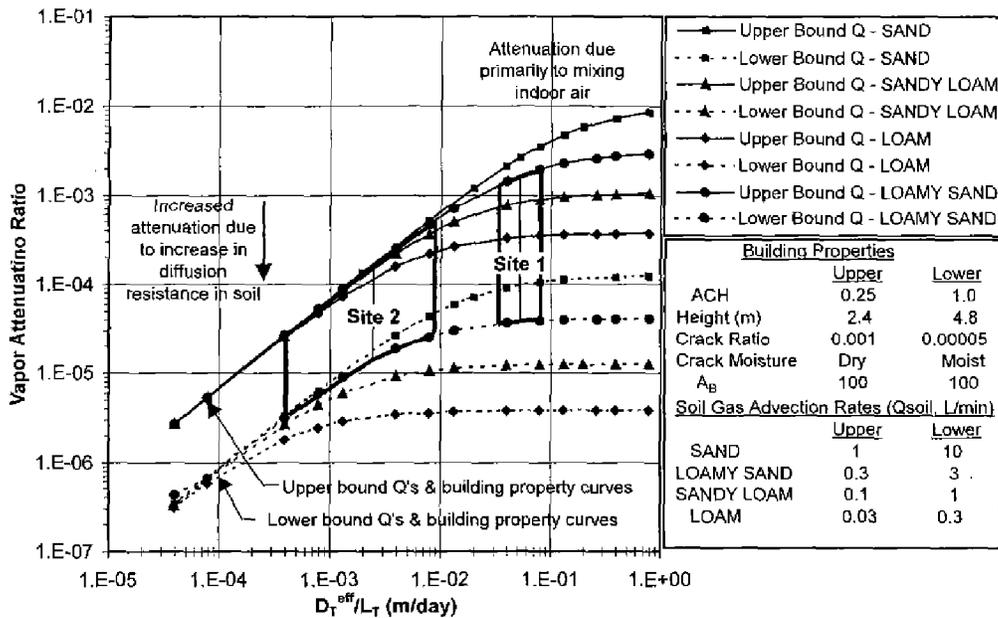


Figure 6. Predicted vapor attenuation ratio (benzene) for vapor concentrations at source and indoor air using Johnson and Ettinger (1991) model. Figure adapted from Johnson et al. (1998). Dry dust-filled cracks: Total porosity = 0.3; moist dust-filled cracks: water-filled porosity = 0.1, and total porosity = 0.3.

Parameters	Best Estimate Values		Uncertainty
	Site 1	Site 2	
Input Parameters			
Contamination	Above WT	Dissolved in Gdw	N/A
Contamination depth (m)	1.5	6.0	constant
U.S. SCS soil classification	Sandy Loam	Sandy Loam	N/A
Total porosity (θ)	0.390	0.390	+/- 10%
$S_R (\theta_w/\theta)$ above CZ (S)	0.265	0.265	+/- 25%
Height of CZ (L_{CZ}) (m)	N/A	0.250	+/- 25%
$S_R (\theta_w/\theta)$ in CZ (S_{CZ})	N/A	0.821	+12/-10%
Calculated Values			
D_T^{eff}/L_T lower est. (m/day)	0.0325	0.00038	
D_T^{eff}/L_T best est. (m/day)	0.0512	0.00248	
D_T^{eff}/L_T lowest est. (m/day)	0.0775	0.00861	
D_T^{eff}/L_T upper/lower range	2.4	23	

Notes: CZ = capillary zone, S_R = relative saturation, Gdw = Ground water, WT = water table.

predicted source vapor concentration (i.e., directly above the water table) estimated using the Henry's law constant assuming equilibrium partitioning between the dissolved and vapor phases. When measured source vapor concentrations are available, the α can be directly calculated. Because some deviation from equilibrium conditions would be expected, the α_m estimated using ground water and soil vapor data are not directly comparable. A key challenge for this approach is that there are numerous other "background" sources of VOCs in indoor and outdoor air for most chemicals of concern at contaminated

sites (Hers et al. 2001). The intrusion of soil vapor into buildings is also highly dependent on site-specific conditions and may vary over time. These factors complicate the interpretation of indoor air measurements when the goal is to deduce the subsurface-derived component.

The *tracer method* involves measurement of the indoor air concentration of a tracer injected below ground (SE_g), or a natural tracer such as radon (Fisher et al. 1996; Garbesi et al. 1993). The measured vapor intrusion for the tracer is, in turn, used to infer intrusion for the VOC of interest. Key factors affecting this approach are that boundary conditions for a tracer injected below a building may be different than those for the VOC of interest (e.g., if contamination is relatively deep) and that typically, an essentially inert tracer is used. When compared to the tracer, the mass loss or attenuation through sorption and/or biodegradation will be greater for most VOCs of interest. For these reasons, the tracer method will typically provide a conservative estimate of intrusion.

The *flux chamber* method involves measurement of soil-gas flow and/or VOC flux through cracks or openings in a building foundation. There are only a few published reports documenting the use of flux chambers to measure VOC flux into buildings (Figley and Snodgrass 1992; Hers and Zapf-Gilje 1998). Challenges for this approach are that these tests are difficult and costly to perform, and the uncertainty associated with "scaling up" the results for a small crack to an entire building.

Results and Discussion of Field Studies and Model Predictions

Indoor VOC Method

Vapor attenuation ratios are evaluated for 11 sites. The sites represent studies available to the authors with reasonable quality field data, and are for residential houses, ground-floor

Table 4
Measured and Model-Predicted Vapour Attenuation Ratios

Site & Reference	Contaminant or Tracer	Building and Foundation Type	Soil Conditions	Depth (m) ¹	Chemical	Source Concentration (ug/L)	N Indoor Air ²	α_m Stat	Measured α_m	J&E model α_p^3	Comments
Indoor VOC Method											
"Virginia (Motiva) Site", Fan and Quinn (2000)	petroleum HC, NAPL above water	SFR, basements, attached garages, cement block foundations	claystone saprolite k ~ 0.01 darcy	0.5	benzene	V: 410	13	50th	<8.3E-6	3.70E-06	
"Chatterton Site" Delta, B.C. Canada	BTX	research greenhouse	surface silt to f. sand, underlain by	1.4	benzene	V: 15,000	3-4	Avg	<5.3E-7	1.3E-05	C1: $\Delta P = 0$ Pa, $\eta = 3.3E-4$
Hers et al. (1998)	petro-chemical plant	slab-on-grade poured concrete	m. sand with		toluene	V: 20,000	3-4	Avg	<1.9E-6	1.3E-05	C1: $\Delta P = 0$ Pa, $\eta = 3.3E-4$
Hers et al. (2000a)	NAPL above water table	2 mm edge crack	k ~ 10 darcies		benzene	V: 15,000	3-4	Avg	4.0E-07	5.9E-05	C2: $\Delta P = 2.5$ Pa, $\eta = 1E-4$
					toluene	V: 20,000	3-4	Avg	5.9E-07	5.9E-05	C2: $\Delta P = 2.5$ Pa, $\eta = 1E-4$
					benzene	V: 15,000	3-4	Avg	9.9E-05	7.8E-05	C3: $\Delta P = 10$ Pa, $\eta = 1E-4$
					toluene	V: 20,000	3-4	Avg	1.3E-04	7.8E-05	C3: $\Delta P = 10$ Pa, $\eta = 1E-4$
					benzene	V: 15,000	3-4	Avg	7.2E-06	8.0E-05	C4: $\Delta P = 10$ Pa, $\eta = 3.3E-4$
					toluene	V: 20,000	3-4	Avg	3.4E-05	8.0E-05	C4: $\Delta P = 10$ Pa, $\eta = 3.3E-4$
					benzene	V: 15,000	3-4	Avg	5.8E-06	2.9E-05	C5: $\Delta P = 30$ Pa, $\eta = 3.3E-4$
					toluene	V: 20,000	3-4	Avg	2.2E-05	2.9E-05	C5: $\Delta P = 30$ Pa, $\eta = 3.3E-4$
"Paulsboro Site", NJ USA, Laubacher et al. (1997)	gasoline NAPL above water table	SFR basement	sand, some silt	2.74	benzene	V: 576	15	Avg	<1.6E-6	4.3E-04	
"Alameda (Air Station) Site", CA, USA	gasoline NAPL above water table	small commercial building, slab-on-grade poured concrete	sand k ~ 1 to 3 darcy	0.7	benzene	V: 200	1	N/A	<9E-6	2.45E-04	
Fischer et al. (1996)				0.7	iso-pentane	V: 28,000	1	N/A	<9E-7	2.46E-04	
"Mass. DEP Sites" USA, Fitzpatrick & Fitzgerald (1996)	petroleum hydrocarbon	N/A (3 sites)	N/A	N/A	benzene	N/A	-	N/A	1E-5 to 4E-5	INS	INS
"Midwest School Site" USA, Moseley and Meyer (1992)	petroleum HC NAPL above water table	Built 50's, at-grade construction, crawl-space, large paved area	sand & gravel, discontinuous clay lenses	- 3	benzene total HC	N/A	N/A	N/A	HC-like odours	INS	crawlspace conc.: benzene - 8.3 mg/m ³ , Total HC ~ 500 mg/m ³
"CDOT HDQ Site" Colorado, USA Johnson et al. (2000)	chlorinated solvents, dissolved plume	mostly apartments, few SFRs, mostly slab-on-grade, few crawl-spaces & basements, AC mostly window units, heating natural gas, baseboard, and/or fireplaces	weathered & fractured claystone above water table	4.6	1,1 DCE	G: 10-10,000	115-	Geom	4.8E-06		α_m values for houses above plume with DCE groundwater concentration > 10 ug/L
					1,1 DCE	G: 10-10,000	150	90th	2.0E-05		
					TCE	G: 3-3,000	115-	Geom	1.4E-05		
					TCE	G: 3-3,000	150	90th	7.0E-05		
					1,1,1 TCA	G: 10-1,000	115-	Geom	1.7E-05		
					1,1,1 TCA	G: 10-1,000	150	90th	6.6E-05		
					above 3 CS		115-	Geom	1.2E-05	8.6E-05	average for 3 chlorinated solvents (CS)
					above 3 CS		150	90th	5.2E-05	2.4E-04 ⁴	
"Redfields Site" Colorado, USA Envirogroup (1999)	chlorinated solvents, dissolved plume	SFRs, built 50's and 60's, mostly basements or crawlspaces, no combustion air intakes	clay & silt, some sand layers, mostly sand or silt near WT	6.1 to 7.3	1,1 DCE	G: 10-1,000	65	50th	1.50E-05	INS	α_m values for houses above plume with DCE groundwater concentration > 10 ug/L
					1,1 DCE	G: 10-1,000	65	Avg	7.60E-05		
					1,1 DCE	G: 10-1,000	65	90th	1.20E-04		
Hamilton Site Colorado, USA (2001), unpublished	chlorinated solvents, dissolved plume	SFRs, built 50's mostly basements	primarily sand & gravel, some clay & silt layers	9.7 to 11	1,1 DCE	G: 15-30	32	30th	6.80E-05	INS	Gravel at water table
					1,1 DCE	G: 15-30	32	90th	1.40E-04		
"Lowry (Air Force Base) Site" Colorado, USA Versar (2000)	chlorinated solvents, dissolved	SFR: mostly basements, some crawlspaces	silty sand to silt, generally silty sand near water table	6.1 to 7	1,1 DCE	G: 1.4-1.9	>50	50th	2.20E-05	INS	max G $\alpha_m = 6.2E-04$
					TCE	G: 120-170	>50	50th	2.20E-05		max G $\alpha_m = 1.2E-03$
					1,1 DCE	V: > 29	>50	50th	6.50E-04		max V _{SS} $\alpha_m = 8.3E-03$
					TCE	V: > 1,000	>50	50th	7.70E-04		max V _{SS} $\alpha_m = 1.4E-02$
"Mountain View Site" California, USA Wu (2000)	chlorinated solvents, leach-field & dissolved ⁵	SFRs, built 1998, at-grade construction with moisture vapor barrier	mostly silty/clayey sand & gravel, some sand or silt lenses	1.5	TCE	V: 84	14	Max	2.80E-04	INS	α_m shallow vapour
					TCE	V: 84	14	2nd ⁶	<1.3E-5		
					TCE	G: 735	14	Max	7.80E-05		α_m groundwater, depth to groundwater = 10.7 m
					TCE	G: 735	14	2nd	<3.6E-5		
"Mass. DEP Sites" USA, Fitzpatrick & Fitzgerald (1996)	chlorinated solvents	N/A (19 sites)	N/A	N/A	CS	N/A	N/A	N/A	2E-6 to 1E-1	INS	high α_m associated with highly permeable building envelopes (earthen floor, block walls & sumps)
Tracer and Flux Chamber Tests											
"Central California Site", Garbesi & Sextro (1989)	SF ₆	SFR, basement poured slab, block walls coated with asphalt	sandy loam to loamy sand, k = 0.1 to 10 darcies	sub-slab	SF ₆	N/A	N/A	N/A	- 1E-3	N/A	$\Delta P = 30$ Pa
"Alameda Site" Fischer et al. (1996)	SF ₆	small commercial, slab on-grade, concrete	sand, k = 1 to 3 darcy	sub-slab	SF ₆	N/A	N/A	N/A	2E-4 to 4E-4	N/A	$\Delta P = 3$ (estimate based on wind loading)
U.S. Sites Little et al. (1992)	radon	SFRs	N/A	sub-slab	radon	N/A	N/A	N/A	1.6E-3 ⁷	N/A	
"Spokane River Valley Sites", WA, USA Rezvan et al. (1992)	radon	SFRs (14), 8 houses slab-on-grade, 6 basement	highly permeable sand & gravel, k ~ 200 darcies	sub-slab	radon	N/A	N/A	N/A	~ 7.9E-3 to 4.5E-2	N/A	water conditions, mean house volume = 500 m ³ , ACH = 0.5/hr

Notes: ¹Depth to contamination from underside of foundation slab; ²N = Number of indoor air samples tested; ³Best estimate unless otherwise noted; ⁴Upper range; ⁵Contamination likely in unsaturated zone; ⁶2nd highest α_m value; ⁷Alpha (α) estimated using mean radon content of soil combined with appropriate constant divided by radon concentration in U.S. homes (55 Bq m⁻³); ⁸N/A = not available or applicable, SFR = single family residence, SF₆ = sulphur hexafluoride; V = vapor, V_{SS} = sub-slab, G = ground water, bgs = below ground surface, HC = hydrocarbon, AC = air-conditioning, INS = insufficient data, ACH = air exchanges per hour, WT = water table, CS = chlorinated solvents.

Table 5
Input Parameter Values Used for Johnson and Ettinger (1991) Model¹

Parameter	Virginia Site	Chatterton Site	Paulsboro Site	Alameda Site	Midwest Site	CDOT			Lowry Site	Mountain West Site
						HDQ Site	Redfields Site	Hamilton Site		
US SCS soil type used for D_T^{eff}/L_T	N/A	N/A	N/A	N/A	N/A	N/A	Loamy Sand	Sand	Loamy Sand	N/A
Depth to contamination (L_T) (m)	0.5	1.4	2.74	0.7	3.0	4.8	6.1	10.3	0.25 ¹	1.5 ²
Total porosity unsaturated zone (θ)	0.43	0.36	0.39	0.36	0.4	0.4	0.39	0.375	0.39	6.1 ³ 10.7 ³
Air-filled θ unsaturated zone (θ_a)	0.28	0.21	0.23	0.22	0.25	0.26	0.287	0.319	0.287	0.41
Height of capillary zone (L_c) (m)	N/A	N/A	N/A	N/A	N/A	0.2	0.25		0.17	0.25
Total θ capillary zone (θ_c)	N/A	N/A	N/A	N/A	N/A	0.4	0.39	0.375	0.39	0.41
Air-filled θ capillary zone ($\theta_{a,c}$)	N/A	N/A	N/A	N/A	N/A	0.08	0.07	0.12	0.07	0.1
D_T^{eff}/L_T (m/day)	0.12 ⁴	0.023 ⁴	0.014 ⁴	0.054 ⁴	0.016 ⁴	3.4E-3 ⁶	2.4E-3 ⁷	8.4E-3 ⁷	0.49 ⁸	0.013 ¹⁰
Soil-air permeability k_a (10^{-12} m ²)	0.01	10	10	3	—	N/A ¹²	—	—	2.4E-3 ⁹	1.5E-3 ¹¹
Building underpressurization (Pa)	1	0, 2.5, 10, 30	5	3	—	N/A ¹²	—	—	—	—
Foundation crack ratio (η)	1.5E-03	3.3E-4 to 1E-4	1.E-04	1.E-04	—	1.E-04	—	—	—	—
x_{crack} (m)	55.9	26.8	27.6	26.8	—	N/A ¹²	—	—	—	—
z_{crack} (m)	2.0	0.3	2.13	0.2	—	N/A ¹²	—	—	—	—
Q_{soil} (L/min)	0.0016	8.2 to 29	2.8	2.2	—	10	—	—	—	—
Total θ dust-filled cracks (θ_{crack})	0.43	0.25	0.25	0.25	—	0.4	—	—	—	—
Air-filled θ dust-filled cracks ($\theta_{a,crack}$)	0.28	0.25	0.25	0.25	—	0.26	—	—	—	—
Air exchange per hour (ACH)	0.76	0.42 to 14.3	0.42	2.1	—	0.45	—	—	—	—
Building mixing height (m)	2.0	2.19	2.74	2.4	—	3.0	—	—	—	—
Subsurface building area (A_B) (m ²)	186	57	39	50	—	89	—	—	—	—

Notes: ¹Depth to sub-slab soil gas probes; ²Depth to shallow gas probes; ³Depth to ground water; ⁴Benzene; ⁵Iso-pentene; ⁶Average 1, 1 DCE, TCE and 1,1,1 TCA; ⁷1,1 DCE; ⁸DCE for sub-slab vapor source (TCE value is 0.43); ⁹DCE for ground water source (value for TCE is 2.2E-03); ¹⁰TCE for shallow vapor source; ¹¹TCE for ground water source; ¹² Q_{soil} is estimated directly; therefore x_{crack} , z_{crack} , ΔP and k_a not needed; ¹³Building foundation thickness not included since has negligible effect.

apartments, or small commercial buildings. Site characteristics and estimated input parameters are summarized, and measured and J&E model-predicted vapor attenuation ratios (α_m and α_p) are compared (Tables 4 and 5, Figure 7). In most cases, the vapor attenuation ratios are estimated by the authors using site data; in a few cases, the ratios given in references cited in Table 4 are reported. This has led to differences in the statistical estimators used to characterize the variability in α_m and α_p . For completeness, the vapor attenuation ratios reported for several Massachusetts sites are also included in Table 4; these sites are not included in the 11 case study sites discussed later.

The quality and quantity of site characterization data, and ability to distinguish measured indoor air concentrations from background VOC sources varies from site to site. For three sites, the VOC concentrations in a relatively large number of houses above the contaminant plume were significantly greater than house concentrations in background areas, resulting in fairly reliable α_m estimates. For the remaining sites, either the vapor-derived VOC concentrations in indoor air were significant in only a small subset of houses above the contaminant plume, or there was no significant difference between above plume and background indoor air concentrations. The vapor attenuation ratio is not measurable when there is no significant vapor-derived component; however, the indoor air concentrations can be used to calculate upper bound α_m values, represented as "less than" values in Table 4, and dashed lines in Figure 7.

For each site (except Chatterton), a predictive "envelope" for

α_p was generated. A best estimate D_T^{eff}/L_T was directly calculated when reasonably good quality moisture content data was available. When good quality data was not available, the U.S. SCS soil texture class was inferred based on soil descriptions and the simplified VG method was used to calculate D_T^{eff}/L_T . We recognize that inference of soil texture is approximate and subjective. The upper and lower bound D_T^{eff}/L_T values were approximated using the same variability calculated for the two hypothetical sites discussed earlier (Table 3). The upper and lower bounds for Q_{soil} and building properties are the curves presented in Figure 6. A Q_{soil} range of 1 to 10 L/min (i.e., representative of sand) was assumed for all sites (except Virginia) because either coarse soils were present below building foundations, or there was no information on soil type (in these cases, sand was assumed to be present below foundations). Based on the fine-grained near-foundation soils at the Virginia site, a Q_{soil} range of 0.03 to 0.3 L/min (i.e., representative of loam) was assumed. When there was sufficient information on building properties and soil gas advection potential, the J&E model-predicted α_p was also estimated (represented as symbols in Figure 7). For the Chatterton site, only the best estimate α_p were plotted because testing at this site involved an experimental building and test cases not representative of generalized predictive envelopes in Figure 6.

Measured Vapor Attenuation Ratios at Petroleum Hydrocarbon Sites

Case study sites with petroleum hydrocarbon contamination have coarse-grained soils (except for the Virginia site) and

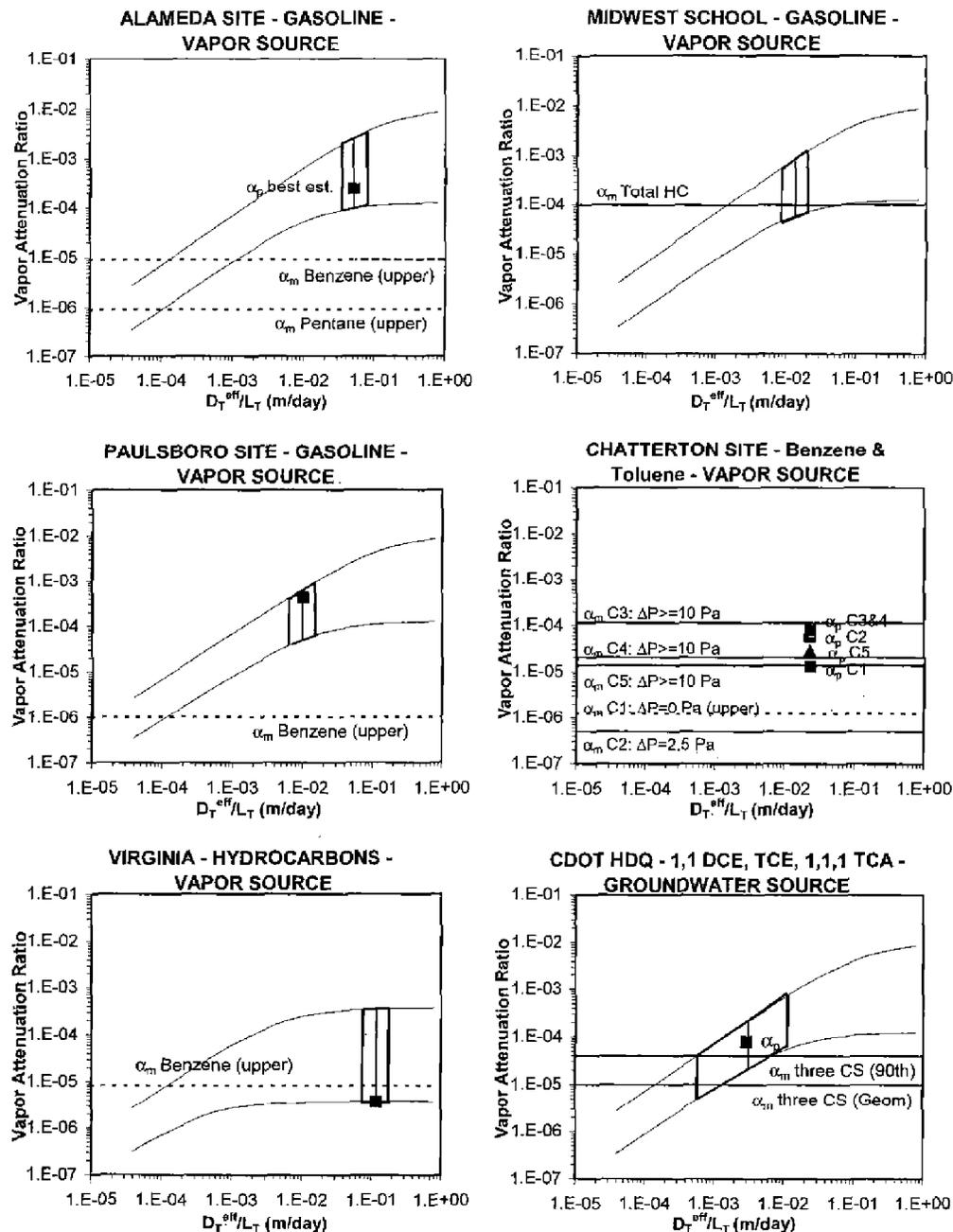


Figure 7a. Comparison between measured and J&E model-predicted vapor attenuation ratio (benzene). Upper and lower bound curves from Figure 6 are included. Dashed lines indicate that α_m is upper bound value. Symbols are best estimate α_p values.

shallow to moderate depths to contamination (0.5 to 3 m). Extensive residual nonaqueous phase liquid (NAPL) is present above the water table at the Chatterton site. There is evidence for some residual NAPL above the water table at the Alameda, Paulsboro, Virginia, and Midwest School sites. Indoor air testing was limited to a single or small number of buildings at each case study site. For petroleum sites, near-source vapor concentrations are available and therefore the α_m is directly calculated (vapor α_m).

At the Virginia, Chatterton (depressurization (ΔP) = 0 Pa case), Paulsboro, and Alameda sites, there was no difference between indoor air concentrations measured in building(s)

above the plume and in background areas, indicating that the α_m are unknown. For these sites, the α_m calculated using the measured indoor air concentrations are upper-bound values and range from $< 4.0 \times 10^{-7}$ to $< 9.0 \times 10^{-6}$. For the Chatterton $\Delta P = 2.5$ Pa case, there was a statistically significant difference in indoor and background indoor air concentrations; however, the α_m remained low (4.0×10^{-7} to 5.9×10^{-7}). For the Chatterton $\Delta P = 10$ and 30 Pa cases, there was a significant increase in indoor air concentrations and α_m .

At the Midwest School site, hydrocarbon-like odors were noted indoors during a period of relatively heavy rains and high water table in September 1992. Subsequent analysis of indoor

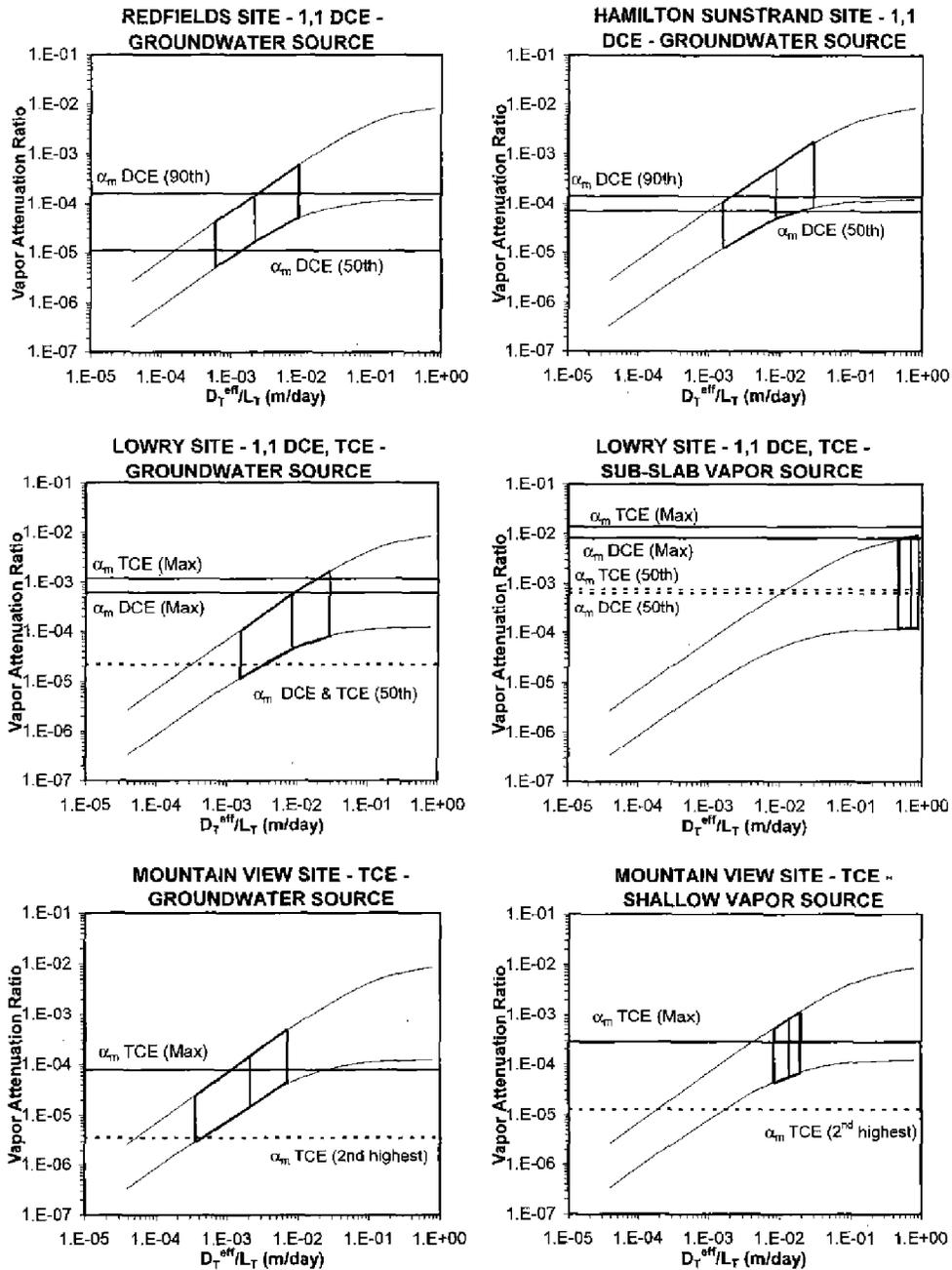


Figure 7b. Comparison between measured and J&E model-predicted vapor attenuation ratio (benzene). Upper and lower bound curves from Figure 6 are included. Dashed lines indicate that α_m is upper bound.

air during October 1992 indicated that hydrocarbon concentrations in indoor air were elevated but could not be conclusively distinguished from background sources at this time. However, the benzene (8 mg/m^3) and total hydrocarbon concentrations (500 mg/m^3) in an unventilated crawlspace below the ground floor were well above background levels. Based on a rough estimate of the source vapor concentrations and odor thresholds for hydrocarbons, the α_m may have been on the order of 1×10^{-4} .

Field data, including soil vapor profiles, indicate there was significant bioattenuation of hydrocarbon vapors for the Alameda and Chatterton ($\Delta P = 0$ and 2.5 Pa cases) sites. This

is consistent with other studies indicating that biodegradation can result in significant vadose zone attenuation of hydrocarbon vapors, provided sufficient O_2 is present (Ostendorf and Kampbell 1991; Ririe and Sweeney 1995). For higher underpressurizations (10 and 30 Pa), at the Chatterton site hydrocarbon vapor concentrations were elevated because of increased vapor flux from deeper soil, and reduced travel times (Hers et al. 2002). The relatively high α_m at the Chatterton site are from the combined effect of shallow contamination, relatively permeable soils, and high building underpressurizations.

The Paulsboro and Midwest School sites had elevated

hydrocarbon vapor levels directly below the building slab. For the Midwest School site, we speculate that elevated indoor hydrocarbon concentrations may have been a result of limited biodegradation owing to a large building and paved area, which reduced oxygen recharge, combined with factors that contributed to vapor intrusion into the building. These factors include building construction (i.e., crawlspace) and/or a sanitary sewer that was located near the water table within the hydrocarbon plume, which may have acted as a preferential pathway. At the Virginia site, contamination was shallow but no significant vapor intrusion was measured possibly because of the presence of fine-grained soils and/or building construction (i.e., tight foundations).

Comparison to Model Predictions for Petroleum Hydrocarbon Sites

Comparisons for the Chatterton ($\Delta P = 0$ and 2.5 Pa cases), Paulsboro, and Alameda sites indicate that the best estimate α_p are one to two orders of magnitude higher than the measured or upper bound α_m indicating the J&E model results in conservative predictions for these sites. Comparisons for the Chatterton ($\Delta P = 10$ and 30 Pa cases) and Virginia sites indicate the best estimate α_p are similar to the α_m . The high soil-gas advection rates for the Chatterton site resulted in significant vapor intrusion rates and hence similar α_p and α_m . For the Virginia site, the α_p is lower than at other sites owing to the influence of the fine-grained soils. For the Midwest site, the predictive envelope for α_p also intersects the α_m ; however, the α_m is highly uncertain.

Measured Vapor Attenuation Ratios at Chlorinated Solvent Sites

At four case study sites with chlorinated solvent contamination (CDOT, Redfields, Hamilton, and Lowry), dissolved plumes have migrated below houses (Table 4). The depth to the water table at these sites ranged from ~4.8 to 10.7 m below ground surface. The ground water plumes at these sites are relatively long and narrow, resulting in significant spatial variability in dissolved ground water concentrations. At the fifth site (Mountain View), houses were constructed on top of a former leach field where chlorinated solvents had been disposed of. Therefore, in addition to ground water, shallow soil is likely contaminated at this site. Soil grain size at the sites is variable (Table 4). For all sites, the α_m are estimated using vapor concentrations predicted from ground water data (ground water α_m). For the Lowry and Mountain View sites, soil vapor data were also available; therefore, the α_m is also directly calculated using vapor data (unless otherwise noted, the α_m given below are for the ground water source scenario).

For the CDOT site, the differences in three chlorinated solvent concentrations (1,1 DCE, TCE, and 1,1,1 TCA) in houses above the plume and at background locations are statistically significant. However, the ground water and indoor air data were found to be unreliable at the periphery of the plume and therefore low ground water and indoor air concentrations were removed from the database prior to calculating the α_m . The resulting database comprises several hundred tests from apartments and houses. The methodology used to estimate α_m is further described in Johnson et al. (2000). The geometric mean and 90th percentile α_m for the CDOT site are 1.0×10^{-5} and 5.2×10^{-5} . Analysis of the intrusion database for the site indi-

cated no strong correlation between seasons and α_m , or difference between basement and slab-on-grade construction (personal communication, Dr. Jeff Kurtz, EMSI Inc.).

For the Redfields site, the difference in 1,1 DCE concentrations in houses above the plume and at background locations are statistically significant. A data screening procedure similar to that used for the CDOT site resulted in α_m only being estimated in areas where the 1,1 DCE concentrations in ground water exceeded 10 $\mu\text{g/L}$. A visual interpolation method was used to estimate ground water concentrations below houses. The resulting database comprises 65 houses nearest to the Redfields site. The 50th and 90th percentile α_m for the Redfields site are 1.1×10^{-5} and 1.2×10^{-4} . Synoptic data for the Redfields site indicated a slight correlation between indoor 1,1 DCE concentrations and season, for some houses, with winter-time values that were two to three times higher than summer-time values (personal communication, Dr. David Folkes 2000).

For the Hamilton site, the difference in 1,1 DCE concentrations in houses above the plume and at background locations are statistically significant. Because ground water data was limited, the attenuation ratio analysis is for a strip of 32 houses parallel and closest to the long axis of the plume (and wells) in the area with 1,1 DCE concentrations above ~10 $\mu\text{g/L}$. The 50th and 90th percentile α_m for the Hamilton site are 6.8×10^{-5} and 1.4×10^{-4} .

At the Lowry site, the database evaluated consists of more than a year of quarterly testing at 13 houses above and near the periphery of the plume. Concurrent testing of indoor air, and subslab vapor concentrations for houses with slab-on-grade or basement construction, and crawlspace air for houses with crawlspaces was conducted. At one house, the maximum TCE and 1,1 DCE concentrations in indoor air were 51 $\mu\text{g/m}^3$ and 0.91 $\mu\text{g/m}^3$, suggesting significant vapor intrusion. At three other houses, the TCE concentrations in indoor air were mostly between 5 and 15 $\mu\text{g/m}^3$. Compared to published background data for TCE (Hers et al. 2001) and data for houses along the periphery of the plume, it is possible that concentrations at these three houses included a soil vapor-derived component. The indoor air concentrations were at background levels in remaining houses.

Measured vapor attenuation ratios are estimated for a subset of four Lowry houses with nearby ground water data. For this data subset, the maximum indoor air TCE concentration was 51 $\mu\text{g/m}^3$, but exceeded 5 $\mu\text{g/m}^3$ in only one house. Therefore, most α_m are upper bound values. When all data are used, the 50th percentile and maximum ground water α_m are 2.2×10^{-5} and 1.2×10^{-3} for TCE, and 2.2×10^{-5} and 6.2×10^{-4} for 1,1 DCE. The maximum, as opposed to 90th percentile α_m , was calculated owing to the relatively limited number of tests for this site. The Lowry subslab vapor concentrations were highly variable and elevated below certain houses (e.g., TCE up to 10,000 $\mu\text{g/m}^3$), but near background levels below other houses above the plume. An analysis of the house data subset where indoor air TCE concentrations exceeded 5 $\mu\text{g/m}^3$ and/or subslab TCE concentrations exceeded 1000 $\mu\text{g/m}^3$ indicated that the 50th percentile and maximum subslab vapor α_m are 7.7×10^{-4} and 1.4×10^{-2} . Available synoptic data for the Lowry site indicated no significant seasonal variation in subslab or indoor air concentrations.

At the Mountain View site, indoor air in seven houses

above the contaminated area and two "background" houses in a noncontaminated area was tested on two occasions. The indoor TCE concentration in one house was 12 and 25 $\mu\text{g}/\text{m}^3$, whereas the TCE concentrations in remaining houses were at background levels (0.26 to 1.1 $\mu\text{g}/\text{m}^3$) (Wu 2000). The maximum ground water α_m is 7.8×10^{-5} while the shallow vapor maximum α_m is 2.8×10^{-4} .

When all five sites are evaluated, the results can be summarized as follows. The 50th percentile (or geometric mean) and 90th percentile (or maximum) α_m values for the ground water to indoor air pathway were remarkably similar for all sites (approximately 1×10^{-5} and 1×10^{-4} , respectively). For individual sites, there is significant house-to-house variability in α_m (e.g., two order of magnitude difference for Redfields site); however, based on the available data there appear to be only slight, if any, seasonally induced variations in vapor intrusion, and similar intrusion rates for houses with basement and slab-on-grade construction. Potential sources of variability in α_m include inaccurate estimation of water table ground water concentrations below houses, geological heterogeneity, differences in house construction and depressurization, and differences in ventilation rates and house activities during indoor air testing. At the Lowry and Mountain View sites, no significant vapor intrusion could be measured for most houses. One likely reason for the generally nonsignificant intrusion is that ground water concentrations are lower at these sites, compared to the CDOT, Redfields, and Hamilton sites. Another possible factor for the Mountain View site is the building construction, which consists of at-grade foundation slab with (moisture) vapor barrier. Overall, the results suggest that geologic conditions and diffusion rates have the greatest influence on vapor intrusion rates at the chlorinated solvent sites, and that building factors are less important.

Comparison to Model Predictions for Chlorinated Solvent Sites

Comparisons for sites with the most reliable data (CDOT, Redfields, and Hamilton) indicates that the predictive envelope for the α_p intersects the α_m . The centroid of the predictive envelope is in all cases higher than the 50th percentile α_m suggesting, on average, the J&E model would result in conservative predictions. For the CDOT site, the best estimate α_p is approximately eight times higher than the 50th percentile α_m . For the Lowry site, the predictive envelope is below the α_m for one house with significant vapor intrusion, indicating a non-conservative prediction in this case. For the Mountain View site, the predictive envelope for α_p intersects the maximum α_m . Overall, the J&E model in most cases results in conservative predictions (i.e., α_p is higher than α_m). However, the comparisons highlight the potential for nonconservative predictions if a combination of low Q_{soil} and low D_T^{eff}/L_T are used.

Tracer Method

There are several sites where tracer tests can be used to estimate α , which range from $\sim 2 \times 10^{-4}$ at the Alameda site to 4.5×10^{-2} at the Spokane River (Valley) sites (Table 4). The Spokane River sites were calculated using an assumed average house volume (500 m^3) and building ventilation rate (air changes per hour (ACH) = 0.5 hour^{-1}) and therefore are approximate. Soils at the Spokane River site are very permeable, and α is based on winter conditions (i.e., highest expected

seasonal building depressurization); therefore, the α for this site is considered an upper range value. It should be remembered that tracer studies represent α values for near-field boundary conditions and, therefore, are not representative of intrusion at many sites contaminated with VOCs. The tracer test α values are, however, consistent with the upper range of the J&E model predictions (Figure 6).

Flux Chamber Method

A method that has been used for radon assessments is the equivalent leakage area (ELA) method (Grimsrud et al. 1982; CSGB 1986). The ELA is obtained by developing an empirical relationship between the soil-gas flow into a building and building depressurization. Soil-gas flows are measured using flux chambers and mass flow meters. In one study involving multiple measurements of soil-gas flow through various building foundation cracks at 10 houses in Saskatchewan, Canada, the total house foundation ELA for the foundation edge cracks and utility penetrations ranged from 0.15 to 16.4 cm^2 (Figley and Snodgrass 1992). The contribution to total ELA from untrapped floor drains, present at a few houses, was excluded from this analysis since untrapped drains are uncommon in newer construction. For example, the National Building Code of Canada (1995) requires sealing of floor drainage systems that have the potential to allow soil-gas entry (Section 9.13.8.3).

The measured total ELA can be used to estimate soil-gas intrusion rates using the method in Figley (1997). A building depressurization representative of severe winter conditions (10 Pa), as proposed by Figley (1997), and possible values for the house volume (500 m^3) and building ventilation rate (0.3 ACH) produces α values between 3.6×10^{-4} and 3.8×10^{-2} . The α obtained in this manner is conservative because it assumes an unlimited and uniform soil-vapor source directly below the foundation slab (i.e., contaminants in vapor are replenished as fast as they are swept into the building).

Flux chamber tests have also been used to measure VOC flux rates through concrete cracks (Schmidt and Zdeb 1997; Hers and Zapf-Gilje 1998). Both studies indicated detectable VOCs were measured in soil gas transmitted through cracks, and the study by Hers and Zapf-Gilje (1998) indicated that the scaled-up flux for the entire building was of the same order as flux measured by the indoor VOC method.

Regulatory Implications

The J&E model is widely used for regulatory and guidance purposes in North America. Several agencies have developed generic screening criteria for the vapor intrusion pathway (Massachusetts 1993; Michigan 1998; Connecticut 1998). Semigenic soil standards have been developed in Canada, based on two soil types (fine- and coarse-grained) and two building types (CCME 2000). Guidance recently developed by the U.S. EPA consists of a multitiered framework to evaluate the soil vapor intrusion pathway (U.S. EPA 2002). A primary (initial) screening step is used to identify sites with significant potential for vapor intrusion (e.g., odors, product in sumps or directly below foundation), and where indoor air monitoring and/or engineering controls is warranted. A secondary screening step involves the use of semigenic curves for α , based

on soil type and depth, and target breathing concentrations in indoor air to back-calculate acceptable source ground water and soil vapor concentrations. Depending on the results of the secondary screening, there is the option to conduct a site-specific pathway assessment.

Derivation of regulatory criteria requires the prediction of cross-media transfer of contaminants, and vapor transport and intrusion into buildings. For the regulatory agencies cited previously (excluding Massachusetts), cross-media transfer between VOCs in ground water and soil vapor is predicted using the Henry's law constant assuming equilibrium partitioning. Under the Massachusetts guidance, the Henry's law constant is divided by 10 to account for source vapor concentrations that are typically lower than those predicted assuming equilibrium partitioning. The vapor attenuation ratios incorporated into regulatory criteria depend on whether the assumed contamination scenario is a dissolved ground water plume or an unsaturated zone contamination source. For a ground water source, the α incorporates vapor transport through both the capillary transition zone and unsaturated zone. For an unsaturated zone source, the α incorporates transport through just the unsaturated zone. For the agencies cited previously, the ground water source α ranges from 4.6×10^{-6} to 1.5×10^{-3} whereas the vapor source α ranges from 3.9×10^{-7} to 6.2×10^{-3} . An analysis of the previous regulatory criteria indicates that the key factor affecting the α is the Q_{soil} value chosen or estimated for predictive purposes. Of lesser importance is the assumed generic or semigenic soil type.

When vapor attenuation ratios incorporated in regulatory criteria are compared to measured ratios for field studies presented in this paper, it is apparent that the low end of the regulatory range may not be conservative for some sites. Of greatest concern would be sites with nonbiodegradable chemicals, shallow to moderate depth contamination, and high advection potential (i.e., coarse soil, high building under-pressurization).

Conclusions and Recommendations

A comprehensive evaluation of the J&E model characteristics and sensitivity, and comparisons of measured to model-predicted vapor attenuation ratios (α_m and α_p), have been provided for residential houses, ground-floor apartments, and small commercial buildings. Based on this analysis, the following conclusions can be drawn:

1. The J&E model is moderately too highly sensitive to soil-gas advection rate into the building (Q_{soil}), at D_T^{eff}/L_T values above $\sim 1 \times 10^{-3}$. Except when Q_{soil} is low, the J&E model is relatively insensitive to building foundation properties. At best, the range or uncertainty in J&E model predictions is about one order of magnitude when relatively good quality site-specific data is available.
2. Estimation of effective diffusion coefficient is subject to considerable uncertainty. Some of this uncertainty can be reduced through better site characterization, including careful lithological descriptions, testing of moisture content, grain size distribution and water retention, and appropriate consideration of the effect of surface barriers on soil moisture content.
3. Several radon and VOC tracer studies indicate that measured Q_{soil} values at coarse-grained soil sites, for single fam-

ily residences, ranged from ~ 1 to 10 L/min. Depending on the input values chosen, much lower Q_{soil} values can be predicted using the soil-gas advection model typically used in conjunction with the J&E model.

4. There are only a limited number of high quality and comprehensive field studies that can be used to help validate models for the vapor intrusion pathway.
5. For petroleum hydrocarbon sites, the vapor α_m for the Chatterton site (high ΔP cases) and Midwest site were on the order of 1×10^{-5} to 1×10^{-4} (the Midwest value is uncertain). For the remaining cases and sites, the possible upper bound vapor α_m ranged from $\sim 5 \times 10^{-7}$ to 1×10^{-5} .
6. For chlorinated solvent sites, the ground water α_m were on the order of 1×10^{-6} to 1×10^{-4} for the three sites with the most reliable data sets (CDOT, Redfields, and Hamilton). For one site with a smaller and somewhat less reliable data set (Lowry), the maximum ground water α_m was $\sim 1 \times 10^{-3}$ while the maximum subslab vapor α_m was $\sim 1 \times 10^{-2}$.
7. For the tracer and flux chamber studies, the α_m was on the order of 1×10^{-4} to 1×10^{-2} . In the context of VOC intrusion, these α_m represent conservative upper bounds owing to boundary conditions and tracer properties that are generally different than those at VOC-contaminated sites.
8. For almost all case studies, the best estimate J&E model-predicted α_p were one to two orders of magnitude less than the 50th percentile or median α_m , indicating that when best estimate and average conditions are evaluated, the J&E model predictions are conservative. There were a few cases studies where the best estimate α_p was less than the 90th percentile or maximum α_m , indicating the J&E model predictions are nonconservative for a small subset of houses or apartments. The comparisons also highlight the potential for non-conservative model predictions if a combination of low Q_{soil} and low D_T^{eff}/L_T are used.

The observed variability in α_m between different field sites, and individual houses at some sites, highlights the complexity of processes affecting vapor intrusion. Numerous factors potentially affect the vapor intrusion pathway including biodegradation, chemical transformation, sorption, contaminant source depletion, geologic heterogeneity, soil properties (moisture content, permeability, organic carbon content), building properties, meteorological conditions, and building ventilation rates. In light of this complexity, it is important to recognize the vapor intrusion modeling paradigm typically followed is a compartmental model for steady-state one-dimensional diffusion through soil, and diffusion and advection through a building foundation having an idealized edge or perimeter crack (J&E model). Often, a homogeneous soil is assumed, although it is relatively easy to model diffusion for multiple soil layers assuming site information is available (Johnson et al. 1998). Simulation of vapor transport through the building foundation and mixing of VOCs within the building airspace is highly simplified. Although not used for this study, it is noted that the J&E model has been modified to include first-order biodegradation for a dominant soil layer (Johnson et al. 1998) and oxygen-limited first-order biodegradation (Johnson et al. 2001).

Notwithstanding the above, the question remains: Can the

J&E model (or other similar screening models) be reliably used for the vapor intrusion pathway? Our answer is a qualified yes, provided that appropriate input values are used and the model sensitivity, uncertainty, and limitations are recognized. The answer may also depend on what the model is used for. For example, the use of the J&E model to set generic criteria is problematic owing to model sensitivity and uncertainty, and the wide range in possible site conditions. In our opinion, a semigenetic approach that incorporates site-specific information on critical factors affecting vapor intrusion (e.g., Q_{soil} and soil properties) improves on a single criteria approach. The technically preferred approach is to use the J&E model on a fully site-specific basis, and to calibrate model predictions using soil vapor profiles, and when possible, indoor air data. In all cases, an appropriate framework for model use and understanding of model characteristics is essential when using models for regulatory purposes.

Several data gaps and sources of uncertainty remain. Additional field-based studies should be conducted to evaluate the vapor intrusion pathway for different site conditions, and to more fully assess specific factors affecting vapor intrusion. Data that would contribute to a more in-depth pathway analysis include soil properties such as moisture content and porosity, soil vapor concentration profiles below buildings, building properties such as depressurization, and meteorological data. Further evaluation of biodegradation kinetics for hydrocarbon vapors, effect of surface barriers (e.g., buildings) on biodegradation, and chlorinated solvent transformation processes are also needed.

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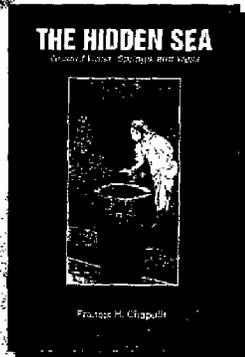


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APPENDIX 4

EXAMPLE PRINTOUTS OF INDOOR AIR IMPACT MODELS

1. Groundwater to indoor air, high-permeability soils, residential exposure scenario.
2. Groundwater to indoor air, low-permeability soils, residential exposure scenario.
3. Groundwater to indoor air, high-permeability soils, commercial/industrial exposure scenario.
4. Groundwater to indoor air, low-permeability soils, commercial/industrial exposure scenario.
5. Soil to indoor air, high-permeability soils, residential exposure scenario.
6. Soil to indoor air, high-permeability soils, commercial/industrial exposure scenario.
7. Soil Gas to indoor air, high-permeability soils, residential exposure scenario.
8. Soil Gas to indoor air, high-permeability soils, commercial/industrial exposure scenario.

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter 'X' in 'YES' box)

YES X

GW-ADV
Version 2.3; 03/01

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter 'X' in 'YES' box and initial groundwater conc. below)

YES

**GROUNDWATER VOC EMISSIONS TO INDOOR AIR
RESIDENTIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS**

ENTER Initial groundwater conc., C_w ($\mu\text{g/L}$)

127184

Chemical: Tetrachloroethylene

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	
Average soil/groundwater temperature, T_s ($^{\circ}\text{C}$)	Depth below grade to enclosed space floor, L_f (cm)	Depth below grade to water table, L_{WT} (cm)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0)	Thickness of soil stratum C, (Enter value or 0)	Thickness of soil stratum D28, h_C (cm)	Soil stratum directly above water table, (Enter A, B, or C)	SCS soil type directly above water table	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	User-defined stratum A soil vapor permeability, k_v (cm^2)
15	15	300	100	200			B	CL	S	

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	Stratum A soil porosity, n^A (unitless)	Stratum A soil dry bulk density, ρ_b^B (g/cm^3)	Stratum B soil porosity, n^B (unitless)	Stratum B soil total porosity, θ_w^B (cm^3/cm^3)	Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	Stratum C soil porosity, n^C (unitless)	Stratum C soil total porosity, θ_w^C (cm^3/cm^3)	Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
1.5	0.43	1.5	0.43	0.3	0.3				

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed space floor thickness, L_{risk} (cm)	Soil-bldg. pressure differential, ΔP ($\text{g/cm}^2\text{-s}^2$)	Enclosed space floor length, L_b (cm)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)	Indoor air exchange rate, ER (1/h)	Indoor air exchange rate, ER (1/h)
15	40	961	961	244	0.1	1	1	1

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT _C (yrs)	Averaging time for noncarcinogens, AT _{NC} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	0.2		

ND

Used to calculate risk-based groundwater concentration.

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant reference temperature, T_R ($^\circ\text{C}$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^\circ\text{K}$)	Critical temperature, T_C ($^\circ\text{K}$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\text{-}1$)	Reference conc., RfC (mg/m^3)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.9E-06	6.0E-01

END

Exposure duration, τ (sec)	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	3,844
Source-building separation, L_T (cm)													
Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_b^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_c^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{b0} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)		
9.46E+08	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	3,844
Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D_{eff}^A (cm^2/s)	Stratum B effective diffusion coefficient, D_{eff}^B (cm^2/s)	Stratum C effective diffusion coefficient, D_{eff}^C (cm^2/s)	Capillary zone effective diffusion coefficient, D_{eff}^{cz} (cm^2/s)	Total overall effective diffusion coefficient, D_{eff}^T (cm^2/s)	Diffusion path length, L_d (cm)	
6.26E+04	9.24E+05	4.16E-04	15	9.502	4.46E-01	1.77E-04	5.62E-03	4.38E-04	0.00E+00	2.85E-05	1.42E-04	285	
Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu\text{g}/\text{m}^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Pelet number, $\exp(\text{Pe}^f)$ (unitless)	Infinite indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu\text{g}/\text{m}^3$)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\text{-}1$)	Reference conc., RfC (mg/m^3)				
15	4.46E+02	0.10	6.74E+01	3.84E+02	2.22E+203	7.29E-06	3.25E-03	6.9E-06	6.0E-01				
END													

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
1.08E+02	3.85E+04	1.08E+02	2.00E+05	1.08E+02

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)
 MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL DOWN TO "END"

END

SCS Soil Type	K_p (cm/h)	α (1/cm)	N (unitless)	M (unitless)	θ_s (cm ³ /cm ³)	θ_r (cm ³ /cm ³)	Mean Grain Diameter (cm)
C	0.61	0.0150	1.253	0.2019	0.459	0.098	0.0092
CL	0.34	0.0158	1.416	0.2938	0.442	0.079	0.016
L	0.50	0.0111	1.472	0.3207	0.399	0.061	0.02
LS	4.38	0.0348	1.746	0.4273	0.39	0.049	0.04
S	26.78	0.0352	3.177	0.6852	0.375	0.053	0.044
SC	0.47	0.0334	1.208	0.1722	0.385	0.117	0.025
SCL	0.55	0.0211	1.33	0.2481	0.384	0.063	0.029
SI	1.82	0.0066	1.679	0.4044	0.489	0.05	0.0046
SIC	0.40	0.0162	1.321	0.3425	0.481	0.111	0.0039
SIL	0.46	0.0084	1.521	0.3425	0.482	0.09	0.0056
SL	0.76	0.0051	1.663	0.3987	0.439	0.065	0.011
SL	1.60	0.0267	1.449	0.3089	0.387	0.039	0.03

Chemical	CAS No.	Organic carbon partition coefficient, K_{ow} (cm ³ /g)	Diffusivity in air, D_a (cm ² /s)	Diffusivity in water, D_w (cm ² /s)	Pure component water solubility, S (mg/L)	Henry's law constant, H (unitless)	Henry's law constant reference temperature, T_h (°C)	Normal boiling point, T_b (°K)	Critical temperature, T_c (°K)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Unit risk factor, URF (µg/m ³) ⁻¹	Reference conc., RIC (mg/m ³)	Molecular weight, MW (g/mol)	URF extrapolated	RIC extrapolated
56235 Carbon tetrachloride		1.74E+02	7.80E-02	8.80E-06	7.93E-06	1.25E+00	25	349.90	556.60	7.127	1.5E-05	2.5E-03	153.82		+
67641 Acetone		7.75E-01	1.24E-01	1.14E-05	1.00E-06	1.25E+00	25	329.20	508.10	6.955	0.0E+00	3.5E-01	58.08	X	+
67663 Chloroform		3.98E+01	1.04E-01	1.00E-05	7.92E-03	1.50E-01	25	334.32	536.40	6.988	0.0E+00	3.0E-03	119.38		+
71432 Benzene		5.98E-01	8.80E-02	9.80E-06	1.75E-03	2.28E-01	25	353.24	582.16	7.342	7.8E-06	6.0E-03	78.11		+
71556 1,1,1-Trichloroethane		1.10E+02	7.80E-02	8.80E-06	1.33E-03	7.05E-01	25	347.24	545.00	7.136	0.0E+00	2.2E+00	133.41		
74839 Methyl bromide (bromomethane)		9.00E+00	7.28E-02	1.21E-05	1.52E+04	2.58E-01	25	276.71	467.00	5.714	0.0E+00	5.0E-03	94.94		X
74873 Chloroethane		3.90E+01	1.10E-01	6.50E-06	8.20E-03	9.84E-01	25	248.94	416.80	5.147	1.8E-06	3.0E-01	51.00		X
75003 Chloroethane		1.47E+01	1.04E-01	1.15E-05	5.70E-03	4.51E-00	25	285.00	460.00	5.892	8.3E-07	1.0E-01	65.00		X
75092 Methylene chloride		1.86E+01	1.06E-01	1.23E-06	2.76E+03	1.11E+00	25	269.25	432.00	5.892	8.9E-06	1.0E-01	62.50		
75274 Bromodichloromethane		1.11E+01	1.01E-01	1.17E-05	1.32E-04	8.98E-02	25	313.00	510.00	6.706	4.7E-07	3.0E+00	84.83		
75343 1,1-Dichloroethane		5.50E+01	2.98E-02	1.06E-05	6.74E-03	6.56E-02	25	363.15	585.85	7.000	1.8E-05	7.0E-02	163.83		+
75354 1,1-Dichloroethylene		3.16E+01	7.42E-02	1.05E-05	5.06E-03	2.30E-01	25	330.55	523.00	6.895	0.0E+00	5.0E-01	98.96		
75975 1,2-Dichloroethane		5.89E+01	9.00E-02	1.04E-05	2.25E-03	1.07E+00	25	304.75	576.05	6.247	5.0E-05	2.0E-01	96.94		
78875 1,2-Dichloropropane		4.37E+01	7.82E-02	8.73E-06	2.80E-03	1.15E-01	25	369.62	572.00	7.590	1.9E-05	4.0E-03	112.98		
78933 Methyl Ethyl Ketone		4.50E+00	9.85E-02	9.80E-06	2.68E+05	1.12E+03	25	353.00	535.00	5.620	0.0E+00	1.0E+00	71.00		
79005 1,1,2-Trichloroethane		5.01E+01	7.80E-02	8.80E-06	4.42E+03	3.74E-02	25	386.15	602.00	8.322	1.1E-05	1.4E-02	133.41		
79016 Trichloroethylene		1.66E+02	7.90E-02	9.10E-06	1.10E+03	4.22E-01	25	380.36	544.20	7.505	1.1E-04	3.5E-02	131.39		
79375 1,1,2,2-Tetrachloroethane		9.37E+01	7.10E-02	7.90E-06	2.97E+03	1.41E-02	25	419.60	661.15	8.996	5.8E-05	2.1E-01	167.85		+
83329 Acenaphthene		4.90E+03	4.21E-02	7.69E-06	4.24E+00	6.36E-03	25	550.54	803.15	12.155	0.0E+00	2.1E-01	154.21		X
86737 Fluorene		1.38E+04	6.08E-02	7.88E-06	1.90E+00	3.16E-03	25	570.44	870.00	12.666	0.0E+00	1.4E-01	166.22		X
90120 1-(2-Methylnaphthalene		7.20E+02	5.90E-02	7.50E-06	2.10E-01	1.19E-02	25	514.70	772.00	11.190	0.0E+00	1.4E-01	142.00		X
91203 Naphthalene		1.19E+03	5.90E-02	7.50E-06	3.10E-01	1.98E-02	25	491.14	748.40	10.373	0.0E+00	3.0E-03	128.18		
95501 1,2-Dichlorobenzene		6.17E+02	6.90E-02	7.90E-06	1.56E-02	7.79E-02	25	453.67	705.00	9.700	0.0E+00	2.0E-01	147.00		X
95578 2-Chlorophenol		3.98E+02	5.01E-01	9.46E-06	2.20E-04	1.60E-02	25	447.53	675.00	9.572	0.0E+00	1.8E-02	128.56		X
95954 2,4,5-Trichlorophenol		8.95E+01	2.91E-02	7.03E-06	1.19E+03	8.94E-03	25	526.15	759.13	13.000	0.0E+00	3.5E-01	197.45		X
100414 Ethylbenzene		3.63E+02	7.50E-02	7.80E-06	1.69E+02	3.23E-01	25	409.34	617.20	8.501	1.1E-06	1.0E+00	106.17		X
100423 Styrene		7.76E+02	7.10E-02	8.00E-06	3.10E+02	1.13E-01	25	418.31	636.00	8.737	0.0E+00	1.0E+00	104.15		X
105679 2,4-Dimethylphenol		4.00E+01	5.64E-02	8.69E-06	7.87E+03	6.97E-04	25	484.13	707.80	11.329	0.0E+00	7.0E-02	122.17		X
106467 1,4-Dichlorobenzene		6.17E+02	6.90E-02	7.90E-06	7.38E-01	9.96E-02	25	447.21	684.75	9.271	6.3E-06	1.1E-01	147.00		X
106934 1,2-dibromoethane		2.81E+01	7.33E-02	8.06E-06	3.40E-03	1.31E-02	25	404.00	582.80	9.996	2.2E-04	2.0E-04	188.00		
107062 1,2-Dichloroethane		1.74E+01	1.04E-01	9.90E-06	8.52E-03	4.01E-02	25	356.65	561.00	7.643	2.6E-05	4.9E-03	98.96		
108101 Methyl Isobutyl Ketone		1.34E+02	7.50E-02	7.80E-06	1.90E-04	5.74E-03	25	389.00	575.00	40.610	0.0E+00	8.1E-02	100.00		X
108383 Xylene (m)		4.07E+02	7.00E-02	8.00E-06	1.61E-02	3.01E-01	25	412.27	617.05	8.523	0.0E+00	1.0E-01	106.17		X
108883 Toluene		1.82E+02	8.70E-02	8.60E-06	5.26E-02	2.72E-01	25	383.78	591.79	7.930	0.0E+00	4.0E-01	92.14		
108907 Chlorobenzene		2.19E+02	7.30E-02	8.70E-06	1.72E+02	1.52E-01	25	404.87	632.40	8.410	0.0E+00	6.0E-02	112.56		
111444 Bis(2-chloroethyl)ether		7.60E+01	6.62E-02	7.53E-06	4.72E+04	7.38E-04	25	451.16	689.79	9.000	0.0E+00	6.0E-02	143.11		
120127 Anthracene		2.39E+04	3.24E-02	7.74E-06	4.34E-02	2.67E-03	25	615.18	873.00	13.121	0.0E+00	1.1E+00	178.24		X
120621 1,2,4-Trichlorobenzene		1.78E+03	3.00E-02	8.23E-06	3.00E-02	5.82E-02	25	486.15	725.00	10.471	0.0E+00	2.0E-01	181.45		
124181 Dibromochloromethane		4.68E+02	9.60E-02	1.00E-05	4.40E-03	3.49E-02	25	416.14	678.20	8.000	2.4E-05	7.0E-02	208.28		X
1258E-02 Tetrachloroethylene		1.55E+02	7.20E-02	8.20E-06	2.00E-02	7.54E-01	25	394.40	620.20	8.288	6.9E-06	6.0E-01	165.83		
129000 Pyrene		3.05E+05	2.72E-02	7.4E-05	1.24E-05	4.51E-04	25	667.95	936.00	14.370	0.0E+00	1.1E-01	202.26		X
156592 cis-1,2-Dichloroethylene		3.55E+01	7.36E-01	1.13E-05	3.50E-03	1.67E-01	25	333.65	544.00	7.192	0.0E+00	3.5E-02	96.94		X
156605 trans-1,2-Dichloroethylene		5.25E+01	7.07E-02	1.19E-05	6.30E-03	3.85E-01	25	320.85	516.50	6.711	0.0E+00	7.0E-02	96.94		X
542756 1,3-Dichloropropane		4.57E+01	6.26E-02	1.00E-05	2.80E-03	7.26E-01	25	381.15	587.38	7.000	4.0E-06	2.0E-02	110.97		X
163044 Methyl tert Butyl Ether		6.02E+00	8.00E-02	1.00E-05	1.50E+05	2.41E-02	25	328.00	497.10	6.678	1.0E-07	3.0E+00	98.00		

Notes:

"x" Additional RIC extrapolated from RID-inhalation factor presented in USEPA Region IX Preliminary Remediation Goals document (USEPA 2002).
 Default physico-chemical constants included in spreadsheet replaced with constants from USEPA Region IX Preliminary Remediation Goals document (USEPA 2002) when available.
 Additional physico-chemical constants from NIST 2001.

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES X OR

GW-ADV
Version 2.3: 03/01

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES

**GROUNDWATER VOC EMISSIONS TO INDOOR AIR
RESIDENTIAL EXPOSURE SCENARIO
LOW-PERMEABILITY (SILTY) SOILS**

ENTER Initial groundwater conc., C_w (numbers only, no dashes) ($\mu\text{g/L}$)

127184

Chemical

Tetrachloroethylene

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Average soil temperature, T_s ($^{\circ}\text{C}$)	Depth below grade to bottom of enclosed space floor, L_f (cm)	Depth below grade to water table, L_{WT} (cm)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, h_B (cm)	Thickness of soil stratum C, h_C (cm)	Soil stratum directly above water table, (Enter A, B, or C)	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	Soil stratum B SCS soil type directly above water table	User-defined stratum A soil vapor permeability, k_v (cm^2)
15	15	300	100	200		B	LS	SI	

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	Stratum A soil porosity, n^A (unitless)	Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	Stratum B soil porosity, n^B (unitless)	Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	Stratum C soil porosity, n^C (unitless)	Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	Stratum C soil total porosity, θ_w^C (cm^3/cm^3)
1.5	0.43	0.15	1.5	0.43	0.3				

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed space floor thickness, L_{crack} (cm)	Soil-bldg. floor pressure differential, ΔP (g/cm-s^2)	Enclosed space floor length, L_f (cm)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)
15	40	961	961	244	0.1	1

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT_{IC} (yrs)	Averaging time for noncarcinogens, AT_{NC} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	0.2

ND Used to calculate risk-based groundwater concentration.

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant reference temperature, T_R ($^\circ\text{C}$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^\circ\text{K}$)	Critical temperature, T_C ($^\circ\text{K}$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\cdot\text{yr}$) ⁻¹	Reference conc., RfC (mg/m^3)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.9E-06	6.0E-01

END

Exposure duration, τ (sec)	9.46E+08	285	Source-building separation, L_T (cm)	0.280	0.130	ERROR	0.265	1.64E-08	0.824	1.35E-08	163.04	0.43	0.048	0.382	3.844
			Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)		Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{e0} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{ra} (cm^2)	Stratum A soil effective vapor permeability, K_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	6.26E+04	9.24E+05	4.16E-04	15	9.502	1.05E-02	4.46E-01	1.77E-04	5.62E-03	4.38E-04	0.00E+00	2.02E-05	3.48E-05	285	
			Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant at ave. groundwater temperature, H_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D_{eff}^A (cm^2/s)	Stratum B effective diffusion coefficient, D_{eff}^B (cm^2/s)	Stratum C effective diffusion coefficient, D_{eff}^C (cm^2/s)	Capillary zone effective diffusion coefficient, D_{eff}^{cz} (cm^2/s)	Total overall effective diffusion coefficient, D_{eff}^T (cm^2/s)	Diffusion path length, L_d (cm)

Convection path length, L_p (cm)	15	4.46E+02	0.10	1.29E+01	5.62E-03	3.84E+02	9.74E+38	1.79E-06	7.98E-04	6.0E-01
			Source vapor conc., C_{source} ($\mu\text{g}/\text{m}^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D_{crack}^{crack} (cm^2/s)	Exponent of equivalent foundation Peclet number, $\exp(Pe)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu\text{g}/\text{m}^3$)	Reference conc., RIC (mg/m^3)

END

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
4.42E+02	1.57E+05	4.42E+02	2.00E+05	4.42E+02

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL
DOWN
TO "END"

END

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES X

GW-ADV
Version 2.3, 03/01

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES

**GROUNDWATER VOC EMISSIONS TO INDOOR AIR
COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS**

Chemical
Tetrachloroethylene

ENTER Initial groundwater conc., C_w ($\mu\text{g/L}$)

127184	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Average soil/groundwater temperature, T_s ($^{\circ}\text{C}$)	Depth below grade to bottom of enclosed space floor, L_f (cm)	Depth below grade to water table, L_{wt} (cm)	Thickness of soil stratum A, (Enter value or 0); t_A (cm)	Thickness of soil stratum B, (Enter value or 0); t_B (cm)	Thickness of soil stratum C, (Enter value or 0); t_C (cm)	Totals must add up to value of L_{wt} (Cell D28)	ENTER	ENTER	ENTER	ENTER
15	15	300	100	200			B	CL	S	
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Soil porosity, n^A (unitless)	Soil porosity, n^B (unitless)	Soil porosity, n^C (unitless)	Soil porosity, n^B (unitless)	Soil porosity, n^B (unitless)	Soil porosity, n^C (unitless)	Soil porosity, n^C (unitless)	Soil stratum directly above water table, (Enter A, B, or C)	Soil stratum directly above water table	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	User-defined stratum A soil vapor permeability, k_v (cm^2)

1.5	0.43	0.15	1.5	0.43	0.3					
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Soil-bldg. pressure differential, ΔP ($\text{g}/\text{cm}^2\text{s}^2$)	Soil-bldg. space length, L_b (cm)	Soil-bldg. space width, W_b (cm)	Soil-bldg. space height, H_b (cm)	Soil-bldg. space width, w (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)	Soil stratum C soil dry bulk density, ρ_b (g/cm^3)	Soil stratum C soil total porosity, n^C (unitless)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)

15	40	25	961	244	0.1	2				
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Soil-bldg. space thickness, L_{-risk} (cm)	Soil-bldg. space length, L_b (cm)	Soil-bldg. space width, W_b (cm)	Soil-bldg. space height, H_b (cm)	Soil-bldg. space width, w (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)	Soil stratum C soil dry bulk density, ρ_b (g/cm^3)	Soil stratum C soil total porosity, n^C (unitless)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)

70	25	250	1.0E-06	1						
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, ATC (yrs)	Averaging time for noncarcinogens, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Soil stratum C soil dry bulk density, ρ_b (g/cm^3)	Soil stratum C soil total porosity, n^C (unitless)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)	Soil stratum C soil water-filled porosity, θ_w (cm^3/cm^3)

Used to calculate risk-based groundwater concentration.

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant reference temperature, T_R ($^\circ\text{C}$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^\circ\text{K}$)	Critical temperature, T_C ($^\circ\text{K}$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\cdot\text{s}^{-1}$)	Reference conc., RfC (mg/m^3)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.9E-06	6.0E-01

END

Exposure duration, τ (sec)	285	0.280	0.130	ERROR	0.257	1.00E-07	0.703	7.04E-08	46.88	0.43	0.055	0.375	3.844
Source-building separation, L_T (cm)													
Stratum A air-filled porosity, $\theta_{s,A}$ (cm^3/cm^3)													
Stratum B soil air-filled porosity, $\theta_{s,B}$ (cm^3/cm^3)													
Stratum C soil air-filled porosity, $\theta_{s,C}$ (cm^3/cm^3)													
Stratum A effective total fluid saturation, S_{w0} (cm^3/cm^3)													
Stratum A soil intrinsic permeability, k_i (cm^2)													
Stratum A soil relative air permeability, k_{ra} (cm^2)													
Stratum A soil effective vapor permeability, k_v (cm^2)													
Thickness of capillary zone, L_{cz} (cm)													
Total porosity in capillary zone, n_{cz} (cm^3/cm^3)													
Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)													
Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)													
Floor-wall seam perimeter, X_{crack} (cm)													

Area of enclosed space below grade, A_B (cm^2)	9.24E+05	4.16E-04	15	9.502	1.05E-02	4.46E-01	1.77E-04	5.62E-03	4.38E-04	0.00E+00	2.85E-05	1.42E-04	285
Bldg. ventilation rate, $Q_{building}$ (cm^3/s)													
Crack-to-total area ratio, η (unitless)													
Crack depth below grade, Z_{crack} (cm)													
Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)													
Henry's law constant at ave. groundwater temperature, H_{TS} (atm-m ³ /mol)													
Henry's law constant at ave. groundwater temperature, H_{TS} (unitless)													
Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)													
Stratum A effective diffusion coefficient, $D_{eff,A}$ (cm^2/s)													
Stratum B effective diffusion coefficient, $D_{eff,B}$ (cm^2/s)													
Stratum C effective diffusion coefficient, $D_{eff,C}$ (cm^2/s)													
Capillary zone effective diffusion coefficient, $D_{eff,cz}$ (cm^2/s)													
Total overall effective diffusion coefficient, $D_{eff,T}$ (cm^2/s)													

Convection path length, L_p (cm)	15	0.10	6.74E+01	5.62E-03	3.84E+02	2.22E+203	3.65E-06	1.63E-03	6.9E-06	6.0E-01
Source vapor conc., C_{source} ($\mu\text{g}/\text{m}^3$)										
Crack radius, r_{crack} (cm)										
Average vapor flow rate into bldg., Q_{soil} (cm^3/s)										
Crack effective diffusion coefficient, D_{crack} (cm^2/s)										
Area of crack, A_{crack} (cm^2)										
Exponent of equivalent foundation Peclet number, $\exp(Pe)$ (unitless)										
Infinite indoor attenuation coefficient, α (unitless)										
Infinite source bldg. conc., $C_{building}$ ($\mu\text{g}/\text{m}^3$)										
Reference conc., RIC (mg/m^3)										
Unit risk factor, URF ($\mu\text{g}/\text{m}^3$) ⁻¹										

END

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
3.64E+02	5.39E+05	3.64E+02	2.00E+05	3.64E+02

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL DOWN TO "END"

END

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES X OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES

ENTER Initial groundwater conc., C_w (ug/L)

ENTER Depth below grade of enclosed space floor, L_F (cm)

ENTER Depth below grade to water table, L_{WT} (cm)

ENTER Thickness of soil stratum A, h_A (cm)

ENTER Thickness of soil stratum B, (Enter value or 0)

ENTER Thickness of soil stratum C, (Enter value or 0)

ENTER Thickness of soil stratum D, (Enter value or 0)

ENTER Thickness of soil stratum E, (Enter value or 0)

ENTER Thickness of soil stratum F, (Enter value or 0)

ENTER Thickness of soil stratum G, (Enter value or 0)

ENTER Thickness of soil stratum H, (Enter value or 0)

ENTER Thickness of soil stratum I, (Enter value or 0)

ENTER Thickness of soil stratum J, (Enter value or 0)

ENTER Thickness of soil stratum K, (Enter value or 0)

ENTER Thickness of soil stratum L, (Enter value or 0)

ENTER Thickness of soil stratum M, (Enter value or 0)

ENTER Thickness of soil stratum N, (Enter value or 0)

ENTER Thickness of soil stratum O, (Enter value or 0)

ENTER Thickness of soil stratum P, (Enter value or 0)

ENTER Thickness of soil stratum Q, (Enter value or 0)

ENTER Thickness of soil stratum R, (Enter value or 0)

ENTER Thickness of soil stratum S, (Enter value or 0)

ENTER Thickness of soil stratum T, (Enter value or 0)

ENTER Thickness of soil stratum U, (Enter value or 0)

ENTER Thickness of soil stratum V, (Enter value or 0)

ENTER Thickness of soil stratum W, (Enter value or 0)

ENTER Thickness of soil stratum X, (Enter value or 0)

ENTER Thickness of soil stratum Y, (Enter value or 0)

ENTER Thickness of soil stratum Z, (Enter value or 0)

ENTER Thickness of soil stratum AA, (Enter value or 0)

ENTER Thickness of soil stratum AB, (Enter value or 0)

ENTER Thickness of soil stratum AC, (Enter value or 0)

ENTER Thickness of soil stratum AD, (Enter value or 0)

ENTER Thickness of soil stratum AE, (Enter value or 0)

ENTER Thickness of soil stratum AF, (Enter value or 0)

ENTER Thickness of soil stratum AG, (Enter value or 0)

ENTER Thickness of soil stratum AH, (Enter value or 0)

ENTER Thickness of soil stratum AI, (Enter value or 0)

ENTER Thickness of soil stratum AJ, (Enter value or 0)

ENTER Thickness of soil stratum AK, (Enter value or 0)

ENTER Thickness of soil stratum AL, (Enter value or 0)

ENTER Thickness of soil stratum AM, (Enter value or 0)

ENTER Thickness of soil stratum AN, (Enter value or 0)

ENTER Thickness of soil stratum AO, (Enter value or 0)

ENTER Thickness of soil stratum AP, (Enter value or 0)

ENTER Thickness of soil stratum AQ, (Enter value or 0)

ENTER Thickness of soil stratum AR, (Enter value or 0)

ENTER Thickness of soil stratum AS, (Enter value or 0)

ENTER Thickness of soil stratum AT, (Enter value or 0)

ENTER Thickness of soil stratum AU, (Enter value or 0)

ENTER Thickness of soil stratum AV, (Enter value or 0)

ENTER Thickness of soil stratum AW, (Enter value or 0)

ENTER Thickness of soil stratum AX, (Enter value or 0)

ENTER Thickness of soil stratum AY, (Enter value or 0)

ENTER Thickness of soil stratum AZ, (Enter value or 0)

ENTER Thickness of soil stratum BA, (Enter value or 0)

ENTER Thickness of soil stratum BB, (Enter value or 0)

GROUNDWATER VOC EMISSIONS TO INDOOR AIR COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO LOW-PERMEABILITY (SILTY) SOILS

Chemical

Tetrachloroethylene

127184	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Average soil/groundwater temperature, T_s (°C)	L_s (cm)	Depth below grade of enclosed space floor, L_F (cm)	Depth below grade to water table, L_{WT} (cm)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0)	Thickness of soil stratum C, (Enter value or 0)	Thickness of soil stratum D, (Enter value or 0)	Thickness of soil stratum E, (Enter value or 0)	Thickness of soil stratum F, (Enter value or 0)	Thickness of soil stratum G, (Enter value or 0)	Thickness of soil stratum H, (Enter value or 0)	Thickness of soil stratum I, (Enter value or 0)
15	15	300	300	100	200							
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Soil dry bulk density, ρ_b^A (g/cm ³)	Soil total porosity, n^A (unitless)	Soil water-filled porosity, θ_w^A (cm ³ /cm ³)	Soil water-filled porosity, θ_w^A (cm ³ /cm ³)	Soil dry bulk density, ρ_b^B (g/cm ³)	Soil total porosity, n^B (unitless)	Soil water-filled porosity, θ_w^B (cm ³ /cm ³)	Soil dry bulk density, ρ_b^C (g/cm ³)	Soil total porosity, n^C (unitless)	Soil water-filled porosity, θ_w^C (cm ³ /cm ³)	Soil dry bulk density, ρ_b^D (g/cm ³)	Soil total porosity, n^D (unitless)	Soil water-filled porosity, θ_w^D (cm ³ /cm ³)
1.5	0.43	0.15	0.15	1.5	0.43	0.3						
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed space floor thickness, L_{CRACK} (cm)	Soil-bldg. pressure differential, ΔP (g/cm-s ²)	Enclosed space floor length, L_g (cm)	Enclosed space floor width, W_g (cm)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)					
15	40	961	961	961	244	0.1	2					
ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT _C (yrs)	Averaging time for noncarcinogens, AT _{NC} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target risk for noncarcinogens, TR (unitless)	Target hazard quotient for THO (unitless)	Used to calculate risk-based groundwater concentration.					
70	25	25	250	1.0E-06	0.2							

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant reference temperature, T_R ($^{\circ}\text{C}$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^{\circ}\text{K}$)	Critical temperature, T_C ($^{\circ}\text{K}$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\cdot\text{yr}^{-1}$)	Reference conc., RfC (mg/m^3)
---------------------------------------------------------------	-----------------------------------------------------------------	--------------------------------------------------------------------------------------------------------------	-----------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------	----------------------------------------------------------------	-------------------------------------------------------------	------------------------------------------------------------------------------------------	------------------------------------------------------------------------------	-----------------------------------------------------------------------------------	----------------------------------------------------------

7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.9E-06	6.0E-01
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END

Exposure duration, τ (sec)	7.88E+08	285	0.280	0.130	ERROR	0.265	1.64E-08	0.824	1.35E-08	163.04	0.43	0.048	0.382	3,844
Source-building separation, L_T (cm)														
Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)														
Stratum B soil air-filled porosity, θ_B (cm^3/cm^3)														
Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)														
Stratum A effective total fluid saturation, S_{fb} (cm^3/cm^3)														
Stratum A soil intrinsic permeability, k_i (cm^2)														
Stratum A soil relative air permeability, k_{rg} (cm^2)														
Stratum A soil effective vapor permeability, k_v (cm^2)														
Thickness of capillary zone, L_{cz} (cm)														
Total porosity in capillary zone, n_{cz} (cm^3/cm^3)														
Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)														
Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)														
Floor-wall seam perimeter, X_{seam} (cm)														

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)														
Area of enclosed space below grade, A_B (cm^2)														
Crack-to-total area ratio, η (unitless)														
Crack depth below grade, Z_{crack} (cm)														
Crack-enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)														
Henry's law constant at ave. groundwater temperature, H_{TS} (atm-m ³ /mol)														
Henry's law constant at ave. groundwater temperature, H_{TS} (unitless)														
Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)														
Stratum A effective diffusion coefficient, D_{eff}^A (cm^2/s)														
Stratum B effective diffusion coefficient, D_{eff}^B (cm^2/s)														
Stratum C effective diffusion coefficient, D_{eff}^C (cm^2/s)														
Capillary zone effective diffusion coefficient, D_{eff}^{cz} (cm^2/s)														
Total overall effective diffusion coefficient, D_{eff}^T (cm^2/s)														
Diffusion path length, L_d (cm)														

Convection path length, L_p (cm)	1.25E+05	9.24E+05	4.16E-04	15	9.502	1.05E-02	4.46E-01	1.77E-04	5.62E-03	4.38E-04	0.00E+00	2.02E-05	3.48E-05	285
Source vapor conc., C_{source} ($\mu\text{g}/\text{m}^3$)														
Average vapor flow rate into bldg., Q_{soil} (cm^3/s)														
Crack radius, r_{crack} (cm)														
Crack effective diffusion coefficient, D_{crack} (cm^2/s)														
Area of crack, A_{crack} (cm^2)														
Exponent of equivalent foundation Pecllet number, $\exp(Pe)$ (unitless)														
Infinite source indoor attenuation coefficient, α (unitless)														
Infinite source bldg. conc., $C_{building}$ ($\mu\text{g}/\text{m}^3$)														
Unit risk factor, URF ($\mu\text{g}/\text{m}^3\text{-}1$)														
Reference conc., RIC (mg/m ³)														

END

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)
1.49E+03	4.39E+05	1.49E+03	2.00E+05	1.49E+03

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)
 MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL
DOWN
TO "END"

END

SL-ADV
Version 2.3; 03/01

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES X

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES

**SOIL VOC EMISSIONS TO INDOOR AIR
RESIDENTIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS**

ENTER
Chemical
CAS No.
(numbers only,
no dashes)

127184

Chemical

Tetrachloroethylene

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Average soil temperature, T_s (°C)	Depth below grade to bottom of enclosed space floor, L_f (cm)	Depth below grade to top of contamination, L_t (cm)	Depth below grade to bottom of contamination, if value is unknown (enter value of 0)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, h_B (cm)	Thickness of soil stratum C, h_C (cm)	Totals must add up to value of L_t (cell D28)	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	User-defined stratum A soil vapor permeability, k_a (cm ²)
20	15	15	215	15				S	

MORE ↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	
Stratum A soil dry bulk density, ρ_b^A (g/cm ³)	Stratum A soil total porosity, n^A (unitless)	Stratum A soil water-filled porosity, θ_w^A (cm ³ /cm ³)	Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	Stratum B soil total porosity, n^B (unitless)	Stratum B soil dry bulk density, ρ_b^B (g/cm ³)	Stratum B soil water-filled porosity, θ_w^B (cm ³ /cm ³)	Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	Stratum C soil total porosity, n^C (unitless)	Stratum C soil dry bulk density, ρ_b^C (g/cm ³)	Stratum C soil water-filled porosity, θ_w^C (cm ³ /cm ³)	Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
1.5	0.43	0.15	0.006									

MORE ↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed floor thickness, L_{rock} (cm)	Soil-bldg. pressure differential, ΔP (g/cm-s ²)	Enclosed space floor length, L_b (cm)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)	Indoor air exchange rate, ER (1/h)
15	40	961	961	244	0.1	1	1

END

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT _C (yrs)	Averaging time for noncarcinogens, AT _{NC} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($atm \cdot m^3/mol$)	Henry's law constant reference temperature, T_R ($^{\circ}C$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^{\circ}K$)	Critical temperature, T_C ($^{\circ}K$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu g/m^3 \cdot s^{-1}$)	Reference conc., RfC (mg/m^3)	Physical state at soil temperature, (S, L, G)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.0E-06	3.5E-02	1.7E+02

END

Exposure duration, τ (sec)	9.46E+08	1	0.280	ERROR	0.257	1.01E-07	0.703	7.10E-08	3.844	1.00E+00	6.26E+04
Source-building separation, LT (cm)	Stratum A	Stratum B	Stratum C	Stratum A	Stratum A	Stratum A	Stratum A	Stratum A	Floor-wall seam perimeter, Xcrack (cm)	Initial soil concentration used, CR (mg/kg)	Bldg. ventilation rate, Obuilding (cm ³ /s)
	soil air-filled porosity, $\theta_{\alpha A}$ (cm ³ /cm ³)	soil air-filled porosity, $\theta_{\alpha B}$ (cm ³ /cm ³)	soil air-filled porosity, $\theta_{\alpha X}$ (cm ³ /cm ³)	effective total fluid saturation, Ste (cm ³ /cm ³)	soil intrinsic permeability, ki (cm ²)	soil relative air permeability, krg (cm ²)	soil effective vapor permeability, kv (cm ²)	soil effective vapor permeability, kv (cm ²)			

Area of enclosed space below grade, AB (cm ²)	9.24E+05	4.16E-04	15	10.138	2.28E-01	1.78E-04	5.46E-03	0.00E+00	0.00E+00	5.46E-03	1	15
Crack-to-total area ratio, η (unitless)	Crack depth below grade, Zcrack (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{\alpha, T_{\alpha}}$ (cal/mol)	Henry's law constant at ave. soil temperature, HTS (atm-m ³ /mol)	Henry's law constant at ave. soil temperature, HTS (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{T_{\alpha}}$ (g/cm-s)	effective diffusion coefficient, DeffA (cm ² /s)	effective diffusion coefficient, DeffB (cm ² /s)	effective diffusion coefficient, DeffC (cm ² /s)	Total overall effective diffusion coefficient, DeffT (cm ² /s)	Diffusion path length, Ld (cm)	Convection path length, Lp (cm)	

Soil-water partition coefficient, Kd (cm ³ /g)	9.30E-01	2.12E+02	0.10	6.74E+01	3.84E+02	1.41E+209	NA	NA	7.58E+01	7.73E-04	4.55E+07	YES
Source vapor conc., Csource (mg/m ³)	Source vapor conc., Crack radius, rcrack (cm)	Average vapor flow rate into bldg., Qsoil (cm ³ /s)	Crack effective diffusion coefficient, Dcrack (cm ² /s)	Crack effective diffusion coefficient, Dcrack (cm ² /s)	Area of crack, Acrack (cm ²)	Exponent of equivalent foundation Peclet number, exp(Pef) (unitless)	Infinite indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., Cbuilding (mg/m ³)	Finite source β (unitless)	Finite source ψ (sec) ⁻¹	Time for source depletion, τ_d (sec)	Exposure duration > source depletion (YES/NO)

Finite indoor attenuation coefficient, <a> (unitless)	NA	4.68E-03	NA	4.68E-03	6.0E-06	3.5E-02
Mass limit bldg. conc., Cbuilding (mg/m ³)	Finite source bldg. conc., Cbuilding (mg/m ³)	Final finite source conc., Cbuilding (mg/m ³)	Unit risk factor, URF (mg/m ³) ⁻¹	Reference conc., RIC (mg/m ³)		

END

INCREMENTAL RISK CALCULATIONS:

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
NA	NA

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C _{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
8.67E+01	7.80E+03	8.67E+01	2.15E+05	8.67E+01

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

MESSAGE: The values of C_{source} and C_{building} on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL DOWN TO "END"

END

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

SL-ADV
Version 2.3; 03/01

YES X OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES

**SOIL VOC EMISSIONS TO INDOOR AIR
COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS**

ENTER Initial soil conc., C_H ($\mu\text{g}/\text{kg}$)

127184 Tetrachloroethylene

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Chemical CAS No. (numbers only, no dashes)	Depth below grade to bottom of enclosed space floor, L_f (cm)	Depth below grade to bottom of contamination, L_b (cm)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, h_B (cm)	Thickness of soil stratum C, h_C (cm)	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	User-defined stratum A soil vapor permeability, k_v (cm^2)
20	15	215	15			S			

MORE ↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	Stratum A soil total porosity, n^A (unitless)	Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	Stratum B soil total porosity, n^B (unitless)	Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	Stratum C soil total porosity, n^C (unitless)	Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	Stratum C soil organic carbon fraction, f_{oc}^C (unitless)	Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	Stratum C soil organic carbon fraction, f_{oc}^C (unitless)	Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	Stratum C soil organic carbon fraction, f_{oc}^C (unitless)	Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
1.5	0.43	0.006																	

MORE ↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed space floor thickness, L_{crack} (cm)	Soil-bldg. pressure differential, ΔP ($\text{g}/\text{cm}^2\text{-s}^2$)	Enclosed space floor length, L_b (cm)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, W (cm)	Indoor air exchange rate, ER (1/h)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, W (cm)	Indoor air exchange rate, ER (1/h)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, W (cm)	Indoor air exchange rate, ER (1/h)	Enclosed space floor width, W_b (cm)	Enclosed space height, H_b (cm)	Floor-wall seam crack width, W (cm)	Indoor air exchange rate, ER (1/h)	Enclosed space floor width, W_b (cm)
15	40	961	961	244	0.1	2	961	244	0.1	2	961	244	0.1	2	961	244	0.1	2	961

MORE ↓

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT_c (yrs)	Averaging time for noncarcinogens, AT_{nc} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target risk for noncarcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target risk for noncarcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target risk for noncarcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)
70	25	25	250	1.0E-06	0.2	0.2	25	250	1.0E-06	0.2	0.2	25	250	1.0E-06	0.2	0.2	25	250	1.0E-06

END

Used to calculate risk-based soil concentration.

Diffusivity in air, D_a (cm^2/s)	Diffusivity in water, D_w (cm^2/s)	Henry's law constant at reference temperature, H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	Henry's law constant reference temperature, T_R ($^\circ\text{C}$)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, T_B ($^\circ\text{K}$)	Critical temperature, T_C ($^\circ\text{K}$)	Organic carbon partition coefficient, K_{oc} (cm^3/g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF ($\mu\text{g}/\text{m}^3\cdot\text{y}^{-1}$)	Reference conc., RfC (mg/m^3)	Physical state at soil temperature, (S,L,G)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	6.0E-06	3.5E-02	1.7E+02

END

Exposure duration, τ (sec)	7.88E+08	1	0.280	ERROR	ERROR	0.257	1.01E-07	0.703	7.10E-08	3.844	1.00E+00	1.25E+05
Source-building separation, LT (cm)												
Stratum A soil air-filled porosity, $\theta_{\alpha A}$ (cm ³ /cm ³)												
Stratum B soil air-filled porosity, $\theta_{\alpha B}$ (cm ³ /cm ³)												
Stratum C soil air-filled porosity, $\theta_{\alpha C}$ (cm ³ /cm ³)												
Stratum A effective total fluid saturation, S_{te} (cm ³ /cm ³)												
Stratum A soil intrinsic permeability, k_i (cm ²)												
Stratum A soil relative air permeability, k_{rg} (cm ²)												
Stratum A soil effective vapor permeability, k_v (cm ²)												
Floor-wall seam perimeter, X_{crack} (cm)												
Initial soil concentration used, CR (mg/kg)												
Bldg. ventilation rate, $Q_{building}$ (cm ³ /s)												

Area of enclosed space below grade, AB (cm ²)	9.24E+05	4.16E-04	15	9.451	1.40E-02	5.83E-01	1.78E-04	5.62E-03	0.00E+00	0.00E+00	5.62E-03	1	15
Crack-to-total area ratio, η (unitless)													
Crack depth below grade, Z _{crack} (cm)													
Enthalpy of vaporization at ave. soil temperature, $\Delta H_m, T_s$ (cal/mol)													
Henry's law constant at ave. soil temperature, HTS (atm-m ³ /mol)													
Henry's law constant at ave. soil temperature, HTS (unitless)													
Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)													
Stratum A effective diffusion coefficient, DeffA (cm ² /s)													
Stratum B effective diffusion coefficient, DeffB (cm ² /s)													
Stratum C effective diffusion coefficient, DeffC (cm ² /s)													
Total overall effective diffusion coefficient, DeffT (cm ² /s)													
Diffusion path length, L _d (cm)													
Convection path length, L _p (cm)													

Soil-water partition coefficient, K _d (cm ³ /g)	9.30E-01	5.12E+02	0.10	6.74E+01	5.62E-03	3.84E+02	2.23E+203	NA	NA	7.80E+01	1.92E-03	1.86E+07	YES
Source vapor conc., C _{source} (mg/m ³)													
Crack radius, r _{crack} (cm)													
Average vapor flow rate into bldg., Q _{soil} (cm ³ /s)													
Crack effective diffusion coefficient, D _{crack} (cm ² /s)													
Exponent of equivalent foundation Peclet number, exp(P _{ef}) (unitless)													
Infinite indoor attenuation coefficient, α (unitless)													
Infinite source bldg. conc., C _{building} (mg/m ³)													
Finite source depletion, τ_{β} (sec)													
Finite source depletion, τ_{β} (unitless)													
Finite source depletion, τ_{β} (sec) ⁻¹													
Exposure duration > time for source depletion (YES/NO)													

Finite source indoor attenuation coefficient, <a> (unitless)	NA	2.81E-03	NA	2.81E-03	6.0E-06	3.5E-02							
Mass limit bldg. conc., C _{building} (mg/m ³)													
Finite source bldg. conc., C _{building} (mg/m ³)													
Final finite source bldg. conc., C _{building} (mg/m ³)													
Unit risk factor, URF (mg/m ³) ⁻¹													
Reference conc., RFC (mg/m ³)													

END

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen ($\mu\text{g}/\text{kg}$)	Indoor exposure soil conc., noncarcinogen ($\mu\text{g}/\text{kg}$)	Risk-based indoor exposure soil conc., ($\mu\text{g}/\text{kg}$)	Soil saturation conc., C_{sat} ($\mu\text{g}/\text{kg}$)	Final indoor exposure soil conc., ($\mu\text{g}/\text{kg}$)	Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
2.43E+02	3.64E+03	2.43E+02	2.28E+05	2.43E+02	NA	NA

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)
 MESSAGE: The values of Csource and Cbuilding on the INTERCALCS worksheet are based on unity and do not represent actual values.

SCROLL
DOWN
TO "END"

END

INCREMENTAL RISK CALCULATIONS:

Soil Gas Concentration Data

**SOIL VOC EMISSIONS TO INDOOR AIR
RESIDENTIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS
SOIL GAS:INDOOR AIR ATTENUATION FACTOR = 0.001**

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu\text{g}/\text{m}^3$)	OR	ENTER Soil gas conc., C_g (ppmv)
--------------------------------------------------------------	-------------------------------------------------------------------------	----	---------------------------------------------------

127184	3.88E+02		
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Enter soil gas concentration in only one set of units.

Chemical

Tetrachloroethylene

ENTER Depth below grade to bottom of enclosed space floor, L_f (cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_s (°C)	ENTER Totals must add up to value of L_s (cell C24)		ENTER Soil stratum A SCS soil type soil vapor permeability, k_v (cm^2)
	15	10	ENTER Thickness of soil stratum A, h_a (cm)	ENTER Thickness of soil stratum B, h_b (cm)	ENTER Soil stratum C, soil type (Enter value or 0) h_c (cm)
15	15	15			S

MORE
↓

ENTER Soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
1.5	0.43	0.15						

MORE
↓

ENTER Enclosed space thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($\text{g}/\text{cm-s}^2$)	ENTER Enclosed space floor length, L_b (cm)	ENTER Enclosed space width, W_b (cm)	ENTER Enclosed space height, H_b (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)
15	40	961	961	244	0.1	1

MORE
↓

ENTER Averaging time for carcinogens, AT_c (yrs)	ENTER Averaging time for noncarcinogens, AT_{nc} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

END

Diffusivity in air, Da (cm ² /s)	Henry's law constant at reference temperature, H (atm-m ³ /mol)	Henry's law constant reference temperature, TR (oC)	Enthalpy of vaporization at the normal boiling point, ΔH_{vap} (cal/mol)	Normal boiling point, TB (oK)	Critical temperature, TC (oK)	Molecular weight, MW (g/mol)	Unit risk factor, URF (mg/m ³)-1	Reference conc., RfC (mg/m ³)	
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	165.83	6.9E-06	6.0E-01

END

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
----------------------------------------------------------------------------------------------	------------------------------------------------------------------------------------------------

1.2E-06	6.6E-04
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MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL
DOWN
TO "END"

END

Soil Gas Concentration Data

**SOIL VOC EMISSIONS TO INDOOR AIR
COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO
HIGH-PERMEABILITY (SANDY) SOILS
SOIL GAS:INDOOR AIR ATTENUATION FACTOR = 0.0005**

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu\text{g}/\text{m}^3$)	OR	ENTER Soil gas conc., C_g (ppmv)
127184	1.30E+03		

Enter soil gas concentration in only one set of units.

Chemical

Tetrachloroethylene

ENTER Depth below grade to bottom of enclosed space floor, L_f (cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_s (°C)	ENTER Totals must add up to value of L_s (cell C24)		ENTER Soil stratum A SCS soil type soil type soil vapor permeability, k_v (cm^2)
	15	10	15	ENTER Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum C, h_C (cm) (Enter value or 0)
15	15	10	15	ENTER Soil stratum A SCS soil type soil vapor permeability	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)

MORE
↓

ENTER Stratum A soil dry bulk density, ρ_w^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A bulk density, ρ_w^B (g/cm^3)	ENTER Stratum B soil dry bulk density, ρ_w^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum C soil dry bulk density, ρ_w^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
1.5	0.43	0.15							

MORE
↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($\text{g}/\text{cm}^2\text{-s}^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Enclosed space width, W_B (cm)	ENTER Floor-wall seam crack width, W (cm)	ENTER Indoor air exchange rate, ER (1/h)
15	40	961	244	961	0.1	2

MORE
↓

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	25	25	250

END

Diffusivity in air, Da (cm ² /s)	Diffusivity in water, Dw (cm ² /s)	Henry's law constant at reference temperature, H (atm-m ³ /mol)	Henry's law constant reference temperature, TR (oC)	Enthalpy of vaporization at the normal boiling point, ΔH _{v,β} (cal/mol)	Normal boiling point, TB (oK)	Critical temperature, TC (oK)	Molecular weight, MW (g/mol)	Unit risk factor, URF (mg/m ³)-1	Reference conc., RfC (mg/m ³)
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	165.83	6.9E-06	6.0E-01

END

Exposure duration, t (sec)	7.88E+08	Source-building separation, LT (cm)	1	Stratum A air-filled porosity, qaA (cm3/cm3)	0.28	Stratum B soil air-filled porosity, qaB (cm3/cm3)	ERROR	Stratum C air-filled porosity, qaC (cm3/cm3)	ERROR	Stratum A effective total fluid saturation, Ste (cm3/cm3)	0.25729443	Stratum A soil intrinsic permeability, ki (cm2)	9.92425E-08	Stratum A soil relative air permeability, krg (cm2)	0.703228129	Stratum A effective vapor permeability, kv (cm2)	6.97901E-08	Floor-wall seam perimeter, Xcrack (cm)	3844	Soil gas conc. (mg/m3)	1304	Bldg. ventilation rate, Qbuilding (cm3/s)	125188.4022
Area of enclosed space below grade, AB (cm2)	923521	Crack-to-total area ratio, h (unitless)	0.000416233	Crack depth below grade, Zcrack (cm)	15	Enthalpy of vaporization at ave. soil temperature, DHv,TS (cal/mol)	9552.934617	Henry's law constant at ave. soil temperature, HTS (atm-m3/mol)	7.83E-03	Henry's law constant at ave. soil temperature, HTS (unitless)	0.337067044	Vapor viscosity at ave. soil temperature, mTS (g/cm-s)	0.000175414	Stratum A effective diffusion coefficient, DeffA (cm2/s)	5.62E-03	Stratum B effective diffusion coefficient, DeffB (cm2/s)	0	Stratum C effective diffusion coefficient, DeffC (cm2/s)	0	Total overall effective diffusion coefficient, DeffT (cm2/s)	0.005616299	Diffusion path length, Ld (cm)	1
Convection path length, Lp (cm)	15	Source vapor conc., Csource (mg/m3)	1304	Crack radius, rcrack (cm)	0.1	Average vapor flow rate into bldg., Qsoil (cm3/s)	67.38925148	Crack effective diffusion coefficient, Dcrack (cm2/s)	0.005616299	Exponent of equivalent foundation Pecler number, exp(Pef) (unitless)	2.211E+203	Area of crack, Acrack (cm2)	384.4	Infinite source indoor attenuation coefficient, a (unitless)	0.000531398	Infinite source bldg. conc., Cbuilding (mg/m3)	0.692943596	Unit risk factor, URF (mg/m3)-1	0.0000069	Reference conc., RfC (mg/m3)	0.6		
END																							

Qsoil (L/min)
4.0

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
----------------------------------------------------------------------------	------------------------------------------------------------------------------

1.2E-06	7.9E-04
---------	---------

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL
DOWN
TO "END"

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APPENDIX 5

DEVELOPMENT OF SOIL LEACHING
SCREENING LEVELS

MADEP SESOIL ALGORITHM

The method used by the Ontario Ministry of Environment and Energy (MOEE 1996) to develop soil screening levels for leaching concerns was adopted from guidance published by the Massachusetts Department of Environment Protection (MADEP). This appendix provides relevant sections and appendices from the 1994 MADEP publication entitled "Background Documentation for the Development of the Massachusetts Contingency Plan Numerical Standards".

**BACKGROUND DOCUMENTATION
FOR THE DEVELOPMENT OF THE
MCP NUMERICAL STANDARDS**

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup
and
Office of Research and Standards

April 1994

MCP APPENDIX F

**DEVELOPMENT OF
DILUTION/ATTENUATION FACTORS
(DAFs)
FOR THE LEACHING-BASED
SOIL STANDARDS**

DEVELOPMENT OF DILUTION/ATTENUATION FACTORS (DAFs) FOR THE LEACHING-BASED SOIL STANDARDS

INTRODUCTION

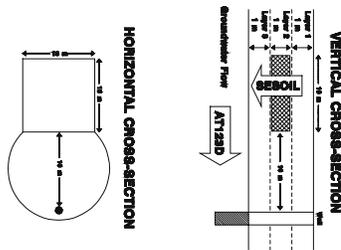
The Massachusetts Department of Environmental Protection has developed dilution attenuation factors (DAFs) in order to establish soil cleanup criteria for the protection of groundwater from leaching of residual contaminants in soil. DEP has adopted the modeling approach utilized by the State of Oregon in a similar process. This report describes the model and its application toward the development of DAFs for Massachusetts for a limited number of compounds of concern, and the subsequent development of one regression algorithm that relates DAFs developed by Oregon to those applicable in Massachusetts, and another algorithm that relates DAFs to chemical specific parameters. The pathway to groundwater is only one consideration in the final determination of an acceptable soil cleanup level.

THE OREGON MODEL

The Oregon model (Anderson, 1992) assumes a generic setting for a release of contaminant in the unsaturated zone and then applies the combination of SESOIL and AT123D models to estimate impact of the initial soil loading on a receptor assumed directly downgradient of the site via the groundwater pathway. The SESOIL and AT123D models, while previously individually developed (see References, Bonazountas, 1984 and Yeh, 1981), are a part of the risk assessment Graphical Exposure Modeling System (GEMS) developed by USEPA. A pc-based version of this (PCGEMS) was developed for USEPA by General Sciences Corporation (1989). The two models can now be linked so that SESOIL can pass leachate loadings to the saturated zone AT123D model.

The Oregon model's site setting (see Figure 1) assumes a 3-meter thick unsaturated zone, divided into three 1-meter layers. Contamination is initially released in the middle layer, as might occur for a leaking tank or for a residual contaminant remaining after some remedial excavation with clean cover backfill, and is uniformly distributed in this layer over a 10 meter by 10 meter area. The unsaturated zone and aquifer are assumed to be the same sandy soil with uniform properties. The upper and lower unsaturated zone layers are initially clean, as is the aquifer.

FIGURE 1
CONCEPTUAL SETTING



Source: Anderson (1991)

SESOIL inputs include the soil type parameters, chemical properties, application rates, and the climatic conditions of the area. The model is run as a transient monthly estimator of leachate volumes and concentrations. Initially, no other transport mechanisms other than leaching, partitioning, and volatilization were considered. Oregon used default values in SESOIL for Portland Oregon climatic conditions, but distributed total precipitation uniformly over the year.

SESOIL was initially found to overestimate losses via volatilization. A parameter, the volatilization fraction (VOLF), was introduced to allow adjustment of losses through this pathway and allow a site-specific calibration. This factor may be varied in time and space. The Oregon study used a uniform VOLF factor of 0.2, based on consultation with a panel of experts. One other soil-related parameter is the disconnectedness index. This parameter varies for and within soil types. Two values are given as SESOIL defaults, and the larger, 7.5, has been used in the simulations. An increase in this parameter appears to result in a higher soil moisture, lower leachate rates, and somewhat lower DAFs (i.e., is more conservative) for the compounds run.

AT123D inputs include general aquifer properties, source configuration, loadings to groundwater, soil partition coefficients, and dispersivity values. The aquifer is assumed to be infinitely wide and thick. The pc-based version of AT123D accepts monthly transient loading rates calculated by SESOIL, and also provides a preprocessor for input file preparation and editing. In utilizing the model, the center of the 10 by 10 meter source area is assumed to be at coordinates 0,0,0. The positive x-axis is in the direction of flow. Calculated concentrations are maximum along the x-axis ($y=0$) and at the water table surface ($z=0$). Since the receptor is assumed to be 10 meters from the downgradient edge of the source area, the concentration at $x=15$, $y=0$, and $z=0$ represents the receptor location. Oregon used longitudinal, transverse, and vertical dispersivities of 20m, 2m, and 2m, respectively. These values seem high for a sandy aquifer, but the values have been retained to be consistent with the Oregon base values and to be protective of the Commonwealth's sensitive aquifers on Cape Cod. DAFs are proportional to the dispersivities, particularly sensitive to the vertical dispersivity.

Oregon ran the model for 10 indicator compounds and then developed a multiple linear regression model relating the DAF to the organic partition coefficient (K_{oc}) and the Henry's Law constant (H) to provide preliminary DAFs for sixty other organic compounds. Soil cleanup levels were generated based on the regression algorithm and a safe drinking water level for each compound. In some cases, risk based levels determined by other pathways were lower than the levels required to protect groundwater. In these instances, the lower value was selected as the soil target level. A similar approach was taken to develop the MCP Method 1 Standards, as described in Section 5.3.

SIMULATIONS FOR MASSACHUSETTS

The approach taken to develop DAFs for Massachusetts was to determine the effect that varying the location (changing the climatic conditions from Portland, Oregon to Boston, Massachusetts in SESOIL) would have on the Oregon calculated DAFs. If the model system was essentially linear with respect to loading, then DAFs already calculated for Oregon would be directly related to DAFs appropriate for Massachusetts, and the general algorithm developed by Oregon (with coefficients adjusted) could also be used to estimate DAFs for other compounds. To this end, model runs were made using the Oregon input values for SESOIL and AT123D with the exception of climate parameter values. Eight indicator compounds were selected: benzene, toluene, ethylbenzene, o-xylene, trichloroethene, tetrachloroethene, 1,1,1-trichloroethane, and naphthalene.

The input values for SESOIL are shown in Tables F-1 through F-4, and those for AT123D are shown on Table F-5. Depending on the mobility of the compound through the transport pathway, model runs varied from 2 years to 6 years as necessary to determine the maximum concentration attained at the receptor location for a specific compound. A point to consider in the adoption of the Oregon values, or adjustments to them, is the need to agree with the physio-chemical parameters that were used to generate the DAFs. Even in the eight indicator compounds selected, various accepted databases provide some widely varying values for S, H and K_{oc} . For example, for PCE, H is reported with an order of magnitude difference, and values of K_{oc} and solubility differing by a factor of 2 are reported for ethylbenzene in the literature.

Output concentrations at the selected receptor location demonstrated a cyclical nature due to seasonal variations in precipitation and net recharge. Maximum concentrations were not always attained in the first cycle due to seasonal variability. However, the model output appeared to be linear with respect to the initial loading, allowing soil cleanup levels to be estimated based on the linear DAF approach. Table F-6 shows the model-based DAFs for Oregon and Massachusetts, and also, based on listed safe drinking water levels and the estimated DAFs for Massachusetts, what soil target levels would be for the eight indicator compounds run.

**TABLE F-1
CLIMATE PARAMETER VALUES
FOR THE SESOIL MODEL**

Default climate values for Boston as contained in the
SESOIL model. Latitude = 42 degrees.

TABLE F-2
SOIL PARAMETER VALUES
FOR THE SESOIL MODEL

Intrinsic permeability = $1 \times 10^{-7} \text{ cm}^2$
Source area = $1,000,000 \text{ cm}^2$
Porosity = 0.3
Disconnectedness index = 7.5
Soil bulk density = 1.5 gm/cm^3
Soil organic carbon = 0.1%

Layer 1 thickness = 100 cm
Layer 2 thickness = 100 cm
Layer 3 thickness = 100 cm
No further sublayering specified

Clay content = 0%

All other parameters set to zero
except those to indicate uniform
parameters in all layers.

**TABLE F-3
APPLICATIONS DATA
FOR SESOIL MODEL**

Application month = October only
layer = 2
rate = 1500 microgm/cm²
year = 1 only

Based on the area, thickness and bulk density, this produces an initial concentration of 10 ppm. No other sources are added.

Volatile fraction (VOLF) = 0.2

Uniform in time and space.

All other parameter values set to zero.

**TABLE F-4
CHEMICAL DATA FOR SESOIL MODEL**

Compound	MW	K_{oc} ml/g	S mg/L	H atm-m ³ /mol	DA cm ² /sec
benzene	78	83	1780	0.0055	0.109
ethylbenzene	106	575	161	0.00343	0.093
toluene	92	270	535	0.00668	0.100
o-xylene	106	302	171	0.00527	0.093
TCE	131	124	1100	0.00912	0.083
PCE	166	468	200	0.00204	0.075
1,1,1-TCA	133	157	730	0.0231	0.080
naphthalene	128	1288	31	0.00118	0.085

MW = molecular weight
 K_{oc} = organic carbon partition coefficient
S = solubility in water
H = Henry's Law constant
DA = diffusion coefficient in air

TABLE F-5
AT123D MODEL INPUT PARAMETER VALUES

Soil bulk density	= 1.5 g/cc
Porosity	= 0.3
Hydraulic conductivity	= 0.5 m/hr
Hydraulic gradient	= 0.005
Longitudinal dispersivity	= 20.0 m
Transverse dispersivity	= 2.0 m
Vertical dispersivity	= 2.0 m

Loading (kg/hr) passed by SESOIL link program
Distribution coefficient = K_{oc} * fraction organic carbon
Source area = 10 m by 10 m, centered at 0,0
initial z penetration = 0

Degradation rates initially zero

**TABLE F-6
MODEL OUTPUT DRAFT DAFS
COMPARISON AND SOIL LEVELS**

Oregon Compound	Mass DAF	DAF	DRINKING WATER LEVEL mg/L	SOIL TARGET LEVEL ppm
benzene	44.4	56.5	0.005	0.28
ethylbenzene	103.5	121.1	0.700	84.8
toluene	64.5	80.6	1.000	80.6
o-xylene	65.4	83.3	10.000	833.3
TCE	65.4	76.3	0.005	0.38
PCE	73.0	86.2	0.005	0.43
1,1,1-TCA	133.2	169.2	0.200	33.8
naphthalene	207.0	222.2	0.280	62.2

STATISTICAL RELATIONSHIPS

A linear regression was run on the eight DAF data pairs with DAFs for Oregon as the independent variable. The model was :

$$DAF_{\text{Mass}} = A + B * DAF_{\text{Oregon}}$$

That is, the regression was not forced through the origin. For the eight data pairs, the equation was

$$DAF_{\text{Mass}} = 12.39 + 1.053 * DAF_{\text{Oregon}}$$

with an r of 0.9913. Thus, over the range of data spanned by these eight compounds, the correlation appears good. Table F-7 shows a comparison of the DAFs calculated by the model and those by the linear regression equation above for the eight indicator compounds. Differences between the two methods are less than 10 percent.

A multiple linear regression algorithm for DAF(Mass) as a function of K_{oc} and H was also developed along the same lines as that developed by Oregon. This allows the calculation of DAFs for compounds for which Oregon did not consider, and which also may be used exclusively from the linear regression cited above. Two models were considered:

- (a) $DAF = A + B * H + C * K_{oc}$, and
- (b) $DAF = B * H + C * K_{oc}$.

where A, B, and C are regression coefficients. As with the Oregon analysis, it proved that the constant term was not statistically different from zero, and the simpler second model was adopted. Regression analysis yielded:

The fit here is somewhat better than the r-squared value of .956 for the Oregon model in that one compound with a large residual (carbon tetrachloride with a residual of 30) was not used here, and the average difference is much smaller with the eight compounds than for Oregon's ten. Table F-8 shows the relationship between the model DAFs and the regression expression predicted values. Only one compound varies more than 10 percent while six of the eight have percent differences less than five.

$$DAF = 6207 * H + 0.166 * K_{oc}$$

**TABLE F-7
COMPARISON BETWEEN MODEL DAFS
AND LINEAR REGRESSION DAFS
BASED ON OREGON DAFS**

Compound	Model DAF	Regr. DAF	%Diff.
benzene	56.5	59.1	4.60
ethylbenzene	121.1	121.4	0.25
toluene	80.6	80.3	-0.37
o-xylene	83.3	81.3	-2.40
TCE	76.3	81.3	6.55
PCE	86.2	89.3	3.60
1,1,1-TCA	169.2	152.6	-9.81
naphthalene	222.2	230.4	3.69

**TABLE F-8
RESULTS OF THE MULTIPLE LINEAR REGRESSION
EQUATION FOR H AND KOC**

Compound	Model DAF	Predicted	% Diff.
benzene	56.5	47.9	-15.2
ethylbenzene	121.1	116.7	- 3.6
toluene	80.6	86.3	7.1
o-xylene	83.3	82.8	- 0.5
TCE	76.3	77.2	1.2
PCE	86.2	90.4	4.9
1,1,1-TCA	169.2	169.4	0.1
naphthalene	222.2	221.1	- 0.5

BIODEGRADATION

It is intuitive that biodegradation may play an important role in attenuating the potential impact of residual contaminants in soils on groundwater. However, there are a great many site-specific conditions that will determine actual biodegradation rates. Further, literature values cover a wide range and the exact conditions under which they were estimated are rarely known. Literature values should be applied only with great caution

to any estimation of contaminant fate and transport. In order to evaluate the potential effect of biodegradation, rate constants cited by Howard et al (1991) were input to the model for the five compounds of the eight indicator compounds known to degrade aerobically. This eliminated the chlorinated compounds TCE, PCE, and 1,1,1-TCA. In addition, one additional rate for benzene (0.002/day from the California LUFT guidance) was also run. Four runs were made for benzene as the most critical compound, at the California rate, at the high and low rates cited by Howard and at the geometric mean of the Howard high and low rates. Only one rate, the low Howard value, was used for each of the other four compounds. The reason for this will be seen shortly.

The degradation rates in Howard appear to be high, with half lives for the BTEX compounds on the order of days. This implies that within a year, residual concentrations in soil would be reduced by biodegradation several (three to six) orders of magnitude. Table F-9 presents the results of the model runs.

For all situations except for the two lowest rates for benzene, the DAFs become huge. In essence, this indicates that only trace amounts of the contaminants ever reach the groundwater table. Soil target level estimation using large DAFs and the linear approach should be done only with extreme caution. A contaminant in the subsurface will attempt to reach equilibrium concentrations in the air, moisture and sorbed to soil. At some total concentration, equilibrium solubility in moisture would be exceeded, indicating the probable presence of free product. In this case, the linearity and basic assumptions in the model may be violated. Of further consideration are the potential toxic effects on the biological population as concentrations of the compounds increase. For these circumstances, estimation of soil target levels considering biodegradation is very difficult.

**TABLE F-9
RESULTS OF THE BIODEGRADATION RUNS**

Compound	Rate in Soil 1/day	Rate in Water 1/day	DAF

benzene	0.002	0.001 *	84.7
benzene	0.0433	0.000963	2178.
benzene	0.0775	0.00817	1.5×10^4
benzene	0.1386	0.0693	5.7×10^7
toluene	0.0315	0.02475	8.7×10^6
ethylbenzene	0.0693	0.00304	1.8×10^{13}
o-xylene	0.02475	0.001899	2.8×10^5
naphthalene	0.01444	0.00269	8.6×10^{10}

<p>* Note: Odencrantz's article on the California LUFT parameter values did not cite a rate for water. This was assumed here to be half that in soil. Note that not much more degradation occurs in the aquifer due to the rapid travel time to the receptor of about 11 to 12 days (large longitudinal dispersivity and low retardation).</p>			

SENSITIVITY

A detailed sensitivity analysis was not done at this point in time. However, Oregon did perform some sensitivity analyses, and sensitivity of these models as applied in California's LUFT program is discussed in another article (Odenchantz, et al, 1992)

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APPENDIX 6

RATIONAL FOR MOEE ECOTOXICITY-BASED SOIL CRITERIA

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**RATIONALE FOR
THE DEVELOPMENT AND APPLICATION
OF GENERIC SOIL, GROUNDWATER AND SEDIMENT
CRITERIA FOR USE AT
CONTAMINATED SITES IN ONTARIO**

Report prepared by:

Standards Development Branch
Ontario Ministry of Environment and Energy

December 1996

Report prepared for:

Ontario Ministry of Environment and Energy

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1 INTRODUCTION

This document describes the rationale behind the development of effects-based generic soil, groundwater and sediment quality criteria, to be used in place of the 1989 soil clean-up levels in the remediation of contaminated sites in Ontario. This rationale document replaces the document entitled "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development". The use and application of these criteria are described in the "Guideline for Use at Contaminated Sites in Ontario" (1996) which replaces the MOE 1989 "Guideline for the Decommissioning and Clean-up of Sites in Ontario" and the 1993 "Interim Guidelines for the Assessment and Management of Petroleum Contaminated Sites in Ontario".

This introduction is the first of four sections comprising the rationale document. Section 2 provides an overview of the environmental approach, guiding principles, and remediation options and their linkage with the criteria development process. Section 3 describes in detail, the process and assumptions used in the development of the soil and groundwater criteria. This includes a full description of the Massachusetts methodology that was adopted for use in Ontario, as well as the modifications and additional components that were utilized. All references utilized in this document are listed in Section 4. The criteria tables, on which decisions relating to site remediation will be based, are found in Appendix A. Also provided in Appendix A are summary tables of all criteria components. Additional scientific documents and supporting information for the development of the criteria are found in Appendix B.

2 OVERVIEW OF THE APPROACH, GUIDING PRINCIPLES AND MAJOR ASPECTS OF THE CRITERIA DEVELOPMENT PROCESS.

2.1 General Approach

The revision of the Ministry's 1989 guideline for the decommissioning and clean-up of contaminated sites is predicated on providing a more flexible, environmentally protective approach which will be applicable to a greater number of environmental contaminants and provide an increased level of guidance and remediation options to proponents. From an environmental aspect, this flexibility was achieved by more closely matching receptors and exposure pathways to land and groundwater use categories, and to the extent possible, to site conditions which affect contaminant transport and exposure.

The MOEE has participated in the development of a protocol for setting effects-based soil quality criteria under the National Contaminated Sites Remediation Program of the Canadian Council of Ministers of Environment (CCME). These protocols are summarized in the CCME document entitled "A Protocol for the Derivation of Ecological Effects Based and Human Health Based Soil Quality Criteria for Contaminated Sites." (1994). However, as the development of soil clean-up criteria based on CCME criteria documents will take several years, the MOEE explored other options to provide effects-based criteria.

The Department of Environmental Protection, Bureau of Waste Site Cleanup and the Office of Research and Standards for the Commonwealth of Massachusetts, have jointly produced chemical-specific standards for use under their revised Massachusetts Contingency Plan (MCP) which was promulgated in October 1993. Generic criteria for 106 inorganic/organic contaminants were developed using a risk characterization approach to provide protection to human and environmental health.

After a review of the general assumptions and multi-media components of the MCP approach, a decision was made to adopt and modify this approach for generic soil and groundwater "risk-based" site remediation criteria in Ontario. The MCP approach was selected as it appeared to best meet Ontario's needs for a large number of effects-based soil and groundwater criteria which address most potential human health and aquatic exposure pathways. It was also chosen because both the toxicological assessments and exposure scenarios carried out by the Massachusetts Department of Environmental Protection (DEP) had been subjected to extensive public consultation and had been promulgated as standards.

All assumptions for risk characterization, dose-response and toxicity information, methods, calculations and data inputs to the MCP standards development process are detailed in the Massachusetts document entitled "Background Documentation for the Development of the MCP Numerical Standards" (1994). The relevant portions of this document have been included in Appendix B.5. Modifications were made to various inputs into the MCP spreadsheets so that the criteria for the 106 chemicals would better represent the Ontario situation.

3.2.3 Additional Soil Criteria Components Incorporated by MOEE

3.2.3.1 Terrestrial Ecological Soil Criteria Component

The MCP approach addresses primarily human-health effects with some consideration of indirect ecological effects (aquatic) through the soil/groundwater leaching-based concentrations (GW-3).

However, there is no consideration for direct soil contact exposure for terrestrial ecological receptors. As MOEE is also committed to providing ecological protection, ecotoxicity criteria were included in the development process for soil criteria. Ontario ecological effects-based criteria for inorganics were incorporated into the process to develop surface restoration criteria for soils. The decision was made that terrestrial ecological protection for direct contact below the 1.5 meter depth, was not appropriate. Therefore, only human health and indirect ecological effects through leaching (via groundwater to surface water) were considered for sub-surface soil criteria (>1.5m depth).

The Netherlands have also developed ecosystem toxicity-based soil criteria for several inorganic and organic contaminants. These concentrations were utilized in the process when Ontario ecological criteria did not already exist. The Massachusetts DEP developed soil and groundwater criteria (based on human health) for 106 inorganic and organic chemicals. The integration of additional criteria for metals and inorganic parameters, based on ecological data, increased the soil chemical list to 115.

The following inorganic parameters were added to the soil criteria development process: barium, boron, chromium (total), cobalt, copper, molybdenum, electrical conductivity (mS/cm), nitrogen (total), and sodium absorption ratio (SAR).

The Massachusetts DEP chose to develop a human health risk-based criterion for chromium III and VI but not for total chromium. MOEE has ecological effects-based criteria for total chromium. Therefore, the committee decided to include total chromium on the chemical list. The Phytotoxicology Section of the MOEE Standards Development Branch has recently developed soil quality criteria for boron based on phytotoxicity effects data. Boron has been included in the chemical list; however, the boron criteria, which address the 'available' boron in soil are based on a 'hot water extract' rather than bulk soil analysis. The development of the boron criteria is described in detail in Appendix B.3.

3.2.3.1.1 Exposure Pathways and Protection of Ecological Receptors at Various Land Uses

In determining numerical criteria for soil based on potential ecological effects, it was necessary to make judgements as to what receptors should be protected and what level of protection was required for each land use category. A full range of philosophies exist, from protection against the earliest detectable effects to any species that could potentially occur on a site, or be affected by contamination at a site, to protection against the most severe of effects to very common

species which normally occur on sites of a particular land use category. The philosophy that is adopted can, therefore, strongly influence the final generic criteria derived. This section outlines the level of ecological protection which forms the basis for the development of the ecological criteria for each of the three land use categories: agricultural, residential/parkland and industrial/commercial.

To the extent permitted by available scientific evidence, these types of protection were incorporated into the criteria development process for each land use category. However, it must be stressed that in many cases, the lack of scientific evidence prohibited the development of an ecological component.

Agricultural Land Use Category

Soils that are to be used for agricultural purposes should be able to support the growth of a wide range of commercial crops as well as the raising of livestock. Contamination due to anthropogenic activities should not result in noticeable yield reductions of commercial crops that cannot be remedied through normal farming practices. Soil concentrations of chemical parameters also should be sufficiently low that there are no known or suspected adverse impacts on domestic grazing animals, including migratory and transitory wildlife, through both direct soil ingestion or through ingestion of plants grown on the soil. Since soil invertebrates and microorganisms provide important functions for the overall health of a soil, and the plants supported by the soil, these populations should not be adversely affected to the point where functions such as nutrient cycling, soil:root symbiotic relationships and decomposition are significantly reduced or impaired.

A consideration of all of the above factors also must recognize that in certain situations, agricultural chemicals are utilized because they are capable of selective toxicological action against undesirable plants and soil organisms. In these situations, a case specific approach will be necessary in the soil remediation process.

Residential/Parkland Land Use Category

The need for protection of commercial crops in the residential/parkland land use category is not as apparent as for agriculture; nevertheless, the common practice of growing backyard vegetable gardens and allotment gardens results in there being little practical difference between the plant species to be protected at residential sites and those at agricultural sites. Since parkland is included with residential land use in this category, it is also necessary to protect migratory and transitory species that may utilize such sites. The major difference from agricultural sites is that, for residential/parkland sites, the protection of domestic grazing animals such as sheep and cattle is not an important consideration.

Industrial/Commercial Land Use Category

It is not necessary to require as high a degree of protection for on-site ecological receptors at an industrial or commercial site as it is for agricultural or residential/parkland sites. The soil at industrial sites should be capable of supporting the growth of some native and ornamental trees, shrubs and grasses, but, it is not as important to protect against yield or growth reductions to the same extent as for residential and agricultural properties, nor to protect as wide a range of species. Since it would be highly undesirable to have transitory or migratory species being affected by utilizing any specific industrial or commercial property, criteria should be sufficiently protective to prevent such adverse effects on these species.

3.2.3.1.2 Existing MOEE Soil Clean-up/Decommissioning Guidelines (SCUGs)

The rationale on which the 1989 guidelines was based was described in the MOE publication "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development" (MOE, 1991). This publication has been replaced and relevant information applicable to those parameters that were utilized in the 1995 criteria development process can be found in Appendix B.3.

Soil clean-up criteria were developed for the following parameters: As, Cd, Cr (total), CrVI, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, Zn, soil pH range, Electrical Conductivity and Sodium Absorption Ratio. However, in the case of Cd, Pb, and Hg, the 1989 criteria were influenced more by human health considerations rather than ecological effects, and accordingly these criteria were discarded (with the exception of Cd for the agricultural land use category).

Re-examination of the rationale for the 1989 ecological criteria indicated that although the process was much less rigorous than the most recent CCME protocol for the development of ecological criteria, it did offer several important features:

- the criteria have been utilized in Ontario for 15 years without any evidence to indicate that protection was not provided
- the criteria have been widely adopted for use in other jurisdictions including the CCME without any evidence of problems
- early evidence from the new CCME process which has been applied to a limited number of parameters indicates that the 1989 ecological criteria are in reasonable agreement with the results from this process
- a thorough review of the available literature combined with an experimental program by the Phytotoxicology Section has confirmed that in the case of copper, the 1989 values are

fully in line with values that emerge from this type of analysis

Based on this assessment, a decision was made to incorporate the 1989 ecological criteria. The following additional considerations were utilized.

A strong argument can be made that the 1989 SCUGs for Cd (i.e. 3 ppm for coarse-textured soils and 4 ppm for medium/fine textured soils) are still valid for the agricultural use category. Cd is an element that is not readily eliminated in mammals, and it is known to bio-accumulate in tissue. Grazing animals that are ingesting Cd accumulated in plants growing on contaminated soils and from the soils themselves may be more at risk from Cd accumulation than is accounted for by any criterion higher than the current MOEE SCUG of 3 ppm (e.g. the Netherlands ecotoxicity criterion for Cd is 12 ug/g). It is known that wild ungulates grazing on lands with natural background Cd concentrations can accumulate Cd in the kidneys to the point where the kidneys are unfit for consumption. Some species of food plants (i.e. spinach and lettuce) have been observed to accumulate Cd in the edible portions of the plant to levels that would be of concern, even at relatively low soil Cd concentrations. Although the change of the Cd guideline from 3 µg/g to 12 ug may be suitable for residential purposes, there is little evidence that it takes the above factors into consideration for agricultural land uses.

The CCME draft document "A Protocol for the Derivation of Ecological Effects Based and Human-Health Based Soil Quality Criteria" (1994) contains some equations that are useful for estimating guidelines based on food ingestion and soil ingestion by animals utilizing the land. Using these equations and data presented in the draft CCME assessment document on Cadmium (Canadian Soil Quality Criteria for Contaminated Sites: Cadmium), a guideline of 3 µg Cd/g is indicated to be appropriate for agricultural use. These equations are presented below. For these reasons, it was decided to continue using the 3 µg/g guideline for cadmium for agricultural use unless and until there is substantial justification to indicate that it too should be changed. The following is a CCME calculation of soil quality criteria based on food ingestion by animals (e.g. cattle):

$$\begin{aligned} \text{EDFI} &= \text{DTED} \times \text{BW}/\text{FIR} \\ &= 0.0028 \text{ mg Cd kg}^{-1}\text{BW} \times \text{day}^{-1} \times 100\text{kg} / 3\text{kg day}^{-1} \\ &= 0.093 \text{ mg/kg dw food} \end{aligned}$$

$$\begin{aligned} \text{SQCfi} &= \text{EDFI} \times \text{Affi}/\text{BCF} \\ &= 0.093 \text{ mg/kg} \times 0.85/0.025 \\ &= 3.16 \text{ mg/kg} \end{aligned}$$

CCME calculation of soil quality criteria based on soil ingestion by animals

$$\text{EDFI} = \text{DTED} \times \text{BW}/\text{SIR}$$

$$= 0.0028 \text{ mg Cd kg}^{-1}\text{BW} \times \text{day}^{-1} \times 100\text{kg} / 0.54\text{kg day}^{-1}$$

$$= 0.519 \text{ mg/kg dw soil}$$

$$\text{SQCSI} = \text{EDSI} \times \text{AFsi} / \text{BF}$$

$$= 0.519 \text{ mg/kg} \times 0.18 / 0.025$$

$$= 3.74 \text{ mg/kg}$$

Where:

SQCFI =	Soil Quality Criteria for Food Ingestion
SQCSI =	Soil Quality Criteria for Soil Ingestion
EDFI =	Estimated dose for Food Ingestion
DTED =	Daily Threshold Effects Dose
BW =	Body Weight
FIR =	Food Ingestion Rate
SIR =	Soil Ingestion Rate
AFfi =	Apportionment factor for Food ingestion
AFsi =	Apportionment Factor for Soil Ingestion
BCF =	Bioconcentration Factor
BF =	Bioavailability Factor

The 1989 Cu, Mo, and Se SCUG criteria for agricultural/residential/parkland land uses were developed to protect grazing livestock. The industrial/commercial SCUG criteria for these three parameters provided protection to vegetation only. For this reason, the industrial/commercial SCUG criteria (for coarse-textured and medium-fine textured soils) were selected for both the residential/parkland and industrial/commercial land use categories where grazing animals are not likely to occur. The Cu, Mo and Se SCUG values that were based on protection of grazing livestock will apply to the agricultural land use category only.

The electrical conductivity of soil is essentially a measurement of the total concentration of soluble salts in the soil solution and can have a large osmotic influence on plant growth, as well as on soil organisms. The existing MOEE SCUGs for electrical conductivity (E.C.) of a soil required the use of a saturated extract. This procedure is time consuming and results are subjective; i.e. the end point of saturation is determined by the technician's expert opinion.

A fixed 2:1 water:soil procedure eliminates this uncertainty and provides a more rapid and reliable test. Both MOEE (Phytotoxicology Section) and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) now use the 2:1 procedure for most routine samples. The water:soil ratio used for the extract affects the resultant electrical conductivity; hence, the existing SCUG of 2.0 mS/cm (agricultural/residential/parkland) and 4.0 mS/cm (commercial/industrial) were adjusted to account for the change in water:soil ratio for this criterion.

Data in Extension Bulletin E-1736 (Michigan State University, 1983) made available to the committee by the Department of Land Resource Science, University of Guelph, show that for a given E.C., in saturation extract, the expected E.C. in a 2:1 water:soil ratio would be one third of the former. The appropriate E.C. for both agricultural and residential/parkland land use categories is 0.667 mS/cm. When rounded to 0.7 mS/cm, this value corresponds with the boundary between what McKeague (1978) states "may result in a slightly stunted condition in most plants" and "slight to severe burning of most plants". This is a reasonable concentration at which to establish the E.C. SCUG and confirmed the use of the divisor of 3 as a conversion factor. Using this conversion factor, the industrial/commercial SCUG for E.C. becomes 1.4 mS/cm.

Provisional soil clean-up guidelines were also produced in 1989 for Sb, Ba, Be and V for which the knowledge of their potential adverse phytotoxic effects was more limited than for the other inorganic parameters. These provisional criteria were also incorporated into the current modified criteria development process.

In all cases, MOE SCUG criteria values for coarse-textured soils, as well as medium and fine textured soils have been adopted from the 1989 guidelines for use in the current criteria development process. Coarse-textured soils are defined here as greater than 70% sand. The medium and fine textured soil SCUGs are 20-25% higher than the corresponding values for coarse-textured soils.

3.2.3.1.3 The Netherlands "C Level" Ecotoxicity Criteria

The Dutch government published soil and groundwater clean up guidelines, "ABC values", in 1983. These guidelines have undergone revision over the last 7 years to include both human health and ecological effects-based data. A new set of C-values has been proposed (Vegter, 1993). The final integrated C-value includes a human health component, as well as the ecological component, and includes risk management adjustments. The ecological component of the C-value is derived by taking the geometric mean or the average value of the logarithm of the No Observable Adverse Effect Concentration (NOEC) (Denneman and van Gestel, 1990). This means that the C-value represents the chemical concentration at which the NOEC for 50% of the ecological species has been exceeded.

For the purposes of this guideline, the ecotoxicity component of the C-value was incorporated into the soil criteria development process in all cases where a 1989 MOE SCUG value was not available. In addition to the references listed above, more information on the Dutch guidelines can be found in the following references: van den Berg and Roels (1993); van den Berg et al. (1993); and Denneman and Robberse (1990).

Appendix B.3: Rationale for MOEE Ecotoxicity-Based Soil Criteria.

(IN: *Rational For The Development And Application Of Generic Soil Groundwater, And Sediment Criteria For Use At Contaminated Sites In Ontario*, Standards Development Branch, Ontario Ministry of Environment and Energy, December 1996 (ISBN: 0-7778-2818-9))

Appendix B.3

This appendix replaces the rationale which was the basis for the 1989 ecotoxicity-based soil remediation criteria. The original rationale is described in the 1991 MOE publication entitled "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development". Those parameters in the original rationale, which were based on human health effects, have been removed. A rationale for a boron soil criterion (hot water extract), based on protection of vegetation and grazing animals, has been added.

All relevant information applicable to MOEE ecotoxicity-based soil values utilized in the 1995 soil remediation criteria development process are contained in the following sections. As more information on these and other soil parameters becomes available, the information will be included in this appendix as part of the rationale for deriving ecotoxicity criteria for soil remediation.

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1 BACKGROUND

In February, 1984, the Phytotoxicology Section was requested by the Halton-Peel District Office of the MOE to provide input into the development of soil criteria for the decommissioning of certain oil refinery lands. Proposed land uses made it desirable to have separate criteria for residential and industrial redevelopment. Monenco Consultants, on behalf of one of the oil companies, undertook a large-scale literature survey in an attempt to relate contaminant concentrations in soil to toxic effects on vegetation and animals. As a result of this effort, Monenco recommended site-specific ecotoxicity-based soil criteria for a number of contaminants (Monenco Ontario Ltd., 1984a & 1984b).

Subsequent to the above-described exercise, the Phytotoxicology Section was asked to recommend soil clean-up criteria for additional contaminants. Provisional criteria for these additional elements were developed, based on literature reviews. The Phytotoxicology Section was requested by the MOE Waste Management Branch to develop clean-up levels for agricultural land use. This request was brought to the attention of the Sludge and Waste Utilization Committee. It was the opinion of this Committee that the residential/parkland clean-up levels previously developed were, with minor modifications/qualifications, also suitable for application to agricultural situations.

2 RATIONALES FOR ECOTOXICITY-BASED SOIL CRITERIA

The recommended ecotoxicity-based soil remediation criteria are shown in Section 5.1 (Table 5.1). The rationales for their development include considerations of phytotoxicity and animal health. In general, the most conservative of these considerations was used to establish agricultural and residential soil criteria. Redevelopment as parkland also was felt to warrant this conservative approach, because parkland often is used by children at play, and occasionally is used for allotment gardening.

Different industrial/commercial remediation levels (normally set at twice the residential levels) were recommended where the residential and industrial criteria were both set on the same basis but where phytotoxic concerns were judged to be considerably less significant in the industrial/commercial environment. For two elements (molybdenum and selenium), residential soil remediation levels were established to prevent toxicity to grazing animals, whereas a higher industrial level was established to prevent toxicity to vegetation.

Provisional ecotoxicity-based soil remediation criteria recommended for four additional contaminants are shown in Section 5.2 (Table 5.2). Because knowledge of potential adverse effects of these elements in soil is generally more limited than for the Table 1 criteria, the provisional criteria were purposefully established in an even more conservative vein.

Since the mobility and availability of metals in soils may be highly dependent on form of

the metal, soil texture, pH and organic matter content, site-specific considerations of these parameters may reveal the suitability of different criteria. For example, where metals are known to be present in specific forms of very limited availability, higher levels may be considered. Furthermore, in researching the clean-up criteria, Monenco Consultants utilized data from studies on medium to fine textured soils (i.e. sandy soils excluded), in which mobility (availability) of metals would be lower than in coarse-textured sand (hence, metals are less likely to accumulate in sand than in clay). Therefore, it is recommended that the remediation levels for the metals and metalloids be reduced in the case of coarse-textured (greater than 70% sand) mineral soils (less than 17% organic matter). This recommendation is reflected in the remediation levels shown in Tables 5.1 and 5.2.

The rationales for individual parameters are summarized in the following sections (RATIONAL FOR As, B, Cr, Co, Cu, Mo, Ni, Ag, Zn, SAR, Sb, Ba, Be, V; NOT INCLUDED IN THIS APPENDIX).

APPENDIX 7

SUMMARY OF MADEP CARBON RANGE AND TOTAL PETROLEUM HYDROCARBON RISK-BASED SCREENING LEVELS

ISBN: 0-7778-2818-9

**RATIONALE FOR
THE DEVELOPMENT AND APPLICATION
OF GENERIC SOIL, GROUNDWATER AND SEDIMENT
CRITERIA FOR USE AT
CONTAMINATED SITES IN ONTARIO**

Report prepared by:

Standards Development Branch
Ontario Ministry of Environment and Energy

December 1996

Report prepared for:

Ontario Ministry of Environment and Energy

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1 INTRODUCTION

This document describes the rationale behind the development of effects-based generic soil, groundwater and sediment quality criteria, to be used in place of the 1989 soil clean-up levels in the remediation of contaminated sites in Ontario. This rationale document replaces the document entitled "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development". The use and application of these criteria are described in the "Guideline for Use at Contaminated Sites in Ontario" (1996) which replaces the MOE 1989 "Guideline for the Decommissioning and Clean-up of Sites in Ontario" and the 1993 "Interim Guidelines for the Assessment and Management of Petroleum Contaminated Sites in Ontario".

This introduction is the first of four sections comprising the rationale document. Section 2 provides an overview of the environmental approach, guiding principles, and remediation options and their linkage with the criteria development process. Section 3 describes in detail, the process and assumptions used in the development of the soil and groundwater criteria. This includes a full description of the Massachusetts methodology that was adopted for use in Ontario, as well as the modifications and additional components that were utilized. All references utilized in this document are listed in Section 4. The criteria tables, on which decisions relating to site remediation will be based, are found in Appendix A. Also provided in Appendix A are summary tables of all criteria components. Additional scientific documents and supporting information for the development of the criteria are found in Appendix B.

2 OVERVIEW OF THE APPROACH, GUIDING PRINCIPLES AND MAJOR ASPECTS OF THE CRITERIA DEVELOPMENT PROCESS.

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The revision of the Ministry's 1989 guideline for the decommissioning and clean-up of contaminated sites is predicated on providing a more flexible, environmentally protective approach which will be applicable to a greater number of environmental contaminants and provide an increased level of guidance and remediation options to proponents. From an environmental aspect, this flexibility was achieved by more closely matching receptors and exposure pathways to land and groundwater use categories, and to the extent possible, to site conditions which affect contaminant transport and exposure.

The MOEE has participated in the development of a protocol for setting effects-based soil quality criteria under the National Contaminated Sites Remediation Program of the Canadian Council of Ministers of Environment (CCME). These protocols are summarized in the CCME document entitled "A Protocol for the Derivation of Ecological Effects Based and Human Health Based Soil Quality Criteria for Contaminated Sites." (1994). However, as the development of soil clean-up criteria based on CCME criteria documents will take several years, the MOEE explored other options to provide effects-based criteria.

The Department of Environmental Protection, Bureau of Waste Site Cleanup and the Office of Research and Standards for the Commonwealth of Massachusetts, have jointly produced chemical-specific standards for use under their revised Massachusetts Contingency Plan (MCP) which was promulgated in October 1993. Generic criteria for 106 inorganic/organic contaminants were developed using a risk characterization approach to provide protection to human and environmental health.

After a review of the general assumptions and multi-media components of the MCP approach, a decision was made to adopt and modify this approach for generic soil and groundwater "risk-based" site remediation criteria in Ontario. The MCP approach was selected as it appeared to best meet Ontario's needs for a large number of effects-based soil and groundwater criteria which address most potential human health and aquatic exposure pathways. It was also chosen because both the toxicological assessments and exposure scenarios carried out by the Massachusetts Department of Environmental Protection (DEP) had been subjected to extensive public consultation and had been promulgated as standards.

All assumptions for risk characterization, dose-response and toxicity information, methods, calculations and data inputs to the MCP standards development process are detailed in the Massachusetts document entitled "Background Documentation for the Development of the MCP Numerical Standards" (1994). The relevant portions of this document have been included in Appendix B.5. Modifications were made to various inputs into the MCP spreadsheets so that the criteria for the 106 chemicals would better represent the Ontario situation.

3.2.3 Additional Soil Criteria Components Incorporated by MOEE

3.2.3.1 Terrestrial Ecological Soil Criteria Component

The MCP approach addresses primarily human-health effects with some consideration of indirect ecological effects (aquatic) through the soil/groundwater leaching-based concentrations (GW-3).

However, there is no consideration for direct soil contact exposure for terrestrial ecological receptors. As MOEE is also committed to providing ecological protection, ecotoxicity criteria were included in the development process for soil criteria. Ontario ecological effects-based criteria for inorganics were incorporated into the process to develop surface restoration criteria for soils. The decision was made that terrestrial ecological protection for direct contact below the 1.5 meter depth, was not appropriate. Therefore, only human health and indirect ecological effects through leaching (via groundwater to surface water) were considered for sub-surface soil criteria (>1.5m depth).

The Netherlands have also developed ecosystem toxicity-based soil criteria for several inorganic and organic contaminants. These concentrations were utilized in the process when Ontario ecological criteria did not already exist. The Massachusetts DEP developed soil and groundwater criteria (based on human health) for 106 inorganic and organic chemicals. The integration of additional criteria for metals and inorganic parameters, based on ecological data, increased the soil chemical list to 115.

The following inorganic parameters were added to the soil criteria development process: barium, boron, chromium (total), cobalt, copper, molybdenum, electrical conductivity (mS/cm), nitrogen (total), and sodium absorption ratio (SAR).

The Massachusetts DEP chose to develop a human health risk-based criterion for chromium III and VI but not for total chromium. MOEE has ecological effects-based criteria for total chromium. Therefore, the committee decided to include total chromium on the chemical list. The Phytotoxicology Section of the MOEE Standards Development Branch has recently developed soil quality criteria for boron based on phytotoxicity effects data. Boron has been included in the chemical list; however, the boron criteria, which address the 'available' boron in soil are based on a 'hot water extract' rather than bulk soil analysis. The development of the boron criteria is described in detail in Appendix B.3.

3.2.3.1.1 Exposure Pathways and Protection of Ecological Receptors at Various Land Uses

In determining numerical criteria for soil based on potential ecological effects, it was necessary to make judgements as to what receptors should be protected and what level of protection was required for each land use category. A full range of philosophies exist, from protection against the earliest detectable effects to any species that could potentially occur on a site, or be affected by contamination at a site, to protection against the most severe of effects to very common

species which normally occur on sites of a particular land use category. The philosophy that is adopted can, therefore, strongly influence the final generic criteria derived. This section outlines the level of ecological protection which forms the basis for the development of the ecological criteria for each of the three land use categories: agricultural, residential/parkland and industrial/commercial.

To the extent permitted by available scientific evidence, these types of protection were incorporated into the criteria development process for each land use category. However, it must be stressed that in many cases, the lack of scientific evidence prohibited the development of an ecological component.

Agricultural Land Use Category

Soils that are to be used for agricultural purposes should be able to support the growth of a wide range of commercial crops as well as the raising of livestock. Contamination due to anthropogenic activities should not result in noticeable yield reductions of commercial crops that cannot be remedied through normal farming practices. Soil concentrations of chemical parameters also should be sufficiently low that there are no known or suspected adverse impacts on domestic grazing animals, including migratory and transitory wildlife, through both direct soil ingestion or through ingestion of plants grown on the soil. Since soil invertebrates and microorganisms provide important functions for the overall health of a soil, and the plants supported by the soil, these populations should not be adversely affected to the point where functions such as nutrient cycling, soil:root symbiotic relationships and decomposition are significantly reduced or impaired.

A consideration of all of the above factors also must recognize that in certain situations, agricultural chemicals are utilized because they are capable of selective toxicological action against undesirable plants and soil organisms. In these situations, a case specific approach will be necessary in the soil remediation process.

Residential/Parkland Land Use Category

The need for protection of commercial crops in the residential/parkland land use category is not as apparent as for agriculture; nevertheless, the common practice of growing backyard vegetable gardens and allotment gardens results in there being little practical difference between the plant species to be protected at residential sites and those at agricultural sites. Since parkland is included with residential land use in this category, it is also necessary to protect migratory and transitory species that may utilize such sites. The major difference from agricultural sites is that, for residential/parkland sites, the protection of domestic grazing animals such as sheep and cattle is not an important consideration.

Industrial/Commercial Land Use Category

It is not necessary to require as high a degree of protection for on-site ecological receptors at an industrial or commercial site as it is for agricultural or residential/parkland sites. The soil at industrial sites should be capable of supporting the growth of some native and ornamental trees, shrubs and grasses, but, it is not as important to protect against yield or growth reductions to the same extent as for residential and agricultural properties, nor to protect as wide a range of species. Since it would be highly undesirable to have transitory or migratory species being affected by utilizing any specific industrial or commercial property, criteria should be sufficiently protective to prevent such adverse effects on these species.

3.2.3.1.2 Existing MOEE Soil Clean-up/Decommissioning Guidelines (SCUGs)

The rationale on which the 1989 guidelines was based was described in the MOE publication "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development" (MOE, 1991). This publication has been replaced and relevant information applicable to those parameters that were utilized in the 1995 criteria development process can be found in Appendix B.3.

Soil clean-up criteria were developed for the following parameters: As, Cd, Cr (total), CrVI, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, Zn, soil pH range, Electrical Conductivity and Sodium Absorption Ratio. However, in the case of Cd, Pb, and Hg, the 1989 criteria were influenced more by human health considerations rather than ecological effects, and accordingly these criteria were discarded (with the exception of Cd for the agricultural land use category).

Re-examination of the rationale for the 1989 ecological criteria indicated that although the process was much less rigorous than the most recent CCME protocol for the development of ecological criteria, it did offer several important features:

- the criteria have been utilized in Ontario for 15 years without any evidence to indicate that protection was not provided
- the criteria have been widely adopted for use in other jurisdictions including the CCME without any evidence of problems
- early evidence from the new CCME process which has been applied to a limited number of parameters indicates that the 1989 ecological criteria are in reasonable agreement with the results from this process
- a thorough review of the available literature combined with an experimental program by the Phytotoxicology Section has confirmed that in the case of copper, the 1989 values are

fully in line with values that emerge from this type of analysis

Based on this assessment, a decision was made to incorporate the 1989 ecological criteria. The following additional considerations were utilized.

A strong argument can be made that the 1989 SCUGs for Cd (i.e. 3 ppm for coarse-textured soils and 4 ppm for medium/fine textured soils) are still valid for the agricultural use category. Cd is an element that is not readily eliminated in mammals, and it is known to bio-accumulate in tissue. Grazing animals that are ingesting Cd accumulated in plants growing on contaminated soils and from the soils themselves may be more at risk from Cd accumulation than is accounted for by any criterion higher than the current MOEE SCUG of 3 ppm (e.g. the Netherlands ecotoxicity criterion for Cd is 12 ug/g). It is known that wild ungulates grazing on lands with natural background Cd concentrations can accumulate Cd in the kidneys to the point where the kidneys are unfit for consumption. Some species of food plants (i.e. spinach and lettuce) have been observed to accumulate Cd in the edible portions of the plant to levels that would be of concern, even at relatively low soil Cd concentrations. Although the change of the Cd guideline from 3 µg/g to 12 ug may be suitable for residential purposes, there is little evidence that it takes the above factors into consideration for agricultural land uses.

The CCME draft document "A Protocol for the Derivation of Ecological Effects Based and Human-Health Based Soil Quality Criteria" (1994) contains some equations that are useful for estimating guidelines based on food ingestion and soil ingestion by animals utilizing the land. Using these equations and data presented in the draft CCME assessment document on Cadmium (Canadian Soil Quality Criteria for Contaminated Sites: Cadmium), a guideline of 3 µg Cd/g is indicated to be appropriate for agricultural use. These equations are presented below. For these reasons, it was decided to continue using the 3 µg/g guideline for cadmium for agricultural use unless and until there is substantial justification to indicate that it too should be changed. The following is a CCME calculation of soil quality criteria based on food ingestion by animals (e.g. cattle):

$$\begin{aligned} \text{EDFI} &= \text{DTED} \times \text{BW}/\text{FIR} \\ &= 0.0028 \text{ mg Cd kg}^{-1}\text{BW} \times \text{day}^{-1} \times 100\text{kg} / 3\text{kg day}^{-1} \\ &= 0.093 \text{ mg/kg dw food} \end{aligned}$$

$$\begin{aligned} \text{SQCFI} &= \text{EDFI} \times \text{AFfi}/\text{BCF} \\ &= 0.093 \text{ mg/kg} \times 0.85/0.025 \\ &= 3.16 \text{ mg/kg} \end{aligned}$$

CCME calculation of soil quality criteria based on soil ingestion by animals

$$\text{EDFI} = \text{DTED} \times \text{BW}/\text{SIR}$$

$$= 0.0028 \text{ mg Cd kg-1BW x day-1 x 100kg} / 0.54\text{kg day-1}$$

$$= 0.519 \text{ mg/kg dw soil}$$

$$\text{SQCSI} = \text{EDSI} \times \text{AFsi} / \text{BF}$$

$$= 0.519 \text{ mg/kg} \times 0.18 / 0.025$$

$$= 3.74 \text{ mg/kg}$$

Where:

SQCFI =	Soil Quality Criteria for Food Ingestion
SQCSI =	Soil Quality Criteria for Soil Ingestion
EDFI =	Estimated dose for Food Ingestion
DTED =	Daily Threshold Effects Dose
BW =	Body Weight
FIR =	Food Ingestion Rate
SIR =	Soil Ingestion Rate
AFfi =	Apportionment factor for Food ingestion
AFsi =	Apportionment Factor for Soil Ingestion
BCF =	Bioconcentration Factor
BF =	Bioavailability Factor

The 1989 Cu, Mo, and Se SCUG criteria for agricultural/residential/parkland land uses were developed to protect grazing livestock. The industrial/commercial SCUG criteria for these three parameters provided protection to vegetation only. For this reason, the industrial/commercial SCUG criteria (for coarse-textured and medium-fine textured soils) were selected for both the residential/parkland and industrial/commercial land use categories where grazing animals are not likely to occur. The Cu, Mo and Se SCUG values that were based on protection of grazing livestock will apply to the agricultural land use category only.

The electrical conductivity of soil is essentially a measurement of the total concentration of soluble salts in the soil solution and can have a large osmotic influence on plant growth, as well as on soil organisms. The existing MOEE SCUGs for electrical conductivity (E.C.) of a soil required the use of a saturated extract. This procedure is time consuming and results are subjective; i.e. the end point of saturation is determined by the technician's expert opinion.

A fixed 2:1 water:soil procedure eliminates this uncertainty and provides a more rapid and reliable test. Both MOEE (Phytotoxicology Section) and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) now use the 2:1 procedure for most routine samples. The water:soil ratio used for the extract affects the resultant electrical conductivity; hence, the existing SCUG of 2.0 mS/cm (agricultural/residential/parkland) and 4.0 mS/cm (commercial/industrial) were adjusted to account for the change in water:soil ratio for this criterion.

Data in Extension Bulletin E-1736 (Michigan State University, 1983) made available to the committee by the Department of Land Resource Science, University of Guelph, show that for a given E.C., in saturation extract, the expected E.C. in a 2:1 water:soil ratio would be one third of the former. The appropriate E.C. for both agricultural and residential/parkland land use categories is 0.667 mS/cm. When rounded to 0.7 mS/cm, this value corresponds with the boundary between what McKeague (1978) states "may result in a slightly stunted condition in most plants" and "slight to severe burning of most plants". This is a reasonable concentration at which to establish the E.C. SCUG and confirmed the use of the divisor of 3 as a conversion factor. Using this conversion factor, the industrial/commercial SCUG for E.C. becomes 1.4 mS/cm.

Provisional soil clean-up guidelines were also produced in 1989 for Sb, Ba, Be and V for which the knowledge of their potential adverse phytotoxic effects was more limited than for the other inorganic parameters. These provisional criteria were also incorporated into the current modified criteria development process.

In all cases, MOE SCUG criteria values for coarse-textured soils, as well as medium and fine textured soils have been adopted from the 1989 guidelines for use in the current criteria development process. Coarse-textured soils are defined here as greater than 70% sand. The medium and fine textured soil SCUGs are 20-25% higher than the corresponding values for coarse-textured soils.

3.2.3.1.3 The Netherlands "C Level" Ecotoxicity Criteria

The Dutch government published soil and groundwater clean up guidelines, "ABC values", in 1983. These guidelines have undergone revision over the last 7 years to include both human health and ecological effects-based data. A new set of C-values has been proposed (Vegter, 1993). The final integrated C-value includes a human health component, as well as the ecological component, and includes risk management adjustments. The ecological component of the C-value is derived by taking the geometric mean or the average value of the logarithm of the No Observable Adverse Effect Concentration (NOEC) (Denneman and van Gestel, 1990). This means that the C-value represents the chemical concentration at which the NOEC for 50% of the ecological species has been exceeded.

For the purposes of this guideline, the ecotoxicity component of the C-value was incorporated into the soil criteria development process in all cases where a 1989 MOE SCUG value was not available. In addition to the references listed above, more information on the Dutch guidelines can be found in the following references: van den Berg and Roels (1993); van den Berg et al. (1993); and Denneman and Robberse (1990).

Appendix B.3: Rationale for MOEE Ecotoxicity-Based Soil Criteria.

(IN: *Rational For The Development And Application Of Generic Soil Groundwater, And Sediment Criteria For Use At Contaminated Sites In Ontario*, Standards Development Branch, Ontario Ministry of Environment and Energy, December 1996 (ISBN: 0-7778-2818-9)

Appendix B.3

This appendix replaces the rationale which was the basis for the 1989 ecotoxicity-based soil remediation criteria. The original rationale is described in the 1991 MOE publication entitled "Soil Clean-up Guidelines for Decommissioning of Industrial Lands: Background and Rationale for Development". Those parameters in the original rationale, which were based on human health effects, have been removed. A rationale for a boron soil criterion (hot water extract), based on protection of vegetation and grazing animals, has been added.

All relevant information applicable to MOEE ecotoxicity-based soil values utilized in the 1995 soil remediation criteria development process are contained in the following sections. As more information on these and other soil parameters becomes available, the information will be included in this appendix as part of the rationale for deriving ecotoxicity criteria for soil remediation.

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1 BACKGROUND

In February, 1984, the Phytotoxicology Section was requested by the Halton-Peel District Office of the MOE to provide input into the development of soil criteria for the decommissioning of certain oil refinery lands. Proposed land uses made it desirable to have separate criteria for residential and industrial redevelopment. Monenco Consultants, on behalf of one of the oil companies, undertook a large-scale literature survey in an attempt to relate contaminant concentrations in soil to toxic effects on vegetation and animals. As a result of this effort, Monenco recommended site-specific ecotoxicity-based soil criteria for a number of contaminants (Monenco Ontario Ltd., 1984a & 1984b).

Subsequent to the above-described exercise, the Phytotoxicology Section was asked to recommend soil clean-up criteria for additional contaminants. Provisional criteria for these additional elements were developed, based on literature reviews. The Phytotoxicology Section was requested by the MOE Waste Management Branch to develop clean-up levels for agricultural land use. This request was brought to the attention of the Sludge and Waste Utilization Committee. It was the opinion of this Committee that the residential/parkland clean-up levels previously developed were, with minor modifications/qualifications, also suitable for application to agricultural situations.

2 RATIONALES FOR ECOTOXICITY-BASED SOIL CRITERIA

The recommended ecotoxicity-based soil remediation criteria are shown in Section 5.1 (Table 5.1). The rationales for their development include considerations of phytotoxicity and animal health. In general, the most conservative of these considerations was used to establish agricultural and residential soil criteria. Redevelopment as parkland also was felt to warrant this conservative approach, because parkland often is used by children at play, and occasionally is used for allotment gardening.

Different industrial/commercial remediation levels (normally set at twice the residential levels) were recommended where the residential and industrial criteria were both set on the same basis but where phytotoxic concerns were judged to be considerably less significant in the industrial/commercial environment. For two elements (molybdenum and selenium), residential soil remediation levels were established to prevent toxicity to grazing animals, whereas a higher industrial level was established to prevent toxicity to vegetation.

Provisional ecotoxicity-based soil remediation criteria recommended for four additional contaminants are shown in Section 5.2 (Table 5.2). Because knowledge of potential adverse effects of these elements in soil is generally more limited than for the Table 1 criteria, the provisional criteria were purposefully established in an even more conservative vein.

Since the mobility and availability of metals in soils may be highly dependent on form of

the metal, soil texture, pH and organic matter content, site-specific considerations of these parameters may reveal the suitability of different criteria. For example, where metals are known to be present in specific forms of very limited availability, higher levels may be considered. Furthermore, in researching the clean-up criteria, Monenco Consultants utilized data from studies on medium to fine textured soils (i.e. sandy soils excluded), in which mobility (availability) of metals would be lower than in coarse-textured sand (hence, metals are less likely to accumulate in sand than in clay). Therefore, it is recommended that the remediation levels for the metals and metalloids be reduced in the case of coarse-textured (greater than 70% sand) mineral soils (less than 17% organic matter). This recommendation is reflected in the remediation levels shown in Tables 5.1 and 5.2.

The rationales for individual parameters are summarized in the following sections (RATIONAL FOR As, B, Cr, Co, Cu, Mo, Ni, Ag, Zn, SAR, Sb, Ba, Be, V; NOT INCLUDED IN THIS APPENDIX).

APPENDIX 8

DETERMINATION OF GROUNDWATER UTILITY
(SEPTEMBER 19, 1995)



STATE OF HAWAII
DEPARTMENT OF HEALTH
ENVIRONMENTAL MANAGEMENT DIVISION
SOLID AND HAZARDOUS WASTE BRANCH
919 ALA MOANA BLVD., #212
HONOLULU, HAWAII 96814

in reply, please refer to:
EMD / SHW

September 19, 1995

POLICY UPDATE
Technical Guidance Manual
for Underground Storage Tank Closure and Release Response

**Determination of Groundwater Utility
at Leaking Underground Storage Tank Sites**

TO ALL INTERESTED PARTIES:

The Hawai'i Department of Health's Solid and Hazardous Waste Branch, Underground Storage Tank Section, is issuing a policy update to its *Technical Guidance Manual for Underground Storage Tank Closure and Release Response* (August 1992). **This policy update is effective September 13, 1995.**

Recommended cleanup criteria at leaking underground storage tank (LUST) sites depend on, among other things, whether the ground water underlying the site is used or intended for use as a drinking water source. This policy directs owners and operators of USTs to use the aquifer system classification reports developed by the University of Hawai'i at Mānoa's Water Resources Research Center in determining the use of the ground water underlying the site.

This new policy allows for more efficient allocation of limited cleanup resources by ensuring that cleanup requirements applied to a site are appropriate for the use of the site and the surrounding area, while at the same time maintaining effective protection of human health and the environment.

Please bring this policy update to the attention of anyone you know who may have an interest in this matter. Should you have any questions regarding this policy update, please contact the Underground Storage Tank Section at (808) 586-4226.

Sincerely,


STEVEN Y.K. CHANG, P.E., MANAGER
Solid and Hazardous Waste Branch

Attachment

DETERMINATION OF GROUNDWATER UTILITY
AT LEAKING UNDERGROUND STORAGE TANK SITES

Background

Soil and groundwater cleanup criteria for remedial activities pursuant to 40 CFR Part 280 Subpart F (RCRA I) and Hawai'i Revised Statutes, Chapters 342L and 128D, are based in part on the utility of the groundwater impacted or potentially impacted by the release. Cleanup criteria for release that threaten sources of drinking water are based primarily on human health concerns. Cleanup criteria for releases that threaten non-drinking water sources are based primarily on ecological/aquatic-life concerns. In general, cleanup criteria for releases that threaten drinking water are much more stringent than for those that do not.

As a useful first approximation, and in order to help maintain consistency in groundwater protection policies within the Department of Health (DOH), the SHWB informally adopted the Underground Injection Control (UIC) line as an initial demarcation between aquifer systems that serve or could potentially serve as sources of drinking water (generally beneath the inland areas of the islands) and those that could not (generally beneath the coastal areas of the islands). The UIC line was established by the DOH Safe Drinking Water Branch (working in cooperation with the Honolulu City & County Board of Water Supply, the U.S. Geological Survey, and the Water Resources Research Center of the University of Hawai'i - Mānoa, among others) for purposes of regulating the location of underground injection wells. Reference to the use of the UIC line for SHWB purposes is made in the document "Technical Guidance Manual for Underground Storage Tank (UST) Closure and Release Response (TGM, August, 1992)," prepared by the UST Section of the SHWB.

In accordance with UIC guidelines, aquifer systems mauka (inland) of the UIC line are by default considered to be current or potential sources of drinking water. Aquifer systems makai (oceanward) of the UIC line are considered by default to not be current or potential sources of drinking water. Correspondingly, cleanup criteria for release sites located mauka of the UIC line are initially set to be protective to drinking water standards. Cleanup criteria for release sites located makai of the UIC line are initially set to be protective to generally less stringent non-drinking water (surface water) standards.

Statement of Problem

The UST section of the SHWB deals with hundreds of facilities with leaking underground storage tank (LUST) sites that are required by federal and state law to report UST-related releases to DOH. Most, if not all, LUST sites are too small to technically or economically warrant a full-scale investigation of the utility of the groundwater that has been or could potentially be impacted by the release. This necessitates the use of approximated, regional groundwater-utility "zones", defined by use of such tools as the UIC line.

Numerous LUST facilities located mauka of the UIC line, however, have requested variance from use of the UIC line to approximate groundwater utility beneath their sites. The requests have been based on the known geology of the site and a position that the release does not threaten an aquifer system that currently or could potentially serve as a source of drinking water. Indeed, many of the subject sites overlie clay-rich, "caprock" coastal plain sediments that are not suitable as sources of drinking water. An extensive, subsurface investigation of the local groundwater system would likely support this at many of the sites if such an investigation was technically and economically feasible. Fortunately, recent research on aquifer systems throughout the islands addresses the bulk of these problem areas.

Aquifer Identification and Classification Technical Report Series

Since establishment of the UIC line, DOH has sponsored additional research regarding the identification, classification, and protection of groundwater resources in Hawai'i. The most important outcome of this research to date has been the "Aquifer Identification and Classification" technical report series published for each island by the Water Resources Research Center (WRRC) at the University of Hawai'i - Mānoa (see references). The reports have been incorporated into the draft Water Resources Protection Plan (March, 1992), prepared by the Department of Land and Natural Resources as part of the Hawai'i Water Plan under provisions set in Chapter 174C of the Hawai'i Revised Statutes. The DOH Office of Hazard Evaluation and Emergency Response currently uses the WRRC aquifer identification and classification reports to screen sites for prioritization.

The WRRC reports systematically review aquifer systems throughout each island and, as one element, indicate whether the aquifer system as a whole can or cannot be utilized as a source of drinking water (aquifer system "utility," second digit in aquifer system status code). Because division of the aquifer systems is based largely on geology, the WRRC aquifer classification system reports address many of the problem areas brought about by reliance on only the UIC line to approximate groundwater utility.

One of the shortcomings of the aquifer system classification reports, recognized by the authors (Mink, personal communication - Attachment A), is a lack of sufficient data to subdivide geologically-defined aquifer "types" into more narrowly-defined "units" based on the variability of groundwater quality within the aquifer system. This can be especially important in coastal areas where groundwater quality within an otherwise "drinking water" aquifer system degrades to below drinking water standards as the freshwater lens pinches out and mixes with saline water within the same geological formation. Examples include much of the basaltic coastal areas of the islands of Kaua'i, Maui, Moloka'i, and Hawai'i.

In these areas, the groundwater specialists consulted generally agreed that the UIC line can serve as a useful and valid tool for approximating the inland boundary of coastal-zone, aquifer system "units" that are not current or potential sources of drinking water (see Attachment A). Over time, continued investigation of Hawai'i's groundwater resources will naturally lead to a refinement of the boundaries between regional aquifer systems and a better breakdown of distinctive units within individual systems.

Policy Statement

Facilities with releases from USTs regulated by the UST Section of the DOH Solid and Hazardous Waste Branch must determine the utility of groundwater (generally drinking water or non-drinking water) that has been or may potentially be impacted by the release. In support of the determination of groundwater utility, the following information should be submitted to the DOH:

1. a review of the known surface and subsurface geology and hydrogeology of the site, including information gained during investigation of the release and information provided in published or unpublished reports that include the subject area (refer to TGM, August 1992 edition for information required in site investigations)
2. a description of all aquifer systems (classification, status, etc.) that have been impacted and/or could potentially be impacted by the release in accordance with the referenced aquifer system classification reports published by the WRRC, and
3. a map showing the location of the release site with respect to the boundaries of impacted or potentially impacted aquifer systems.

In addition, if the UIC line is used to approximate the inland boundaries of coastal-zone, non-drinking water aquifer system units, then the location of the UIC line with respect to the corresponding aquifer system(s) should be included on the map and discussed in the text of the report.

DOH may request additional site-specific geologic, hydrogeologic, and other pertinent information as necessary on a site-by-site basis to make final groundwater utility determinations. In particular, facilities situated near aquifer system boundaries should evaluate the geological accuracy and applicability of the aquifer system maps to their site.

DOH reserves the right to make final decisions of groundwater utility on a site-specific basis, regardless of the location of the site with respect to regional characterizations of aquifer systems. This may become especially important in areas of extensive soil and groundwater contamination, at sites located near important aquifer system boundaries where detailed subsurface data is not available, or in ecologically sensitive areas (e.g., near bodies of surface water).

The review of an aquifer systems status as a source or potential source of drinking water will be for UST section purposes only and the results of the review should not be construed as an official confirmation or refinement of the UIC line in the area of the release site. Injection well applications, if any, will be processed according to UIC regulations, Chapter 23, by the UIC program of the Safe Drinking Water Branch (SDWB) and such applications will not be excluded from UIC restrictions due to designations of what is or is not a source of drinking water that have not been approved by the SDWB.

APPROVED/~~DISAPPROVED~~



Bruce Anderson, Ph.D., Deputy Director, Environmental Health,
Department of Health

9/13/95
Date

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APPENDIX 9

COMPARISON OF 1996 VERSUS 2005 ACTION LEVELS

Comparison of 1996 versus 2005 Action Levels

Contaminant	Groundwater (in ug/L)						Soil (in mg/kg)							
	DW Source Threatened			DW Source Not Threatened			DW Source Threatened				DW Source Not Threatened			
	1996 Tier 1 AL	2005 AL ≤150m	2005 AL >150m	1996 Tier 1 AL	2005 AL ≤150m	2005 AL >150m	1996 AL ≤200cm	1996 AL >200cm	2005 AL ≤150m	2005 AL >150m	1996 AL ≤200cm	1996 AL >200cm	2005 AL ≤150m	2005 AL >150m
Acenaphthene	320	20	20	320	23	200	18	18	16	16	18	18	19	130
Acetone	610	1500	1500	610	1500	1500	5.8	0.06	0.5	0.5	5.8	0.06	0.5	0.5
Benzene	5	5	5	1700	46	1600	0.05	0.05	0.22	0.22	1.7	0.68	0.53	0.53
Benzo(a)pyrene	0.2	0.014	0.014	0.2	0.014	0.014	1	1	0.62	0.62	1	1	0.62	0.62
Cadmium (total)	5	3	3	9	3	3	38	38	12	12	38	38	12	12
Carbon tetrachloride	5	5	5	12000	9.8	21	0.15	0.024	0.027	0.027	1.9	1.9	0.027	0.027
Chlordane	2	0.004	0.09	4.3	0.004	0.09	0.38	0.38	1.6	1.6	0.38	0.38	1.6	1.6
Chlorobenzene	100	25	50	100	25	160	0.08	0.05	1.5	3	0.08	0.05	1.5	9.5
Chloroform	0.16	100	100	9600	620	1800	0.001	0.0001	0.018	0.018	2.8	2.8	0.018	0.018
4,4'-DDD	0.3	0.001	0.28	0.6	0.001	0.6	1.8	1.8	2.4	2.4	1.8	1.8	2.4	2.4
4,4'-DDE	0.2	0.001	0.28	14	0.001	14	1.3	1.3	2.4	2.4	1.3	1.3	2.4	2.4
4,4'-DDT	0.2	0.001	0.013	0.001	0.001	0.013	0.82	0.82	1.7	1.7	0.82	0.82	1.7	1.7
1,1 Dichloroethylene	46	7	7	3900	25	3900	0.47	0.47	1.2	1.2	0.47	0.47	4.3	45
Di-n-octylphthalate	730	NS	NS	730	NS	NS	31	31	NS	NS	31	31	NS	NS
Dioxins (2,3,7,8-TCDD)	4.50E-07	5.00E-06	3.00E-05	0.003	5.00E-06	0.003	4.00E-06	4.00E-06	3.90E-06	3.90E-06	4.00E-06	4.00E-06	3.90E-06	3.90E-06
Ethylbenzene	140	30	30	140	290	300	0.5	0.13	3.3	3.3	0.5	0.13	32	33
Ethylene glycol	7.30E+07	NS	NS	7.30E+07	NS	NS	18000	18000	NS	NS	18000	18000	NS	NS
Fluoranthene	13	8	40	13	8	40	11	11	40	40	11	11	40	40
Lead (total)	5.6	5.6	15	5.6	5.6	29	400	400	200 (400)	200 (400)	400	400	200 (400)	200 (400)
Methylene chloride	4.3	4.3	4.3	4.3	2200	4100	0.003	0.002	0.067	0.067	0.003	0.002	0.9	0.9
MTBE	20	5	5	2.02E+05	1800	1800	0.005	0.005	0.023	0.023	20	20	0.8	0.8
Naphthalene	240	6.2	6.2	770	24	210	41	41	1.2	1.2	41	41	4.8	18
PCBs (all)	0.5	0.014	0.5	2	0.014	2	1	1	1.1	1.1	1	1	1.1	1.1
Tetrachlorethylene	5	5	5	145	86	86	0.29	0.04	0.069	0.069	5	1.1	0.069	0.069
Toluene	1000	40	40	2100	130	400	16	2.6	2.9	2.9	34	5.5	9.3	29
TPH-gasolines	NS	100	100	NS	500	5000	2000	2000	100/2000	100/2000	2000	2000	100/2000	100/2000
TPH-middle distillates	NS	100	100	NS	640	2500	5000	5000	500/5000	500/5000	5000	5000	500/5000	500/5000
TPH-residual fuels	NS	100	100	NS	640	2500	5000	5000	500/5000	500/5000	5000	5000	500/5000	500/5000
1,1,1 Trichloroethane	200	62	200	6000	62	6000	0.1	0.06	7.8	25	3	1.9	7.8	39
Trichloroethylene	5	5	5	700	77	77	0.01	0.004	0.036	0.036	1.5	0.56	0.036	0.036
Vinyl Chloride	2	2	2	2	26	26	0.18	0.18	0.046	0.046	0.18	0.18	0.046	0.046
Xylene	10000	20	20	10000	100	2000	23	8	2.3	2.3	23	8	11	180

NOTES:

- Groundwater Tier 1 levels apply to areas with any amount of rainfall; Soil Tier 1 levels are given for the rainfall ≤ 200 cm/yr and >200 cm/year
- EALs given for areas ≤ 150 meters and > 150 meters to a surface water body
- EALs for TPH compounds in soil are given for shallow soil / deeper soil; shallow soil = < 10 ft. deep for residential, < 3 ft. deep for comm./industrial
- EALs for lead: First action level is for ecotoxicity concerns; second action level is for human-health, direct-exposure concerns.

APPENDIX 10

COMMENTS AND RESPONSES ON DECEMBER
2003 DRAFT EAL DOCUMENT

**Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater
Draft - December 2003**

Public Comments Summary and Response (comments received Sept. 15 – Nov. 15, 2004):

Section	Comment	Change/Response
General	Will existing cleanups be “grandfathered” under the existing 1996 RBCA guidance? Will an existing cleanup suddenly become subject to this new screening criteria when this criteria is finalized? If so, this would mean that sampling and analysis would have to be redone in order to meet this new screening criteria.	Once the new screening guidelines are finalized HDOH will set a date (several months out) for the new guidelines to be considered “effective” for use. Information and training opportunities on the updated guidelines will be offered before the effective date for use. The updated screening guidelines would in general be considered applicable only to projects/sites which had not completed their final sampling and analysis plan by the chosen “effective date” for use. Periodic workshops will be set up for staff and the general public.
General	The document notes that Drinking Water Levels are utilized for some groundwater screening criteria. This creates an issue for lab analyses, as groundwater matrices must be analyzed using drinking water methods which are more complex, take more time to perform, are performed by fewer labs, and generally the cost is considerably more as well. Environmental consultants and geologists may not be aware of this and send samples to a lab requesting the methods for testing groundwater (typically EPA SW846 methodologies rather than Drinking Water methodologies). It may be wise for HDOH to add the analysis method desired to the tables to clarify this area of concern.	A separate memo that discusses appropriate lab methods and acceptable reporting limits will be prepared in coordination with local labs and used as a supplement to the EAL document.

Section	Comment	Change/Response
General	The document notes that laboratory reporting limits may be used in replacement of recommended ALs, however the language is a little obscure. Will substitution of lab reporting limits be made on a case-by-case (between lab and HDOH) or will HDOH meet with labs to determine any appropriate substitutions before the effective date of the new guidelines? How will reporting limit differences between labs be handled?	A separate memo that discusses appropriate lab methods and acceptable reporting limits will be prepared in coordination with local labs and used as a supplement to the EAL document.
General	Due to the amount of information and number of tables in Vol.2 associated with Tables A-C in Volume 1, it would be very helpful for users to have a flow-chart (in addition to steps provided in Section 2.2.1) to help ensure the guidance is followed properly.	A flow chart has been added to Volume 1 of the document (Figure 5).
General	The "l" in "levels" is not capitalized in headers throughout the document.	Corrected.
General	Provide EALs for butylbenzenes and propylbenzenes.	<p>Propylbenzenes (e.g., n propylbenzene), a component of gasoline and other petroleum fuels, are collectively included in "Total Petroleum Hydrocarbons (TPH)". They do not need to be evaluated separately under most circumstances.</p> <p>Specific EALs for butylbenzenes will be added to future updates of the EAL document. In the interim, refer to USEPA Region IX PRGs for soil, ambient air and tapwater. Although not addressed in the USEPA document, butylbenzene is not anticipated to pose vapor intrusion or nuisance concerns at the PRG levels due to it's relatively low toxicity. The SESOIL-based algorithm presented in Section 3.4.1 of Appendix 1 of the EAL document can be used to develop soil action levels for leaching concerns as needed.</p>

Section	Comment	Change/Response
General (2004 PRGs)	<p>The document references 2002 EPA Region IX PRGs, however these were updated in 2004 – are the soil action levels for direct exposure concerns going to be updated to reflect the current PRGs (and future revisions)?</p> <p>The guidance should provide some flexibility in use of more recent PRG criteria. In general, the 2004 changes to tap water PRGs would have minimal impact to the drinking water GALs in this draft since many of the changes to tap water PRGs were for chemicals (e.g. ethylbenzene, tetrachloroethylene, etc) where the drinking water MCLs were selected as final ALs. However, soil criteria are impacted to varying degrees.</p>	<p>The December 2003 draft EALs have been updated to reflect revised toxicity as well as fate and transport factors incorporated into the 2004 USEPA Region IX PRGs. Future updates to the PRGs can be used to revise previously published EALs at any time under a Tier 2 risk assessment.</p>
General (GW action levels for evaluation of indoor-air impacts)	<p>The GWAL values for indoor air impacts of a number of the volatiles (e.g. vinyl chloride) appear too high. For example, recent risk assessments (using the same model as indicated in the HDOH guidance) conducted in California have come up with more conservative GWAL values for vinyl chloride.</p>	<p>Toxicologists with the State of California consider vinyl chloride to be a more potent carcinogen than do USEPA toxicologists. This is reflected in the toxicity factors used to develop GWALs for vapor intrusion concerns in California. The state of Hawaii uses determinations of USEPA toxicologists in its guidance document. For vinyl chloride, this results in somewhat higher action levels.</p>

Section	Comment	Change/Response
General (Soil Ecotox Criteria)	<p>Soil Action levels for terrestrial habitats were included in the selection of Tier 1 final SALs. The soil ecotoxicity criteria are largely based on phytotoxicity to vegetation. However, the application of ecotoxicity values based on phytotoxicity should only be applied under site-specific conditions given that flora on Hawaii is often comprised of non-native species or hardy species (e.g. kiawe) in urban areas and soil amendments are often used in landscaped areas. For instance, the consideration of these criteria for industrial sites with disturbed habitat does not appear appropriate, nor as noted in the guidance, are these values necessarily appropriate for threatened and endangered species. Thus, ecotoxicity criteria should not be included in the selection of the final SALs, rather the soil criteria should be treated similarly to the approach for final GALs whereby the seafood ingestion pathway should be considered, but is not included in the selection of the final GALs (page 2-1).</p>	<p>The soil ecotoxicity action level was retained for use in the final SALs. This is intended to help identify sites where potentially significant ecotoxicity could exist even after cleanup of contaminated soil to meet residential, direct-exposure concerns. It is understood that the ecotoxicity action levels can be omitted on a site-by-site basis in highly developed areas where there is no significant open space or habitat.</p>

Section	Comment	Change/Response
<p>General (Ceiling Levels, Odors, Nuisance Criteria)</p>	<p>GALs included criteria for taste and odor in drinking water and odors in surface waters. Because GALs are often applied to subsurface GW where odor thresholds are likely to be of little or no concern, particularly in highly industrial areas, the nuisance criteria should not be included in the selection of the final GALs, rather, the GW criteria should be treated similarly to the seafood ingestion pathway, whereby the criteria are considered, as appropriate, but are not included in the selection of the final Tier 1 GALs (page 2-1)</p>	<p>The EAL document is specifically designed to ensure that all potential environmental concerns are included in an initial review of site data. This relieves the need to prepare a detailed environmental risk assessment at every site and helps ensure that potential concerns are not inadvertently overlooked.</p> <p>Ceiling values are intended to address gross contamination and nuisance concerns. DOH does not allow wastes to be indiscriminately buried on a site even if no health concerns are posed. The same holds true for product floating on or dissolved in groundwater. Ceiling values are also intended to address nuisance concerns should the contaminated soil or groundwater be exposed at the surface in the future. Many industrial properties are situated adjacent to public waterways where gross contamination and nuisance issues must be considered.</p> <p>Following an initial assessment of site data, the need to address specific concerns can be evaluated in more detail as warranted by site conditions and other considerations (e.g., elimination of nuisance concerns (but perhaps not gross contamination concerns) for groundwater under heavily industrialized areas that is not likely to discharge to a surface water body; elimination of terrestrial ecotoxicity concerns in similar areas with no open spaces; etc.),</p>

Section	Comment	Change/Response
General (Aquatic Habitat Goals)	For aquatic habitat goals, the selection approach to establish criteria appear to be overly conservative (selection of lowest concentration or adjusting concentrations 10-50%) or inappropriate (use of drinking water criteria). No rationale is provided for the magnitude of the applied adjustment factors and it is unclear why the acute and chronic habitat goals are the same	Approaches used to select acute and chronic surface water goals are summarized in Section 2.3.2 of Appendix 1 and follow guidance published in the USEPA document <i>Final Water Quality Guidance for the Great Lakes System</i> , (USEPA 1996, refer to full reference in Appendix 1). The approaches were reviewed by Dr. Lynn Suer, currently with USEPA Region IX in San Francisco. Alternatives can be proposed in Tier 2 assessments.
Executive Summary, 1 st paragraph, 1 st sentence	A definition of “hazardous chemicals” would be beneficial since HDOH’s definition differs slightly from the federal definition.	Term “hazardous chemicals” revised to “hazardous substances.” Reference to definition in Hawai’i Revised Statutes added.
Vol. 1, 1.3.1.4, Updates to Soil Action Levels	<p>Since EALs are not regulatory “cleanup standards”, do human health direct exposure values (PRGs) take precedence when Tier 1 EALs are based on ecotoxicity and the site only has human receptors (e.g. lead at 400 mg/kg vs 200 mg/kg)?</p> <p>Volume 1 does not always clarify how and when tables in Volume 2 are to be implemented.</p>	<p>The EALs and the USEPA IX PRGs are not promulgated, regulatory cleanup standards. Both are intended to be used for initial screening of contaminated sites at the option of the responsibility party. The USEPA IX PRGs do not take precedence over the EALs (and vice versa).</p> <p>The EALs for soil are intended to address five potential environmental concerns: 1) direct exposure to humans, 2) vapor emissions to indoor air, 3) leaching of chemicals to groundwater, 4) toxicity to terrestrial flora and fauna, and 5) gross contamination and nuisances. The USEPA IX PRGs were incorporated into the EAL document to address human health, direct exposure concerns. Additional action levels were compiled from</p>

Section	Comment	Change/Response
		<p>various sources to address the other concerns.</p> <p>The summary tables in Volume 1 of the document provide the lowest action level for a given contaminant. This allows someone with limited time and/or experience to quickly screen soil, groundwater or air data for a site and determine if a potential problem exists. If so, the site can be remediated to the Tier 1 action levels or a more detailed evaluation of specific environmental concerns can be carried out.</p> <p>The detailed tables in Volume 2, Appendix 1 allow someone with more time and/or experience to pinpoint the specific environmental concerns that may be present at a site and determine the need to evaluate the concerns further. This level of effort may not be required at some sites (e.g., all data below lowest EALs) or it may be cost-beneficial to simply remove the contaminated soil or groundwater without further evaluation.</p> <p>Over time, it is anticipated that the majority of the consulting community and agency staff will refer to the detailed tables in Volume 2 of the EAL document.</p>

Section	Comment	Change/Response
<p>Vol. 1, 1.3.1.5, Soil and GW “Ceiling Levels”</p>	<p>The paragraph doesn’t provide an example of when the application of GW ceiling levels are appropriate – an example would help, and it would also be helpful to provide a reference to Vol. 3, Tables F1, 2, or 3. In addition, there is no discussion of shallow vs deep soil ceiling levels.</p> <p>In several cases Tier 1 GWALs are set at the ceiling level because it is more conservative than the risk based level – which implies that HDOH could require remediation of GW to levels below concentrations deemed to be safe to human health and environment. In these cases, wouldn’t a Tier 2 or Tier 3 risk assessment always demonstrate that the contaminant risk is acceptable because the concentration is below the risk-based criteria? And, if so, why have ALs based on ceiling levels that are more conservative than risk-based values?</p>	<p>Examples will be discussed in upcoming EAL workshops. See above comment on applicability of groundwater ceiling levels. As noted, DOH can require additional remediation of contaminated groundwater (and soil) to address gross contamination and nuisance concerns even after concerns regarding human health from purely a toxicity standpoint have been met.</p> <p>It is important to understand the difference between an <i>environmental</i> risk assessment and a <i>toxicological</i> risk assessment. A toxicological risk assessment is used to evaluate the risk to human health (or ecological receptors) posed by exposure to a potentially toxic chemical. As noted above, this is only a subset of the potential environmental concerns that must be evaluated at contaminated sites. It is likewise only one component of a more comprehensive, environmental risk assessment required under a Tier 1, Tier 2 or Tier 3 assessment.</p> <p>The assessment and cleanup of contaminated sites must address all potential environmental concerns, not simply concerns directly related to human health risk. For example, cleanup of soil contaminated with highly toxic, relatively immobile substances will most often be driven by human-health (direct-exposure) concerns (e.g., PCBs). Cleanup of soil contaminated with relatively mobile, noncarcinogenic, volatile substances will, however, most often be driven by leaching and groundwater protection concerns (e.g., xylenes). Cleanup of soil contaminated with metals or pesticides that are more toxic to flora and fauna than to humans may be driven by ecotoxicity concerns (e.g., copper and lead). Under a Tier 3 assessment,</p>

Section	Comment	Change/Response
Vol. 1, 1.3.3, OSHA PELs, 3 rd paragraph	The example provided for TCE states that Table C in Vol. 1 and Table C-3 provide ALs between 2 and 10 ug/m3 for industrial/commercial carcinogenic and non-carcinogenic effects, respectively. However, Table C shows the industrial/commercial level as 0.037 ug/m3 and Table C-3 show these levels as 0.036 ug/m3 and 51 ug/m3 for carcinogenic and non-carcinogenic effects respectively.	Revised as noted.
Vol. 1, 1.5, Limitations	<p>3rd bullet – suggest replacing reference to “low pH at mine sites” with an example that has more relevance to Hawaii sites.</p> <p>3rd paragraph – the example provided notes that if LTM demonstrates that actual impacts to GW do not exceed ALs, then soil ALs for leaching concerns could be omitted from consideration in a Tier 2 risk assessment. This may lead the reader to conclude that if there are subsurface TPH concentrations above the TPH leaching level that are demonstrated not to impact GW, then that soil may remain in place since the Tier 2 risk assessment would not address this contamination. Additional clarification is requested for this scenario since several sites in Hawaii involve TPH-only contamination.</p> <p>5th paragraph – This paragraph uses a reference to houses with heating systems in basements. Suggest replacing this reference with one more relevant to Hawaii sites.</p>	<p>Revised to using landfills as an example.</p> <p>As noted above, other concerns must also be addressed under a Tier 2 assessment. In the example noted, impacted soil should be remediated to address gross contamination concerns at a minimum (to the extent feasible).</p> <p>Revised to note enhanced vapor intrusion related to wind effects and use of HVAC systems.</p>
Vol. 1, 2.1, Organization of Lookup Tables, 8 th paragraph	This paragraph provides benzene EALs for drinking water concerns and action levels for vapor intrusion concerns. Since this document differs significantly from previous guidance, we recommend providing references to tables where this information can be found. This will help readers familiarize themselves with the layout of the document. This comment applies to other statements in the document where examples are provided but references to applicable tables are not.	Reference to appropriate tables noted.

Section	Comment	Change/Response
Vol. 1, 2.2.1, Steps to Use of Tables, Step 5, 3 rd sentence	This sentence is slightly misleading since moisture content can significantly affect reported analyte concentrations and contradicts what is stated in Volume 2, Section 6.2, 1 st paragraph.	Text clarified. From a risk assessment standpoint, reporting analyte concentrations on a wet-weight versus dry-weight basis is not likely to significantly affect decisions about site cleanup. As noted in Section 6.2 of Appendix 1: "For a typical soil sample, the inclusion of soil moisture (i.e., the weight of the water in the soil) in calculation of chemical concentrations can effectively reduce the reported concentrations by 10-20% or greater... For consistency and for comparison to soil EALs presented in this document, however, soil data should be reported on dry-weight basis. This is in part because soil ingestion rates assumed in direct-exposure models are based on dry weight data."
Vol. 1, 2.5, Screening for Indoor-Air Impact Concerns 3 rd paragraph, Step 2	Please clarify in this paragraph that soil gas investigations should be performed using active (not passive) soil gas collection techniques as recommended by the EPA VI guidance.	Text clarified.
Vol. 1, 2.6, Ambient Background Concentrations, 3 rd paragraph, 1 st sentence	The use of the term "professional judgment" in regards to ambient background concentrations of arsenic and chromium (20 and 500 mg/kg, respectively) is subjective with respect to estimating background metal concentrations. If the values posed by HDOH are based on previous technically sound studies, then that should be so stated and a reference to those studies provided.	Default background action level for total chromium dropped. References for information on background metals in soils added to text. Soil samples should be tested for Cr III and Cr VI when a release is identified. Additional justification for arsenic action level added to text.
Vol. 1, 2.7, Implied Land-use Restrictions under Tier 1, 4 th	This sentence implies that EALs from the Tier 1 lookup tables may be chosen by the end user based on land use restrictions. However, according to the Tier 1 Tables, the SALs are based only on residential exposure scenarios. Clarification is requested	Clarified to note that this applies to use of alternative action levels/cleanup levels under a Tier 2 or Tier 3 risk assessment.

Section	Comment	Change/Response
paragraph, 1 st sentence	on how land use restrictions could affect selection of Tier 1 ALs.	
Vol. 1, 2.8, Cumulative Risks at sites with Multiple COCs	2 nd paragraph, 2 nd sentence – missing “than” between “more” and “three” 2 nd paragraph, 4 th sentence – replace “my” with “may”	Revised as noted.
Vol. 1, 3.3.3, Laboratory-based soil leaching tests	2 nd paragraph, last sentence – Did the author mean to refer to TCLP instead of SPLP? If the author is referring to treated hazardous waste, then that should be clarified. 7 th paragraph, 2 nd sentence – There is a portion of this sentence missing after “Hawaii”.	Revised to “TCLP.” Revised (word “the” deleted).
Appendix 1, 5.2, TPH Action Levels for GW, 2 nd paragraph, last sentence	This section references Section 2.3, however Section 2.3 is Groundwater Utility – should it reference Section 2.4, Threat to Surface Water Habitats?	Refers to Section 2.3 of Appendix 1.
Appendix 1, 5.3.2, TPH (residual fuels), 2 nd paragraph	This paragraph states that the screening level of 1,000 mg/kg was adopted for use as protective of drinking water resources and references Table E-1, however Table E-1 presents the screening level of 5,000 mg/kg.	Revised to clarify sources of TPH action levels.
Tables	Methylnaphthalene in the tables is noted as a total of 1 & 2 isomers. Because the 1 & 2 methylnaphthalene isomers are easily distinguished by EPA method 8270C, it would seem reasonable for a lab to report both isomers rather than having to perform a calculation for these (this would be similar to how a number of other chemicals with multiple isomers are handled).	Separate fate and transport and toxicity factors are not available for 1 and 2 Methylnaphthalene. They are therefore combined in the lookup tables assuming similar toxicity and mobility.
Tables	The Tables provide for TPH defined loosely as gasoline, middle distillates, and residual fuels. Carbon ranges, as defined in EPA methodologies, would be appreciated. Consultants and labs often read different meaning into loosely defined regulations, leaving room for poorly designed SAPs, etc...	Footnotes in tables refer to TPH carbon range discussion in Appendix 1, Chapter 5. This chapter can be expanded in the future if needed.

Section	Comment	Change/Response
Vol. 1, Table A	<p>There is a note “3” assigned to the GW columns, yet there is no footnote 3 at the end of the Table. There are notes 1 and 2 at the end of the Table, but these notes are not assigned to anything in the Table.</p> <p>Suggest rephrasing difficult to understand footnote starting “Groundwater Action level intended to be address” to “Groundwater action levels are intended to address surface water impacts, indoor-air, and nuisance concerns. The groundwater action levels should be used in conjunction with soil gas action levels to more closely evaluate potential impacts to indoor-air if applicable, and if groundwater action levels for contaminants are approached or exceeded. See Section 2.5 and Table C.”</p>	<p>Revised to match footnotes.</p> <p>Footnote discussing groundwater action levels revised for clarity.</p>
Vol. 1, Table B	<p>Notes 2 and 3 are assigned to the soil and groundwater columns respectively, however the end of the table only has notes 1 and 2. Note 2 at the end of the table pertains to groundwater, not soil, note 3 is not defined, and there is no note 1 assigned to anything in the Table.</p> <p>Suggest rephrasing difficult to understand footnote starting “Groundwater Action level intended to be address” to “Groundwater action levels are intended to address surface water impacts, indoor-air, and nuisance concerns. The groundwater action levels should be used in conjunction with soil gas action levels to more closely evaluate potential impacts to indoor-air if applicable, and if groundwater action levels for contaminants are approached or exceeded. See Section 2.5 and Table C.”</p>	<p>Revised to match footnotes.</p> <p>Footnote discussing groundwater action levels revised for clarity.</p>

Section	Comment	Change/Response
Volume 2, 2.3.3	The final Tier 1 GALs for aquatic habitats were based on the lower of the freshwater or marine criteria. Although this may be appropriate for estuarine environments, it is likely to be overly conservative for selected chemicals in a given environment. As such, separate final Tier 1 GALs should be developed for freshwater and marine environments rather than requiring a Tier 2 or Tier 3 assessment to address this assumption. Separate goals have already been developed for the two environs in Tables D-3a and D-3b.	<p>Final Tier 1 action levels for discharge of groundwater into surface water bodies are based on an assumption that contaminated groundwater could discharge into an estuarine environment (D-1 series tables in Appendix 1). Action levels for this concern are based on the lowest of goals for marine vs freshwater habitats. This negates the need for an evaluation of nearby aquatic habitats at every site and simplifies use of the Tier 1 lookup tables.</p> <p>The applicability of marine vs freshwater aquatic habitat goals can be carried evaluated in more detail under a Tier 2 assessment. Provision of separate action levels in Appendix 1 simplifies this process. Over time, it is anticipated that users of the document will refer directly to the detailed tables in Appendix 1 for evaluation of contaminated sites rather than the summary tables provided in Volume 1.</p>
Volume 2, 2.4.1, Indoor Air Impact Model Parameters, 4 th paragraph	This paragraph implies that only residential land use exposure scenarios are included in the final action levels, however the industrial use exposure scenario is included in Vol. 1, Table C.	Note added: "Soil gas and indoor air screening levels for commercial/industrial exposure scenarios are, however, included in Table C of the summary lookup tables."
Volume 2, 3.2.2	The Cal-Mod PRGs for TCE in the 2004 PRG document should be considered an appropriate alternative for consideration	Based on discussions with Dr. Barbara Brooks of HDOH, only the USEPA cancer slope factors for TCE should be presented in the document. The applicability of the CalEPA toxicity factors (and related action levels) can, however, be discussed in site-specific risk assessments.

Section	Comment	Change/Response
Volume 2, 3.5	See general comment on Soil Ecotox criteria. At a minimum, consider adding the following text to the last sentence of paragraph 3 – “where receptor exposure can reasonably be anticipated”.	Revised as noted.
Volume 2, 5.2, TPH Action Levels for GW	The reference provided for the derivation of the TPH levels in GW (RWQCBSF Order No. 99-045) does not clearly provide justification for the levels proposed in this document. Order 99-045 establishes risk-based Tier 1 cleanup standards for soil and GW and also provides Tier 0 cleanup standards for TPH for “dischargers who wish not to be burdened by any subsequent risk management and monitoring requirements”. Order No. 99-045 currently posted on the Internet (http://www.waterboards.ca.gov/sanfranciscobay/order_nos.htm) contains the Tier 0 cleanup standards but does not provide the Tier 1 cleanup standards. Since the HDOH proposed GW TPH EALs are derived from this Order, it would be beneficial to provide both the Tier 0 and Tier 1 TPH cleanup standards of Order No. 99-045 in this document and include a discussion of how the TPH EALs were derived from these cleanup standards.	A detailed discussion of the derivation of the TPH action levels for aquatic habitats is beyond the scope of the EL document. Additional information can be provided, however, by contacting the San Francisco Bay Regional Water Quality Control Board and requesting copies of the background documents for review. A copy of these documents will also be provided to HDOH for inclusion in the EAL document file.
Vol. 2, Tables	In the tables where screening values are estimated for volatiles in soils and groundwater, there are a number of chemicals where the value given is “use soil gas”. This is not so helpful. A value should be given. The footnotes state that no value was derived because physical constants could not be derived for these chemicals, but some of those chemicals do have constants and the other ones you could use surrogates for them (i.e., closely related compounds).	Vapor intrusion action levels for additional chemicals can be added to the lookup tables as needed. Consultants should request that action levels be developed for additional chemicals and, to the extent possible, provide references for constants that can be used in the models.
Vol. 2, Tables A-1 and A-2	SALs may be impacted by 2004 updates to PRGs. For petroleum compounds, none of the PRGs for PAHs or toluene were changed. Although PRGS for BEX and MTBE were changed, no net impact on the final SALs would occur since the SALs all are driven by groundwater protection.	The December 2003 EALs were updated with respect to revised toxicity factors and fate and transport constants presented in the 2004 PRGs.

Section	Comment	Change/Response
Vol. 2, Tables B-1 and B-2	SALS may be impacted by updates to PRGs. The guidance should include text to allow for changes based on updated information. For instance, the benzene SAL should be increased from 0.59 to 0.64 mg/kg. The endpoint for ethylbenzene has been re-established as a noncarcinogenic effect I the 2004 PRGs. Because the final SAL for ethylbenzene is indoor air, it is not readily apparent the overall impact of this change on the final SAL. However, the 2004 PRG concentration for residential exposure is 400 mg/kg as opposed to 8.7 mg/kg identified for direct exposure in the HDOH guidance	The December 2003 EALs were updated with respect to revised toxicity factors and fate and transport constants presented in the 2004 PRGs.
Volume 2, Table D1a	This table expresses distance from the shore in feet whereas all other tables use meters to express this distance.	Revised to meters.
Volume 2, Tables D-1a and D-1b	Drinking Water Toxicity Column. This column references Table D-3, however, the correct reference is Table D-2?	Revised as noted.
Vol. 2, Table D-1d	Table D-1d is incorrectly labeled as "surface water IS located within 150m of release". It should be labeled IS NOT.	Revised as noted.
Vol. 2, Tables D-3a and D-3b	The confidence in each criteria should be ranked high, medium, or low and a footnote should be added as to whether the criteria should be compared to total or dissolved phase chemical concentrations. A rationale for use of drinking water criteria (e.g. for benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene) for aquatic habitats should be provided.	<p>Discussion of confidence in each criteria is beyond the scope of the current edition of the EAL document but this can be elaborated on in future updates.</p> <p>Footnote added to text and Volume 1 tables stating that the criteria should be compared to dissolved phase chemical concentrations unless otherwise instructed by HDOH.</p> <p>As noted in Section 2.3.2 of Appendix 1, drinking water action levels are used as surrogates for aquatic habitat goals when published aquatic habitat goals for a given chemical are not available. Alternative published goals or goals from site-specific</p>

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Section	Comment	Change/Response
		studies may be substituted under a Tier 2 assessment if subsequently available.
Vol. 2, Table D-3b (Chronic summary)	The title is in error. It should indicate Table D-3b, not Table D-3a. The footer is correct.	Revised as noted.
Vol. 2, Table D-3c (Acute Summary)	The title is in error. It should indicate Table D-3c, not Table D-3b. The footer is correct.	Revised as noted.
Vol. 2, Table D-3d (Hawaii standards summary)	The title is in error. It should indicate Table D-3d, not Table D-3c. The footer is correct.	Revised as noted.
Vol. 2, Table D-3e (USEPA and others standards summary)	The title is in error. It should indicate Table D-3e, not Table D-3d. The footer is correct.	Revised as noted.
Vol. 2, Table D-3f (Bioaccumulation)	The title is in error. It should indicate Table D-3f, not Table D-3e. The footer is correct.	Revised as noted.
Vol. 2, Table D-4	Although final GALs are not expected to be impacted by 2004 updates to the tap water PRGs, Table D-4 data is affected. The guidance should include text to allow for changes based on updated information. For instance, the benzene tap water goal should be increased from 0.34 to 0.35 ug/l and the MTBE concentration should decrease from 13 to 6.2 ug/l. Changes to tetrachloroethylene and 1,2,4-trichlorobenzene should also be incorporated. The carcinogenic endpoint for ethylbenzene should shift back to the noncarcinogenic effect. The Cal-Mod PRG for TCE in the 2004 PRG document should be considered an appropriate alternative value for consideration.	Tapwater action levels revised with respect to updated toxicity factors presented in 2004 PRGs. As stated in Volume 2, Chapter 3 of the EAL document, updated or alternative toxicity factors and fate and transport constants may be incorporated into a Tier 2 or Tier 3 assessment at any time. The EALs will be updated on a regular basis to reflect revisions to the USEPA IX PRGs and other new information.
Volume 2, Appendix 3	The USEPA User's Guide for the Johnson & Ettinger vapor intrusion model was updated in 2003. Documentation should be adjusted accordingly.	Updated reference incorporated into text. The 2003 vapor intrusion spreadsheets were used to develop the action levels presented in the tables.