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Canadian Council
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des ministres
de l'environnement

A PROTOCOL FOR THE DERIVATION OF SOIL VAPOUR QUALITY GUIDELINES FOR PROTECTION OF HUMAN EXPOSURES VIA INHALATION OF VAPOURS

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Canadian Council of Ministers of the Environment

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern.

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READER COMMENTS

This protocol was published as a working document so that the revised methodology can be applied and tested. CCME recognizes that some refinements or changes may become necessary or desirable as scientific understanding of issues related to contaminated sites improves.

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NOTICE

This document provides the rationale and guidance for developing human health soil vapour quality guidelines. It is based on, and acts as a companion document to, *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME, 2006). This document is intended for general guidance only, and does not establish or affect legal rights or obligations. It does not establish a binding norm, or prohibit alternatives not included in the document and is not finally determinative of the issues addressed. Decisions in any particular case will be made by applying the law and regulations on the basis of specific facts when regulations are promulgated or permits are issued.

OVERVIEW

The Canadian Council of Ministers of the Environment (CCME) establishes numerical environmental quality guidelines for the National Contaminated Sites Remediation Program (NCSRP) to promote consistency and provide guidance in assessing and remediating contaminated sites in Canada. CCME has published guidelines for soil quality, which have included consideration of contaminant volatilization and their potential migration into indoor air since 1996. However, it is also useful to have numerical guidelines for soil vapour when considering human exposure via inhalation, since the medium of exposure is air, and collection and analysis of soil gas samples avoids uncertainties involved in calculating vapour concentrations from bulk soil or groundwater concentrations. There are a number of scenarios where the inhalation pathway poses the most significant risks, which is the main justification for the soil vapour guideline development.

This document describes a protocol for developing guidelines to protect human receptors from the inhalation of vapours originating in the subsurface. This is intended to be complementary to the multi-receptor and multi-pathway scenarios employed for soil guideline values in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guideline*s, issued by CCME in 1996 and revised in 2006.

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Acknowledgements

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Document Organization

This document is divided into four parts, consistent with *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME, 2006). A glossary is presented at the beginning of the document for terms that are specific to this Protocol. For other terms, the reader should refer to the aforementioned Soil Quality Guidelines Protocol. Background information on the development of the Soil Vapour Quality Guidelines Protocol, including the scientific tools that have been developed to help assess and remediate contaminated sites in Canada, is provided in Part A. Information on the principles is also included in Part A. The processes for deriving environmental and human health guidelines are described in Part B and Part C respectively. Part D concludes this document by providing guidance on the derivation of the final soil vapour quality guidelines. Equations and model input parameters are provided in Appendices A and B, respectively. Additional appendices detail the rationale for the revised model parameters (Appendix C), a method for screening chemicals to determine whether they should be considered volatile (Appendix D), and guidance on site-specific guideline adjustments (Appendix E).

LIST OF FREQUENTLY USED ACRONYMS AND ABBREVIATIONS

α	Attenuation factor
AF	Allocation factor
AQG	Air quality guideline
BW	Body weight
CCME	Canadian Council of Ministers of the Environment
CEQG	Canadian Environmental Quality Guidelines
DQRA	Detailed quantitative risk assessment
EDI	Estimated daily intake
LEL	Lower explosive limit
NAPL	Non-aqueous phase liquid
IUR	Inhalation unit risk
IR	Inhalation rate
Q_{soil}	Volumetric flow of soil gas into the building
$Q_{building}$	Volumetric flow of air from the building
PQRA	Preliminary quantitative risk assessment
RAF	Relative absorption factor
RSC	Risk-specific concentration
RSD	Risk-specific dose
RTDI	Residual tolerable daily intake
SF	Slope factor
SQG	Soil quality guideline
SQGTG	Soil Quality Guidelines Task Group
SVQG	Soil vapour quality guideline
$SVQG_{IAQ}$	Soil vapour quality guideline (indoor air)
$SVQG_{OAQ}$	Soil vapour quality guideline (outdoor air)
$SVQG_{F}$	Soil vapour quality guideline (final)
$SVQG_{M}$	Soil vapour quality guideline (with management considerations)
TC	Tolerable concentration
TDI	Tolerable daily intake
TRV	Toxicity reference value
UF	Uncertainty factor
US EPA	United States Environmental Protection Agency

Glossary

This section contains only some of the terms that are specific for this soil vapour protocol, for other terms please refer to A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME, 2006) that contains a more comprehensive glossary.

Aerobic condition: Requiring oxygen.

Anaerobic condition: Without oxygen.

Allocation factor (source allocation factor): The relative proportion that is allowable for a given media to constitute in the Residual Tolerable Daily Intake (RTDI) from various environmental pathways (air, soil, food, water, consumer products).

Attenuation factor: A value applied within the calculation of the soil vapour quality guidelines to address the decrease in concentration as contaminants are transported from soil vapour to the receptor.

Background concentration: A representative ambient level for a contaminant in a given media. Ambient concentrations may reflect natural geological variations in relatively undeveloped areas or the influence of generalized industrial or urban activity in a region.

Background exposure: Exposure to receptors from ambient concentrations of contaminants.

Bioattenuation (biodegradation): A microbiologically mediated process (e.g., due to the action of bacteria, yeasts, and fungi) that chemically alters the structure of a chemical, the common result being the breakup of the chemical into smaller components.

Degradation: The chemical, physical, and biological breakdown of contaminants.

Guidelines: Generic numerical limits or narrative statements that are recommended to protect and maintain the specified uses of water, sediment, or soil, (referred to as criteria in some previous CCME publications).

Henry's law constant: A partition coefficient defined as the ratio of a chemical's concentration in air to its concentration in water at steady state. The dimensionless Henry's law constant is obtained by dividing the Henry's law constant by the gas constant, R.

Indoor air quality: A term referring to the air quality within buildings and structures, especially as it relates to the health and comfort of building occupants.

Lower explosive limit: The lowest concentration (percentage) of a gas or a vapour in air capable of producing a flash of fire in presence of an ignition source (arc, flame, heat).

Multi-tier framework: A guideline system using multiple approaches (tiers) to setting remediation objectives. The same level of protection is applied regardless of the tier selected, but allows for more realistic remediation targets to be established by collecting additional data from individual sites.

Methanogenic condition: Environmental soil condition that allows the presence of microorganisms that produce methane as a metabolic by-product in anoxic conditions.

Non-threshold contaminant: A contaminant for which additional risk is associated with any amount of exposure (i.e. it is assumed that there is no threshold for effects).

Offset distances: A minimum distance from a receptor where guidelines do not apply, due to limitations in transport models or other invalidated guideline assumptions.

Partitioning relationship: Equation used to represent the relationship between chemical concentration of the contaminant in soil, and pore water and soil vapour at equilibrium.

Raoult's law: The vapour pressure of an ideal solution is dependent on the vapour pressure of each chemical component and the mole fraction of the component present in the solution.

Risk-based approach: A procedure used to determine the qualitative aspects of hazard identification, and usually a quantitative determination of the level of risk based on deterministic or probabilistic techniques.

Slope factor: The relationship between an exposure dose or concentration and the risk of developing cancer.

Soil pore water: The water occupying the space between particles of sediment or soil.

Soil Vapour intrusion: The process of entry of subsurface vapours to indoor air.

Solubility: The maximum concentration of a chemical that can be dissolved in water when water is both in contact and at equilibrium with the pure chemical.

Subsurface: Unconsolidated regolith material above the water table not subject to soil forming processes.

Stack effect: The overall upward movement of air inside a building that results from heated air rising and escaping through openings in the building super structure, thus causing an indoor pressure level lower than that in the soil gas beneath or surrounding the building foundation.

Target cancer risk: A specified risk of a receptor developing cancer based on exposure to contaminants. Target cancer risks are used as a means to determine acceptable cancer risk when developing guidelines.

Unit risk: See 'slope factor'.

Unsaturated soil: Soil in which there is less than the maximum possible amount of soil pore water present (considered to be above the water table).

Vadose zone: The zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Vapour: A compound present in a gaseous phase.

Vapour pressure: The pressure exerted by a vapour in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system.

Volatilization: The chemical process by which chemicals spontaneously convert from a liquid or solid state into a gas and then disperse into the air above contaminated soil.

Water table: Depth below which soil is saturated with groundwater.

PART A

1. Background and Context

The Canadian Council of Ministers of the Environment (CCME) has developed and published environmental quality guidelines for several different media, compiled in the Canadian Environmental Quality Guidelines (CCME, 1999). These guidelines are routinely used for the assessment and remediation of federal contaminated sites, and also have been adopted by several other Canadian jurisdictions. The CCME Soil Quality Guidelines Task Group (SQGTG) is responsible for the development of soil quality guidelines, based on A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME, 2006), and referred to herein as the "soil protocol".

While Canadian Soil Quality Guidelines - CSoQG (CCME, 1999) include consideration of the protection of indoor air for organic chemicals based on partitioning into soil vapour and subsequent intrusion into indoor air, soil vapour quality guidelines were not included in the CSoQG. However, there are significant uncertainties associated with calculating soil vapour concentrations from bulk soil or groundwater concentrations, and risks can generally be better predicted by sampling soil vapour directly. Furthermore, there are additional pathways for exposure to volatile contaminants in soil that are not presently included in the soil protocol. Therefore, there is a need for consistent, comprehensive and defensible soil vapour quality guidelines.

This document establishes a framework for the development of soil vapour quality guidelines that ensures an appropriate level of protection for human receptors; at this time methods have not been developed for environmental receptors. This document serves as a companion document to the soil protocol. The pathways and receptors used to derive soil vapour quality guidelines are based on those in the soil protocol, except as discussed in Section A.4 below, and the models and assumptions used are generally the same. The soil protocol should be consulted for additional background and underlying principles; detailed information from the soil protocol was not duplicated in this document.

2. Framework for the Derivation of Soil Vapour Quality Guidelines

2.1 What is the Protocol?

This protocol was developed to guide the establishment of scientifically defensible generic guidelines for organic chemicals in soil vapour at contaminated sites across Canada, in parallel with soil guidelines derived using the soil protocol (CCME, 2006). The protocol details the steps needed to generate effects-based soil vapour quality guidelines for protection of human health. Some information on the rationale for the choice of receptors, exposure pathways, models, assumptions and minimum data requirements is provided, with reference to further supporting rationale in the soil protocol.

The guidelines are developed and/or revised on a substance-by-substance basis as required, in accordance with the protocol, after a comprehensive review of the physical/chemical characteristics, toxicity and environmental fate and behaviour of each substance. This supporting information is presented in a series of guideline-supporting technical documents from Environment Canada, Health Canada, and CCME.

2.2 Guiding Principles

The development of generic soil vapour quality guidelines is based on both scientific and management/policy considerations, and takes into consideration risks to human health. In many respects, the guiding principles for the development of soil vapour quality guidelines are similar to those for the development of soil guidelines, described in Section A.2.2 of the soil protocol.

The soil vapour protocol is based on the migration of vapours from the contaminant source to potential human receptors. While there are potential ecological receptors, including wildlife which could be exposed after migration of vapours to burrows or outdoor air, as well as plants and soil organisms which could be exposed directly to contaminant vapours, at present this protocol does not directly evaluate environmental health. Human exposure considers the migration of contaminants in vapour phase to indoor air, outdoor air and/or trenches/excavations.

The level of protection afforded by the soil vapour quality guidelines is based on the soil protocol. Human health soil vapour quality guidelines (SVQGs) are concentrations in soil vapour at or below which no appreciable human health risk is expected from long-term exposure.

2.3 Land Use

Soil quality guidelines are derived for four defined land uses (agricultural, residential/parkland, commercial and industrial), as described in Section A.2.3 of the soil protocol. These same land uses are used herein; however, there are only two different sets of exposure assumptions and building characteristics. Therefore, guidelines are established for both an agricultural/residential and a commercial/industrial scenario, rather than four separate land uses. Some jurisdictions may allow for the exclusion of the agricultural/residential guideline at commercial or industrial sites, although there may be requirements for offset distances from more sensitive land uses to reflect the mobility of soil vapours.

2.4 Chemical Classification

Section A.2.4 of the soil protocol classifies chemicals as organic or inorganic, dissociating or non-dissociating, volatile or non-volatile, and soluble or non-soluble. These same classifications are used for this protocol. Soil vapour quality guidelines are only derived for volatile chemicals, since these are the only chemicals which can be found in the vapour phase at concentrations high enough to pose a risk. Further guidance on determining whether a chemical should be considered volatile is provided in Appendix D.

2.5 Soil Type

Contaminant fate and transport, including the migration of vapours towards a building, is dependent to some extent on soil properties, many of which are related to soil texture. To minimize the uncertainty in guideline derivation introduced by soil variability, the protocol considers two generic soil types: coarse-textured soils (soil which contains more than 50% by mass particles greater than 75 µm mean diameter- D50 > 75 µm) and fine-textured soils (soil which contains more than 50% by mass particles less or equal than 75 µm mean diameter- D50 ≤ 75 µm). Generic soil properties representative of typical soils in each category have been assigned for the purposes of guideline development; these are summarized in Appendix B.

It should be noted that an individual jurisdiction may choose to use alternative soil types or soil properties to reflect conditions in that jurisdiction.

2.6 Summary of the Guideline Development Process

The guideline development process is detailed in Parts B through D of this document. A brief summary of the process is presented as follows.

At this time, environmental health pathways are not evaluated. Human health pathways include the migration of vapours to indoor air (residences or commercial/industrial buildings), outdoor air and air in trenches/excavations; however, only inhalation of indoor and outdoor air is considered for the development of Tier 1 soil vapour quality guidelines since these pathways are considered the most critical. The receptors and exposure pathways considered are summarized in Figure 1.

The lowest of the guidelines established for each pathway becomes the final soil vapour quality guideline ($SVQG_F$) per land use category. The $SVQG_F$ is also checked against non-toxicity considerations and analytical detection limits.

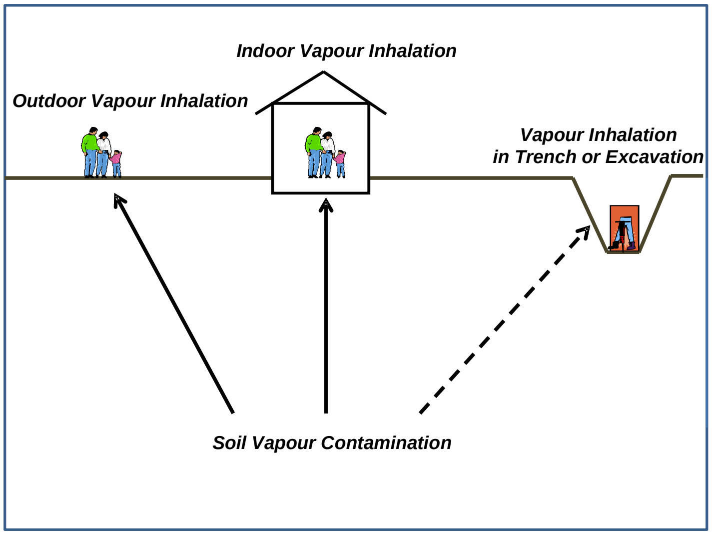

Figure 1. Exposure Pathways Considered in Soil Vapour Quality Guideline Development

Tier 1 SVQGs protective of indoor air are developed for two scenarios:

1. soil vapour concentrations measured deeper than 1 metre below building foundation
2. soil vapour concentrations measured immediately below the building foundation, e.g., sub slab measurement or within 1 metre from the building foundation.

3. Use of Canadian Soil Vapour Quality Guidelines

3.1 General

Canadian soil vapour quality guidelines represent "clean down to levels" at contaminated sites and not "pollute up to levels" for less contaminated sites. They are not intended to be used to manage sites not affected by anthropogenic activities.

The Canadian Soil Vapour Quality Guidelines are intended to be used for assessing in-place contaminants in soil and/or groundwater that can generate soil vapour. The guidelines should be compared to concentrations from soil vapour samples collected from the subsurface, and not at the point of exposure (e.g., indoor or outdoor air). Use of the soil vapour quality guidelines for anything other than their intended purpose should only be done with great care and with an understanding of the guideline development process and its relevance to the proposed use.

As discussed in Section 3.2 below, the guidelines are implemented within a tiered framework which allows for the inclusion of site-specific considerations.

The guidelines should be used in combination with acceptable sampling and analytical methods. Guidance documents on sampling methods and site characterization have been published by CCME (1993) and ASTM (2006), as well as by numerous jurisdictions. Several jurisdictions have recently developed sampling guidance specific to soil vapour. Typical analytical methods are summarized in the scientific supporting documents prepared for each guideline.

Several uncertainties apply to effects-based soil vapour quality guidelines. Uncertainties related to soil guidelines, as discussed in Section A.3 of the soil protocol, are also generally applicable to soil vapour quality guidelines.

3.2 Tiered Framework

Consistent with soil quality guidelines, soil vapour quality guidelines are intended to be applied within a multi-tiered framework at contaminated sites. The tiers include:

- direct application of the generic numerical guidelines (Tier 1)
- limited modification of the generic/default assumptions based on site-specific conditions (Tier 2)
- use of risk assessment based on site-specific conditions and exposures (Tier 3)

While this protocol is concerned primarily with the development of generic numerical guidelines (Tier 1), it is anticipated that it may also be used as the basis for the other tiers. Specific requirements for the application of these tiers are left to each jurisdiction; however some general guidance is provided in this document.

One method of modifying guidelines based on site-specific conditions is the elimination of guidelines for pathways that are not operative at or near a contaminated site. Individual jurisdictions may specify requirements for the elimination of specific pathways. These requirements may, in some cases, be based on land use. For example, jurisdictions may allow the elimination of the indoor vapour inhalation guidelines at sites where there are no current or anticipated future buildings. Further discussion of these pathways is provided in Part C and Appendix E of this document; in all cases the requirements of the jurisdiction with authority over the site should be determined.

Site-specific guidelines may also be established by re-calculating guidelines using the models presented in Appendix A with site-specific values instead of the default model parameters (Appendix B). In general, only stable and readily measurable parameters should be adjusted, and only within ranges appropriate for the models. Further guidance on these adjustments is provided in Appendix E of this document, or guidance documents published by specific jurisdictions. Again, the requirements of the jurisdiction should be confirmed prior to modifying the guidelines.

Site-specific risk assessment, sometimes referred to as “Tier 3”, may involve the use of different models and assumptions, and generally requires more site-specific data than application of the generic guidelines or site-specific modification of guidelines (Tier 2). Detailed guidance on site-specific risk assessment is beyond the scope of this document; guidance has been published by agencies such as Environment Canada, Health Canada, CCME and several international agencies. Particularly relevant documents for federal contaminated sites include (note that some of these documents are updated from time to time):

- A Framework for Ecological Risk Assessment: General Guidance (CCME, 1996).
- A Framework for Ecological Risk Assessment: Technical Appendices (CCME, 1997).
- Federal Contaminated Sites Risk Assessment in Canada Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA) (Health Canada, 2010a).
- Federal Contaminated Sites Risk Assessment in Canada Part II: Health Canada Toxicological Reference Values (TRVs) (Health Canada, 2010b).
- Federal Contaminated Sites Risk Assessment in Canada Part V: Guidance on Human Health Detailed Quantitative Risk Assessment of Chemicals ($DQRA_{chem}$) (Health Canada, 2010c).
- Federal Contaminated Sites Risk Assessment in Canada Part VII: Guidance for Soil Vapour Intrusion Assessment at Contaminated Sites (Health Canada, 2010d).
- A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME, 2006).

3.3 Limitations on the Use of the Generic Numerical Guidelines

Soil vapour quality guidelines are developed using a specific set of assumptions and models (see Appendix B). In some cases, the assumptions used to derive these guidelines may not be protective for particularly sensitive sites. Any of the following conditions may invalidate some of the assumptions used to develop soil vapour quality guidelines:

- The water table is within 1 m of a building foundation (possible wet-basement scenario) or the source of vapours is in close proximity to the foundation (floor drains, or other sub-floor utilities). In these cases, the soil vapour screening may be done through shallow soil vapour samples (short distance below building foundation) or sub-slab samples.
- The source-building separation distance is less than 1 m (e.g., shallow unsaturated soils with elevated VOC concentrations). In these cases, the soil vapour screening may be done through shallow soil vapour samples (short distance below building foundation) or sub-slab soil vapour samples.
- The building is taller than 4 floors (possible enhanced stack effect resulting in greater pressure differential than typical default values).
- Preferential pathways are present in the subsurface that provide a direct conduit from the vapour source to the inside of the building over and above that of a typical residential building (e.g., wet basements, highly permeable and atypical utility conduits, dirt floors, fractured media immediately below the building, etc.).
- Methanogenic conditions (or anaerobic conditions) are observed in close proximity to the building foundation (possible gas pressure-driven flow and/or explosion risk).

Further discussion of these conditions and appropriate actions is provided in Part C and Appendix E.

4. Deviations from *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines*

While in general this protocol is based on the soil protocol, there are some aspects where it deviates from the soil protocol, either due to unique considerations for soil vapour or to reflect changes in science and policy since the soil protocol was updated. Specific deviations include:

- Guidelines are not developed separately for the four land uses defined in the soil protocol. Separate vapour inhalation guidelines are calculated based on agricultural/residential and commercial/industrial exposure scenarios, however, and jurisdictions may allow for the exclusion of certain pathways based on land use, potentially subject to offset distances to more sensitive land uses.
- Only human receptors are currently evaluated for the derivation of soil vapour quality guidelines.
- Additional human vapour inhalation pathways have been added.
- Certain input parameters for the fate and transport models have been updated to reflect recent improvements in the science and research discussed in the 2008 update of the Canada-wide Standard for Petroleum Hydrocarbons in Soil (CCME, 2008), as well as more recent research conducted regarding the intrusion of soil vapours into buildings (see Appendix C).

PART B

1. Environmental Soil Vapour Quality Guidelines

Ecological receptors can potentially be exposed to soil vapours by several pathways, including:

- Wildlife exposed to vapours in underground burrows
- Wildlife exposed to vapours migrating into outdoor air
- Direct exposure of plant roots and soil organisms to soil vapours.

At the present time, the methods for evaluating these pathways and assessing the effects of contaminant vapours on environmental receptors are not considered to be sufficiently developed for the derivation of soil vapour quality guidelines. At sites where these pathways are believed to be important, they should be addressed through site-specific risk assessment.

PART C

1. Derivation of Soil Vapour Quality Guidelines Protective of Human Health

1.1 Introduction

As detailed in Section C.1 of the soil protocol, the derivation of soil vapour quality guidelines protective of human health involves:

- assessing the toxicological hazard or risk posed by a chemical
- determining estimated daily intake (EDI) and background indoor and outdoor air concentrations of that chemical, unrelated to any specific contaminated site (i.e., "background" exposure)
- defining generic exposure scenarios for the residential/agricultural and commercial/industrial land uses
- integrating exposure and toxicity information to set soil vapour quality guidelines. These guidelines must ensure that total exposure to a contaminant (background and site-related exposure) will present no appreciable human health risk.

The steps employed to derive soil vapour quality guidelines are similar to those used for site-specific risk assessment, and are subject to several sources of uncertainty, detailed in Section C.1.3 of the soil protocol. Exposure pathways are evaluated using mathematical models. The input values for the models depend on the choice of sensitive human receptor, exposure duration, frequency, and intensity. Evaluation of indirect pathways also requires input values representing physical characteristics of the site, which are affected by the soil type classification. Simplified models were deliberately chosen to represent the indirect pathways to limit the number of assumed input parameters; at a site-specific level, more complex models, along with detailed site-specific information, can provide more precise modelling results.

The potential exposure pathways considered in the development of Tier 1 human health soil vapour quality guidelines are:

- migration of vapours into indoor air and subsequent inhalation by site occupants
- migration of vapours into outdoor air and subsequent inhalation by site occupants

Migration of vapours into trenches or excavations and inhalation by construction or utility workers is also considered to be an operative exposure pathway. However, there is limited empirical information about vapour concentrations in trenches and trench model results are highly dependent of site-specific conditions such as trench dimensions and air exchanges. Therefore, it is recommended that this exposure be considered as part of Tier 3 based on site-specific considerations.

The development of site-specific objectives via limited modification of the generic guidelines, or the development of objectives using risk assessment, permits the flexibility required to remove or add pathways or to use site-specific models and inputs to develop more accurate values.

1.2 Guiding Principles

The guiding principles (listed below) for the derivation of generic soil vapour quality guidelines protective of human health reflect the principles adopted by CCME for contaminated sites (CCME, 2006):

1. There should be no appreciable risk to humans from contamination at a contaminated site. Within the allowable land uses, there should be no restrictions as to the extent or nature of the interaction with the site. All activities normally associated with the intended land use should be free of any appreciable health risk.
2. Guidelines are based on defined, representative situations. Deriving numerical guidelines necessitates defining specific scenarios within which the exposure likely to arise on the site can be predicted with some degree of certainty.
3. Guidelines are derived by considering exposure through all relevant pathways. The total exposure from soil, air, water, food and consumer products is considered in the development of guidelines.
4. The defined exposure scenarios are based on the most sensitive receptor to the chemical, and the most critical health effect, to ensure that the guidelines do not limit the use of a site within a given land use classification.
5. Guidelines should be reasonable, workable and usable. Guidelines are developed by applying scientifically derived information, backed by professional judgement where data gaps occur.

1.3 Investigation of Contaminant Toxicology

Contaminant toxicology is discussed in detail in Section C.2 of the soil protocol. The toxicity of contaminants is represented by the Toxicity Reference Values (TRVs). Specifically, for threshold substances, a Tolerable Daily Intake (TDI) and/or Tolerable Concentration (TC) is used to evaluate chemical toxicity to humans; for non-threshold substances, a Risk-Specific Dose (RSD) and/or Risk-Specific Concentration (RSC), derived from a Slope Factor (SF) or Inhalation Unit Risk (IUR) is used. For soil vapour guidelines, the TC, RSC and/or IUR are normally used if they are available (refer to Section C.5.4 of the soil protocol). If only oral TRVs are available, an evaluation of pharmacokinetics and mode of action after oral and inhalation exposure should be undertaken to ensure that it is appropriate to use these values for inhalation exposures. Any inhalation guideline developed using an oral TRV should be considered a provisional guideline.

Several different agencies derive or endorse TRVs. In general, the use of TRVs developed or endorsed by Health Canada (2004b) is recommended. However in some cases, it may be appropriate to adopt TRVs developed by other agencies, particularly the United States Environmental Protection Agency (US EPA) or the World Health Organization (WHO).

1.4 Exposure to Contaminants

Section C.3 of the soil protocol provides information on addressing mixtures of chemicals and for establishing the Estimated Daily Intake (EDI) to represent background exposure to a contaminant; this information is not repeated herein.

1.5 Relationships between Soil Vapour Quality Guidelines and Soil Quality Guidelines

Soil vapour quality guidelines are not explicitly based on any other guidelines. However, the approach used for their calculation is consistent with the approach used in the derivation of the Canadian soil quality guidelines for soil to indoor air pathway.

2. Exposure Scenarios and Pathways

The exposure scenarios and pathways used for the derivation of soil vapour quality guidelines are based on those applied for Canadian Soil Quality Guidelines. The reader is referred to Section C.4 of the soil protocol (CCME, 2006) for a more in-depth examination of the exposure scenarios and pathways; a brief summary with emphasis on exposures to soil vapour is provided as follows.

2.1 Exposure Assumptions

Soil vapour quality guidelines for the protection of human health are developed to ensure that contaminants present at the guideline concentration will not result in adverse human health effects. For the purpose of guideline development, CCME assumes a chronic exposure scenario (i.e., lifetime exposure to a remediated site).

Guidelines are developed to consider potential human exposure pathways within a multimedia context. Humans are assumed to be potentially exposed to 5 different media at contaminated sites: soil, water, air, food and consumer products. Humans are not generally directly exposed to soil vapours, but rather indirectly exposed in indoor or outdoor air. Therefore the soil vapour quality guidelines are based on the migration of contaminants in soil vapour to indoor or outdoor air. Potential soil vapour exposure pathways are presented in Figure 1.

If the defined exposure scenario used in developing the generic guidelines is thought to be inappropriate for a particular site, the generic guidelines may be modified under a Tier 2 or Tier 3 approach for setting site-specific objectives. This may involve the removal, addition or calibration of exposure pathways (e.g., a trench) to more accurately represent the exposure scenario present at a specific site.

2.1.1 Threshold Contaminants

For threshold contaminants, the guidelines consider that exposure occurs from multiple media at the contaminated site, as well as background exposure as represented by the EDI and background concentration in air. As discussed in the soil protocol, guidelines are derived by calculating the residual tolerable daily intake (RTDI) as the difference between the TDI and EDI (RTDI = TDI – EDI), then allocating the RTDI between the primary exposure media. By default, 20% of the RTDI is allocated to each of the five primary media (air, water, soil, food and consumer products), as shown in Figure 2. This allocation is implemented by multiplying the RTDI by an "allocation factor" (AF), which by default has a value of 0.2 (20%).

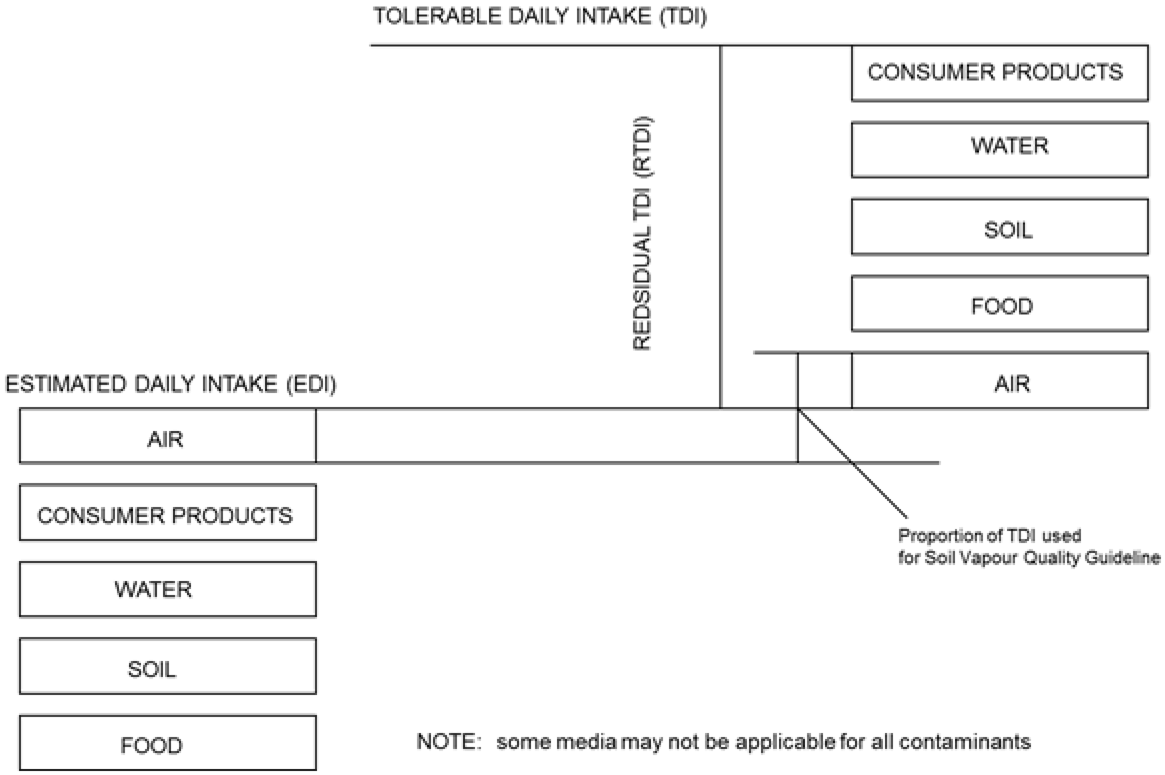

Figure 2. Conceptual Derivation of the Soil Vapour Guidelines for Threshold Substances from the Multimedia Exposure Assessment and Assumed Allocation Factor from the Residual Tolerable Daily Intake

Inhalation exposures are usually evaluated using a TC instead of the TDI. In this case, a similar approach is applied, where the background concentration in air is subtracted from the TC and the resulting "residual TC" is multiplied by the AF.

Depending on their physical and chemical properties, some soil vapour contaminants may not normally be present in all four of the remaining media (water, soil, food and consumer products). For example, some very volatile chemicals exhibit very low bioaccumulation and, as a result, the contribution of food to overall human exposure may be insignificant. If defensible contaminant-specific evidence exists demonstrating that the contaminant does not occur in a given medium, the RTDI may be distributed amongst fewer media and the allocation factor may be increased from 20% to a value given by:

$$\text{AF} = 1 / (\text{number of applicable exposure media}) \qquad \text{(Equation C.2.1)}$$

For some chemicals, the EDI may be greater than the TDI (or the background concentration in air may be greater than the TC), resulting in an RTDI (or residual TC) of 0. In these circumstances, Health Canada or the corresponding agency in the given jurisdiction should be consulted to determine an appropriate approach for developing a soil vapour quality guideline.

2.1.2 Non-threshold Contaminants

Soil vapour quality guidelines for non-threshold substances, like soil guidelines, are derived based on a specified incremental risk above background. Typically, Guidelines are derived for both 1 x 10^{-5} or 1 x 10^{-6} incremental risk; individual jurisdictions may apply guidelines based on either one of these risk levels.

2.2 Absorption of Chemicals into Human Body

As discussed in Section C.4.2 of the soil protocol (CCME, 2006), the health risk posed by a particular exposure depends on the absorbed dose; where the critical toxicological study has used a different exposure medium than that under investigation, a relative absorption factor (RAF) may be applied to account for the difference in absorption of the contaminant by the body in the two different media if adequate supporting information is available.

However, TRVs used to address the vapour inhalation pathway are normally based on exposure to air; therefore it is anticipated that soil vapour quality guidelines will almost always be derived using a RAF of 1.

2.3 Receptors and Exposure Pathways

The development of human health soil vapour quality guidelines considers inhalation of contaminants from vapours migrating into indoor and outdoor air.

Guidelines for the protection of indoor air are calculated separately for two scenarios: an agricultural/residential guideline reflecting an individual residing at the site full-time, and a commercial/industrial scenario reflecting a typical occupational exposure scenario. Individual jurisdictions should be consulted regarding whether the agricultural/residential guideline can be excluded at commercial/industrial sites, and if so if there are any offset requirements to account for potential lateral vapour migration to more sensitive neighbouring land uses.

The appropriate exposure factors for generic soil vapour guideline development are shown in Table B.1.

3. Human Health Guideline Derivation Process

As discussed in Section C.2, soil vapour quality guidelines are derived for the protection of indoor air and outdoor air quality. These two pathways are detailed in Sections C.3.1 and C.3.2 below; the equations and model input parameters are summarized in Appendices A and B, respectively.

3.1 Guidelines for the Protection of Indoor Air Quality

In general, the soil vapour guideline for the protection of indoor air quality ($SVQG_{IAQ}$) is based on the migration of soil vapours from the subsurface into buildings. The $SVQG_{IAQ}$ guidelines apply to soil vapour collected a minimum of 1 m from the building foundation, and assume that at least 1 m of clean soil is present immediately beneath the building. However, this protocol also provides the option of calculating $SVQG_{IAQ}$ applicable in situations where the minimum separation distance of 1 m cannot be met (e.g., shallow groundwater, sub-slab soil vapour sampling).

Soil vapour measurements should preferably be collected just above the source(s) of vapours or, if that is not practical, at the midpoint between the foundation and vapour source. Some details on the appropriate collection methods for soil vapour are available in the CCME report *Scoping Assessment of Soil Vapour Monitoring Protocols for Evaluating Subsurface Vapour Intrusion into Indoor Air* (Geosyntec, 2008). However several jurisdictions have recently developed sampling guidance specific to soil vapour that could also be used.

The most commonly used mathematical model for calculating attenuation factors for soil vapour migration into indoor air is the Johnson and Ettinger (1991) model (or J&E Model). The J&E Model is a 1-dimensional, steady-state analytical model that considers upward diffusion through unsaturated soil, convection into the building, and uniform dilution inside the building, as shown in Figure 3 (Johnson and Ettinger, 1991). The soil vapour concentration protective of potential risks via the vapour intrusion pathway is simply the risk-based target indoor air concentration divided by the attenuation factor (α), which is a dimensionless ratio that expresses the magnitude of the reduction in concentration from the subsurface to indoor air. .

If any of the limitations described in Section A.3.3 are present on a site, it is recommended that the generic $SVQG_{IAQ}$ calculated using the J&E Model not be used. Instead the $SVQG_{IAQ}$ calculated using default attenuation factors of 0.01 for a commercial building or 0.03 for a residential building should be used. The default/generic attenuation factors are considered sufficiently protective to be applied for all soil vapour to indoor air scenarios. Details on the development and use of the default attenuation factors are presented in Appendix C.

The $SVQG_{IAQ}$ is not intended to apply to sub-slab vapour measurements (i.e., vapour measurements directly below an existing building foundation). The default attenuation factors (0.01, commercial; 0.03, residential building) are used for the development of soil vapour guidelines applicable to sub-slab vapour measurements and for soil vapour measurements collected at a separation distance from the building foundation of less than 1 m.

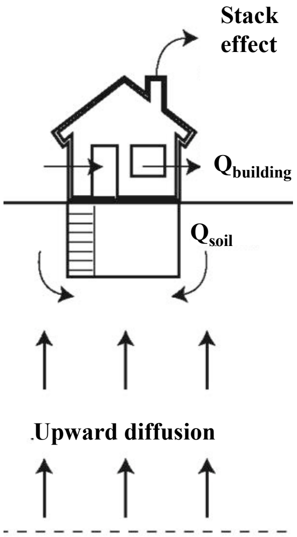

Figure 3. Conceptual Diagram of the J&E Model

3.1.1 Biodegradation Considerations

If the compound is a petroleum hydrocarbon (such as benzene, toluene, ethylbenzene, xylenes, n-hexane or n-decane), the $SVQG_{IAQ}$ should be increased by a factor to account for the expected amount of degradation. This is applicable if there is a minimum of 1 m of clean (no presence of volatile contaminants at elevated concentrations) unsaturated soil between the vapour source and the building foundation. In Tier 1, this should be a modest amount (a factor of 10), with additional consideration reserved for Tier 2 and Tier 3 (See Appendix C). If at a site there is overwhelming evidence of bioattenuation, the bioattenuation factors applied can be adjusted accordingly in Tier 2 or Tier 3. Risk management considerations for Tier 2 and Tier 3 should include verification of the oxygen distribution and temporal trends in the subsurface when aerobic degradation is assumed to occur. If oxygen levels are less than 5% by volume, additional sampling and analysis or mitigation should be recommended, and additional bioattenuation may not be applicable.

3.2 Guidelines for the Protection of Outdoor Air Quality

The soil vapour guideline protective of outdoor air quality ($SVQG_{OAQ}$) is calculated using the outdoor air volatilization factor developed by ASTM (2004). The conceptual model for the outdoor modelling is shown in Figure 4. Subsurface vapours diffuse upwards through the vadose zone through the soil surface and the released vapours are mixed with outdoor air at a rate based on the ambient wind speed and the assumptions of the dimensions of breathing zone.

The guideline protocol assumes that the soil surface is not covered or paved with asphalt or sidewalks, and thus would likely be conservative in situations where the ground surface is not native soil.

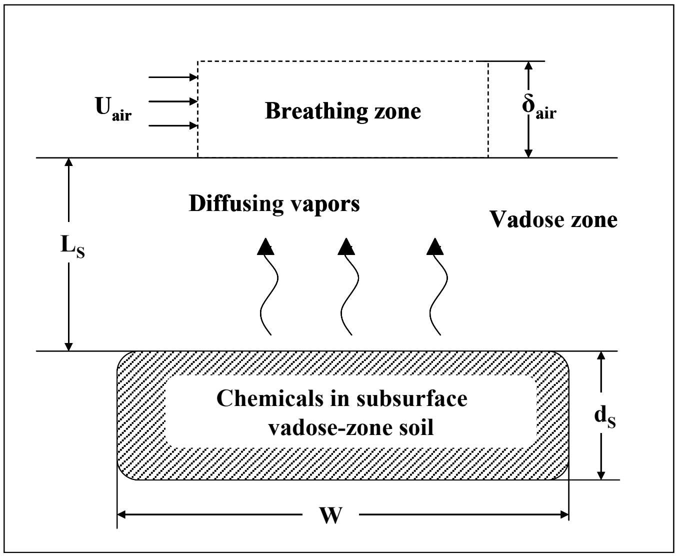

Figure 4. Volatilization from Subsurface Soils to Outdoor Air (ASTM, 2004)

For the Tier 1 SVQGs protective of outdoor air, it is recommended that the exposure assumptions be representative of the most sensitive receptor (e.g., residential) since sensitive land uses may be located immediately beside a less sensitive land use (e.g., commercial/industrial). Therefore, only one set of SVQG for outdoor air is required.

PART D

1. Derivation of the Final Soil Vapour Quality Guideline

1.1 Final Guideline Derivation

The goal of the final recommended soil vapour quality guideline ($SVQG_F$) is to protect all receptors and exposure pathways included in the conceptual model for the land use. The lowest of the pathway-specific guidelines calculated in Part C of this protocol is recommended as the $SVQG_F$ per land use (residential $SVQG_{F-R}$ and commercial $SVQG_{F-C}$), subject to restrictions discussed in Section D.1.2 below. A general overview of the entire guidelines derivation process outlining major steps leading to derivation of the final soil vapour quality guideline is illustrated in Figure 5.

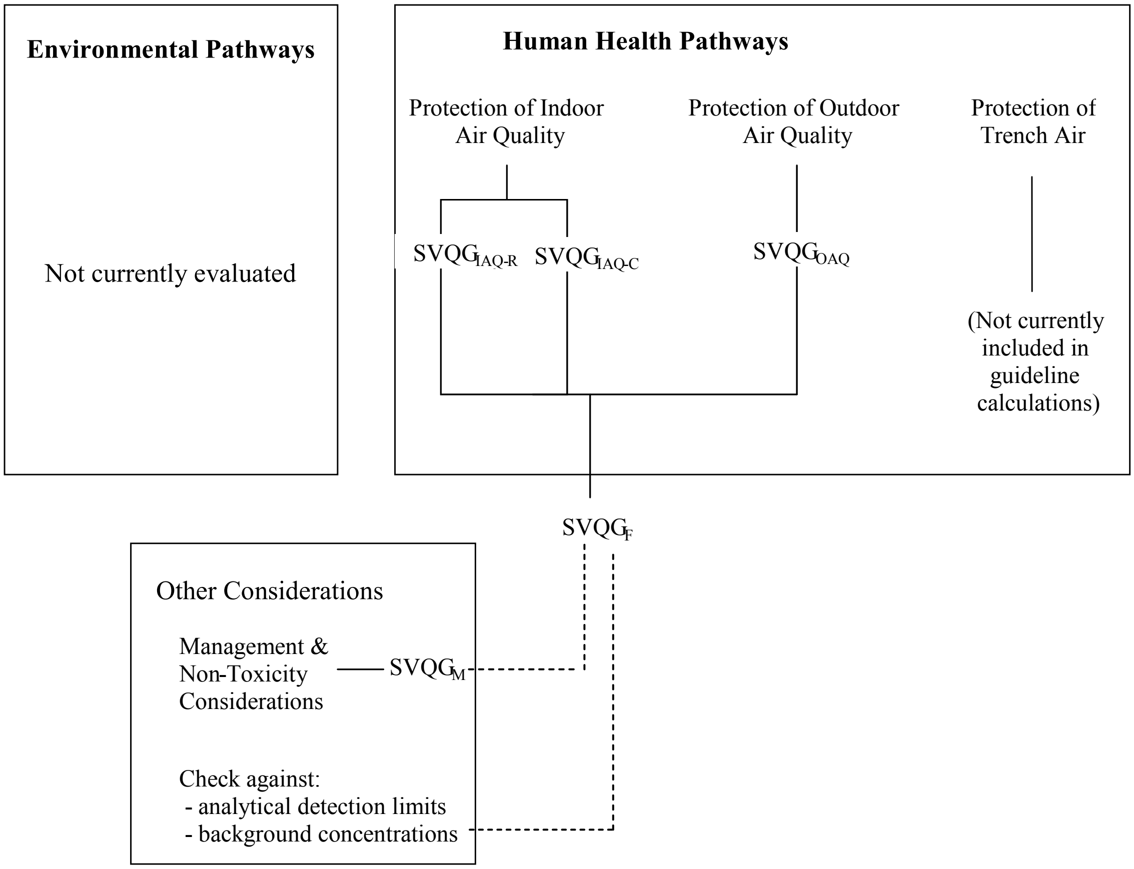

Figure 5. Overview of Steps Leading to Derivation of Final Soil Vapour Quality Guideline

The guideline for the protection of indoor air quality ($SVQG_{IAQ}$) is considered to be a required pathway; if this guideline cannot be established or if it is calculated based on an oral TRV then the $SVQG_F$ is considered to be a provisional guideline.

Development of Canadian soil vapour quality guidelines is complex and involves many parameters. While some parameters are known with great precision, most of them are estimates with considerable variability. In consideration of this and other uncertainties in the guideline development process, $SVQG_F$ are rounded to not more than two significant figures for presentation in assessment documents.

1.2 Considerations Other than Toxicity - Management Limits

Contaminants may have adverse effects in addition to producing toxic responses in human and ecological receptors. These may include aesthetic concerns (e.g., odours), explosive hazards, or damage to utilities and infrastructure. Additionally, certain pathways may be relevant for a chemical, but be subject to uncertainties or not have well-defined methods for their evaluation.

If there is evidence that a contaminant may cause significant environmental effects beyond toxicity to human and ecological receptors as captured in the pathways detailed in Parts B and C, then it should be evaluated. A soil vapour quality guideline for management considerations ($SVQG_M$) may be developed to reflect any additional concerns associated with the contaminant. At this time, standard methods for the calculation of management limits have not been established, and each chemical should be evaluated on a case-by-case basis. However, some considerations are listed below.

For chemicals that are potentially explosive, the $SVQG_M$ should include consideration of safety. A value of 50% of the lower explosive limit (LEL) is recommended.

For chemicals where a noticeable odour is likely to occur close to or at a lower concentration than toxicity, it may be appropriate to consider the potential for odours in indoor air. This value can be calculated by using the same model and assumptions as for the indoor vapour inhalation pathway (Appendices A and B), but replacing the TC with the odour threshold of the chemical. Odour sensitivity varies considerably between individuals. Therefore, the odour thresholds should be reviewed to assure that a central value is used and not an upper estimate. The allocation factor should be set to 1 for this calculation, and there should be no amortization of exposure (i.e., use the residential exposure scenario, regardless of the land use).

There may be considerable uncertainties in the development of the $SVQG_M$, and for some concerns associated with contaminants only a qualitative evaluation may be possible. Therefore, professional judgement should be used as to whether the $SVQG_F$ should be adjusted based on the $SVQG_M$, if it is lower than the guidelines for other pathways. If the $SVQG_M$ is higher than guidelines for other pathways, then it may be appropriate to use the $SVQG_M$ as an upper limit on “Tier 2 or Tier 3” site-specific guidelines.

1.3 Degradation Products

Certain contaminants may potentially degrade into more toxic or more mobile chemicals (e.g., degradation of tetrachloroethylene or trichloroethylene to vinyl chloride). Since degradation rates are affected by several site-specific factors, at this time a formal method for adjusting soil vapour quality guidelines to reflect degradation into more toxic compounds is not specified. However, where data support doing so, accounting for degradation to more toxic compounds should be considered on a chemical-specific basis. Furthermore, major degradation products should be highlighted in scientific supporting documents and fact sheets to ensure that users are aware of these degradation products and that site assessments take degradation products into consideration, particularly when developing long-term monitoring strategies.

1.4 Evaluation against Background Concentrations, Practical Quantitation Limits and Maximum Vapour Concentration

Guidelines should be reasonable, workable and usable. Guidelines are developed by applying scientifically derived information, backed by professional judgement where data gaps exist.

Occasionally, a calculated guideline may be lower than background concentrations or practical quantitation limits. It is expected that for most volatile chemicals, background concentrations in soil vapour will not be available and the default soil vapour background concentration is assumed to be 0 mg/m^3. Where background data are available, and the $SVQG_F$ is less than typical Canadian (or given jurisdiction) background concentrations, the accepted background concentration should replace the $SVQG_F$ generated using this protocol. There may also be circumstances where the $SVQG_F$ may be higher than the typical Canada or jurisdiction-wide background concentration, but specific locations may have unusually high background concentrations exceeding the $SVQG_F$. In these cases, jurisdictions have the option to set site-specific or regional guidelines that consider naturally occurring background concentrations.

A candidate $SVQG_F$ should also be checked against the current practical quantitation limit of available analytical methods achievable in Canada (generally 5 times the analytical detection limit). Where the $SVQG_F$ is below the limit of practical quantitation, a footnote should be added to the $SVQG_F$ stating, “laboratories may not be able to reliably measure concentrations of this magnitude.” The $SVQG_F$ should not be adjusted based on the practical quantitation limit, however, individual jurisdictions may incorporate practical quantitation limits in their implementation of the guideline.

Where any of the evaluation procedures described above does result in modification of a candidate $SVQG_F$, this condition will be noted in the assessment document for the substance.

1.5 Presentation of Soil Vapour Quality Guidelines

The soil vapour quality guidelines will be presented in tabular format, showing the guidelines developed for each pathway and the final soil vapour quality guideline ($SVQG_F$). An additional table can be prepared to show the alternative Tier 1 $SVQG_F$ when using the default attenuation factor to calculate $SVQG_{IAQ}$. An example is shown in Table 1 below (separate tables will be prepared for both 1 x 10^{-5} and 1 x 10^{-6} incremental risk levels for non-threshold substances).

Table 1. Example of Soil Vapour Quality Guideline Presentation

Guidelines (SVQG)	**Agricultural or Residential**		**Commercial or Industrial**	
	Coarse-textured	*Fine-textured*	*Coarse-textured*	*Fine-textured*
Final ($SVQG_F$)	##	##	##	##
Protection of indoor air quality ($SVQG_{IAQ}$)	##	##	##	##
Protection of outdoor air quality ($SVQG_{OAQ}$)	##	##	##	##
Management considerations ($SVQG_M$)	##	##	##	##

1.6 Scientific Criteria Documents

Scientific criteria documents and fact sheets are described in Section D.1.6 of the soil protocol (CCME, 2006). For substances with an existing soil quality guideline, the soil vapour quality guideline should draw on (or update) the existing scientific criteria documents; the document should be updated to reflect the soil vapour quality guideline or an addendum should be produced describing the derivation of the soil vapour quality guideline. If there is no existing soil quality guideline, then a new scientific criteria document will be prepared; it is anticipated that in these cases the soil vapour quality guideline would be developed in parallel with a soil quality guideline and groundwater quality guideline.

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APPENDIX A - SUMMARY OF MODELS AND EQUATIONS USED IN SOIL VAPOUR QUALITY GUIDELINE DEVELOPMENT

Indoor Air Pathway

Threshold chemicals:

$$SVQG_{IAQ} = \frac{(TC - \mathrm{Ca}) \cdot AF}{\alpha \cdot ET} \qquad \text{Equation A-1}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \qquad \text{Equation A-2}$$

Non-threshold chemicals:

$$SVQG_{IAQ} = \frac{(RsC)}{\alpha \cdot ET} \qquad \text{Equation A-3}$$

$$ET = D_1 \cdot D_2 \cdot D_3 \cdot D_4 \qquad \text{Equation A-4}$$

where:

$SVQG_{IAQ}$ = soil vapour quality guideline (mg/m^3) protective of indoor air quality;
TC = tolerable concentration or reference concentration (mg/m^3);
RsC = risk-specific concentration (mg/m^3);
C_a = background indoor air concentration (mg/m^3), background should be zero if no reliable local information is available;
AF = allocation factor (unitless);
α = soil vapour to building air attenuation factor (unitless) – Equation A-5;
ET = exposure term (unitless);
D_1 = hours per day exposed / 24 hours per day;
D_2 = days per week exposed / 7 days per week;
D_3 = weeks per year exposed / 52 weeks per year; and
D_4 = total years exposed (years) / life expectancy (years).

Calculation of attenuation factor (α) for indoor air pathway:

$$\alpha = [\frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right)\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right)}{\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]}].BAF \qquad \text{Equation A-5}$$

where:

α = attenuation factor (unitless);
D_T^{eff} = overall effective porous media diffusion coefficient (cm^2/s);

A_B = building area – floor and subgrade walls (cm^2);
Q_B = building ventilation rate (cm^3/s);
L_T = distance from contaminant source to foundation (cm);
Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s);
L_{crack} = thickness of the foundation (cm);
D_{crack} = overall effective vapour-pressure diffusion coefficient through the crack (cm^2/s); and
A_{crack} = area of cracks through which contaminant vapours enter the building (cm^2).
BAF = bioattenuation factor (unitless) = 10 at Tier 1 for petroleum hydrocarbons (BTEX, F1 and F2 (except when aviation fuel)), trimethylbenzenes, naphthalene, and straight-chain alkane compounds (e.g., hexane, octane); see Appendix E for details for Tier 2 BAF values.

Calculation of effective porous media diffusion coefficient in the unsaturated zone (D_T^{eff}):

$$D_T^{eff} = D^{air} \cdot \frac{\theta_a^{3.33}}{n^2} + \left(\frac{D^{water}}{H'}\right) \cdot \left(\frac{\theta_w^{3.33}}{n^2}\right) \qquad \text{Equation A-6}$$

where:
D_T^{eff} = overall effective porous media diffusion coefficient (cm^2/s);
D^{air} = pure component molecular diffusivity in air (cm^2/s);
D^{water} = pure component molecular diffusivity in water (cm^2/s);
H' = dimensionless Henry's Law constant (unitless) at soil temperature (e.g. 15C);
θ_w = moisture-filled porosity (unitless);
θ_a = vapour-filled porosity (unitless) = effective porosity (n) –moisture-filled porosity;
n = total soil porosity (unitless)

Calculation of effective diffusion coefficient through the crack (D_{crack}):

$$D_{crack} \approx D^{air} \cdot \left(\frac{\theta_a^{\frac{10}{3}}}{n^2}\right) \qquad \text{Equation A-7}$$

D_{crack} = effective diffusion coefficient through the crack (cm^2/s);
D^{air} = chemical-specific molecular diffusion coefficient in air (cm^2/s);
θ_a = vapour-filled porosity for coarse soil, regardless of native soil type (0.36); and
n = total soil porosity for coarse soil, regardless of native soil type (0.36).

For the effective diffusion coefficient through the crack (D_{crack}), it is assumed that a coarse, granular material is used as the base for the floor and footings. Therefore, it is assumed that the cracks are filled with coarse soil, even if the native soil is fine/medium textured.

Calculation of building ventilation rate (Q_B):

$$Q_B = \frac{L_B \cdot W_B \cdot H_B \cdot ACH}{3{,}600}$$ Equation A-8

Q_B = building ventilation rate (cm^3/s);
L_B = building length (cm);
W_B = building width (cm);
H_B = building height, including basement (cm);
ACH = air exchanges per hour (h^{-1}); and
3,600 = conversion factor (s/h).

Calculation of soil gas flow rate (Q_{soil})

Q_{soil} is no longer calculated from soil/building properties, but rather is a fixed value based on soil texture and land use (see Appendix B for details).

Outdoor Air Pathway

Threshold chemicals:

$$SVQG_{OAQnc} = \frac{(TC - Ca) \cdot AF \cdot BAF}{VF_{sv,amb} \cdot ET}$$ Equation A-9

$$ET = D_1 \cdot D_2 \cdot D_3$$ Equation A-10

Non-threshold chemicals:

$$SVQG_{OAQc} = \frac{(RsC) \cdot BAF}{VF_{sv,amb} \cdot ET}$$ Equation A-11

$$ET = D_1 \cdot D_2 \cdot D_3 \cdot D_4$$ Equation A-12

where:
$SVQG_{OAQ}$ = soil vapour quality guideline (mg/m^3) protective of outdoor air quality;
TC = tolerable concentration or reference concentration (mg/m^3);
RsC = risk-specific concentration (mg/m^3);
C_a = background outdoor air concentration (mg/m^3), background should be zero if no reliable local information is available;
AF = allocation factor;
$VF_{sv,\ amb}$ = volatilization factor, subsurface soil vapour to ambient air (dimensionless);
ET = exposure term (unitless);
D_1 = hours per day exposed / 24 hours per day;
D_2 = days per week exposed / 7 days per week;
D_3 = weeks per year exposed / 52 weeks per year; and
D_4 = total years exposed (years) / life expectancy (years).

BAF = bioattenuation factor (unitless) = 10 at Tier 1 for petroleum hydrocarbons (BTEX, F1 and F2 (except when aviation fuel)), trimethylbenzenes, naphthalene, and straight-chain alkane compounds (e.g., hexane, octane); see Appendix E for details for Tier 2 BAF values.

Calculation of volatilization factor for soil vapour to ambient air ($VF_{sv,amb}$):

$$VF_{sv,amb} = \left(1 + \frac{L_s \cdot U_{air} \cdot \delta_{air}}{D_{eff} \cdot W}\right)^{-1} \qquad \text{Equation A-13}$$

where:

$VF_{sv,amb}$ = volatilization factor, subsurface soil vapour to ambient air (dimensionless);
$D_{eff,}$ = effective diffusion coefficient, vadose zone soils, using Equation A-6 (cm^2/sec);
L_s = depth to subsurface soil vapour sample (cm);
U_{air} = ambient air velocity in mixing zone (cm/s);
W = width of source-zone area parallel to the wind direction (cm); and
δ_{air} = mixing zone height (cm).

APPENDIX B - DEFAULT PARAMETERS FOR GUIDELINE DEVELOPMENT

This appendix presents the recommended default values used to calculate soil vapour quality guidelines, along with relevant background information. It is recommended that any user of this Protocol consults with the relevant jurisdictional authority regarding the default parameters presented below.

Table B. 1 Exposure Scenarios[a]

Parameter	**Symbol**	**Indoor**		**Outdoor**
		Agricultural / Residential	*Commercial/ Industrial*	
Hours per Day	D_1	24	10	24
Days per Week on Site	D_2	7	5	7
Weeks per Year on Site	D_3	52	48	52
Total years exposed per life expectancy[b]	D_4	56	56	56

a – all values from CCME (2006) unless otherwise specified

b – For Tier 1, Exposure Term for non-threshold is defaulted as "one" as the exposure time (e.g., 10hr/day, 5 days/week, 48weeks/year for 30-40 years over a lifetime) exceeds the likely latency period for most carcinogens, as explained in Heath Canada - Part I (2004).

Exposure Duration and Exposure Term

Exposure terms were adopted from CCME (2006) without change. For Tier 1 defaults for outdoor air, a residential scenario is assumed at the property boundary immediately downwind from the contaminated area.

Table B. 2 Soil Parameters

Parameter	**Symbol**	**Soil Type** **Coarse-grained**	**Fine-grained**
Soil Bulk Density (g/cm^3)	ρ_b	1.7	1.4
Total Soil Porosity	n	0.36	0.47
Vapour-Filled Porosity	θ_a	0.31	0.303
Moisture-Filled Porosity	θ_w	0.05	0.167
Soil Gas Flow Rate (cm^3/s)[a]	Q_{soil}	167	16.7

a – based on a flow rate of 10 L/min for coarse soils and 1 L/min for fine soils

all values from CCME (2006) unless otherwise specified

Soil Bulk Density and Moisture Content

The default soil bulk densities and moisture contents were chosen to be representative of typical sand (coarse-textured) and clay (fine-textured) soils. CCME assigns a water-filled porosity value of 0.119 for coarse-textured soil, which results in a tortuosity value lower than the fine-textured soil. This is counter-intuitive because fine-textured soils would be expected to have a lower effective diffusion coefficient (lower tortuosity value) than coarse-textured soil. It would be defensible to use a lower value for water-filled porosity in coarse-textured soils, such as 0.05, which is consistent with the Health Canada value. Considering that buildings act to shield soil from rainwater infiltration, it is reasonable to expect soils to be relatively dry beneath buildings.

Porosity

The total soil porosity is calculated from the soil bulk density, assuming a particle density of 2.65 g/cm^3. The moisture-filled porosity is calculated as the soil bulk density multiplied by the moisture content (assuming a water density of 1 g/cm^3). The vapour-filled porosity is obtained by subtracting the moisture-filled porosity from the total porosity.

Minimum Soil Vapour Flow Rate into Buildings

The CCME (2006) soil protocol calculated a soil vapour flow rate based on soil vapour permeability and pressure differentials; due to the difficulties associated with reliably measuring these parameters and more recent research into this pathway, the ratio of the soil gas flow rate to the building air flow rate is now defined directly (see Appendix C).

Table B. 3 Building Parameters

Parameter	Symbol	Residential	Commercial
Building Length (cm)	L_B	1225	2000
Building Width (cm)	W_B	1225	1500
Building Area (cm^2)	A_B	2.7×10^6	3.0×10^6
Building Height (cm)[a]	H_B	360	300
Thickness of Building Foundation (cm)	L_{crack}	11.25	11.25
Area of Crack (cm^2)	A_{crack}	994.5	1846
Air Exchanges per Hour (1/h)	ACH	0.5	0.9

a – including basement
all values from CCME (2006) unless otherwise specified

Building parameters have been adopted from CCME (2006), and were originally based on a review of typical building characteristics and building codes.

Soil guidelines (CCME, 2006) have historically been calculated for both slab-on-grade and basement scenarios for the residential land use, with slab-on-grade residential building typically more sensitive with default site parameters than the residential building with a basement due to higher advective flow. However, with the fixed Q_{soil} value recommended herein, the advective flow is no longer dependent on foundation depth. While foundation depth does not affect the calculation of generic guidelines, where a fixed source-foundation separation of 100 cm is assumed, it becomes important when determining the source-foundation separation on a site-specific basis (i.e., Tier 2 or Tier 3 guidelines). When assessing risks to existing buildings, the actual building characteristics can be used; when assessing risk to potential future residential buildings, a basement should be assumed unless the jurisdiction allows otherwise in areas where residences do not typically have basements. For commercial and industrial land uses, only slab-on-grade construction is considered for the calculation of generic guidelines.

Minimum separation distance from vapour measurement to building foundation (L_T in cm)

For the calculation of the Tier 1 guidelines, a minimum separation distance of 1 metre (source to building foundation) is recommended. Consistently, the soil vapour measurements should be collected at a minimum of 1 m (to top of the screen) below the building foundation. Generally, vapour measurements should be collected in the vadose zone and just above the vapour source or at a midpoint between the foundation and the vapour source. It is assumed that there is at least 1 m of clean soil (not impacted by elevated concentrations of volatile contaminants) between the building foundation and the source.

If conditions do not allow the collection of samples deeper than 1 m below the building foundation, sub-slab or shallow soil vapour samples could be used (with appropriate QA/QC measures to ensure samples are representative) and results should be compared against the Tier 1 guideline values developed using the default attenuation factors of 0.03 (residential) and 0.01 (commercial/industrial).

Table B. 4 Outdoor Air Parameters

Parameter	Symbol	Value
Mixing zone height (cm)	δ_{air}	150
Ambient air velocity in mixing zone (cm/s)	U_{air}	400
Depth to soil vapour sample (cm)	L_s	100
Width of source-zone area parallel to the wind direction (cm)	W	3,000

Mixing Zone Height

The mixing zone height is often taken as the height of the breathing zone for a passer-by, roughly 1.5 m. In reality, the mixing zone extends to much higher levels, so this assumption will tend to overestimate outdoor air concentrations, which is protective to address children with a lower breathing zone height.

Ambient Air Velocity

Ambient air velocities across North America are approximately 4 m/s on average (Environment Canada, 2008).

Depth to Soil Vapour Sample

The depth to the soil vapour sample is assumed to be at least 1 m below ground surface for Tier 1. When calculating site-specific guidelines, the depth to soil vapour sample should be based on the actual depth of the top of the screen of the soil vapour probe.

Width of Source Zone

A default value for the width of the source zone was assumed to be 30 m, based on the typical size of most underground storage tank site plumes. Jurisdictional guidance should be consulted to determine the appropriate definition of the source size.

Required Chemical Properties

- Tolerable Daily Intake and/or Risk-Specific Dose
- Tolerable Concentration and/or Risk-Specific Concentration
- Background Indoor and Outdoor Air Concentration (threshold chemicals)
- Henry's Law Constant
- Diffusion Coefficient in Air
- Diffusion Coefficient in Water
- Bioattenuation factor applicable only to petroleum hydrocarbons (BTEX, F1 and F2 [except when aviation fuel]), trimethylbenzenes, naphthalene, and straight-chain alkane compounds (e.g., hexane, octane). In Tier 1, a factor of 10 is applicable assuming at least one metre of clean soil between the top of the soil vapour probe screen and building foundation, or ground surface in the case of outdoor air guidelines. If at a site there is overwhelming evidence of bioattenuation, the bioattenuation factors applied can be adjusted accordingly in Tier 2 or Tier 3.

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APPENDIX C – UPDATED ASSUMPTIONS FOR INDOOR VAPOUR INTRUSION MODELLING

Volumetric Flow of Soil Gas into the Building (Q_{soil})

Recent research has provided an improved understanding of vapour intrusion and the application of the Johnson and Ettinger (J&E) Model has evolved accordingly. The original J&E Model calculated the volumetric flow of soil gas into the building (Q_{soil}) using the "perimeter crack model" equation:

$$Q_{soil} = \frac{2 \cdot \pi \cdot \Delta P \cdot k_v \cdot X_{crack}}{\mu \cdot \ln\left[\dfrac{2 \cdot Z_{crack}}{r_{crack}}\right]} \qquad \text{Equation C-1}$$

where:

Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s);
ΔP = pressure differential ($g/cm/s^2$);
k_v = soil permeability to vapour flow (cm^2);
X_{crack} = length of idealized cylinder (cm);
μ = vapour viscosity (g/cm/s);
Z_{crack} = distance below grade to idealized cylinder (cm); and
r_{crack} = radius of idealized cylinder (cm).

One potential issue with the perimeter crack model is that the J&E Model is a steady-state model and the pressure differential from the subsurface to indoor air is not steady. Recent studies have conclusively shown that the pressure gradient is variable, and frequently reverses direction (Luo *et al*., 2009). Furthermore, the average building under-pressurization assigned for generic J&E Model simulations (typically about 4 Pascal) accounts for the stack effect in a low-rise building, but is not sufficient to account for the Bernoulli effect, which causes building under-pressurization to increase as the wind-speed increases, as much as 30 Pascal for a single story building, as documented by Luo *et al*. (2009).

In recent years, alternative approaches have been adopted for estimating Q_{soil}. Johnson (2005) used mass balance principles to show that the $Q_{soil}/Q_{building}$ ratio is equal to the ratio of indoor air concentrations divided by sub-slab vapour concentrations (i.e., the sub-slab to indoor air attenuation factor). Empirical data are available to show that this ratio is commonly in the range of 0.05 to 0.0001 (Johnson, 2005), after accounting for background sources, but not accounting for the influence of spatial and temporal variability in the empirical data. If the building air exchange rate and volume are known or can be reasonably estimated (i.e., if $Q_{building}$ is known), then the Q_{soil} value could be calculated from this ratio. For a typical residential building, this approach could lead to Q_{soil} values from about 100 to about 0.01 L/min; however, regulatory agencies have typically selected values in the range of 1 to 10 L/min. The Health Canada approach (Health Canada, 2010) uses a default Q_{soil} value of 10 L/min instead of the perimeter crack model; whereas, the CCME (2008) CWS-PHC approach uses the perimeter crack model and calculates a Q_{soil} value of 3.3 L/min for coarse soil and only 0.055 L/min for fine soil. The CCME CWS-PHC approach calculates very low attenuation factors for shallow soil gas (approximately 10^{-3} to 10^{-5} range) that are lower than typical empirical attenuation factors (Dawson, 2008, US EPA 2012a), and therefore potentially not protective. As a result, for the purposes of this protocol for the derivation of generic soil vapour guidelines, the CCME is using Qsoil values of 10 L/min (167 cm^3 /sec) for coarse textured soils and 1 L/min (16.7cm^3/sec) for fine and medium textured soils.

Empirical Attenuation Factor for the Vapour Intrusion Pathway

Background

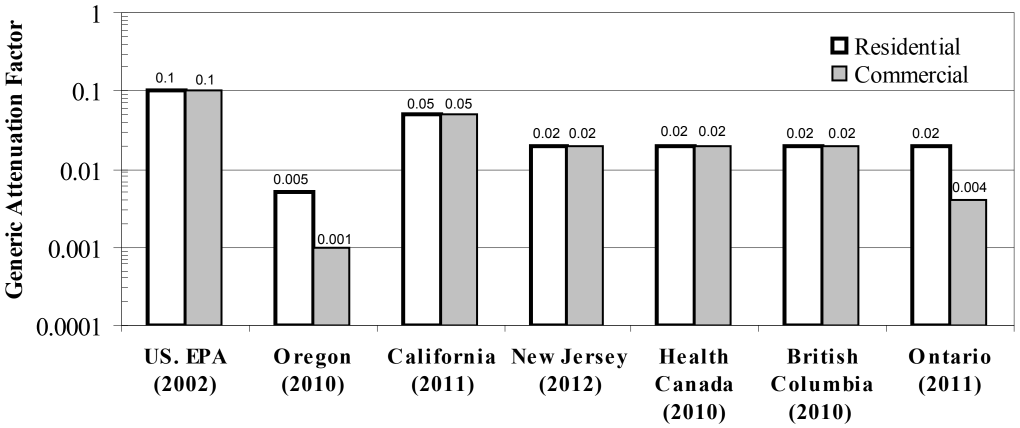
In recent years, many guidance documents have recommended using empirical attenuation factors instead of the J&E Model for developing screening levels protective of the vapour intrusion pathway (US EPA, 2002; Oregon DEQ, 2010). Empirical attenuation factors are derived from measurements of indoor air and a subsurface medium (e.g., groundwater, soil vapour, sub-slab soil vapour, or crawlspace air). They are defined as a ratio where the numerator is the indoor air concentration and the denominator is the subsurface concentration.

For situations where precluding conditions prevent the use of the J&E model to calculate attenuation factors, it is recommended that empirical sub-slab attenuation factors be used. Many agencies recommend selecting empirical sub-slab attenuation factors near the upper end of the range (e.g., 95th percentile), instead of mid-range values (50th percentile).

In 2002, the US EPA recommended a 95th percentile value of 0.1 as a generic attenuation factor for sub-slab. However, the 2002 database contained 86 sub-slab soil vapour samples that were collected at only one site (US EPA, 2008). Shortly after the release of the draft vapour intrusion guidance in 2002, the US EPA significantly expanded the number of sub-slab samples (1584 from 15 different sites) (US EPA, 2008) in its database. Also, to facilitate the evaluation of the vapour intrusion data, the US EPA implemented some data screening criteria including: indication of background sources, comparison with reporting limits (RLs) and application of the 95th percentile of the background indoor air concentration. Subsequently, a sub-slab attenuation factor of 0.15 was reported as the 95th percentile (US EPA 2008). However, none of the analyses of the USEPA empirical database had specifically addressed how spatial and temporal variability inherent in the empirical data might bias the statistical distribution of attenuation factors.

The database also included uncertain soil vapour data, and biases due to background interferences, all of which could cause increased range and skewness in the distribution of attenuation factors. The empirical data set was, for instance, comprised mostly of 24-hour indoor air samples, which have been shown to have a range of temporal variability of about one order of magnitude (Kuehster *et al*., 2004). Sub-slab samples were typically small-volume and short-duration samples and had been shown to have similar or higher levels of spatial variability, in addition to temporal variability (USEPA, 2006; Luo *et al*., 2009). The significant variability in both the numerator and denominator of the empirical attenuation factors triggered the argument that the mean or median values may still be representative of average numbers, while the upper 95th percentile value tended to overestimate the true long-term average 95th percentile attenuation factor. A number of regulatory agencies recommended generic sub-slab attenuation factors lower than the US EPA's 95th percentile value, ranging from 0.005 (Oregon DEQ, 2010) to 0.05 (California DTSC, 2011), as shown in Figure 1. Several other agencies (e.g., Health Canada, Ontario Ministry of Environment (MOE), British Columbia Ministry of Environment (MOE), and New Jersey Department of Environmental Protection (DEP)) recommended a generic attenuation factor of 0.02 for residential buildings. It is notable that while Oregon and Ontario reported the 5 time difference in generic attenuation factors between commercial and residential buildings, the rest suggested the same factor values for both building types.

Figure C. 1 Recommended Generic Sub-slab Attenuation Factors for Residential and Commercial Buildings in North America.



Sources: US. EPA, 2002; Oregon DEQ, 2010; California DTSC, 2011; New Jersey DEP, 2012; Health Canada 2010; Ontario MOE, 2011; British Columbia MOE, 2010.

Recently, US EPA released its report on the evaluation and characterization of attenuation factors for chlorinated volatile organic compounds (CVOCs) and residential buildings (US EPA, 2012a), based on the 2010 database with basic data quality controls (e.g., sampling design, QA/QC, temporal/spatial concurrency of paired vapour samples). A number of issues that potentially influence empirical vapour attenuation factors were revised, including temporal/spatial variability, background indoor air concentration, and handling data below reporting limits. Several screening criteria were analyzed and explained thoroughly in the US EPA's 2012a report. Briefly, to estimate an empirical attenuation factor for which subsurface sources of vapours (rather than background sources) were likely to be the principal contributor to contaminants of concern observed in building structures, three different criteria were considered:

- **Subsurface concentration screen: s**creening out subsurface concentrations less than reporting limits (RLs).
- **Data consistency screen:** screening out samples for which field notes indicate the presence of indoor ("background") sources of VOCs, indoor air concentrations are greater than the corresponding subsurface concentration, or attenuation factors for an individual chemical are inconsistent with the attenuation factors for other chemicals reported for the same pair of samples.

- **Source strength screens:** screening out source-strength concentrations less than certain multipliers of the 90th percentile of background levels. The selected multiplier was 50X for sub-slab soil vapour. The rationale for using the background levels was described in US EPA (2011). US EPA (2012a) also emphasized this criterion as the best approach to minimize the influence of background sources on the sub-slab vapour dataset while retaining a reasonable number of data points.

Development of default attenuation factor

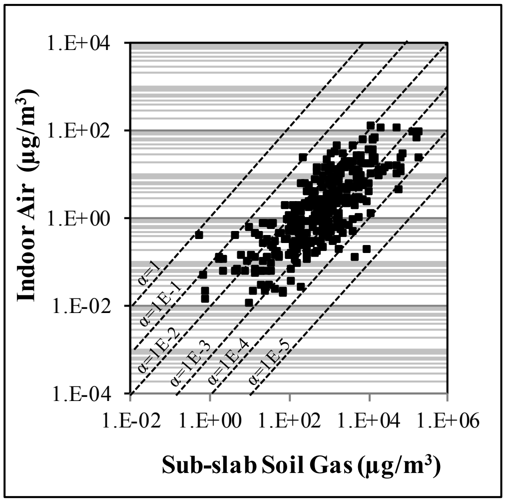
For the purpose of developing SVQGs, default attenuation factors were developed by CCME based on the sub-slab soil vapour and indoor air quality data contained in the US EPA's vapour intrusion database (US EPA 2012b). To derive a reasonable estimation of attenuation factors for residential and commercial buildings, the three aforementioned screening criteria used by the US EPA (2012a) were employed to create a data subset of 391 paired samples for residential and 92 for commercial buildings.

Figure C.2 shows a scatter plot of all the sub-slab soil vapour and indoor air concentrations (left), a statistical summary table (central), and a box-whisker plot for attenuation factors (right) for residential properties. There appears to be a linear relationship between sub-slab soil vapour and indoor air concentrations. As shown in the scatter plot, the data distributions developed a very defined positive slope, attenuation factors mostly varied within only two orders of magnitude; 3.4E-04 for 5th percentile and 3.04E-02 for 95th percentile. These calculated percentile values are consistent with those reported by Dawson (2007). To further evaluate the strength and direction of the relationship between sub-slab soil gas and indoor air concentrations, Kendall's tau, a measure of correlation with a value ranging from +1 (positive correlation) to -1 (negative correlation), was calculated, and the coefficient value of 0.61 confirmed this highly significant correlation.

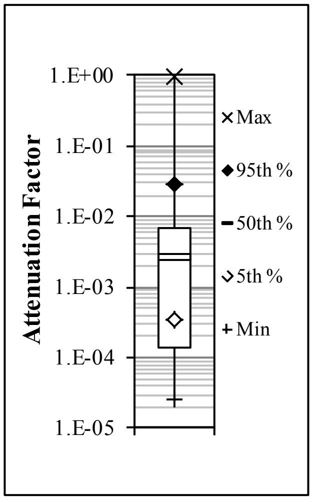
Accordingly, the use of the 95th percentile value of 0.03 as the default attenuation factor for residential properties is recommended. This value is slightly higher than the 0.02 (corresponding to 92nd percentile) value adopted by Health Canada, Ontario and British Columbia, but within the range of values among other regulatory agencies across North America (as shown in Figure C.1). It is notable that the data subset contained almost exclusively samples for chlorinated volatile organic compounds (only one PHC out of 391 paired samples). Therefore, the recommended default attenuation factors (α=0.03) may not be representative of sub-slab attenuation factor at sites impacted by petroleum hydrocarbons; however, since a minimal level of bioattenuation can be anticipated from sub-slab to indoor air vapour migration, the proposed default attenuation factor should still be considered a reasonably conservative value for PHC sites.

For commercial properties, the same approach was applied for sub-slab soil vapour with paired indoor air samples collected at properties labelled as commercial, residential/commercial, commercial/residential and school/commercial. Limited information about indoor air background levels in commercial settings is available. However, the sources of indoor air background concentrations (e.g., paints, degreasers, vanish removers and other consumer products), can also be found in both residential and commercial settings; thus the residential background indoor air levels described in US EPA (2011) were used in the evaluation of the sub-slab attenuation factors. Figure C.3 displays a scatter plot of all VOC data in sub-slab soil gas relative to indoor air concentration (left), a statistical summary table (central), and a box-whisker plot for attenuation factors (right). A highly significant correlation was also observed (Kendall's tau correlation coefficient of 0.63). The 95th percentile value of 0.01 (to one significant digit) is also recommended as a default attenuation factor for commercial properties.

Figure C. 2. Empirical Sub-slab Attenuation Factors for Residential Buildings[1]



Statistics	AF Value
Min	2.5E-05
5th %	3.4E-04
25th %	1.4E-03
50th %	2.7E-03
75th %	7.1E-03
95th %	3.0E-02
Max	9.4E-01
Sample Count*	391 (390CHC+1PHC)
No. of Site	12

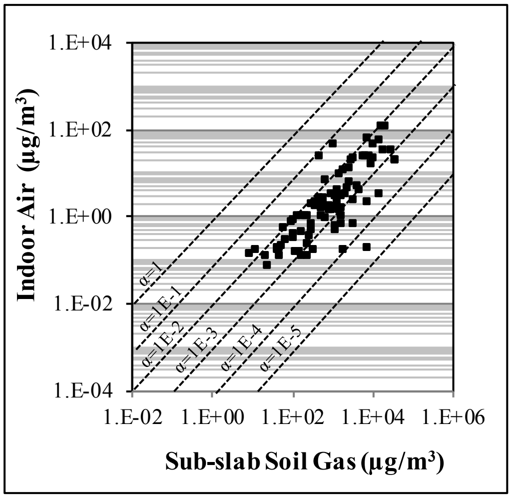


*: sample number for Chlorinated Hydrocarbons (CHC) and for Petroleum Hydrocarbon (PHC)

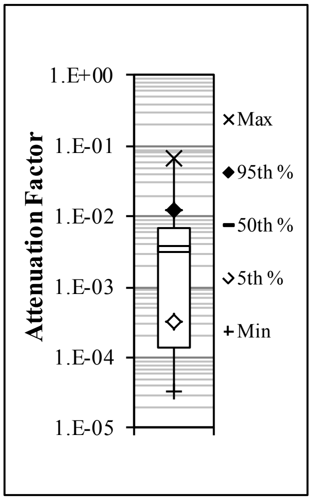
[1]: samples collected in all buildings, labelled as residential, residential/commercial, and commercial/residential

The rationale for a lower attenuation factor for commercial buildings is supported by the fact that commercial properties generally have air handling units that blow air into the building, and are designed to maintain a slight positive pressure to avoid unpleasant cold drafts in the winter and to avoid condensation in the summer. This slight net positive pressure, combined with an increased ventilation rate, results in a lower ratio of $Q_{soil}/Q_{building}$. Variations in wind and barometric pressure will cause fluctuations in the pressure gradient between the building and the subsurface, so even where there is a net positive pressure, there still may be some amount of vapour intrusion during short-term pressure reversals. The lower attenuation factor of 0.01 may also be used for residential buildings with parking beneath the entire building footprint. That is because building codes specify a ventilation rate (e.g., 3.9 L/s/m^2), which would result in an air-exchange rate higher than a typical residential building, and therefore, contribute to additional dilution of vapours in the parking area.

Figure C. 3. Empirical Sub-slab Attenuation Factors for Commercial Buildings[1]



Statistics	AF Value
Min	3.4E-05
5th %	3.3E-04
25th %	1.4E-03
50th %	3.4E-03
75th %	5.9E-03
95th %	1.2E-02
Max	6.7E-02
Sample Count*	92 (90CHC+2PHC)
No. of Site	5



*: sample number for Chlorinated Hydrocarbons (CHC) and for Petroleum Hydrocarbon (PHC)

[1]: samples collected in all buildings, labelled as commercial, residential/commercial, commercial/residential, school/commercial

In summary, based on the evaluation of the available empirical data regarding sub-slab attenuation factors, the recommended default attenuation factors are:

- 0.03 for residential buildings and
- 0.01 (rounded to one significant figure) for commercial/industrial buildings and for residential buildings where vehicle parking occurs beneath the entire footprint of the building.

Water-Filled Porosity

In the past, CCME assigned a water-filled porosity value of 0.119 for coarse soil, which results in a tortuosity value lower than the fine soil. This is counter-intuitive because fine-grained soils would be expected to have a lower effective diffusion coefficient (lower tortuosity value) than coarse soil. It is defensible to use a lower value for water-filled porosity in coarse soils, such as 0.05, which is consistent with the Health Canada and US EPA value. Considering that buildings act to shield soil from rainwater infiltration, it is reasonable to expect soils to be relatively dry beneath buildings. The default coarse water-filled porosity parameter has been updated in this protocol.

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APPENDIX D – DETERMINATION OF VOLATILE COMPOUNDS OF POTENTIAL CONCERN

In this protocol, volatile compounds of potential concern (COPCs) are defined as compounds that could potentially pose unacceptable risks to human health via inhalation exposures attributable to migration as vapours in soil gas. From a practical perspective, this means the vapour concentrations can exceed risk-based concentration limits after accounting for a *de minimus* amount of attenuation (a factor of 30 is considered a conservative estimate from available data on sub-slab to indoor air attenuation rates) from the subsurface to the breathing zone. This definition accounts for the fact that there are some chemicals with low vapour pressures that are nevertheless capable of posing a potential risk because they are highly toxic, and some highly volatile compounds are not capable of posing a risk via inhalation because they are insufficiently toxic. This approach is consistent with the Health Canada vapour intrusion guidance, although there might be differences in the assumed values for attenuation. Most of the compounds of potential concern are organic, and so the term volatile organic compounds (VOCs) will be used to refer generally to the volatile compounds of potential concern throughout the remainder of this document.

The exposure point concentration depends on the exposure scenario. For a residential scenario, the assumed exposure for Tier 1 is typically 24 hours/day, 365 days/year and for carcinogens, the exposure duration is typically 56 years (Health Canada, 2004). For a commercial/industrial scenario, the assumed exposure is typically 10 hours/day, 5 days per week, 48 weeks/year. Exposure scenarios for workers and passers-by for outdoor air exposures are typically very different than indoor air exposure durations and frequencies.

Maximum vapour concentrations (Cv_{max}) from a groundwater source can be calculated by multiplying the aqueous solubility (typically mass/volume) by the dimensionless Henry's Law Constant (for an appropriate temperature). Exhibit 1 presents the equations to calculate the maximum vapour concentrations from a non-aqueous phase liquid (NAPL) release in the subsurface. If the NAPL contains multiple chemicals, then Raoult's Law may be applied:

$$Cv_{max}\ (g/m^3) = \frac{x_i\ VP(T)\ MW}{R\ T}$$

where:

x_i = mole fraction of chemical on NAPL (mol/mol)
VP(T) = vapour pressure at specified temperature (atm)
MW = molecular weight (g/mol)
R = Universal Gas Constant (0.00008206 m^3atm/mol/K)
T = average soil temperature (K)

Compounds that are very strongly adsorbed or absorbed to geologic media may not be sufficiently mobile to pose an unacceptable risk for some of the pathways considered in this Protocol. For example, there are several polycyclic aromatic hydrocarbons (PAHs) and polycyclic biphenyls (PCBs) considered to pose a potential risk via vapour intrusion by the United States Environmental Protection Agency (US EPA) (2002), ASTM (2008) and others; however, this is based on assumptions that have not been rigorously tested. Basic research is needed in this area, but with the present knowledge, it is conservative to assume that adsorptive sites become occupied and retardation diminishes to negligible levels over time periods shorter than the duration of the exposure scenarios considered here.

EXHIBIT 1.
SCREENING PROCESS TO DETERMINE IF CHEMICAL IS VOLATILE AND TOXIC

1. Estimate Maximum Vapour Concentration

NAPL Present: $C_v^{NAPL} = UCF_1 * MW*P/(R*T)$
No NAPL Present: $C_v^{NO\ NAPL} = UCF_2 * S * H'$
Maximum Vapour Concentration: $C_v = Max\ (C_v^{NAPL}, C_v^{NO\ NAPL})$

Parameter	Default
C_v^{NAPL} = Vapour concentration NAPL is present (mg/m^3)	Calculated
$C_v^{NO\ NAPL}$ = Vapour concentration NAPL not present (mg/m^3)	Calculated
MW = Molecular weight (g/mole)	Chemical specific
P = Pure chemical vapour pressure (atm)	Chemical specific
R = Gas constant (m^3-atm/K-mole)	$8.21x10^{-5}$
T = Absolute temperature (K, 273^{o}C + T(^{o}C))	288
H' = Dimensionless Henry's Law Constant	Chemical specific
S = Pure chemical aqueous solubility (mg/L)	Chemical specific
UCF_1 = Unit Conversion Factor (mg/g)	1,000
UCF_2 = Unit Conversion Factor (L/m^3)	1,000
C_a = Concentration in air (mg/m^3)	Calculated

2. Calculate Maximum Indoor Air Concentration

$C_{air} = C_v * \alpha$ where $\alpha = 0.03$ (dilution factor of about 30) for residential and $\alpha = 0.01$ for commercial buildings.

3. Calculate Target Air Concentration

This section is outside the scope of this CCME protocol and is presented only as an example. The Target Air Concentrations must be calculated based on the policies and technical requirements of each jurisdiction.

Carcinogen

$C_{airc}^{T} = ILCR^{T} / (UR * ET)$

*Note: If UR is not available then convert SF to UR: UR = SF $(mg/kg)^{-1}$ * IR / BW, use IR and BW for adult for COPC screening purposes.

Non-carcinogen ($TC_{air} = R_fC$)

$C_{airnc}^{T} = AF * (TC_{air} – C_b)/ ET$

*Note: If TC not available then convert R_fD to TC: TC = R_fD(mg/kg-day) * BW / IR (use BW and IR for toddler for chemical screening purposes)

Parameter	Default
C_{air}^{T} = Target concentration of contaminant in air (mg/m^3)	Calculated
C_b = background air concentration (mg/m^3)	Zero
R_fC = Reference Concentration (mg/m^3)	Chemical specific
R_fD = Reference Dose (mg/kg(BW)-day)	Chemical specific
$ILCR^{T}$ = Target incremental lifetime cancer risk (dimensionless)	10^{-6} - 10^{-5}
AF = Allocation factor	0.2 - 1.0
SF = Slope factor $(mg/kg\text{-}day)^{-1}$	Chemical Specific
IR = Receptor air intake rate (m^3/day) (toddler non carcinogens)	9.3
IR = Receptor air intake rate (m^3/day) (adult carcinogens)	15.8
BW = Body weight (kg) (toddler non carcinogens)	16.5
BW = Body weight (kg) (adult carcinogens)	70.7
UR = Unit risk factor $(mg/m^3)^{-1}$	Chemical Specific
ET = Fraction of time exposed (dimensionless)	1.0
TC_{air} = Tolerable concentration in air (mg/m^3)	Chemical specific

4. Determine if Chemical is Volatile and Sufficiently Toxic

If $C_{air} \geq C_{airc}^{T}$ or C_{airnc}^{T} then chemical is considered volatile for purpose of selecting COPCs.

If $C_{air} \leq C_{airc}^{T}$ and C_{airnc}^{T} then chemical is not considered volatile for purpose of selecting COPCs.

References

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APPENDIX E – GUIDANCE ON THE DERIVATION OF SITE-SPECIFIC (TIER 2 AND TIER 3) SOIL VAPOUR QUALITY GUIDELINES

Tier 2 and Tier 3 allow for adjustment of the soil vapour guideline values with consideration of site-specific conditions, within limits. The specific requirements for and implementation of Tier 2 and Tier 3 are governed by the jurisdiction with authority over the site; however general guidance is provided herein.

The recommended approach for Tier 2 SVQGs consists of two components: 1) exclusion of certain pathways of potential exposure where they are not relevant for a particular site, and 2) use of site-specific input values in the equations used to calculate guideline values, to the extent that there are data to support the site-specific model input value(s). Each of these is described in some detail in the subsections below.

E.1 Tier 2 Pathway Exclusion Considerations

In Tier 2, pathways could be excluded if they are not applicable for a specific site. Conditions under which specific pathways could be eliminated in Tier 2 include:

Protection of Indoor Air Quality Pathway:
- Sites with no potential for future buildings, either due to physical characteristics of the site or land use restrictions.

Protection of Outdoor Air Quality Pathway:
- Remote locations with negligible frequency and duration of exposure and/or
- Sites with no occupancy, limited access (e.g., fences and barriers) and deed restrictions.

Documentation of the condition justifying exclusion of the pathway is an important consideration, as well as the possible need to reassess whether the conditions change at any point in the future. Control instruments should be considered for assessing and assuring the sustainability of any pathway exclusions.

E.2 Approaches for Customizing Exposure Scenarios and Pathways

This section describes options for modifying the input values or assumptions for the mathematical models used to develop soil vapour guideline values. The scope of options included in this section is intended to be limited to those that can be implemented expeditiously. More complex changes can be addressed in Tier 3.

E.2.1 Human exposures to indoor air via vapour intrusion

Tier 2 should allow modification of some of the input values for the Johnson and Ettinger (1991) model (the J&E model), within technically defensible ranges (e.g., Johnson, 2005), and as supported by site-specific data collection. It should be noted that the J&E Model is particularly sensitive to the volumetric water content of the soil, and since this is an easy and inexpensive parameter to measure, it will often be considered for site-specific modelling. However, soils under buildings are likely to be drier than soils beside buildings because the building often prevents infiltration and percolation from above, and moisture content can be highly variable both spatially and temporally. Therefore, the maximum moisture contents used in Tier 2 should be similar to the field capacity for the soil type unless moisture content measurements from soil samples collected beneath the building floor are available to support higher values.

The J&E Model is formulated based on a number of assumptions. If any of these assumptions is not appropriate for a particular site, then the model may not provide an appropriate attenuation factor, and the generic attenuation factors should be used instead of the J&E model. The J&E Model should not be used where the following precluding conditions are present:

- The water table is within 1 m of the building foundation (possible wet-basement scenario) or the source of vapours is in close proximity to the foundation (floor drains, or other sub-floor utilities)
- The building is taller than 4 floors (possible enhanced stack effect)
- Preferential pathways are present in the subsurface that provide a direct conduit from the vapour source to the inside of the building over and above that of a typical residential building (e.g., wet basements, highly permeable and atypical utility conduits, dirt floors, fractured media immediately below the building, etc.)
- The source-building separation is negligible (e.g., the J&E Model was not formulated to simulate attenuation factors for sub-slab soil gas samples, and this should also preclude source-building separation distances that are very small, for example, less than 1 m) or
- Methanogenic conditions (or anaerobic conditions) are observed in close proximity to the building foundation (possible gas pressure-driven flow and/or explosion risk).

Where precluding factors are present, the J&E Model should not be used, and conservative generic attenuation factors, risk management, or a site-specific (Tier 3) risk assessment should be used instead.

The soil vapour guideline values protective of vapour intrusion risks will increase with depth because of the way the J&E model is formulated. At a minimum, soil vapour samples should be collected at a finite distance deeper than the foundation (recommended minimum of 1 m), but in locations with a thick vadose zone, it is possible to collect deeper samples and the value of L_s in the J&E model can be modified to match the site-specific distance between the sample (top of probe screen interval) and the foundation. Rigorous methods for calculating soil vapour screening levels as a function of lateral distance from a building are not yet developed to the stage of being appropriate to apply to development of Tier 1 or Tier 2 Guidelines, and would also generally have to account for potential future buildings in different locations. Any such detailed analysis could be considered in Tier 3 at the discretion of the agency with jurisdiction over the site.

Other input values that should be allowed to be adjusted in the J&E Model for Tier 2 or Tier 3 guideline values are:

- **The building height**, as measured for a particular building, but it should be limited to the height of the first 1.5 occupied floors above the foundation.

- **The indoor air exchange rate**, as documented in a Test and Balance Report certified by a licensed Mechanical Engineer, or by a building-specific tracer test.

- **Q_{soil}, $Q_{soil}/Q_{building}$ and generic attenuation factors**, as documented through indoor and sub-slab concentrations measurements for compounds that are clearly resolved above typical background levels (e.g., 1,1-dichloroethene, cis-1,2-dichloroethene, radon, or other site-specific tracer compounds).

- **The source-building separation distance**, as the measured depth of the source below the deepest part of the building foundation, which has a linear and inverse relation to the concentration gradient, which is the driving force for upward diffusion.

- **Soil porosity and texture, from which the irreducible water content may be calculated** and used as an input instead of the J&E model default water-filled porosity value. Soils under a building may be drier (approaching field capacity), so moisture measurements beside the building may not be representative. However, irreducible water content may be calculated from the texture of the soil and/or a pressure-drainage curve either measured or from the scientific literature.

Aerobic Biodegradation

Aerobic biodegradation can also be considered at Tier 2 or Tier 3 for petroleum hydrocarbons (BTEX, F1 and F2 - except when aviation fuel), trimethylbenzenes, naphthalene, and straight-chain alkane compounds (e.g., hexane, octane). Where degradation occurs, the attenuation factor is a function of the source concentration and depth (API, 2009, Abreu *et al*., 2009). Degradation may be assumed to occur for most aliphatic, branched and aromatic hydrocarbons where oxygen is present at greater than a few percent by volume. Absence of data to demonstrate the oxygen distribution should be considered a precluding factor. To estimate the magnitude of the biodegradation, site-specific data would be needed to assess the concentration of total hydrocarbons (including methane) at the depth of the hydrocarbon source to assess the oxygen demand. It is also recommended that data be collected to assess the depth of oxygenated soil gas (e.g., >5% oxygen by volume) in samples drawn from a well-sealed probe. The additional attenuation from biodegradation can be very significant (up to about 16 orders of magnitude) for low concentration hydrocarbon vapour sources in aerobic soils (see Figure E-1 and E-2); however, at Tier 2, more conservative values for the bio-attenuation factor are recommended to account for the fact that first order decay rates may be lower than the average values used in the model (see DeVaull, 2007).

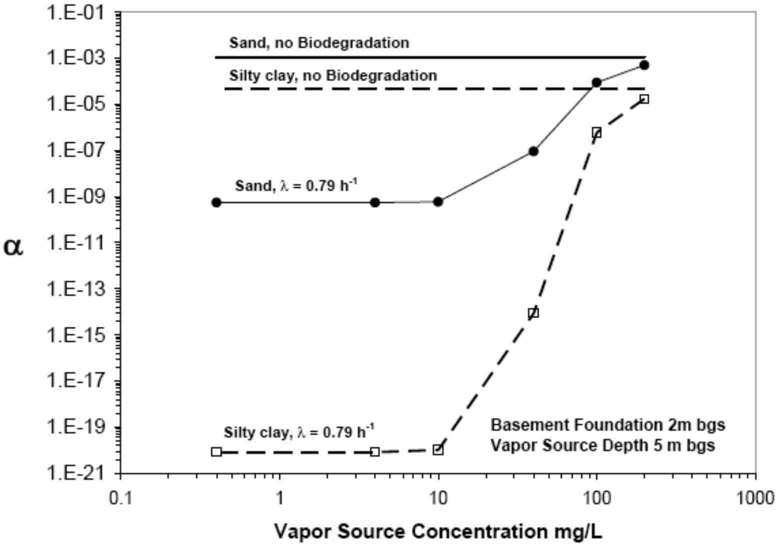

Figure E. 1. Example of the Difference in Attenuation Factors for different soil types with and Without Biodegradation (reprinted with permission from API, 2009).

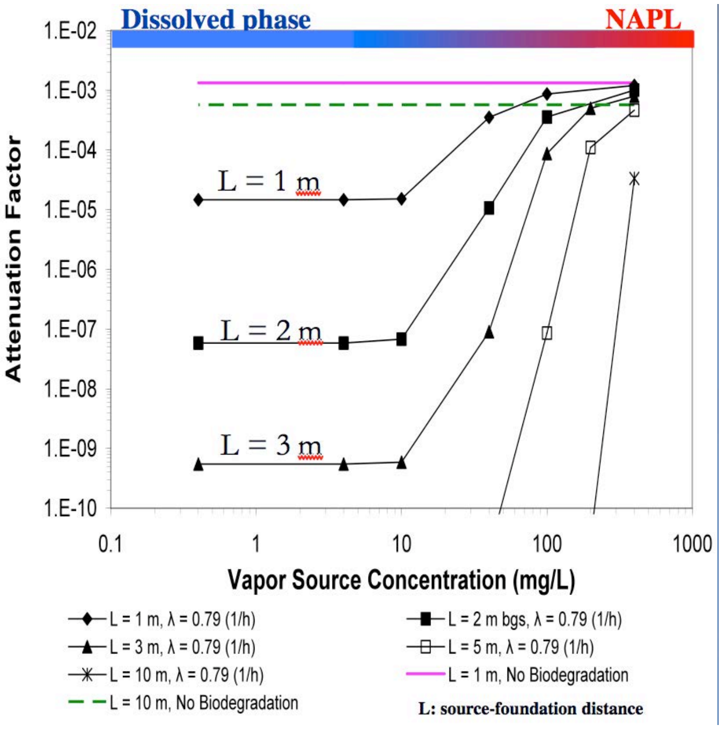

Figure E. 2. Example of the Difference in Attenuation Factors for different source-building separation (L) with and without biodegradation (after Abreu *et al*., 2009).

A bioattenuation factor is included in Equations A-5 (Appendix A). At Tier 2 or Tier 3, the default bioattenuation factor is based on the source depth and concentration (see Table E-1), as follows:

Table E. 1. Example Bioattenuation Factors

Contamination	Criteria for application of BF	Bioattenuation Factor (BF) as a function of source to building separation distance
No NAPL	C_g < 10 mg/L TVOCs Subsurface Oxygen>5% v/v	10X for separation distance > 1 - 3 m 100X for separation distance > 3 -5 m 1000X for separation distance > 5 m

Notes:

- Above BAFs should only be applied when there are aerobic conditions beneath the building of interest. Verification of the oxygen distribution and temporal trends in the subsurface is required. Oxygen levels should be 5% by volume or more.
- C_g = total hydrocarbon vapour concentration, including methane

The values in Table E-1 are conservative compared to recommendations by Davis (2009), who states that 1.5 meters of clean soil is sufficient to attenuate total petroleum hydrocarbon (TPH) vapours at 10,000 µg/L in groundwater (attenuation factor approximately 10,000,000X). Davis also shows data from six free product sites that show benzene is typically attenuated with 7 m of clean soil. Considering the vapour pressure of benzene is approximately 0.1 atmospheres and the proportion of benzene in gasoline is typically about 5% mol/mol, then the saturated benzene vapour concentration above a gasoline product layer would be about 5,000,000 parts per billion by volume (ppbv). To be completely attenuated, the concentration would be reduced below 1 ppbv, which corresponds to >1,000,000X attenuation. From both of these comparisons, as well as the comparisons to the model simulations in Figures E-1 and E-2, the recommended values in Table E-1 are conservative. If at a site there is overwhelming evidence of bioattenuation, the bioattenuation factors recommended in Table E-1 can be adjusted accordingly.

E.2.2 Human exposures to outdoor air emissions

Outdoor air emissions will vary with soil types and air dispersion parameters. The model for calculating vapour emissions to outdoor air could be modified using:

- **Soil properties (porosity and moisture content)** to calculate the effective diffusion coefficient
- **Wind-speed** based on annual average values from a local weather station to adjust the dilution in the outdoor air mixing model and
- **Source size,** based on site characterization data.

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