Canadian Council of Ministers of the Environment
Le Conseil canadien des ministres de l'environnement

CANADA-WIDE STANDARD FOR PETROLEUM HYDROCARBONS (PHC) IN SOIL

USER GUIDANCE

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1.0 INTRODUCTION

1.1 General

The Canada-Wide Standard for Petroleum Hydrocarbons in Soil (PHC CWS) was developed by the Canadian Council of Ministers of the Environment (CCME) under the Harmonization Sub-Agreement on Environmental Standards. Development of the Standard was led by a national Development Committee, with the assistance and input of four multi-stakeholder technical advisory groups and a dedicated working group.

The original standard, developed in 1999-2000, was endorsed by most jurisdictions in 2001. Its adoption included a commitment to review the standard after five years to reflect new scientific and technical information and stakeholder experience in implementation, a process that was initiated in 2005. The five-year review was conducted by three multi-stakeholder advisory subgroups, which made recommendations to CCME's Soil Quality Guidelines Task Group.

The PHC CWS is a remedial standard for petroleum hydrocarbon impacted soil and subsoil under various land use categories. The standard is grounded in the science of risk assessment and can be applied at any one of three levels or "Tiers": Tier 1 - generic numerical standards corresponding to four generic land use scenarios; Tier 2 - adjustments to Tier 1 levels based on site-specific conditions; Tier 3 - site-specific risk assessment and/or risk management. The same degree of human health and environmental protection is required at all three tiers; higher Tiers require more detailed site-specific data. For more information on specific levels of protection related to different pathways and receptors, see CCME (2006).

Because the PHC CWS is tiered and risk-based, there is necessarily some complexity in its development and application. Details regarding the technical and scientific basis for the development of the numerical Tier 1 values are provided separately in a Scientific Rationale document (CCME, 2008). The purpose of the present document is to provide management and technical guidance to jurisdictions and other users regarding the implementation of the PHC CWS.

1.2 PHC Definition and Characterization

1.2.1 General description

Petroleum hydrocarbons (PHC) describe a mixture of organic compounds found in or derived from geological substances such as oil, bitumen and coal. Petroleum products released to the environment, such as petroleum, crude oil and jet fuel, typically contain thousands of compounds in varying proportions, composed predominantly of carbon and hydrogen, with minor amounts of nitrogen, sulphur and oxygen. PHC contamination in soils varies with the petroleum source, soil type, the composition, degree of processing (crude, blended or refined) and the extent of weathering caused by exposure to the environment. Such factors complicate the assessment of the human and environmental health risks associated with PHC contamination in soils.

PHC in the environment are a concern for several reasons. First, their reduced nature and volatility pose a fire/explosion hazard. Second, PHC constituents are toxic to varying degrees. Third, lighter hydrocarbons are mobile and can be a problem at considerable distances from their point of release due to transport in groundwater or air. Fourth, larger and branched chain hydrocarbons are persistent in the environment. Fifth, PHC may create aesthetic problems such as offensive odour, taste or appearance in environmental media. Finally, under some conditions PHC can degrade soil quality by interfering with water retention and transmission, and with nutrient supplies.

1.2.2 PHC fractions and subfractions

Much work has been conducted since the late 1980s towards the assessment and management of PHC impacted soil. Of particular significance is the work of the US Total Petroleum Hydrocarbons Criteria Working Group (TPHCWG), which has been used as a starting point for the development of the PHC CWS. For the purposes of the PHC CWS, petroleum hydrocarbons are subdivided according to specified ranges of equivalent carbon number (ECN). Each fraction is, in turn, made of subfractions previously defined by the TPHCWG. The subfractions have been described according to their relevant physical and chemical properties and toxicological characteristics. The divisions between the fractions have been established in consideration of analytical factors, physical and chemical properties, the expected relevance to biological response in soils and the ability to utilize the definitions and associated properties of the TPHCWG subfractions.

Fraction 1 (F1) encompasses the range of ECN from C6 to C10. It represents the volatile fraction of most hydrocarbon mixtures and consists of the aromatic subfraction in the range C>8 to C10, as well as aliphatic subfractions in the ranges of C6 to C8 and C>8 to C10. Specific aromatic compounds falling within this fraction (i.e. benzene, toluene, ethylbenzene and xylenes, BTEX) are assumed herein to be managed separately and should, therefore, be subtracted from the aromatics in this fraction.

Fraction 2 (F2) encompasses the range of ECN from C>10 to C16. It represents the semi-volatile fraction and comprises aromatic and aliphatic subfractions in the ranges C>10 to C12 and C>12 to C16.

Fraction 3 (F3) encompasses the range of ECN from C>16 to C34. It includes both aromatics and aliphatics in the C>16 to C21 and C>21 to C34 ranges.

Fraction 4 (F4) encompasses compounds with ECN of C>34 to C50+. PHC within this range often make up a significant proportion of crude oils and petroleum products, although the fraction is generally considered to be of low mobility (volatility and solubility).

Polycyclic aromatic hydrocarbons (PAH), particularly those that are considered to be carcinogenic, are assumed herein to be assessed and managed separately and should, therefore, be subtracted from the aromatics in the F2 or F3 fraction, as appropriate.

1.2.3 Physical/chemical properties and toxicity

The physical and chemical properties of a PHC compound or subfraction determine its mobility, fate and availability to receptors via an exposure route. Fractions 1 and 2 comprise compounds that are both soluble and volatile, whereas Fractions 3 and 4 comprise less mobile compounds. Physical and chemical properties were identified and/or defined by TPHCWG for the subfractions considered in the four PHC CWS fractions. In fact, the TPHCWG subfractions were selected in part to encompass reasonably narrow ranges of physical and chemical properties in order that representative subfraction properties could be established (Gustafson et al., 1997).

Toxicity reference values (TRVs) have also been assigned by TPHCWG to each subfraction in the form of tolerable daily intakes (TDI) or reference doses (RfD) and, for volatile subfractions, reference concentrations (RfC) (Edwards et al., 1997). These toxicity constants are selected on the basis of published values for surrogate compounds considered to be representative of the overall subfraction toxicity. Further discussion of the TRVs is presented in the Scientific Rationale (CCME, 2008).

1.3 Land Use Definitions

1.3.1 Prescribed Generic Land Uses

Consistent with the CCME *Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME, 1996a; 2006), the PHC CWS in soils has been developed for four generic land uses - agricultural, residential/parkland, commercial and industrial. A generic land use scenario has been envisioned for each category based on the >normal= activities on these lands. The risk-based nature of the PHC CWS means that, for each land use, all values to be protected (life-forms or receptors, ecosystem properties) are explicitly documented as well as the contaminants considered within PHC and the pathways by which PHC can affect these values. This approach provides great flexibility, it allows assessment and management of different variations within a land use and even extension of the standard to other land use categories (e.g., wild lands). The vision, or exposure scenario, attached to each land use is the heart of the PHC CWS. The four land uses are defined as follows:

Agricultural lands: where the primary land use is growing crops or tending livestock. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. Agricultural land may also include a farm residence.

Residential/Parkland: where the primary activity is residential or recreational activity. The ecologically-based approach assumes parkland is used as a buffer between areas of residency (i.e., urban/suburban parkland), but this does not include wild lands such as national or provincial parks, other than campground areas.

Commercial: where the primary activity is commercial (e.g., shopping mall) and there is free access to all members of the public, including children. Of particular concern is the possible presence of commercial day-care centres, which could potentially facilitate exposure to young children. It does not include operations where food is grown.

Industrial: where the primary activity involves the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

1.3.2 Other Land Uses

Other land use categories, or variations within the generic scenarios, may be addressed through the procedures described in this guidance for Tier 2 and Tier 3. Alternatively, jurisdictions may extend Tier 1 levels for the four generic land uses to other land uses, based on equivalent exposure scenarios. For example, exposure pathways for wild lands or natural areas would include ecological soil contact, ecological soil ingestion, nutrient cycling and, potentially, the protection of groundwater pathways. These pathways are also operative at agricultural sites, so a jurisdiction may rule that the Tier 1 agricultural levels can be applied at wild lands sites. It should be noted that the ecological soil contact criteria are based primarily on agricultural soils; however, in the absence of toxicity data specific to other types of soil (e.g. forest), the agricultural ecological soil contact criteria are likely to be the most appropriate available data.

Institutional land use would normally conform to a residential exposure scenario. While some institutional land uses (i.e. schools) more closely resemble a commercial exposure scenario (exposure 5 days per week, 10 hours per day), others, such as hospitals and senior citizen's homes, are essentially residential land uses. To ensure that future land use restrictions are not required, jurisdictions should either specify the Tier 1 levels for residential land use, or require the application of Tier 2 or Tier 3 procedures.

1.4 Groundwater/Surface Water Use Definitions

Soils are hydrologically linked to groundwater and surface water systems. The PHC CWS is intended to manage the soil-to-groundwater pathway in order to prevent unacceptable transfer of contaminants from the soil, which may ultimately affect groundwater and surface water use.

The Tier 1 PHC CWS has been developed for three generic uses of groundwater or surface water affected by groundwater discharge:

- *Human consumption (potable water)*
- *Aquatic life*
- *Livestock watering*

The above water uses are linked to land uses through the definitions of the generic land use categories. Other water use categories, or variations in water use within a defined land use category, may be addressed through the procedures described in this guidance for Tier 2 and Tier 3.

1.5 Human Health and Ecological Protection Goals

The intent of the PHC CWS is to promote a consistent, high level of protection for human health and the environment. The environmental and human health protection goals do not change between tiers; the objective of all tiers is to ensure that exposures to humans and ecological receptors are maintained at or below levels at which adverse effects may be expected. Human health and ecological protection is an overriding goal, but is not the only basis for the standard. Other considerations are discussed in the next section.

Pollution prevention is the preferred approach to environmental protection. Hence the PHC CWS does not represent "pollute up to" levels for un-impacted land or water. The PHC CWS is a remedial standard and is envisioned to be applied to sites where PHC impacts have occurred, in order to accommodate a new or intensified land use or a return to a land use equivalent to that prevailing prior to any petroleum-related activity.

The goal of the human health risk-based numerical standards is to ensure that exposure via the identified land use-specific exposure pathways would not lead to an overall level of human exposure in excess of that considered tolerable from a toxicological standpoint. While certain PHC compounds are known human carcinogens (e.g. benzene) and are managed through the use of separate compound-specific guidelines, most compounds as well as the defined PHC fractions and subfractions are understood to act as threshold toxins. For these compounds or fractions, tolerable daily intakes, or reference doses, have been established at or below which the likelihood of adverse effects is considered to be negligible. Background exposures, unrelated to the site-specific sources of PHC contamination, are considered in establishing the allowable levels of human exposure due to soil contamination.

The goal of the ecological risk-based numerical standards is to protect the key ecological receptors that sustain normal activities within the four defined land use categories. Specifically, the allowable soil concentrations are intended to ensure that no adverse effects of biological importance are likely to occur, based on toxicological data associated with acute, subchronic and chronic responses in representative species.

Points of compliance for human health and ecological receptors are linked to the management requirements associated with each tier of the PHC CWS. The Tier 1 values are intended to protect human and ecological receptors that may be present on-site (except where specifically prescribed by the generic land use definitions). Points of compliance at locations physically removed from the site may be accommodated under Tiers 2 or 3, but may lead to land or water use restrictions and related management requirements.

1.6 Non Toxicity-Based Considerations

In order to achieve a practically attainable, yet environmentally protective standard, socio-economic considerations have also been incorporated at various stages in the development of the standard, in terms of both the implementation framework for the standard as well as the Tier 1 numerical values.

Whereas the primary focus of the PHC CWS is the protection of human health and ecological receptors, in certain situations the potential human and ecological exposure pathways may be of little immediate concern, or may not be operative. In these cases, certain other considerations that reflect the unique nature and properties of PHC apply, and are incorporated as management guidelines in the development of the Tier 1 values. These reflect a number of policy factors including the avoidance or minimization of ignition or explosive hazard, non-aqueous phase liquids (NAPL) or free product, effects on buried infrastructure, aesthetic considerations, and potential exposure of workers in trenches excavated in PHC-impacted soils. The management guidelines are normally considered to be relevant at all sites, and are not subject to Tier 2 modification.

1.7 States of Closure or Management

The use of risk-based criteria as remediation objectives for contaminated sites requires that the assumptions made in the risk assessment with respect to conditions affecting human and ecological exposure should remain valid indefinitely, or as long as residual impacts (post-remediation) may be present. In the case of the PHC CWS, the generic Tier 1 values are derived for four generic land uses using a set of exposure assumptions that would ensure protection in most normal cases involving each land use. Provided a site complies with the conditions assumed, management to Tier 1 would usually permit unrestricted future development or use within the particular land use designation. Completion of remediation to such a state is often referred to as unconditional closure.

When more detailed site-specific information is taken into account in determining risk-based objectives, a distinction must be made between those parameters that are fixed or stable, such as soil type and other physical or chemical factors, and those that may subsequently change without a substantial change in land use, such as building configuration, frequency of human exposure or the presence of a well. In the former case the site-specific conditions can be expected to be preserved without the need for site management or other controls. In the latter case controls or land use restrictions may be required to ensure that human health or environmental risks do not increase. Regulatory acceptance of such a state would normally be subject to certain conditions and is referred to as conditional closure. Conditional closure may also apply where long-term remediation or natural attenuation is proposed, whereby PHC concentrations in excess of Tier 1 values may prevail for a period of time. In the case of a conditional closure, one of the requirements that is typically imposed is the need for the management plan to be accepted by affected stakeholders.

1.8 Overview of Framework for PHC CWS Implementation

The general framework for the implementation of the PHC CWS is illustrated by the flow chart presented in Figure 1. Detailed discussion of the management and technical aspects of each of the components and decision points of the framework is the subject of this user guidance and is presented in subsequent sections of this document.

The PHC CWS is a tiered framework offering the proponent the option to comply with a set of reasonably conservative risk-based standards corresponding to a number of defined land uses, exposure scenarios and site characteristics (Tier 1) or to use additional site-specific information to assess and manage the risks through a more precise knowledge of actual or potential exposure (Tiers 2 and 3).

The Tier 1 process comprises an initial site assessment and characterization followed by the selection of the applicable Tier 1 values. If feasible and appropriate, management to Tier 1 would normally be undertaken, leading to unconditional acceptance or closure of the site. Where Tier 1 management is not feasible and/or appropriate, the proponent would proceed to Tier 2 or, in some cases, directly to Tier 3.

Tier 2 levels may be established and used when site-specific information indicates conditions that modify human or ecological exposure to PHC contamination, thereby altering the risks relative to the generic conditions used to derive Tier 1 levels. The Tier 2 levels are determined by adjusting the Tier 1 values using site-specific values for certain parameters determined as part of a more detailed site assessment. Adjustment is limited to parameters that are measurable and stable and, in most cases, do not lead to a requirement for ongoing management. Furthermore, adjustment is only relevant to parameters affecting the governing exposure pathway. This may preclude Tier 2 as an option when the governing pathway is not influenced by any Tier 2 adjustable parameters.

Upon determination of Tier 2 levels, the proponent has the option of managing to the established levels, if feasible and appropriate, or of proceeding to Tier 3. Management to Tier 2 may result in either unconditional or conditional acceptance, depending on the nature of the site specific adjustments and their site management implications.

In some cases a Tier 3 site-specific ecological risk assessment (ERA) and/or human health risk assessment (HHRA) may be warranted and may be used to derive site-specific remediation objectives or to develop a risk management strategy. Quantitative risk assessment is a complex process with more intensive data requirements than either Tier 1 or Tier 2. Different descriptions of contaminant fate, behaviour and exposure may be involved and models may be used that differ from those used in Tiers 1 and 2, although all models must be validated and calibrated for the site. Tier 3 may be followed when there are technical or socio-economic barriers to the implementation of Tiers 1 and 2, or when the generic land uses defined for Tiers 1 and 2 do not adequately characterize the receptors and exposure pathways present. Since Tier 3 relies on site specific input and, in most cases, involves some form of risk management, sites managed at Tier 3 are usually subject to conditional acceptance or closure.

Regardless of the parameters used as the basis for management at any tier, the target level of human health and ecological protection afforded at each tier does not change. See CCME (2006) for more information on levels of human health and ecological protection for different pathways.

2.0 MANAGEMENT GUIDANCE FOR CWS IMPLEMENTATION – TIER 1

The process for implementing Tier 1 is illustrated schematically by the flow diagram presented in Figure 2.

2.1 Tier 1 Assessment

2.1.1 General

The Tier 1 assessment comprises, as a minimum, the preliminary phase of site characterization, the purpose of which is to adequately describe site conditions in order to address assessment and management options within the scope of Tier 1.

The Tier 1 assessment may be more comprehensive and detailed, at the discretion of the proponent, providing additional information for use at Tier 2 or Tier 3. While there are advantages associated with a phased approach to site assessment, there may also be economies in combining data collection activities into a single investigation, particularly at locations where mobilization and demobilization costs are significant.

The minimum data requirements for a PHC CWS site assessment include:

- site description
- land use
- proximity of the site to surface water and drinking water supplies
- depth to groundwater
- actual and potential uses of groundwater
- human receptors
- ecological receptors
- primary exposure pathways
- stratigraphy and properties of surficial materials
- depth to contamination and distances to points of exposure/compliance
- presence and types of buildings and other structures
- contamination characterization and delineation

The above information is generally required at all tiers, to a level of detail commensurate with the requirements of the evaluation and decision stages of each tier. This information can be divided into three categories: land use and sensitivity factors; physical conditions; and contaminant characteristics and distribution. Technical requirements for a Tier 1 assessment are detailed in Appendix A.

2.1.2 Land use and sensitivity factors

One of the objectives of the Tier 1 site assessment is to determine whether the site broadly fits any of the four generic land use categories. In this regard, the minimum data requirements for a Tier 1 assessment are as follows:

Site description

The site description should include basic identifying data such as location and legal description, site dimensions, registered owner(s) etc., as well as a description of the physical surface expression of the site (surface topography), vegetative cover, nature of site development and, where applicable, site history.

Land use

In determining land use, consideration should be given not only to present land use but also to historic and potential future land uses, including the most sensitive likely land use consistent with the surrounding area. In terms of residential, commercial or industrial development, the land use is normally prescribed by the current and/or future zoning of the land and local development trends. In the case of agricultural land use, parkland and other potential non development-related settings, the target land use may be expressed in terms of the ability of the land to support uses equivalent to those existing prior to a petroleum-related activity being conducted on the land.

Sufficient descriptive and legal or administrative information should be obtained to determine the generic land use category, (agricultural, residential/parkland, commercial, industrial) and whether the land use may be considered "normal" for the assigned category. The four generic land uses are defined and described in Section 1.3.

Other generic land uses may be defined by jurisdictions on a local or regional basis as geographically appropriate. For example, managed or unmanaged forest, grasslands, wetlands or other wild lands may constitute significant land uses in their own right, thereby justifying the establishment of additional generic categories.

Land uses of adjacent or nearby properties should also be documented, as the presence of more sensitive off-site land uses may drive the site management requirements. The distance beyond which different land uses become insignificant or irrelevant is a matter of professional judgement at Tier 1, and requires consideration of factors such as access to receptors, fate and transport of contaminants, and spatial limitations on exposure pathways. At Tiers 2 and 3, the significance of nearby receptors can be more readily quantified. Jurisdictions may establish nominal zones or distances within which other land uses must be considered.

Proximity of site to surface water and drinking water supplies, to aquatic or marine habitats and to other points of groundwater or surface water use

The assessment must document all existing and potential uses of groundwater and surface water. Again, the distance beyond which water uses are not significant or relevant depends on site-specific conditions but, as a general rule for Tier 1, water uses within 500 m should be identified, and water uses at greater distances should be considered on a case-by-case basis when subsurface conditions are such that adverse impact may be possible. For example, municipal water supply wells located more than 500 m from a site might be expected to be at risk from a PHC source located anywhere within the zone of capture of the wells.

The assessment should recognize that, while the locations of most natural surface water bodies are essentially fixed, seasonal water bodies may exist at other locations, and anthropogenic groundwater uses could be initiated at any location relative to the site, in areas of usable groundwater.

Human and ecological receptors

In general, the presence of human receptors will be directly related to the land uses. However, sufficient information must be obtained at Tier 1 to determine whether the land use within the respective category is considered "normal", or whether receptors are present that would warrant a variation from the defined generic land use categories.

Similarly the presence of any ecological receptors that may necessitate a variation from the generic land uses should be established at Tier 1. In particular, the presence of rare and/or endangered species, ecological reserves and sensitive habitats should be identified.

2.1.3 Physical conditions

The determination of certain physical conditions and parameters is required at Tier 1, to a level of detail sufficient to permit the implementation of Tier 1 management. The minimum physical data requirements are discussed below:

Soil texture

As a minimum, since Tier 1 numerical values are prescribed for coarse-grained and fine-grained soils, sufficient textural information should be obtained to permit classification of the soils as either coarse or fine. Fine-grained soils are defined as having a median grain size of less than 75 μm; coarse-grained soils have a median grain size of greater than 75 μm. The absence of sufficient textural information may result in the default application of the more conservative Tier 1 values.

Soil stratigraphy and physical properties

Information on soil stratigraphy and physical properties is normally obtained by means of an intrusive subsurface investigation, although preliminary, qualitative information can often be obtained from other sources including published surficial geological information or the results of other subsurface investigations conducted in the area. In certain circumstances, it may be possible to proceed with Tier 1 without a prior subsurface investigation. For example, the decision could be made to manage a spill of limited extent by removing all materials containing PHC concentrations in excess of Tier 1 levels, and confirmation of the degree and extent of impact, as well as the subsurface conditions, could be obtained at the time of soil excavation. However, subsurface investigations are commonly conducted at Tier 1, in part for the purpose of contaminant characterization.

The Tier 1 assessment should provide an overall description of the subsurface soil conditions and their vertical and spatial variability. Of particular importance is the uniformity of the soil texture and the presence of any depositional or structural features, such as lenses or fissures, that could influence the fate and transport of PHC in the subsurface.

For Tier 1 implementation a full characterization of soil physical properties is not required; however, certain parameters, notably organic carbon fraction, bulk density and moisture content, were assigned default values for determination of Tier 1 levels and are in some cases strongly influential. Therefore determination of these parameters at Tier 1 is recommended in order to determine the validity of the Tier 1 values as well as to facilitate consideration of the benefits of proceeding to Tier 2 or Tier 3.

Soil stratigraphy and soil properties should be investigated both above and below the groundwater table.

Hydrogeological conditions

A hydrogeological investigation would normally form part of any subsurface investigation. Information is commonly collected on depth to groundwater table, groundwater flow direction, hydraulic gradient and, with the appropriate field tests, hydraulic conductivity. While all of these parameters are influential, their quantitative determination is not required for the basic implementation of Tier 1, and qualitative information may be available from other sources. However, as with soil parameters, they can facilitate the decision between managing to Tier 1 and proceeding to Tier 2 or Tier 3.

2.1.4 Contaminant characteristics and distribution

Sufficient characterization of PHC contamination should be conducted for the purpose of comparing contaminant concentrations with Tier 1 values. This will normally comprise the collection and laboratory analysis of representative soil samples to determine concentrations of the four PHC fractions. As part of the Tier 1 assessment, the proponent will, in most cases, conduct sufficient sampling to delineate the lateral and vertical extent of impacted soils, as a basis for assessing the practical and economic feasibility of remediation to the Tier 1 standard. Furthermore, should the site be found to comply with Tier 1, the data collected must be sufficient to provide the necessary level of confidence to the agency granting acceptance.

Depending on the nature and history of the PHC source, additional chemical analysis of soil samples may also be conducted to determine concentrations of subfractions within each of the four PHC fractions, in order to assess, as part of the decision process, the opportunity to proceed with a Tier 2 adjustment based on composition (described in more detail in a subsequent section).

PHC contamination must be no closer than 30 cm to the foundation of an occupied building in order for Tier 1 to be applied. In cases where PHC contamination is less than 30 cm from the nearest point of a building foundation, Tier 3 assessment and management is required. Also, PHC contamination must be no closer than 10 m to a surface water body; otherwise, Tier 2 or Tier 3 applies.
The above discussion pertains solely to the assessment requirements for implementation of the Tier 1 PHC CWS. It is the responsibility of the proponent to ensure that sufficient site characterization is carried out to address local regulatory requirements and to address other potential contaminants of concern and their respective guidelines and standards.

Special Analytical Considerations

Certain soil samples, particularly soils with a high natural organic carbon content (such as peats) or soils that have been remediated with manure, may give a “false positive” result when analyzed (CCME, 2001). Specifically, laboratory results for F2, F3 and F4 may be falsely elevated. If there is reason to suspect that soils may have a high organic carbon content, it may be beneficial to collect samples for organic carbon content analysis from background soils, and to analyze background soils for PHC concentrations. This is detailed further in Appendix A.

2.2 Tier 1 Evaluation

2.2.1 Establishment of land use and water use conditions and primary soil type

Land use and water use conditions are established on the basis of the information compiled for the Tier 1 assessment. Land use conditions are compared with the descriptions of the generic land use categories (agricultural, residential/parkland, commercial, industrial) in order to assign the site to the most sensitive applicable category.

Groundwater and surface water use conditions are assigned, if applicable, to one or more of the generic categories of potable water, surface water sustaining aquatic life and water used for livestock watering.

Exceptions to the above categories are discussed in the following section.

2.2.2 Determination of conformity with generic land and water use categories

The principal criterion for the application of the Tier 1 PHC CWS is conformity with the generic land and water use scenarios and exposure conditions assumed in the development of the Tier 1 values. The generic land and water uses and the associated human and ecological exposure pathways are presented in Table 1.

Firstly, the land and water use must normally be encompassed by one or more of the defined generic categories. Examples of land uses not addressed in the development of the Tier 1 values are: managed or unmanaged forest, non-agricultural grasslands, wetlands, riparian zones and other wild lands. Examples of water uses not addressed by Tier 1 are: water used for irrigation; water used in the food processing industry (although the latter may be represented by the potable water scenario); surface water used for swimming or similar recreational activity. Individual jurisdictions may define additional generic land and water uses and establish applicable Tier 1 standards. However, in the absence of an applicable Tier 1 standard for the actual land or water use, a Tier 3 approach should be followed.

Secondly, the exposure conditions associated with the identified land and water use must not be more sensitive or critical than those assumed in the determination of the Tier 1 values. Examples of factors giving rise to greater sensitivity are: the presence of ecological receptors of greater sensitivity or socio-economic value (such as rare or endangered species); a greater frequency or intensity of human or ecological exposure, beyond that associated with "normal" use of the land or water; variations in physical site conditions resulting in increased exposure relative to that assumed. The human and ecological exposure parameters used for the Tier 1 values are presented in Appendix B. These values should be used as the basis for assessing whether site-specific factors are indicative of more frequent or intense exposure. The effect on exposure of variations in selected influential physical conditions can be seen by referring to the illustrative Tier 2 adjustments presented in Section 3.2 and Appendix D. Parameter variations leading to lower pathway-specific numerical standards are indicative of greater sensitivity and, if significant, are a trigger for Tier 2 or Tier 3.

It is the responsibility of the proponent to identify and respond to any site or receptor factors that could unduly accentuate exposure or risk beyond that envisioned in the Tier 1 exposure scenarios and, where necessary, move to Tier 2 or Tier 3.

2.2.3 Identification of applicable Tier 1 objectives

The Tier 1 values are presented in Tables 2 and 3 for coarse-grained soils and fine-grained soils respectively. Selection of the appropriate set of values is based on the texture of the dominant soil type as determined in the Tier 1 assessment. It should be noted that the dominant soil type is generally that which governs the fate and transport of PHC via the various transport and exposure pathways. For example, a continuous layer of coarse-grained soil beneath the water table will often govern groundwater flow in the saturated zone, even though its thickness may be small in relation to the total thickness of saturated fine-grained soils. Similarly, a thin layer of coarse-grained soil in the unsaturated zone may make a greater contribution to the migration of vapours than a thicker layer of fine-grained soil. Professional judgement should be exercised in establishing the dominant soil type.

Where the dominant soil type is in doubt the more conservative of the Tier 1 values for coarse-grained and fine-grained soils should be applied.

In the table corresponding to the established soil type, for each fraction, the lowest value tabulated for the identified land use defines the governing exposure pathway/receptor and, hence, the governing Tier 1 value. However, when the governing value is based on a soil to groundwater or surface water pathway that is not applicable to the site, based on the prior identification of water uses, the Tier 1 value will default to the next higher applicable value. Exclusion of a particular water use at Tier 1 must be based on stable or fixed conditions that do not require any form of ongoing management or intervention.

Tables 4 and 5 summarize, for coarse- and fine-grained soils respectively, the governing exposure pathways for each of the four PHC fractions under each defined land and water use.

2.3 Tier 1 Decision

The Tier 1 decision process is illustrated schematically by the lower part of the flow diagram presented in Figure 2. The process consists of a number of decision nodes. The decision process and criteria at each node are discussed in the following paragraphs.

2.3.1 Comparison of conditions with identified Tier 1 objectives

If no exceedances are found in the Tier 1 assessment, relative to the identified Tier 1 standards, and PHC contamination is at least 30 cm from the foundation of an occupied building and 10 m from any nearby surface water bodies, the site can be considered to be in compliance with Tier 1 and no further action is necessary. If exceedances are found, the proponent enters a decision process whereby the option of managing to Tier 1 is weighed against the option of proceeding to Tier 2 or Tier 3. If PHC contamination is less than 30 cm from the foundation of an occupied building or less than 10 m from any surface water body, the proponent must proceed to Tier 2 or Tier 3.

As discussed in Section 2.1.4 and Appendix A, elevated background PHC concentrations (particularly false positives caused by high soil organic carbon levels) may be subtracted from the measured PHC concentrations in contaminated soil prior to comparison with the Tier 1 levels.

2.3.2 Assessment of feasibility and appropriateness of management to Tier 1

The first consideration is the practical and economic feasibility of management to Tier 1. Since management to Tier 1 in most cases will involve reduction of concentrations to Tier 1 levels or removal of soils containing PHC concentrations in excess of Tier 1 levels, methods or approaches being considered for use in remediation will be assessed according to their practical and technological capability to achieve the required remedial objectives, and their associated costs.

If management to Tier 1 is clearly infeasible from a practical and/or technological standpoint, the proponent will have to move to Tier 2 or Tier 3 site management. If, however, achieving Tier 1 objectives is attainable, the decision will likely be governed by socio-economic factors. In cases where the degree and extent of PHC impact is limited, remediating the site to Tier 1 and securing unconditional acceptance may be the most expedient and cost-effective approach, all things considered. Assessment of the economic feasibility will include consideration not only of remedial costs, but also of the costs and benefits of returning the land to productive use, as well as other business costs and liabilities. Depending on the economics, the proponent may choose to assess the feasibility of managing the site to Tier 2 or Tier 3, particularly if the Tier 1 objectives are not considered appropriate.

Consideration of the appropriateness of Tier 1 will take into account a number of factors, including, but not limited to:

- whether the generic scenarios used in the establishment of the Tier 1 values are appropriate to the site in terms of exposure (sites with greater sensitivity will have been identified at a prior stage; sites with lower sensitivity are potential candidates for management at Tier 2 or Tier 3 - see below);

- whether the future land or water uses identified for the site are currently in effect;

- whether the site is presently subject to ongoing management (such as an operating facility).

A determination at this point that Tier 1 is both feasible and appropriate will generally lead to the implementation of Tier 1 management. If Tier 1 is infeasible, or feasible but inappropriate, the proponent would normally proceed to the next step of the decision process.

2.3.3 Assessment of opportunity for Tier 2 or Tier 3 management

If the default assumptions used in the derivation of the governing Tier 1 values are conservative relative to actual site-specific conditions, the replacement of default assumptions with site-specific data for certain influential parameters may permit the development and implementation of less stringent remediation objectives without compromising health and environmental protection goals. Furthermore, point-of-exposure measurements, if lower than those predicted using the relatively conservative modelling procedures employed at Tier 1, may also permit the implementation of less stringent objectives. In such cases, proceeding to Tier 2 or Tier 3 would generally be advantageous.

Tier 2 adjustments are only likely to be of benefit when applied to parameters that affect the governing exposure pathway. Tables 6 and 7 present a summary, for coarse- and fine-grained soils respectively, of the land and water uses, exposure pathways and related parameters indicating the relative influence of each parameter on the adjusted soil value. Tables 6 and 7, in combination with Tables 4 and 5, may be used to facilitate initial screening of the opportunity for Tier 2 or Tier 3 management. If the governing exposure pathway (Tables 4 and 5) is one for which no Tier 2 adjustments are available (Tables 6 and 7), such as ecological soil contact, then there is no opportunity for Tier 2 management.

Ecological soil contact is the governing pathway for fractions F3 and F4, for all land uses. Therefore, Tier 2 adjustments are not available for F3 and F4 unless the soil contact pathway is eliminated under the conditions described in Section 3.2.4. The same would apply to fractions F1 and F2 for fine-grained soils, if potable water use is not applicable.

If site-specific conditions do not result in PHC exposures lower than those predicted by conservative Tier 1 assumptions, or if Tier 2 adjustment is not available for the critical exposure pathway, then the derivation of site-specific objectives would not provide relief with respect to remediation levels. However, there may still be an opportunity for exposures to be managed without complete remediation, such that health and ecological protection goals are preserved. In some cases this may allow natural time-dependent processes to be utilized towards achieving gradual remediation. It would also maintain acceptable conditions on a managed basis pending the availability of alternate remedial technologies. Such management would fall under Tier 3 and would be subject to a number of other conditions, described in a subsequent section.
If site-specific conditions are anticipated to offer relief with respect to the Tier 1 level, it is necessary to determine whether such adjustments constitute a Tier 2 or Tier 3 level of site management. Site-specific adjustments or substitutions made at Tier 2 are not unlimited, and must meet three principal criteria:

1. They must be limited to factors influencing exposure that can be measured and verified

   Adjustments must relate to stable site characteristics that affect contaminant fate and transport and human and ecological exposure. Examples include physical soil properties, distances to receptor locations (where these can be considered fixed) and PHC composition. These characteristics must be readily quantifiable, and their effects on the numerical objectives must be capable of determination without departing from the scientific principles used in the derivation of the Tier 1 standards.

2. They must support clear and consistent land and water use decision making

   Adjustments cannot compromise the generality of the defined land and water uses or, if they lead to restrictions, these must be clearly stated and understood and be consistent with jurisdictional policies.

3. They must be simple and straightforward in their determination and application

   Part of the philosophy of a multi-tiered system is that each successive tier requires a greater level of investigative effort, and a greater degree of regulatory intervention. It is expected that a majority of sites will be managed at Tier 1, and progressively fewer at the higher tiers. Incorporation of added complexity at Tier 2, and hence the need for greater resources during regulatory review and approval, would not be consistent with this philosophy.

Several parameters and assumptions that influence the Tier 1 (and hence Tier 2) values have been identified, which also meet the above requirements. These are listed in Table 8 and are referred to as primary Tier 2 adjustable parameters. The influence of variations of these parameters on the remediation objectives is discussed elsewhere in this guidance.

In addition to the primary parameters, other parameters influence the remediation objectives but do not comply with one or more of the criteria listed above. These are referred to as secondary adjustable parameters. The acceptability of these adjustments at Tier 2 is a jurisdictional decision. The secondary adjustable parameters are listed in Table 9.

Certain point-of-exposure measurements, if substituted for predicted values in the fate and transport models used to determine the Tier 1 objectives, may be used at Tier 2 subject to certain conditions. Guidance with respect to those measurements that may be allowed at Tier 2 is presented in Section 3.2.3.

The incorporation of point-of-exposure measurements may be computationally more complex than the adjustment of input parameters, and requires more thorough verification. Secondly, concentrations measured at points-of-exposure may be a function of time; if measured values are less than predicted values, evidence must be obtained that the values are not likely to increase with time. These complexities may limit the workability of incorporating such adjustments at Tier 2; whether or not they are accepted is a jurisdictional decision.

Based on the foregoing discussion, the proponent will be able to conclude, subject to local jurisdictional acceptance, whether the factors identified as potentially mitigating exposure are permissible Tier 2 adjustments, or whether they necessitate proceeding to Tier 3.

2.3.4 Requirement for land and/or water use restrictions

One of the key jurisdictional issues that may override a decision at this stage to proceed with Tier 2 management is the issue of land and water use restrictions. This is discussed below in the context of possible jurisdictional positions. A more complete discussion is presented in Section 3.0 of this guidance, which deals specifically with the Tier 2 guidance

As noted above, the primary intent of the Tier 2 adjustments is to accommodate site-specific conditions without imposing an associated requirement for ongoing management to ensure that the conditions warranting an adjustment are maintained. Any requirement for ongoing management would lead to conditions being imposed on acceptance, which may or may not be allowed at Tier 2, depending on the policy of the jurisdiction.

Site specific adjustment of stable or fixed physical parameters will normally not invoke land or water use restrictions. Adjustment of exposure factors based on human receptor characteristics will in most cases require restrictions or conditions, without which human exposure cannot be controlled. Between these categories, a number of physical factors affecting human exposure may require certain restrictions that are administratively acceptable. Section 3.2.5 discusses the restrictions that would be necessitated by various Tier 2 adjustments.

If no restrictions are required, the proponent may proceed directly to Tier 2 which would culminate in an unconditional closure or acceptance. If restrictions are required they must be acceptable to affected stakeholders as well as the jurisdiction. Firstly, the jurisdiction must allow conditional closure at Tier 2. Secondly, all affected stakeholders, including the proponent and affected land owners, must accept and adhere to the land or water use restrictions. If both are satisfied, the proponent can proceed to Tier 2 with a view to conditional management. If the restrictions are not acceptable, the proponent should either proceed to Tier 3 (to satisfy jurisdictional policy) or to Tier 1 (if restrictions are not acceptable to other stakeholders under any circumstances).

Further discussion on the identification and implications of restrictions are contained in the Tier 2 guidance in Section 3.

2.3.5 Other considerations related to Tier 1 decision

As part of the decision process described in the preceding sections the proponent will weigh the costs of remediation to Tier 1, together with the benefits of securing unconditional acceptance or closure, against several factors related to management to Tier 2 or Tier 3. Many of these factors have cost and other implications, particularly where land use restrictions or conditions may be applied. These factors include:

- cost of obtaining additional data to support Tier 2 or Tier 3 evaluation and decision making
- more intensive assessment, evaluation and reporting, particularly if a risk assessment is required
- more onerous regulatory review and approval process, which may include stakeholder consultation
- cost and commitment of long-term management and monitoring
- potential risks and liabilities associated with residual contamination
- potential financial security requirements imposed by some jurisdictions
- opportunity costs related to restrictions (if any) on land and water use

On the other hand there are potential benefits associated with Tier 2 or Tier 3 management, such as the opportunity to take advantage of long-term remediation techniques and/or natural attenuation. Furthermore, ongoing management may be more appropriate than Tier 1 remediation for operating facilities, and a progressive closure strategy could be tied to the remaining life of the facility.

In the latter case, and under any ongoing site management scenario, potential off-site impacts should be managed unconditionally, unless restrictions are agreed to by all affected stakeholders.

3.0 MANAGEMENT GUIDANCE FOR CWS IMPLEMENTATION – TIER 2

The process for implementing Tier 2 is illustrated schematically by the flow diagram presented in Figure 3.

3.1 Tier 2 Assessment

3.1.1 Additional data collection to support site-specific adjustment of parameters

Upon entering Tier 2, the proponent will have undertaken an assessment that fulfils, as a minimum, the basic requirements of Tier 1 and provides sufficient additional information to support the decision to proceed to Tier 2. In order to complete the Tier 2 evaluation, which essentially comprises the substitution of certain site-specific parameters for Tier 1 default assumptions or the elimination of exposure pathways which are not active at the site, the relevant adjustable parameters must be determined and adequately quantified, and the relevant exposure pathways must be confirmed.

In order to optimize data collection effort and resources at this stage, the governing exposure pathways (based on the Tier 1 evaluation) should be identified (see Tables 4 and 5). Not all Tier 2 adjustable parameters will be influential for every exposure pathway and receptor; therefore, depending upon the critical pathway(s) only a subset of the possible parameters may need to be defined on a site-specific basis.

It should be pointed out, however, that the decision to undertake Tier 2 adjustments implies a commitment to increase the accuracy of the exposure and risk estimates in light of the available site-specific data. Therefore, the values of all readily quantifiable parameters that are influential with respect to the governing pathway should be determined and implemented, even if the effect of one or more of the parameters, adjusted independently, would be to increase the potential level of exposure. This is particularly so with parameters such as total soil porosity and moisture content, which may have opposing influences but are correlated to a degree in practice.

Tables 6 and 7 present a listing of the principal Tier 1 exposure pathways together with the corresponding Tier 2 adjustable parameters that are significant with respect to each pathway. Table 10 summarizes groups of parameters (e.g. hydrological, hydrogeological, etc.) which should be measured and adjusted together, along with the exposure pathways to which each group applies.

Further discussion of the parameters and their recommended method of determination is presented in Appendix C. Some considerations regarding the determination of these parameters are presented below.

Physical soil properties

These properties include soil texture, organic carbon fraction, soil porosity and/or bulk density and soil moisture content. Soil texture will have been determined at the Tier 1 stage; the remaining parameters can be measured and used for Tier 2 adjustments. Sufficient measurements of each parameter must be obtained to establish a representative value for each soil unit or stratum that is relevant to the governing exposure pathway. For instance, moisture content may vary seasonally, and may also be different beneath buildings; therefore, it is necessary to obtain measurements that are representative of long-term, stable conditions and are appropriate to the soils of concern. As noted previously, an understanding of the exposure pathways and associated fate and transport processes is necessary in order to identify the dominant soil type for each exposure pathway.

Soil vapour permeability is related to soil texture, porosity and moisture content and is therefore not commonly measured independently. However, it is influential in the vapour infiltration pathway and, therefore, its determination on a site-specific basis may be advantageous. Since it is affected by moisture content, a stable, long-term value should be determined.

Hydrogeological conditions

Hydrogeological conditions include depth to groundwater table, hydraulic conductivity, hydraulic gradient and hydrological recharge rate. The first three parameters would be obtained from a site-specific groundwater investigation; the last from local data on precipitation, evapotranspiration and runoff. Precipitation can be adjusted at Tier 2 based on local data; however, evapotranspiration and runoff may be affected by site-specific factors that are not necessarily controllable. Although recharge may be estimated regionally, caution will need to be applied to the re-estimate, particularly if site specific conditions are anticipated to be strongly influential., For example, unusually high or low surface runoff, due to surface slope, cover or highly permeable surface soils, could strongly influence the recharge and not allow for use as a primary user adjustable parameter. The vertical separation between the lower limit of impacted soil and the groundwater table, indirectly determined from hydrogeological and contaminant distribution measurements, is relevant to the groundwater pathways.

Where the point of compliance is at a distance from the contaminated site, hydrogeological parameters should be representative of the conditions both on-site and along the groundwater transport pathway.

Site dimensions and distances to receptors

Contaminant source length and width are adjustable parameters with respect to the soil to groundwater pathway. These dimensions are respectively measured parallel and normal to the principal groundwater flow direction. Where the contaminated area is smaller than the site area, the horizontal distance from the contaminant source to the downgradient site boundary may also be determined and applied on a site-specific basis. Site-specific distances to other receptor locations may also be Tier 2 adjustable parameters. However, points of compliance at locations other than the site boundary or fixed surface water bodies would generally lead to land or water use restrictions, and may not be accepted at Tier 2.

Contaminant composition and distribution

Sufficient additional PHC characterization data will be required to support any adjustments involving extent or composition of PHC contamination. The primary adjustable parameters are source dimensions (discussed above) and depth to upper and lower limits of impacted soil. Thus adequate delineation of the impacted soil must be carried out; this information will also be relevant in the decision process associated with Tier 2. Additional adjustable parameters pertain to the composition of the PHC, specifically with respect to the relative concentrations of TPHCWG-defined subfractions. This may be relevant for weathered mixtures or other specific PHC products known to differ from the default case. Further discussion of site-specific composition measurement is presented in Appendix C.

Secondary user-adjustable parameters

A number of other parameters are influential but may not be well-suited to Tier 2 adjustment due either to the fact that they are not readily measured, or that they cannot be controlled in a generic way. These are summarized in Table 9 and include lateral distance to a building (inhalation receptor), depth of unconfined aquifer and building characteristics (foundation configuration, presence of cracks, air exchange rate, etc.).

3.1.2 Direct measurements in relevant media used as a basis for Tier 2 adjustments

Where Tier 1 values are determined by modelling the transport of PHC, concentrations measured in relevant media along the exposure pathway may be used to replace model predictions in order to improve the accuracy of the determination of exposure. While this approach should theoretically be encouraged under Tier 2 and 3, the potential variability in methodology and reliability of direct measurement techniques may lead to inconsistency in implementation. Therefore it is necessary to determine, with the jurisdiction how point of exposure measurements may be used. Where a regulatory framework outlining use of point-of-exposure measurements and prescribing the protocol for obtaining and applying such measurements in a consistent and repeatable manner, there may be opportunity for implementing at tier 2. This may also be considered a Tier 3, site specific approach, particularly where protocols do not exist.

In point of exposure measurements, concentrations would be measured at locations where predicted values can be methodically and reliably substituted, and where doing so would reduce the uncertainty of the modelling. These locations would typically be at or near critical points along the modelled path, such as points of partitioning into the medium of concern or points of exposure. For example, direct measurements of soil vapour concentrations or groundwater concentrations along the critical pathway could be used.

Actual methods of determining PHC concentrations in soil vapour and groundwater are described in Appendix C. Where concentrations are lower than values predicted based on modelling, it must be demonstrated using additional means that the concentrations will not increase with time. Additional measurements of concentrations with time, delineation of the source and/or downgradient plume, and measurements of parameters indicative of conditions supporting natural attenuation can be used, subject to the governing requirements that Tier 2 adjustments be practical, simple and amenable to verification. Further discussion of such measurements is presented in Appendix C.

3.1.3 Establishment of baseline measurements for future monitoring/management

The implementation of Tier 2 may involve ongoing site management and/or monitoring, particularly where there is a requirement to demonstrate the reduction of PHC concentrations with time. In such cases, consideration should be given at the time of the Tier 2 assessment to collecting data at appropriate locations and ensuring that the type of data obtained provides an adequate baseline. Time series measurements of relevant parameters are likely to be restricted to PHC vapour concentrations in the subsurface and dissolved PHC concentrations in groundwater, although additional parameters may be monitored to provide an indication of processes and conditions associated with natural attenuation. These measurements would normally be obtained from monitoring wells, the construction of which should be consistent with the intended life of the installation.

3.2 Tier 2 Evaluation

3.2.1 Establishment of Tier 2 land and water use conditions and adjustment scenario(s)

Prior to entering Tier 2, the land and water use conditions will have been established such that the site remains capable of being managed under one or more of the generic land and water use descriptions. The Tier 2 adjustment will be undertaken relative to the Tier 1 values corresponding to the specified land and water use.

The relevant exposure pathways corresponding to the generic land and water use categories will be identified. These will include the governing Tier 1 exposure pathways as well as any others that may become critical as a result of the proposed Tier 2 adjustments. Tables 4, 5, 6 and 7 may be used as a guide in this regard.

The Tier 2 scenario(s) will be established in terms of the governing exposure pathways, the parameters to be adjusted and the appropriate values to be substituted, based on the Tier 2 assessment. The proposed parameter substitutions need not be constrained by the illustrative ranges presented in this guidance. However, it is emphasized that the parameters to be substituted must be representative of the site, and that all potentially adjustable parameters that are influential with respect to the governing exposure pathway, and can be determined reliably within the scope of Tier 2, should be adjusted to reflect site-specific conditions. Those parameters that have not been determined on a site-specific basis will be held constant at the default values used in Tier 1. **As noted previously, the purpose of the Tier 2 option is to increase the accuracy of the exposure**

assessment by utilizing site-specific information where available. Therefore, if a more representative site-specific value is available for a given parameter, the proponent is obligated to apply it if Tier 2 is to be implemented, even if that parameter has an effect counter to that of other adjusted parameters. It is particularly important that parameters which may be correlated in practice should be adjusted in realistic relation to one another.

The proponent should be prepared to defend the selection of parameters to be adjusted and the values assigned to those parameters.

3.2.2 Recalculation of human health and ecological objectives based on site-specific parameters

Adjustment of the Tier 1 objectives involves conducting exposure calculations and/or modelling for each of the governing pathways, according to the procedures described in Appendix D. For illustrative purposes, the influence of the primary user-adjustable parameters on the Tier 1 values was determined by varying each, independently, within the ranges given in Table 8. The results of these adjustments are presented in Tables D-5 to D-26, inclusive, Appendix D, and are summarized in Tables 11 and 12. In practice, the parameters would not vary independently and, therefore, the adjusted values presented herein may not necessarily be representative of Tier 2 values.

For all Tier 2 adjustments, it is important to understand assumptions made that may limit reliability of model predictions. In particular, the model must be used in a manner that will ensure predictions are conservative for the given site conditions. For instance, recent papers on the Dominico Solution used for groundwater modelling (e.g. West et al, 2007, Srinivasan et al, 2007) suggest that the groundwater predictions may be non conservative, particularly for long distances from the contaminant source. Similarly, for the vapour inhalation pathway, more recent papers have suggested that input ranges for parameters should be limited or that ratios between certain parameters should be maintained to ensure that the model remains reliable (e.g. ,Johnson, 2002, 2005). It is important to be aware of these concerns and ensure that model adjustments are made only within appropriate ranges.

Some important considerations associated with the Tier 2 adjustments for each pathway are discussed in the following paragraphs.

Human health

a) Soil ingestion

Since the soil ingestion algorithm used to determine Tier 1 values is based on direct intake of PHC contaminated soil, there are no Tier 2 adjustable parameters, with the possible exception of composition. A variation in composition of each fraction in terms of its subfractions may have a minor effect on allowable soil concentration. However the Tier 1 values based on soil ingestion are significantly higher than those for a number of other pathways and are therefore not likely to govern.

b) Dermal contact

Composition again is the only possible Tier 2 adjustable parameter; however dermal contact with soil will not be a governing pathway at Tier 2.

c) Vapour inhalation

Vapour inhalation is a potential governing pathway for Fractions 1 and 2, particularly for coarse-grained soils. Influential user adjustable parameters include soil organic carbon fraction, bulk density/porosity, moisture content and depth/distance to contamination (from the nearest point of the foundation of the occupied building). Air (or soil vapour) permeability is also significant in the case of advective flow but is not commonly measured directly. It should be noted that the influence of the major parameters governing vapour flow (bulk density/porosity, moisture content) is greater as the depth to contamination increases. PHC composition may also be significant.

PHC contamination must be no closer than 30 cm to the foundation of an occupied building in order for Tier 1 to be applied. In cases where PHC contamination is less than 30 cm from the nearest point of a building foundation, Tier 3 assessment and management is required. The model used for assessing the vapour inhalation pathway cannot be reliable used for short separation distances between the source and receptor.

Building parameters may differ from default values on a site-specific basis but are not considered adjustable at Tier 2 since the future physical nature and operation of a building is not normally within the control of the proponent or jurisdiction.

d) Protection of drinking water

The dominant parameters with respect to groundwater flow are the hydrogeological properties of the saturated zone, i.e. hydraulic conductivity and hydraulic gradient. Soil organic carbon fraction is significant with respect to PHC partitioning to the groundwater. Recharge rate, source dimensions, and distance from the lower limit of contaminated soil to the groundwater table affect dilution at the water table and, if the latter is non-zero, bulk density/porosity and moisture content are also somewhat influential. PHC composition may also be significant.

In Tier 1, the point of compliance is considered to be at the downgradient boundary of the contaminated site. A horizontal separation distance may be introduced at Tier 2; this would then become an influential parameter. It should be noted that points of compliance beyond the property limits would invoke land/water use restrictions and are discussed further in a subsequent section.

Ecological

e) Protection of aquatic life and livestock watering

The considerations discussed above with respect to drinking water also apply to the aquatic life and livestock watering pathways. However, the need for restrictions vis-a-vis point of compliance may differ; this is discussed in a subsequent section. The aquatic life pathway is a governing pathway for Fraction 2 in certain cases at Tier 1, and may govern in other situations under Tier 2 adjustment. The livestock watering pathway is considered unlikely to be a governing pathway.

In cases where surface water bodies are located within 10 m of the PHC contamination, Tier 2 or Tier 3 assessment and management is required.

f) Nutrient cycling, ecological soil contact and ecological soil ingestion

The Tier 1 values for the ecological soil contact pathway were based on effects endpoints observed in soil invertebrate and plant toxicity testing using certain soil types. Since the methods used were principally empirical, there is no basis for site-specific numerical adjustment of the values for these pathways at Tier 2 at the present time. While it is acknowledged that site-specific conditions, particularly soil type, may affect the availability of PHC compounds to various soil-based receptors and the impacts of PHC on soil processes, there are presently insufficient data to quantify the effects of soil type and other variables, within the terms of reference of a Tier 2 evaluation. Therefore, modifications to the Tier 1 values, if appropriate, can only be performed by proceeding to Tier 3, or by excluding the soil contact pathway as detailed in Section 3.2.4 of this guidance. This precludes Tier 2 as an option for site management in situations where ecological soil contact is the governing pathway at this time. Studies investigating bioavailability indices for the ecological soil contact pathway have been conducted recently, and the collection of such data prior to a complete Tier 3 evaluation of this pathway may provide valuable information about the feasibility of Tier 3.

Tier 1 values for nutrient cycling and ecological soil ingestion have not yet been developed.

3.2.3 Use of direct measurements in relevant media for Tier 2 adjustments

Direct measurements in appropriate media, if made in accordance with Section 3.1.2 and Appendix C of the guidance, may be substituted for predicted values in the relevant fate and transport models. Examples of such measurements are vapour-phase PHC concentrations in soil gas adjacent and dissolved PHC concentrations in groundwater at or near the contaminant source, at the point of compliance, or an intermediate point along the lateral transport pathway.

Although the use of direct measurements is a site-specific, data-based, technical procedure, the application of these measurements at Tier 2 differs from the use of user-adjustable parameters to calculate site-specific objectives. In the derivation of soil quality or remediation objectives, fate and transport modelling is used to establish a relationship between the PHC concentration in soil at the contaminant source and the exposure concentration experienced by the receptor and, hence, risk. The relationship is actually used to determine the allowable source concentration or remediation objective corresponding to a target exposure concentration or risk. Adjusting assumptions used in the modelling would result in a change in remediation objective for the same target risk.

While point-of-exposure measurements can be used to assist in the calibration of fate and transport models, they would not normally be used to recalculate soil objectives. Instead, they would be used in combination with, in most cases, simplified modelling, to ensure that higher source concentrations would not lead to exceedance of the target risk level. This would involve comparing the point-of-exposure measurements with allowable concentrations at the measurement point, which are back-calculated from the modelling.

Direct or point-of-exposure measurement, where allowed by the jurisdiction at Tier 2, would be applicable to the following pathways.

Indoor vapour inhalation

Three main processes govern the vapour inhalation exposure pathway: partitioning of PHC from soil to the vapour phase; vapour phase transport from the contaminant source to the soil adjacent to the building foundation; and infiltration/dilution between the soil and the building air. The measurement of PHC vapour concentrations can reduce the uncertainty and conservatism in the generic modelling of the first two processes.

Modelling of the infiltration/dilution process would be required in order to establish allowable PHC vapour concentrations at the point of measurement that would maintain the same level of risk to receptors as adopted in Tier 1. Generic building assumptions would still be required at Tier 2. Other information may be required to support the use of point-of-exposure measurements, including evidence that concentrations would not be likely to increase with time and that peri-foundational PHC concentrations are typical of sub-slab concentrations, or a management plan to ensure that conditions remain acceptable. Site-specific determination of the proportions of each PHC subfraction in the vapour phase may also be useful. In addition, measurements will need to be made in a reliable and consistent manner. This requires establishment of measurement protocols to ensure consistent determination and application of subsurface vapour concentrations.

Note that the measurement of PHC concentrations in indoor air is not recommended as part of a Tier 2 adjustment. Due to the relatively low indoor air concentrations of PHC that correspond to acceptable human health risks, distinguishing between the contribution to indoor air of subsurface contamination and that of other background PHC sources in and around a building is not always possible.

Further discussion of the use of this approach is presented in Appendix D.

Protection of potable groundwater or livestock watering

The Tier 1 values for the protection of potable groundwater and livestock watering are based on a simple dilution model that describes the relationship between the PHC concentration in soil and that in the groundwater directly beneath the site. The potential groundwater user is assumed to be located at the downgradient boundary of the contaminant source. The measured PHC concentration in the groundwater at that location may be compared directly with allowable point-of-exposure values, thereby lessening reliance on the assumptions involved in the dilution modelling.

Where the potable water or livestock watering source is located outside the PHC contaminated area, groundwater transport modeling can be used to address lateral transport of the contamination from the PHC source area to the point of water use (similar to the modelling of freshwater life exposure, below). This scenario, if allowed by the jurisdiction at Tier 2, would require water use restrictions and stakeholder acceptance. In this case, the so-called point-of-exposure PHC measurements in groundwater could be obtained at the defined point of compliance, at the source or at an intermediate location. In the latter two cases, modelling would be required to establish comparative criteria at the point of measurement corresponding to the allowable PHC concentrations at the point of use. Since partitioning and transport in the unsaturated zone does not need to be addressed, the model can be replaced by a simple advective-dispersive transport model. This is discussed further in Appendix D.

Additional evidence will be required that groundwater concentrations will not increase with time, or a management plan would be needed to ensure concentrations remain within acceptable limits.

Protection of groundwater or surface water sustaining aquatic life

The derivation of Tier 1 values for the protection of groundwater for freshwater life utilizes lateral groundwater transport modelling with a default horizontal distance of 10 m, which can be adjusted on a site-specific basis as described in the preceding section. As in the drinking water scenario, PHC concentrations measured in groundwater at any point along the transport pathways can be used to reduce the dependence on modelling. If the measurement point is other than at the point of use, some modelling will still be required but unsaturated zone behaviour does not need to be addressed. Similar conditions apply as above regarding evidence of stable or declining concentrations. Further discussion is contained in Appendix D.

3.2.4 Other forms of Tier 2 adjustment

Elimination of exposure pathways and receptors

Site-specific adjustment of Tier 1 levels based on the absence or elimination of exposure pathways and/or receptors may be permitted at Tier 2 under certain circumstances. The principal consideration in this regard is whether the relevant site-specific conditions are fixed or stable and can be predicted or controlled in a generic way. In many cases, site management or administrative controls are required to support screening of exposure pathways or receptors within a given generic land use, which would necessitate conditions or limitations being imposed with respect to site closure.

One example of pathway screening that would generally be permitted is the offsite migration check applied to industrial land use. The purpose of the check is to protect adjacent, more sensitive land from the deposition of PHC contaminated soil and dust originating from the erosion of commercial or industrial land. If surrounding land use is similar (i.e. commercial/industrial), this pathway may be eliminated from consideration.

Another example of pathway/receptor elimination that may be allowed, subject to a policy decision of the particular jurisdiction, is the exclusion of soil organisms and related pathways from consideration on commercial or industrial land where the site is completely paved or capped, and where no productive use of the soil system is anticipated or required. Although capping may not eliminate the presence of soil organisms, the need for a functioning soil ecosystem is diminished. Should landscaped areas exist or be planned, ecological soil contact would remain an active pathway.

Other pathways may be excluded in combination with the implementation of management measures or controls, provided that the use of such controls at Tier 2 is supported in the particular jurisdiction. Jurisdictions may also elect to define generic land uses involving the presence or absence of any relevant receptors and pathways, if appropriate in the context of geographic location, local land use and development trends.

Remediation objectives for soils at depth

In some circumstances, alternate remediation objectives may be appropriate for soils at depth, for various reasons. As noted previously, depth to contamination is a parameter, potentially adjustable at Tier 2, which affects the allowable soil concentration for the vapour inhalation pathway. In addition, soils at depth may not be accessible for direct exposure to human and ecological receptors, or may give rise to a lower level of exposure. Therefore, these direct exposure pathways could be excluded from consideration or otherwise modified.

In the original (2001) PHC CWS, a set of generic guideline values was developed for subsoil, defined by CCME as soil at a depth of greater than 1.5 m. The subsoil values were based on exclusion of direct human contact, modification of the ecological soil contact value (given a reduced requirement for ecological soil function) and recalculation of the vapour inhalation pathway based on an increased separation distance between the zone of contamination and the foundation. Management considerations such as explosive hazard and free product formation continued to apply, and in some cases became the limiting factor in establishing subsoil values.

The applicability of depth-based modifications at Tier 2 depends on the jurisdiction; some regulatory frameworks explicitly allow stratified cleanup whereby soils below a certain depth are subject to less stringent remediation criteria. In other cases restrictions are required in order to preserve the critical condition (i.e. the assumed depth). The appropriateness of adjusting ecological soil contact values with depth (as opposed to simply excluding the pathway) has recently been questioned. Therefore, generic subsoil values are no longer provided within this standard.

Site-specific remediation objectives may continue to be developed for soils at depth; the decision of whether they may be implemented at Tier 2 will rest with individual jurisdictions. However, the development of depth-based values should consider the following:

- Soils within the uppermost 1.5 m (i.e. surface soils) are considered to be accessible for direct contact by ecological receptors.
- The ecological soil contact pathway may be eliminated for soils below 3 m depth.
- Soil objectives for other relevant pathways (e.g. vapour inhalation) may be recalculated using normal Tier 2 methods.
- The human direct contact pathway may not be re-evaluated. The human direct contact pathway is generally considered to apply at all depths, due to the potential for soils at depth to be excavated and stockpiled at the surface.
- Management guidelines may not be re-evaluated. Management guidelines always apply, regardless of depth.

The approach for soils within the 1.5 m to 3 m depth interval, and any conditions or restrictions necessary to allow depth-based values to be applied at Tier 2, will be subject to jurisdictional determination.

3.2.5 Identification of limitations and land and/or water use restrictions

As noted previously, the substitution of site-specific data for certain generic assumptions used in the derivation of Tier 1 objectives may lead to the requirement for site management which, in turn, would normally invoke land or water use restrictions and conditional regulatory acceptance. One of the stated objectives of Tier 2 adjustments is that they must support clear and consistent land and water use decision making. For this reason, most of the identified user-adjustable parameters are fixed or stable parameters that would allow Tier 2 sites to be self-managing under the administration of generic land and water uses. However, a number of site-specific variables that affect exposure and, ultimately, the remedial objectives would require direct management. The extent to which such management can be accommodated at Tier 2 is a decision for individual jurisdictions in the context of each jurisdiction's regulatory framework for contaminated sites. The PHC CWS provides the general framework for both unconditional and conditional closure or regulatory acceptance at Tier 2.

Table 13 presents a summary of the parameters that are adjustable or potentially adjustable at Tier 2, together with some additional factors governing exposure that may be varied at Tier 3. The implications of each parameter in terms of land or water use restrictions and associated management requirements are also presented in the table.

Regardless of whether or not such conditions are supported at Tier 2, any land or water use restrictions must have the agreement of all affected stakeholders. These include, but are not limited to, the proponent, the regulatory authorities, the land owner and any party entitled to use of the groundwater or potentially affected surface water. In most cases the imposition of restrictions will carry notification requirements which may include registration on title and submission of a publicly available risk management plan. In some cases financial security provisions may be required.

3.2.6 Site-specific adjustments not supported at Tier 2

Although some site-specific adjustments that lead to management requirements may be permitted by jurisdictions at Tier 2, a number of adjustments would not be supported at Tier 2 under any circumstances, and would require that the site be managed at Tier 3. These include:

- adjustments in parameters that do not meet the three basic requirements of a Tier 2 adjustment (factors that cannot be measured and verified, do not support clear and consistent land and water use decision making, and cannot be applied in a simple and straightforward manner)

- adjustments in human and ecological receptor characteristics, except where related to an additional defined generic land use category established by the jurisdiction

- exclusion of pathways or receptors without appropriate management provisions that would be acceptable under Tier 2

- consideration of processes such as biodegradation and natural attenuation, except where these can be described by well-established and conservative relationships and have been demonstrated to be applicable to the specific site, or by the conservative natural attenuation built into the groundwater transport model for the groundwater protection pathways.

3.3 Tier 2 Decision

The Tier 2 decision process is illustrated schematically by the lower part of the flow diagram presented in Figure 3. The process consists of a number of decision nodes. The decision process and criteria at each node are discussed in the following paragraphs.

3.3.1 Comparison of conditions with identified Tier 2 objectives

Initially the site PHC data are compared with the adjusted numerical objectives established at Tier 2. If no exceedances are found at this point, the site can be considered to be in compliance with Tier 2, subject to any land or water use restrictions. If no land or water use restrictions are required, no further action is necessary. If exceedances are found, the proponent enters a decision process whereby the option of managing to Tier 2 is weighed against the option of proceeding to Tier 3. As detailed earlier in this guidance, it may be permissible to subtract background PHC measurements prior to comparison with the Tier 2 objectives in some circumstances.

3.3.2 Assessment of feasibility and appropriateness of management to Tier 2

The first consideration is the practical and economic feasibility of management to Tier 2. As in Tier 1, remediation techniques will be assessed according to their practical and technological capability to achieve the required remedial objectives, and their associated costs. If management to Tier 2 is feasible from a practical and technological standpoint, the decision will involve weighing the costs and benefits of Tier 2 management against those of Tier 3. Considerations will include short- and long-term remedial costs, the costs and benefits of returning the land to productive use, the liabilities associated with long-term management, and the additional investigative, computational and regulatory costs of Tier 3 and whether site conditions are such that Tier 3 provides opportunities or benefits not available at Tier 2.

If the proponent concludes that Tier 2 is practically and economically feasible and chooses to implement this level of management, the issue of restrictions or conditions must be addressed. If Tier 2 is not considered feasible or appropriate, the proponent will proceed to assessing the applicability of Tier 3.

3.3.3 Assessment of conditions related to Tier 2 management

Based on consideration of the assumptions and adjustments used in the establishment of the Tier 2 objectives, the requirement for land or water use restrictions is identified as described in Section 3.2.5. If there is no requirement for restrictions, Tier 2 management will be considered unconditional, leading to unconditional acceptance upon verification or confirmation.

If restrictions are indicated, the restrictions are subject to acceptance by affected stakeholders. Stakeholder considerations may include, but are not limited to, the following:

- the proponent must be prepared to accept the conditions imposed, including their potential effect on property value, and must commit to fulfil ongoing management requirements

- affected landowners must understand the risk-based process and agree to any land or water use restrictions that would apply to their properties

- regulatory bodies must accept the Tier 2 objectives, ensure that the conditions are consistent with the jurisdiction's regulatory framework, be satisfied that affected stakeholder agreement has been sought and obtained, and prescribe a mechanism to ensure that future management and notification requirements are fulfilled.

If the land and/or water use restrictions are acceptable to all stakeholders, conditional acceptance of Tier 2 would be granted subject to verification and confirmation of the necessary remediation or management measures. If the restrictions are not acceptable to any affected stakeholder, conditional Tier 2 management would not be permitted. In this situation, the proponent would be required to address the restrictions by one of two means. The proponent can return to the Tier 2 evaluation and limit Tier 2 adjustments to those parameters which would not give rise to restrictions, ultimately leading to unconditional acceptance of Tier 2. Alternatively, if feasible, he/she may wish to return to Tier 1, compliance with which would be automatically unconditional.

3.3.4 Assessment of opportunity for Tier 3 management

Since the options for including site-specific information at Tier 2 are limited, the parameters and assumptions may be such that the Tier 2 exposure scenario is still conservative relative to site-specific conditions. Additional site-specific factors may exist that would mitigate exposure, leading to the development of less stringent remediation objectives. If so, these factors may be incorporated at Tier 3. Examples of site-specific conditions that may mitigate exposure, which could be incorporated at Tier 3, include:

- site-specific, manageable human receptor characteristics, such as frequency of exposure
- present building location and configuration
- restrictions on human access
- nature and location of existing water use and opportunity to manage future use

Alternatively, exposure could be mitigated through the implementation of management measures designed to control exposure or off-site migration, such as elimination of exposure pathways by means of engineered controls (e.g. physical barriers, hydraulic controls).

If site-specific factors are not assessed as having the potential for mitigating exposure, or if exposures could not otherwise be managed, Tier 3 would not be considered viable and the proponent will return to Tier 1 or Tier 2.

If, however, there is an opportunity for relief at Tier 3, the proponent should assess the costs and benefits and the impact of restrictions prior to making the decision to proceed to Tier 3. Detailed site-specific human health and ecological risk assessments are considerably more intensive with respect to investigation, data requirements, computation and modelling, and regulatory review, than Tier 2 adjustments or screening level risk assessments. For example, site-specific ecological risk assessments for PHC are likely to require the establishment of toxicity data specific to the receptors, soil type and PHC composition. In general, site-specific risk assessment is a powerful and flexible tool for the purpose of developing appropriate and cost-effective risk management strategies for PHC contaminated sites. However, the proponent should apprise himself/herself of the requirements of the approach before committing to Tier 3 management. Details of the requirements of a site-specific risk assessment are contained in various available guidance documents and are summarized in Section 4 of this document.

If the benefits of site-specific risk assessment and risk management do not outweigh the restrictions, costs and regulatory burden, the proponent will return to Tier 2. If Tier 3 is considered advantageous, the acceptability of the associated restrictions and conditions to all affected stakeholders must be assessed, at least at a preliminary level, before proceeding to the implementation of Tier 3. Guidance with respect to land and water use restrictions and other conditions has been provided in previous sections of this document. If the associated restrictions are not likely to be accepted by stakeholders, the proponent will again return to Tier 1 or Tier 2.

4.0 MANAGEMENT GUIDANCE FOR CWS IMPLEMENTATION – TIER 3

Tier 3 involves the completion of a site-specific risk assessment and the development of a risk management plan. Detailed guidance on human health and ecological risk assessment is beyond the scope of the present document and is presented in a number of available resource documents (see, for example: US EPA, 1989, 1997a; Health Canada, 2004a; 2006; CCME, 1996a, 1996b, 2006); several provincial jurisdictions have also developed risk assessment guidance. The basic steps are summarized herein and are illustrated in Figure 4. The technical activities of Tier 3 must be conducted by professionals competent in the field of human health and ecological risk assessment, which includes the disciplines of contaminated site characterization, toxicology, fate and transport modelling, exposure assessment and risk management.

4.1 Tier 3 Data Collection

The information required for implementation of Tier 3 must include sufficient site and PHC characterization, data pertinent to fate and transport modelling, receptor characteristics, toxicity information and other information needed to permit the site-specific quantification of risk and establishment of remediation objectives.

The actual data required will depend on the critical pathways and receptors, the availability and applicability of relevant data from other sources for aspects such as toxicity, and the approach to the risk assessment calculations (probabilistic versus deterministic; these are discussed in Section 4.2.4). Provision of a detailed protocol for Tier 3 data collection is beyond the scope of this document, but the proponent should be guided by the need to ascertain, with a reasonable level of confidence, the following:

- degree and extent of PHC contamination (by PHC fraction and, if appropriate, subfraction),
- physical, chemical and hydrogeological characteristics of site soil and groundwater
- building characteristics, if applicable
- human and ecological receptors and their associated exposure factors; in the case of ecological receptors it may be necessary to establish a complete inventory of species present prior to identifying critical receptors
- receptor-specific toxicity information which, in the case of ecological receptors, may require toxicity testing and, at more detailed levels of ERA, tissue sampling and analysis

Where Tier 3 is likely to involve risk management that is based on natural attenuation, biodegradation, source depletion and other transformation mechanisms, sufficient evidence of these processes, and of conditions amenable to their occurrence, will be required.

Data collection for Tier 3 should also provide sufficient information to serve as a baseline for long term monitoring of relevant parameters under a risk management scenario.

4.2 Site-Specific Human Health and Ecological Risk Assessment

The user is referred elsewhere for detailed guidance on human health and ecological risk assessment. The basic steps involved in risk assessment are summarized below.

4.2.1 Problem formulation

Problem formulation consists of identifying the potential contaminants of concern (in this case PHC, although other contaminants may be present that would also be addressed as part of the risk assessment). Potential human and ecological receptors are identified together with exposure pathways. Complete exposure pathways require a mechanism of chemical release to the transport medium, a transport pathway from the contaminant source to the receptor, and a route of intake at the receptor location. Incomplete pathways may be eliminated on a site-specific basis at this stage, and the complete or potentially complete pathways are incorporated into a conceptual model of the site which serves as the basis for the subsequent steps of the assessment.

4.2.2 Toxicity assessment/hazard assessment

The toxicity assessment or hazard assessment comprises the establishment of either a dose-response relationship or a toxicological or effects-based endpoint value for each contaminant of concern. Toxicity values for most commonly encountered contaminants are typically obtained from the published literature and/or government sources such as Health Canada (2004b), Environment Canada and US EPA. For human health risk assessment, dose-response relationships are typically applied to carcinogens or non-threshold compounds. For PHC, since potential carcinogenic compounds such as benzene are managed separately, the prescribed fractions are treated as threshold compounds and have been assigned reference doses, which are daily intake values that receptors may receive on a continuing basis without appreciable risk of adverse effect. The establishment of these reference doses is described in the Scientific Rationale (CCME, 2008).

In the case of ecological risk assessment, due to the wide variety of potential receptors, published effects-based data are usually only available for limited test species. Procedures for selecting and utilizing published data to develop threshold effects doses or criteria for various receptors are documented by CCME (1996b; 2006). In the case of PHC, this process is complicated by the fact that the contaminants being considered are mixtures. The Scientific Rationale describes the development of ecotoxicity criteria for PHC. For site-specific and receptor-specific ecological risk assessment, it may be necessary to supplement such values through additional literature review and possibly toxicity testing.

4.2.3 Exposure assessment

Exposure assessment comprises the establishment of a relationship between the contaminant concentration at the source and the exposure or intake at the receptor location, considering both the fate and transport of the contaminant and the behavioural characteristics of the receptor. For direct pathways, exposure assessment involves determining the intake as a direct function of the source concentration to which the receptor is exposed. For indirect pathways the exposure assessment normally involves modelling of the fate and transport mechanisms, including cross-media partitioning. Point-of-exposure measurements may be used to reduce the level of uncertainty in the modelling. The models and algorithms recommended for use in Canada for the principal exposure pathways are described in CCME (1996a, 2006) and Health Canada (2004a). Other methods may be found in ASTM (1995). The methods used in the derivation of the Tier 1 PHC values are described in the Scientific Rationale (CCME, 2008) and are summarized in Appendix B. Data on receptor characteristics for the Canadian population have been compiled by Richardson (1997) and are summarized in CCME (2006) and Health Canada (2004a).

4.2.4 Risk characterization

Risk characterization consists of combining the projected intakes of the contaminants of concern with the established toxicity data to obtain an expression of risk. For PHC, human health risk is expressed in terms of hazard index; ecological risk in terms of exposure ratio. If assumptions in the risk assessment are sufficiently conservative, then hazard indices or exposure ratios of less than unity, based on all sources of exposure, signify negligible potential for adverse effect. For human exposure, other sources of exposure are accounted for by assigning a soil allocation factor (e.g. 0.2 or 0.5) to exposures from PHC contaminated soil. The soil allocation factors actually used in the derivation of the Tier 1 values are described in the Scientific Rationale (CCME, 2008).

As part of the risk characterization process, the established relationships between source concentration and risk are used to back-calculate source concentrations corresponding to target risk levels. In this way site-specific risk-based remediation objectives are established for each pathway and receptor. The critical exposure pathway is identified on the basis of the lowest applicable objective, which then becomes the governing objective for the site.

Site-specific risk assessments may be carried out using deterministic or probabilistic methods. Although deterministic methods have been used in the development of the PHC Tier 1 values, and are implicit in the Tier 2 adjustment procedures, the use of probabilistic methods is becoming increasingly common practice in Canada for site-specific risk assessment, particularly for human health. Probabilistic methods provide a consistent and defensible method of accounting for uncertainty and natural variability in key assumptions such as site conditions and receptor characteristics. They also provide insight that can facilitate risk management decision making from the standpoint of level of protection or conservatism. However, caution should be exercised in comparing the results of a probabilistic analysis with those of a deterministic analysis, since the different methods of defining input assumptions, even between deterministic risk assessments, can lead to different levels of human health or ecological protection. Further discussion of probabilistic methods is presented in Appendix E.

4.3 Development of Remediation/Risk Management Plan and Long Term Monitoring Plan

The results of the site-specific risk assessment are used to develop a strategy for remediation and/or risk management. In broad terms, the options available to the proponent at this stage, all of which carry some associated management requirement, are summarized below.

- *Remediation to the governing site-specific remediation objectives*

  Short or long term remediation would be undertaken to achieve the established site-specific remediation objectives. Restrictions and management conditions would be required to ensure that the physical, land use and receptor characteristics do not vary from those assumed in the risk assessment. Where long term remediation techniques are used, ongoing monitoring would be required to assess the progress of the remediation and to ensure that adverse impacts do not arise from the contamination present prior to completion of remediation.

- *Risk management of critical pathways in combination with remediation*

  By applying risk management to the reduction or elimination of exposure via the critical exposure pathway, other less critical pathways may govern with respect to remediation objective. This could result in a reduction in remedial effort and costs.

- *Long term risk management*

  Under certain circumstances it may be possible, and advantageous, to implement risk management measures, without associated remediation, aimed at providing long term protection of receptors and elimination of exposure pathways. Examples of such situations include operating facilities, sites where natural attenuation is being relied upon in the long term, or sites where remediation can only practically be accomplished at the time of site closure or redevelopment. In these cases, monitoring would be required to ensure that conditions do not become worse with time, and that the risk management measures are effective.

In the above cases, particularly those in which active remediation is not contemplated, the non-toxicity-based considerations outlined in Section 1.6 must be observed and addressed (i.e. explosion hazard, aesthetic considerations and avoidance of free product).

5.0 REGULATORY ACCEPTANCE

5.1 Verification Requirements

Upon completion of remediation to the numerical levels of Tier 1 or Tier 2, regulatory agencies will generally grant approval or acceptance of the remediation, subject to appropriate verification or confirmation. Approval or acceptance is typically provided by means of a certificate of compliance, certificate of reclamation, letter of comfort, record of site condition, or similar mechanism, depending on the jurisdiction. Such approvals may be unconditional or, in some cases, conditional, as outlined in Section 1.7. In all cases, however, the proponent must provide the regulatory agency with evidence that the appropriate Tier 1 or Tier 2 levels have been attained or, in a more general sense, that the health and environmental protection goals have been met.

This would normally be accomplished by confirmatory sampling and analysis, appropriate to the method of remediation, in combination with the information obtained during the Tier 1 and Tier 2 assessments. For example, excavation of soil containing PHC concentrations in excess of the appropriate remediation objectives would be accompanied by analysis of samples obtained from the limits of the excavation. Tier 1 or Tier 2 assessment results would provide the added assurance that the impacted soil had been fully delineated. Data requirements for verification or confirmation of remediation may be prescribed by individual jurisdictions, although the general intent of a confirmatory assessment can be considered to be the same as that of a Tier 1 or Tier 2 assessment from the standpoint of PHC characterization and delineation. Similar confirmatory requirements may be associated with the completion of a Tier 3 remediation, although acceptance of Tier 3 would almost always be conditional.

Methods of PHC characterization, sampling strategies and screening methods are presented in Appendices A and C. Some jurisdictions may prescribe specific methods and protocols for assessment and verification, including the use of statistical methods to determine compliance within a particular stratum or soil unit (see, for example, BC MOE, 2005).

5.2 Site Management Requirements Associated with Conditional Acceptance

The distinctions between unconditional and conditional acceptance, and the requirements and implications associated with conditional closure at Tiers 2 and 3, have been discussed in previous sections of this guidance (see Sections 1.6, 2.3.4, and 3.2.5). They are summarized here in the context of regulatory acceptance.

Unconditional acceptance or closure is normally granted where generic land use administration is sufficient to ensure that the Tier 1 numerical standards or Tier 2 adjusted values will remain appropriate to a particular site. Conditions may be imposed upon certain categories of site management where controls are necessary to preserve the assumptions used in the establishment of the Tier 2 or Tier 3 objectives. These controls may include engineered systems, designed to limit exposure via one or more exposure pathways through physical means such as barriers, and administrative controls designed to limit exposure through land and water use restrictions.

From the regulatory standpoint, any engineered or administrative controls will be subject to a number of requirements:

- provision must be made for the proponent to maintain and operate any engineered systems as long as necessary to fulfill their intended function and preserve human health and environmental risks at acceptable levels

- the proponent or its successor(s) must retain responsibility for ensuring that the site will ultimately meet generic land use requirements, or can ultimately be returned to such use. In some cases jurisdictions will impose financial security requirements for this purpose

- any controls resulting in restriction on land and/or water use must have the agreement of all affected stakeholders including, but not limited to, the proponent, the jurisdiction, the land owner and any party entitled to use of potentially affected land or water

- a mechanism must be in place to ensure that present and future stakeholders are notified of conditions, controls and management requirements

The mechanisms through which these requirements are imposed by jurisdictions will be dependent on the regulatory framework for contaminated sites and the associated risk management policies of each jurisdiction.

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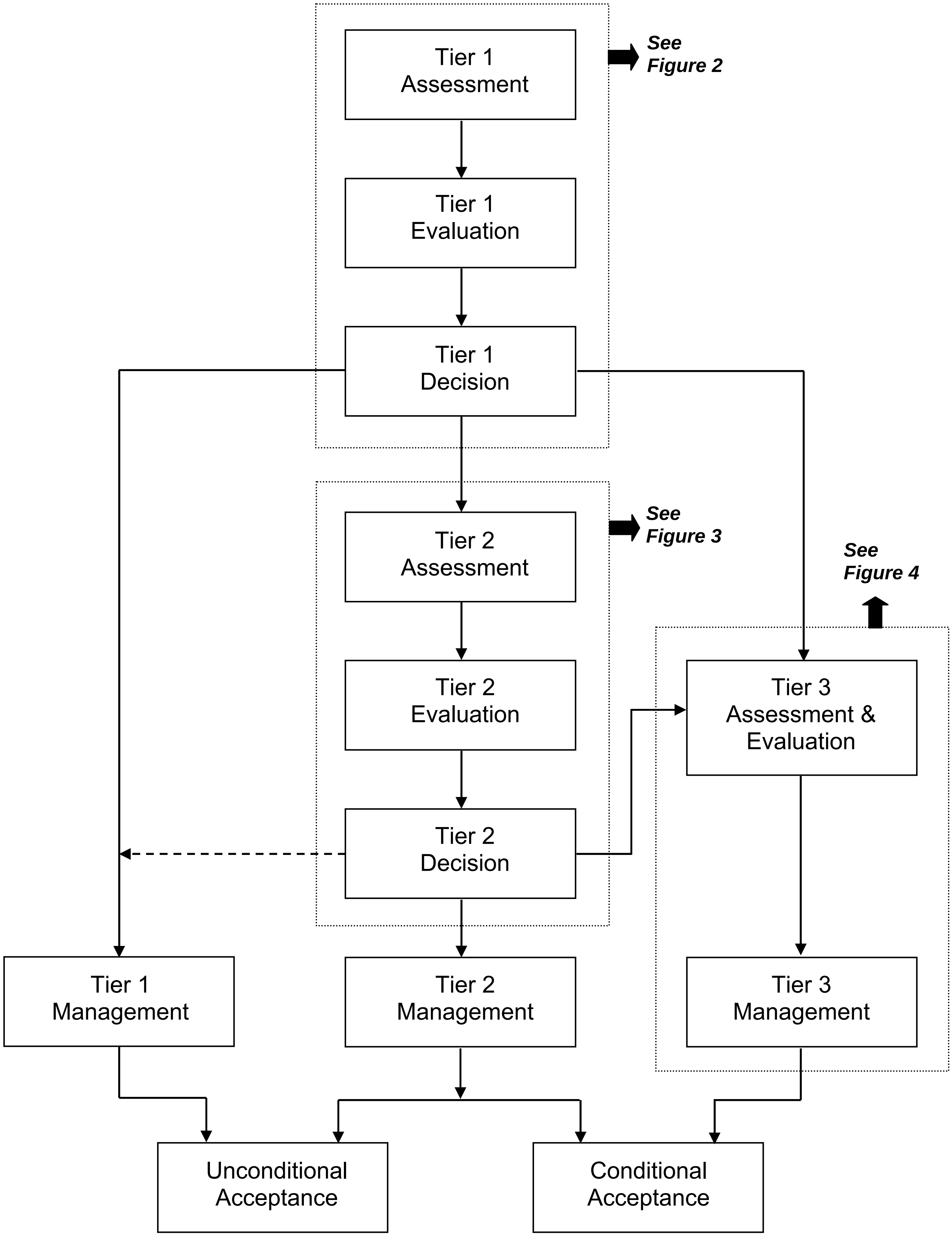

Figure 1: PHC CWS Implementation Framework

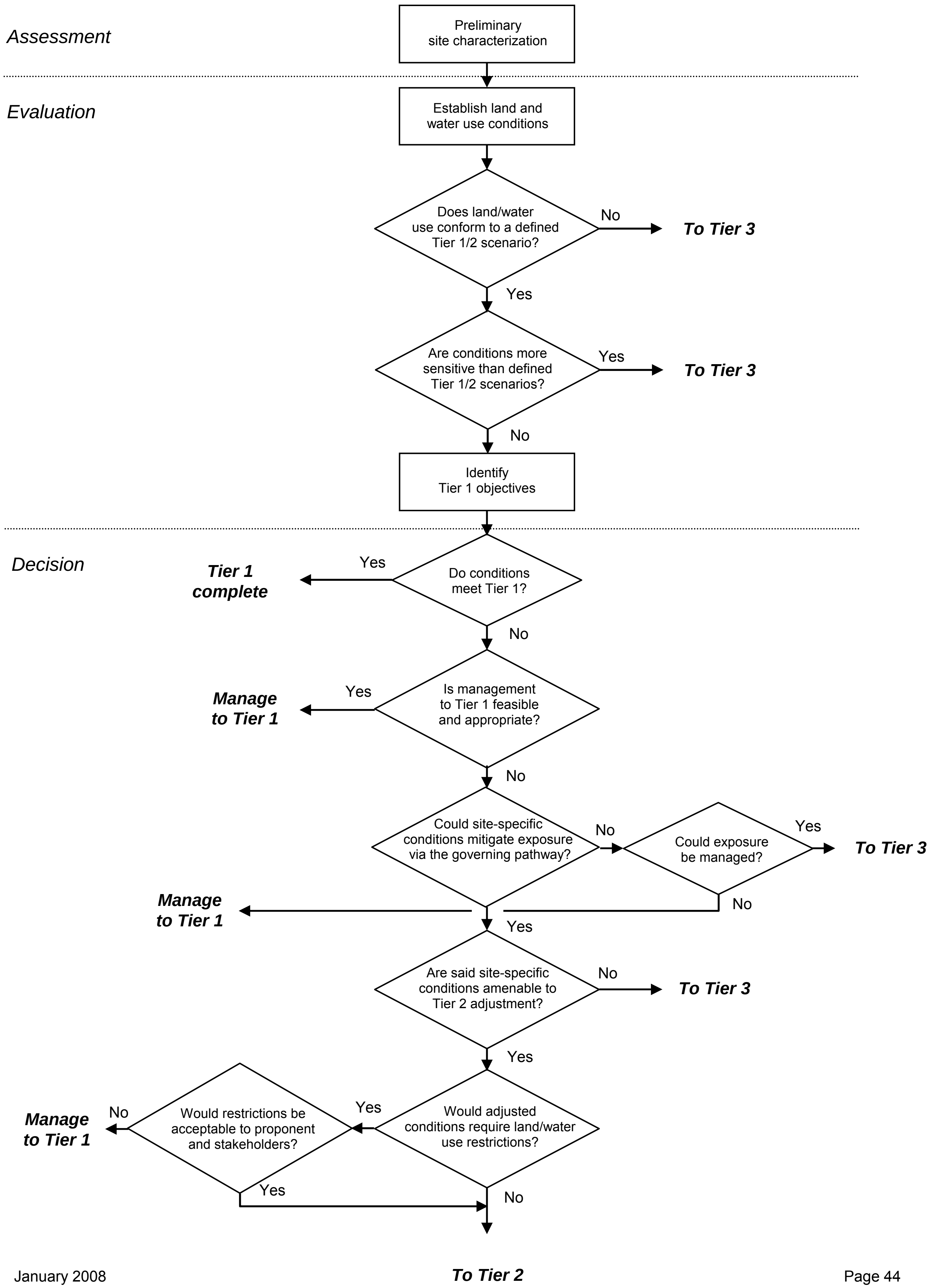

Figure 2: Expanded flow diagram – Tier 1

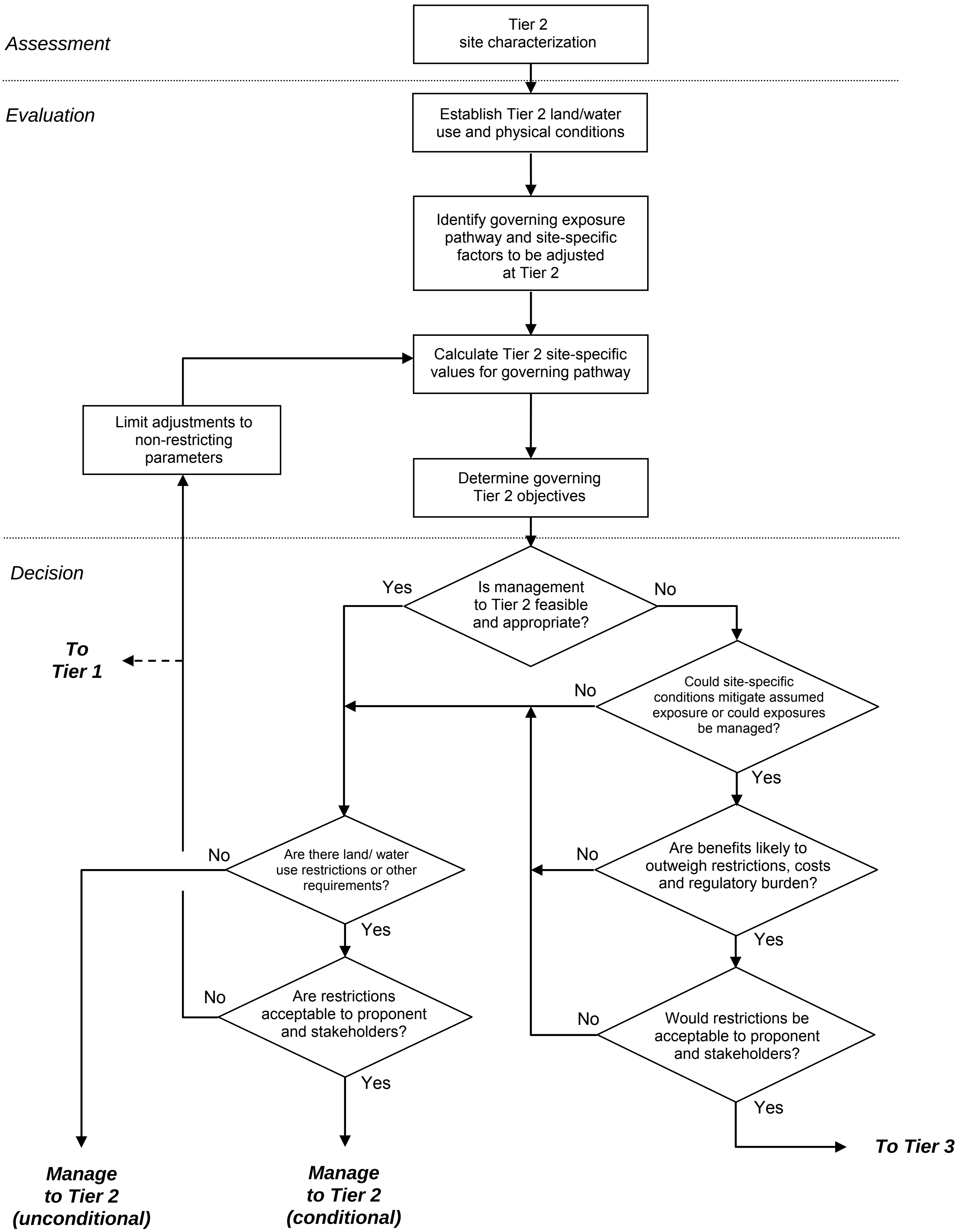

Figure 3: Expanded flow diagram – Tier 2

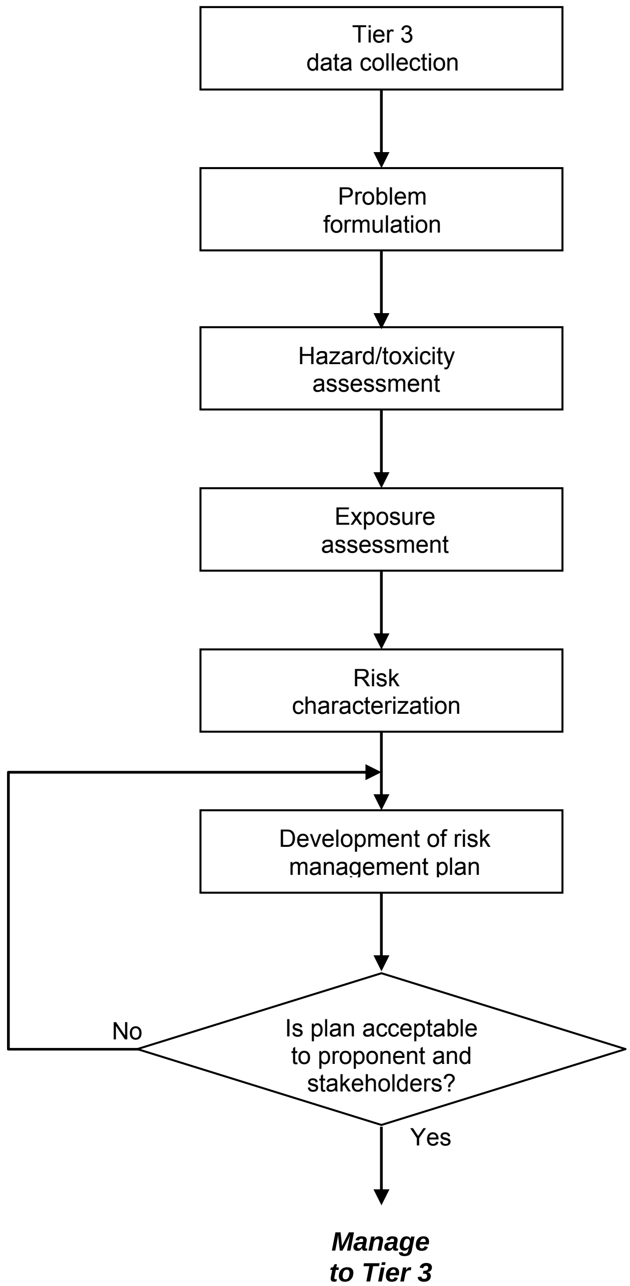

Figure 4: Expanded flow diagram – Tier 3

TABLE 1

LAND-USES, KEY RECEPTORS AND EXPOSURE PATHWAYS

Exposure Pathway	Agriculture	Residential/ Parkland	Commercial	Industrial
Soil Contact	Nutrient cycling[e] Soil invertebrates Crops (plants) Livestock/wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Human (adult)
Soil and Food Ingestion	Herbivores[d] Human (toddler)	(wildlife)[b] Human (toddler)[a]	(wildlife) [b] Human (toddler)[a]	(wildlife) [b] Human (adult)
Groundwater/ Surface Water	Aquatic Life/ Livestock Watering Human (toddler)[a]	Aquatic Life Human (toddler)[a]	Aquatic Life Human (toddler)[a]	Aquatic Life Human (adult)
Indoor Vapour Intrusion	Human (toddler)[a, c]	Human (toddler)[a]	Human (toddler)[a]	Human (adult)
Produce, meat and milk produced on site	Human (toddler)[a, f]	Human (toddler)[a, f] • Produce only		
Off-site migration of Soil/Dust			Human/Eco[d]	Human/Eco [d]

a – Health Canada defines a toddler as a child of age 7 months to 4 years. This age group generally receives the greatest dose per unit body weight and, therefore, represents a critical receptor for human health risk assessment and guidelines development for land uses they may frequent.

b – Wildlife/livestock dermal contact and ingestion data may be particularly important for PHC (e.g., oiling of feathers, etc., although this should be addressed with an initial assessment of the presence of non-aqueous phase liquids - NAPL), but there are unlikely to be sufficient data to develop guidelines that address this exposure pathway.

c – An agricultural site may include a farm residence. Subject to jurisdictional policy, the indoor vapour intrusion pathway may be excluded if there is no existing residence and no potential for a future residence within 30 m of the contamination.

d – Off-site migration of soil/dust is based on the most sensitive exposure pathway for the surrounding properties.

e – CCME intends that nutrient/energy cycling and (for agricultural land) food ingestion by humans and soil and food ingestion by herbivores be considered; however, sufficient data are not available at this time to support derivation of quantitative soil levels for these pathways.

f – In most cases PHC are not expected to bioaccumulate to high concentrations in produce, meat or milk, though some polycyclic aromatic hydrocarbons (PAH) may bioaccumulate to a limited extent; the available data are currently insufficient to evaluate this pathway on a generic basis

TABLE 2
PATHWAY-SPECIFIC TIER 1 LEVELS (mg/kg soil) FOR PHC
FOR COARSE-GRAINED SURFACE SOILS

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[a]	970	380	NA	NA
	Protection of GW for Livestock Watering	5300	14 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	300	2800
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk Ingestion	NC	NC	NC	NC
	Management Limit[b]	700	1000	2500	10000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[a]	970	380	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	300	2800
	Produce Ingestion	NC	NC	NC	NC
	Management Limit[B]	700	1000	2500	10000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[a]	970	380	NC	NC
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[b]	700	1000	3500	10000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[a]	970	380	NC	NC
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[b]	700	1000	3500	10000

NA - Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded.
RES - Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC - Not calculated. Insufficient data to allow derivation.
a - Assumes surface water body at 10 m from site.
b - Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects

TABLE 3

PATHWAY-SPECIFIC TIER 1 LEVELS (mg/kg soil) FOR PHC FOR FINE-GRAINED SURFACE SOILS

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW	170	230	NA	NA
	Protection of GW for Aquatic Life[a]	RES	RES	NA	NA
	Protection of GW for Livestock Watering	4200	10 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	1300	5600
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk Ingestion	NC	NC	NC	NC
	Management Limit[b]	800	1000	3500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW	170	230	NA	NA
	Protection of GW for Aquatic Life[a]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	1300	5600
	Produce Ingestion	NC	NC	NC	NC
	Management Limit[b]	800	1000	3500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW	170	230	NA	NA
	Protection of GW for Aquatic Life[a]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	2500	6600
	Offsite Migration	NA	NA	19 000	RES
	Management Limit[b]	800	1000	5000	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (Indoor)	4600	23 000	NA	NA
	Protection of Potable GW	170	230	NA	NA
	Protection of GW for Aquatic Life[a]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	2500	6600
	Offsite Migration	NA	NA	19 000	RES
	Management Limit[b]	800	1000	5000	10 000

NA - Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded
RES - Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC - Not calculated. Insufficient data to allow derivation.
a - Assumes surface water body at 10 m from site.
b - Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects

TABLE 4

GOVERNING EXPOSURE PATHWAYS AT TIER 1 FOR COARSE-GRAINED SOILS[a]

LAND USE	F1 (C6-C10)	F2 (C>10-C16)	F3 (C>16-C34)	F4 (C>34)
Agricultural	1. Vapour inhalation 2. Ecological soil contact 3. Protection of potable groundwater 4. Management limit 5. Protection of groundwater for aquatic life 6. Protection of groundwater for livestock 7. Direct contact	1. Ecological soil contact 2. Vapour inhalation 3. Protection of potable groundwater 4. Protection of groundwater for aquatic life 5. Management limit 7. Direct contact 6. Protection of groundwater for livestock	1. Ecological soil contact 2. Management limit 3. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact
Residential	1. Vapour inhalation 2. Ecological soil contact 3. Protection of potable groundwater 4. Management limit 5. Protection of groundwater for aquatic life 6. Direct contact	1. Ecological soil contact 2. Vapour inhalation 3. Protection of potable groundwater 4. Protection of groundwater for aquatic life 5. Management limit 6. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact
Commercial	1. Protection of potable groundwater 2. Ecological soil contact 3. Vapour inhalation 4. Management limit 5. Protection of groundwater for aquatic life 6. Direct contact	1. Ecological soil contact 2. Protection of potable groundwater 3. Protection of groundwater for aquatic life 4. Management limit 5. Vapour inhalation 6. Direct contact	1. Ecological soil contact 2. Management limit 3. Offsite migration 4. Direct contact	1. Ecological soil contact 2. Management limit
Industrial	1. Protection of potable groundwater 2. Ecological soil contact 3. Vapour inhalation 4. Management limit 5. Protection of groundwater for aquatic life	1. Ecological soil contact 2. Protection of potable groundwater 3. Protection of groundwater for aquatic life 4. Management limit 5. Vapour inhalation	1. Ecological soil contact 2. Management limit 3. Offsite migration	1. Ecological soil contact 2. Management limit

a – pathways have been ranked based on pathway-specific levels at Tier 1 (lowest to highest); pathways with levels of “RES” or “NA” have been excluded

TABLE 5

GOVERNING EXPOSURE PATHWAYS AT TIER 1 FOR FINE-GRAINED SOILS[a]

LAND USE	F1 (C6-C10)	F2 (C>10-C16)	F3 (C>16-C34)	F4 (C>34)
Agricultural	1. Protection of potable groundwater 2. Ecological soil contact 3. Vapour inhalation 4. Management limit 5. Protection of groundwater for livestock 6. Direct contact	1. Ecological soil contact 2. Protection of potable groundwater 3. Management limit 4. Vapour inhalation 5. Direct contact 6. Protection of groundwater for livestock	1. Ecological soil contact 2. Management limit 3. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact
Residential	1. Protection of potable groundwater 2. Ecological soil contact 3. Vapour inhalation 4. Management limit 5. Direct contact	1. Ecological soil contact 2. Protection of potable groundwater 3. Management limit 4. Vapour inhalation 5. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact	1. Ecological soil contact 2. Management limit 3. Direct contact
Commercial	1. Protection of potable groundwater 2. Ecological soil contact 3. Management limit 4. Vapour inhalation 5. Direct contact	1. Protection of potable groundwater 2. Ecological soil contact 3. Management limit 4. Direct contact 5. Vapour inhalation	1. Ecological soil contact 2. Management limit 3. Offsite migration 4. Direct contact	1. Ecological soil contact 2. Management limit
Industrial	1. Protection of potable groundwater 2. Ecological soil contact 3. Management limit 4. Vapour inhalation	1. Protection of potable groundwater 2. Ecological soil contact 3. Management limit 4. Vapour inhalation	1. Ecological soil contact 2. Management limit 3. Offsite migration	1. Ecological soil contact 2. Management limit

a – pathways have been ranked based on pathway-specific levels at Tier 1 (lowest to highest); pathways with levels of “RES” or “NA” have been excluded

TABLE 6

INFLUENCE OF PRIMARY TIER 2 ADJUSTABLE PARAMETERS ON EXPOSURE PATHWAYS
COARSE-GRAINED SOILS

Land use	Exposure pathway or receptor	PARAMETER											
		Soil Vapour Permeability	Soil Moisture Content	Soil Bulk Density	Organic Carbon Fraction	Hydraulic Conductivity	Recharge Rate	Hydraulic Gradient	Source Length	Depth to Contamination[f]	Depth to Groundwater[e]	Distance to Receptors[b]	Additional Comments
Agricultural	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	-	-	-	
	Vapour inhal. (slab/grade)	OO	XX	X	XX	-	-	-	-	XX	-	-	
	Vapour inhal. (basement)	OO	XX	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Livestock	-	O	O	XX	XX	OO	XX	O	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Residential	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	-	-	-	
	Vapour inhal. (slab/grade)	OO	XX	X	XX	-	-	-	-	XX	-	-	
	Vapour inhal. (basement)	OO	XX	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Commercial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	XX	-	-	
	Vapour inhal. (slab/grade)	OO	X	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a,g
Industrial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	XX	-	-	
	Vapour inhal. (slab/grade)	OO	X	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a, g

XX strongly influential; increasing the parameter increases the Tier 2 level
X somewhat influential; increasing the parameter increases the Tier 2 level
OO strongly influential; increasing the parameter decreases the Tier 2 level
O somewhat influential; increasing the parameter decreases the Tier 2 level
\- no influence
a pathway will not normally govern
b may result in land/water use restriction
c significant if lateral transport is considered
d insufficient data available for Tier 2 modification
e parameter only has significant influence if unsaturated zone transport occurs
f parameter only has significant influence if depth to contamination is greater than slab/basement depth
g dependent on governing residential pathway

TABLE 7

INFLUENCE OF PRIMARY TIER 2 ADJUSTABLE PARAMETERS ON EXPOSURE PATHWAYS FINE-GRAINED SOILS

Land use	Exposure pathway or receptor	PARAMETER											
		Soil Vapour Permeability	Soil Moisture Content	Soil Bulk Density	Organic Carbon Fraction	Hydraulic Conductivity	Recharge Rate	Hydraulic Gradient	Source Length	Depth to Contamination [f]	Depth to Groundwater [e]	Distance to Receptors [b]	Additional Comments
Agricultural	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	Oc	XX	Oc	-	-	-	
	Vapour inhal. (slab/grade)	OO	O	X	XX	-	-	-	-	X	-	-	
	Vapour inhal. (basement)	OO	O	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Livestock	-	O	O	XX	XX	OO	XX	OO	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Residential	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhal. (slab/grade)	OO	O	X	XX	-	-	-	-	X	-	-	
	Vapour inhal. (basement)	OO	O	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Commercial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhal. (slab/grade)	OO	O/X	X	XX	-	-	-	-	X	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a,g
Industrial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhal. (slab/grade)	OO	O/X	X	XX	-	-	-	-	X	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a, g

XX strongly influential; increasing the parameter increases the Tier 2 level
X somewhat influential; increasing the parameter increases the Tier 2 level
OO strongly influential; increasing the parameter decreases the Tier 2 level
O somewhat influential; increasing the parameter decreases the Tier 2 level
- no influence
a pathway will not normally govern
b may result in land/water use restriction
c significant if lateral transport is considered
d insufficient data available for Tier 2 modification
e parameter only has significant influence if unsaturated zone transport occurs
f parameter only has significant influence if depth to contamination is greater than slab/basement depth
g dependent on governing residential pathway

TABLE 8

PRIMARY TIER 2 ADJUSTABLE PARAMETERS AND ILLUSTRATIVE RANGES

PARAMETER	DEFAULT	ILLUSTRATIVE RANGE
Measured Parameters		
Bulk Density (g/cm^3)	c/g: 1.7 f/g: 1.4	c/g: 1.5 - 1.8 f/g: 1.3 - 1.6
Water Content (M_w/M_s)	c/g: 0.07 f/g: 0.12	c/g: 0.03 - 0.15 f/g: 0.07 - 0.16
Organic Carbon Fraction (g/g)	0.005	c/g: 0.0005 - 0.007 f/g: 0.0005 - 0.03
Soil Vapour Permeability (cm^2)	c/g: $5x10^{-8}$ f/g: 10^{-9}	c/g: 10^{-6} - 10^{-8} f/g: 10^{-8} - 10^{-12}
Saturated Hydraulic Conductivity (m/y)	c/g: 320 f/g: 32	c/g: 32 - 3200 f/g: 0.032 – 32
Recharge (m/y)	c/g: 0.28 f/g: 0.20	0.005 - 0.5
Hydraulic Gradient (unitless)	0.028	0.001 - 0.1
Depth/distance to Contamination (m)[a]	0.3	0 – 10
Thickness of Contamination (m)[b]	3	0.5 - 5
Depth to Groundwater (m)[c]	3	0 – 10
Site Length (m) - parallel to GW flow	10	5 – 30
Site Width (m) - perpendicular to GW flow[b]	10	5 – 30
Distance to nearby surface water (m)[b]	10	0 – 500
Distance to potable water or livestock watering (m)	0	0 – 500
Calculated Parameters		
Effective Porosity	c/g: 0.36 f/g: 0.47	See note d
Moisture-filled Porosity	c/g: 0.119 f/g: 0.168	See note e
Distance from Contamination to Groundwater (m)[b]	0	See note f

c/g – coarse-grained soil
f/g – fine-grained soil
a – distance from the nearest point of the foundation of an occupied buidling
b – parameter only used in the calculation of leaching to groundwater and transport to nearby surface water bodies
c – depth below grade
d – calculated from bulk density, assuming soil specific gravity of 2.65
e – derived from bulk density and water content
f – calculated from depth to contamination, depth to groundwater, and thickness of contamination

TABLE 9

SECONDARY TIER 2 ADJUSTABLE PARAMETERS

PARAMETER	TIER 1 DEFAULT VALUE	
Site Characteristics		
Distance (lateral or vertical) from PHC contamination to inhalation receptor (m)	0.3	
Annual Average Soil Temperature (K)	294	
Soil/Groundwater Characteristics		
Effective mixing depth (m)	calculated	
Depth of unconfined aquifer (m)	5	
Building Characteristics		
Building length (cm)	R, A: 1225	C, I: 2000
Building width (cm)	R, A: 1225	C, I: 1500
Building area (cm^2)	R, A: $1.5x10^6$	C, I: $3x10^6$
Building height, including basement (cm)	R, A: 360	C, I: 300
Thickness of building foundation (cm)	11.25	
Distance below grade to idealized cylinder (cm) = depth to bottom of slab	Basement: 244 Slab-on-grade: 11.25	
Air exchanges per hour	R, A: 0.5	C, I: 0.9
Pressure differential ($g/cm{\bullet}s^2$)	R, A: 40	C, I: 20
Diffusivity in cracks (cm^2/s)	calculated	
Area of cracks (cm^2)	R, A: 994.5	C, I: 1846

A – agricultural land use
R – residential land use
C – commercial land use
I – industrial land use

TABLE 10

PRIMARY TIER 2 ADJUSTABLE PARAMETERS BY PATHWAY

GOVERNING PATHWAY	PARAMETER GROUPING	MEASURED PARAMETERS
Protection of potable groundwater, protection of groundwater for aquatic life	Hydrogeological (saturated zone)	Soil bulk density Organic carbon fraction Hydraulic conductivity & hydraulic gradient[a]
	Hydrogeological (unsaturated zone)	Soil bulk density & moisture content[a,b] Organic carbon fraction[c] Depth to groundwater[b]
	Source dimensions	Length (parallel to groundwater flow) Width (normal to groundwater flow)[d] Contaminant thickness[b] Distance between contamination and water table[b]
	Hydrological	Precipitation, evapotranspiration and runoff[a] Days with surface temperature <0°C[b]
	Chemical	PHC composition
Vapour inhalation	Hydrogeological	Soil bulk density[e] & moisture content[a] Organic carbon fraction[c] Unsaturated zone soil vapour permeability
	Source dimensions	Depth or distance to contamination
	Chemical	PHC composition
Ecological soil contact		No user-adjustable parameters
Soil ingestion	Chemical	PHC composition

a – parameters are linked and must be considered together
b – only required if contaminated soil is not in direct contact with groundwater
c – measured in the zone of contaminant partitioning
d – only required for lateral groundwater transport
e – soil bulk density is required in both the zone of contaminant partitioning and in the unsaturated zone (to calculate vadose zone soil porosity)

TABLE 11
SUMMARY OF ILLUSTRATIVE EFFECTS OF SELECTED TIER 2 ADJUSTMENTS
COARSE-GRAINED SOILS (mg/kg)[a]

PARAMETER AND RANGE	LAND USE	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Default Values	A	30	150	300	2800
	R	30	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Vapour Permeability Ranging from 10^{-8} cm^2 to 10^{-6} cm^2	A	20 – 5 [c]	96 – 26 [b, c]	300	2800
	R	20 – 5 [c]	96 – 26 [b, c]	300	2800
	C	180 – 50 [c]	260 – 250 [b]	1700	3300
	I	180 – 50 [c]	260 – 250 [b]	1700	3300
Moisture Content Ranging from 0.03 g/g to 0.15 g/g	A	20 – 100 [b]	120 – 150 [b]	300	2800
	R	20 – 100 [b]	120 – 150 [b]	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Soil Bulk Density Ranging from 1.5 g/cm^3 to 1.8 g/cm^3	A	20 – 30	130 – 150 [b]	300	2800
	R	20 – 30	130 – 150 [b]	300	2800
	C	240 – 230	260	1700	3300
	I	240 – 230	260	1700	3300
Organic Carbon Fraction Ranging from 0.0005 g/g to 0.007 g/g	A	4.7 – 40 [b]	3.9 – 150 [b]	300	2800
	R	4.7 – 40 [b]	3.9 – 150 [b]	300	2800
	C	4.7 – 320 [b]	3.9 – 260 [b]	1700	3300
	I	4.7 – 320 [b]	3.9 – 260 [b]	1700	3300
Hydraulic Conductivity Ranging from 32 m/y to 3200 m/y	A	30	150 – 67 [b]	300	2800
	R	30	150 – 67 [b]	300	2800
	C	160 – 36 [b, c]	210 – 67 [b, c]	1700	3300
	I	160 – 36 [b, c]	210 – 67 [b, c]	1700	3300
Groundwater Recharge Ranging from 0.005 m/y to 0.5 m/y	A	30	150	300	2800
	R	30	150	300	2800
	C	320 – 220 [b]	260	1700	3300
	I	320 – 220 [b]	260	1700	3300
Hydraulic Gradient Ranging from 0.001 to 0.1	A	30	150 – 94 [b]	300	2800
	R	30	150 – 94 [b]	300	2800
	C	110 – 97 [b, c]	150 – 94 [b, c]	1700	3300
	I	110 – 97 [b, c]	150 – 94 [b, c]	1700	3300
Site Length Ranging from 5 m to 30 m	A	30	150	300	2800
	R	30	150	300	2800
	C	240 – 220	260	1700	3300
	I	240 – 220	260	1700	3300
Depth/Distance to Contamination Ranging from 0 m to 10 m Below Grade[d]	A	30 – 150 [b]	150	300	2800
	R	30 – 150 [b]	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Depth to Groundwater[e] Ranging from 3 m to 10 m	A	30	150	300	2800
	R	30	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Distance to Groundwater Receptors[f] Ranging from 0 m to 500 m	A	4.2 – 30 [b]	5.3 – 150 [b]	300	2800
	R	4.2 – 30 [b]	5.3 – 150 [b]	300	2800
	C	4.2 – 320 [b]	5.3 – 260 [b]	1700	3300
	I	4.2 – 320 [b]	5.3 – 260 [b]	1700	3300

a – all results assume that all pathways are active, including groundwater and surface water pathways
b – governing pathway changes
c – both ends of range are less than default value, due to parameter having opposite effects on the protection of potable groundwater and the protection of groundwater for aquatic life pathways
d – minimum 30 cm separation between contamination and building foundation assumed
e – varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m
f – distance to surface water (FAL), potable water user and livestock watering
A – agricultural R – residential C – commercial I – industrial

TABLE 12
SUMMARY OF ILLUSTRATIVE EFFECTS OF SELECTED TIER 2 ADJUSTMENTS
FINE-GRAINED SOILS (mg/kg)[a]

PARAMETER AND RANGE	LAND USE	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Default Values	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Vapour Permeability Ranging from 10^{-12} cm^2 to 10^{-8} cm^2	A	170 – 20 [b]	150 – 87 [b]	1300	5600
	R	170 – 20 [b]	150 – 87 [b]	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Moisture Content Ranging from 0.07 g/g to 0.16 g/g	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Soil Bulk Density Ranging from 1.3 g/cm^3 to 1.6 g/cm^3	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Organic Carbon Fraction Ranging from 0.0005 g/g to 0.03 g/g	A	22 – 210 [b]	25 – 150 [b]	1300	5600
	R	22 – 210 [b]	25 – 150 [b]	1300	5600
	C	22 – 320 [b]	25 – 260 [b]	2500	6600
	I	22 – 320 [b]	25 – 260 [b]	2500	6600
Hydraulic Conductivity Ranging from 0.032 m/y to 32 m/y[c]	A	71 – 170	95 – 150 [b]	1300	5600
	R	71 – 170	95 – 150 [b]	1300	5600
	C	71 – 170	95 – 230	2500	6600
	I	71 – 170	95 – 230	2500	6600
Groundwater Recharge Ranging from 0.005 m/y to 0.5 m/y	A	210 – 130 [b]	150	1300	5600
	R	210 – 130 [b]	150	1300	5600
	C	320 – 130 [b]	260 – 170 [b]	2500	6600
	I	320 – 130 [b]	260 – 170 [b]	2500	6600
Hydraulic Gradient Ranging from 0.001 to 0.1	A	77 – 210 [b]	100 – 150 [b]	1300	5600
	R	77 – 210 [b]	100 – 150 [b]	1300	5600
	C	77 – 220	100 – 260 [b]	2500	6600
	I	77 – 220	100 – 260 [b]	2500	6600
Site Length Ranging from 5 m to 30 m	A	200 – 120	150	1300	5600
	R	200 – 120	150	1300	5600
	C	200 – 120	260 – 170	2500	6600
	I	200 – 120	260 – 170	2500	6600
Depth/Distance to Contamination Ranging from 0 m to 10 m Below Grade[d]	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Depth to Groundwater[e] Ranging from 3 m to 10 m	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Distance to Groundwater Receptors[f] Ranging from 0 m to 500 m	A	3.3 – 210 [b]	3.9 – 150 [b]	1300	5600
	R	3.3 – 210 [b]	3.9 – 150 [b]	1300	5600
	C	3.3 – 320 [b]	3.9 – 260 [b]	2500	6600
	I	3.3 – 320 [b]	3.9 – 260 [b]	2500	6600

a – all results assume that all pathways are active, including groundwater and surface water pathways
b – governing pathway changes
c – hydraulic conductivity of less than 32 m/y may result in insufficient yield for a domestic water well or livestock water supply
d – minimum 30 cm separation between contamination and building foundation assumed
e – varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m
f – distance to surface water (FAL), potable water user and livestock watering
A – agricultural R – residential C – commercial I – industrial

TABLE 13

USER ADJUSTABLE PARAMETERS LEADING TO LAND AND WATER USE RESTRICTIONS OR MANAGEMENT REQUIREMENTS

Parameter	Land/Water Use Restrictions	Management Requirements	Tier at which Adjustment Supported[a]
Soil vapour permeability	No	No	Tier 2
Soil bulk density/ moisture content	No	No	Tier 2
Organic carbon fraction	No	No	Tier 2
Depth to contamination	b	Assurance required that soil will not be disturbed by excavation etc.	Tier 1/Tier 2[e]
Contamination/groundwater separation	No	No	Tier 2
Hydraulic conductivity	No	No[d]	Tier 2
Hydraulic gradient	No	No[d]	Tier 2
Recharge rate	No	Preservation of surface cover assumed in runoff/evapotranspiration value	Tier 2[f]
Distance to property line	No	Property to remain under management	Tier 2
Distance to surface water	No	No[d]	Tier 2
Distance to groundwater user	Yes	No groundwater utilization within management zone	Tier 3
Source dimensions	No	No	Tier 2
PHC composition	No	No	Tier 2
Distance to building	Yes	No construction within management zone	Tier 3
Building configuration	Yes	No changes to building configuration or mechanical systems	Tier 3
Ecological receptors or pathways	c	Access restrictions or preservation of conditions allowing exclusion (e.g site paving)	Tier 2/3
Ecological exposure factors	c	As above	Tier 2/3[g]
Human receptors or pathways	Yes	Engineered controls (e.g. barriers) or administrative controls (land use or access restrictions)	Tier 3
Human exposure factors	Yes	Administrative controls (land use or access restrictions)	Tier 3

a – subject to policies and requirements of individual jurisdictions
b - restrictions may be required where construction activity could disturb soil
c - may be allowed for specific land uses only (e.g. elimination of eco-soil contact beneath paved industrial sites)
d - monitoring requirements may be imposed by some jurisdictions
e - stratified cleanup may be allowed at Tier 1 in some jurisdictions
f - precipitation adjustment may be allowed at Tier 2 by jurisdictions on regional basis; runoff may be a Tier 3 factor
g - substitution of critical receptors is a Tier 3 adjustment; limited exclusion of receptors pathways maybe allowed by jurisdictions at Tier 2 only (e.g. elimination of eco-soil contact beneath paved industrial sites)

APPENDIX A: TIER 1 ASSESSMENT REQUIREMENTS

A.1 Introduction

The provision of a detailed protocol for environmental site assessment is beyond the scope of this document. For more information on this subject, a variety of published documents are available, including the CCME *Subsurface Assessment Handbook for Contaminated Sites* (CCME, 1994). Many regional jurisdictions have also published guidance on environmental investigations (e.g. AENV, 2001; BC MOE, 2005; OMEE, 1996). However, additional guidance on aspects of environmental assessment specifically related to the PHC CWS is presented herein.

In general, environmental site assessments involve three phases, though sometimes two or more of these phases may be combined:

- Phase I involves the review of site conditions and the history of the property and non-intrusive data collection (possibly including geophysical surveys) to determine whether there is potential for the site to be contaminated and to provide information to direct any intrusive investigations

- Phase II is an initial intrusive investigation, generally focusing on potential sources of contamination, to determine whether there is contamination present above the relevant screening criteria (in this case the Tier 1 objectives), and to broadly define soil and groundwater conditions

- Phase III involves further intrusive investigations to delineate and characterize the contamination, and obtain detailed information on the soil and groundwater conditions.

In the context of the PHC CWS, Phases I and II as a minimum are carried out as part of a Tier 1 assessment. The information requirements and general methods used in a Tier 1 assessment are described below.

A.2 Land Use and Sensitivity

The Tier 1 objectives consider four generic land use categories: agricultural, residential/parkland, commercial, and industrial. The definitions of these land uses are specified in Section 1.2.

As part of the site assessment, the land use category must be determined to ensure that the appropriate Tier 1 objectives are applied to the site. Selection of the land use category must consider not only the present usage of the site, but also potential future usage. This may involve obtaining land zoning information for the property, particularly in urban settings.

As part of the land use determination, the potential for underlying groundwater to be used as a source of potable water needs to be assessed. This includes consideration of the following:

- current source of potable water at the site (if any)

- existing water wells in the vicinity of the site
- depth below grade and yield of useable or potentially useable aquifer
- nearby surface water bodies which may be used for potable water

Potential future use of underlying groundwater as potable water as well as present use must be considered. If the groundwater is presently used as a potable water source or may reasonably be used as a potable water source in the future, then the Tier 1 objectives for the site will include the levels for protection of potable groundwater.

The presence of surface water bodies in the vicinity of the site must be assessed; if permanent surface water bodies are present and it is possible that groundwater from the site discharges to the surface water, then the Tier 1 objectives for the site will include the levels for protection of groundwater for aquatic life in nearby surface water. Transient surface water bodies may also need to be considered if they are likely to support aquatic life. For agricultural settings, potential use of groundwater or adjacent surface water for livestock watering will also be assessed.

The distance beyond which groundwater wells or surface water bodies are not significant is a matter of professional judgement at Tier 1. As a general rule, water wells and surface water bodies within 500 m of the PHC contamination should be identified. In some cases, water wells further away may have to be considered, particularly municipal wells which may have a large zone of capture.

A.3 Physical Conditions

General

Information on the site's physical conditions is necessary to identify potential contaminant migration pathways, to determine the appropriate Tier I levels, and to determine appropriate remedial strategies if necessary.

General site features which should be noted prior to conducting a subsurface investigation include the following:

- site location and dimensions
- locations of potential contaminant sources (existing or historical)
- site topography and drainage
- locations of nearby surface water bodies
- locations of onsite and adjacent human and ecological receptors
- locations, status and use of existing groundwater wells within 500 m
- presence, locations, and types of buildings and other structures
- locations and depths of underground utilities, which may act as preferential contaminant migration pathways or be affected by PHC contamination

Additional physical site characteristics which should be assessed during intrusive investigation activities include:

- soil conditions across the site, including soil litho-stratigraphy, spatial variations in soil type and unit thicknesses and presence of structural features such as fissures and fractures
- depth to groundwater and primary direction(s) of groundwater flow in each hydrogeologic unit

Soil Texture Classification

Once the subsurface investigation has been completed, the soil can be classified as coarse-grained or fine-grained. An initial field classification of soils encountered should be made by qualified personnel. This classification should be supported by laboratory grain size analyses for key soil samples. A coarse-grained soil is defined as having a median grain size greater than 75 μm (i.e. more than 50% of the sample is retained on a 75 μm screen); a fine-grained soil has a median grain size less than 75 μm.

Most areas will exhibit heterogeneous litho-stratigraphy. In these cases, it is especially important to log the depths and thicknesses of the stratigraphic units, to determine the depth of groundwater and to identify spatial patterns such as lateral continuity. Approximate depths of the stratigraphic units can be determined from drill cuttings or from visual inspection of excavated test holes; the use of split spoons, direct push technologies, or other methods of collecting relatively undisturbed samples will allow more accurate depth determination and reduce the likelihood of thin soil units being missed. Determination of the soil texture classification should be undertaken for any soil unit(s) significant to the dominant exposure pathways; professional judgement may be required in the identification of dominant exposure pathways.

As noted elsewhere, decisions on soil texture must be made to identify most likely risk with respect to the pathway of concern. In many instances, transport is more dependant on the location of the soil unit relative to the pathway of concern than with the size of the unit. For instance, the soil within approximately 1 m to 2 m below the building foundation has the greatest effect on indoor vapour intrusion and relatively small coarse soil units below the groundwater table may act as preferential pathways for groundwater transport.

A.4 Contaminant Characterization

During the Tier 1 assessment, the contamination needs to be characterized and delineated. The specific requirements for contaminant characterization data are determined by individual jurisdictions; general guidance is provided herein.

A CCME reference method (CCME 2001) was developed for the analyses of PHC fractions in soil. This method includes analyses for volatile PHC (F1) using methanol extraction and gas chromatography, and analyses for extractable PHC (F2, F3 and F4) using solvent extraction and GC-FID. The extract normally undergoes a silica gel cleanup prior to the analyses. If hydrocarbons greater than C_{50} are present in appreciable quantities, a gravimetric determination is used to measure the residual PHC (reported as F4G). If a gravimetric determination is performed, the greater of the $C_{>34}$ to C_{50} GC analysis and the gravimetric result is used for comparison with the Tier 1 objective for F4. Benzene, toluene, ethylbenzene and xylenes (BTEX) are analyzed concurrently and subtracted from F1. Certain polycyclic aromatic hydrocarbons (PAH) should also be subtracted if they are present in quantities sufficient to affect the PHC result. Naphthalene is subtracted from the F2 result, while phenanthrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-c,d)pyrene and pyrene are subtracted from the F3 result. BTEX and PAHs are to be considered separately. The CCME Analytical protocol requires appropriate accreditation for the reference method. Requirements for accreditation may differ between jurisdictions. The local jurisdiction should be contacted to ensure that the appropriate accreditation protocols are followed.

As noted in the reference method, soils with a high natural organic carbon content (such as peats), or soils that have been remediated with manure, may give falsely elevated analytical results for PHC concentrations. If there is reason to suspect that the soils may have a high organic carbon content, then it may be advantageous to collect samples for organic carbon analyses from background (i.e. uncontaminated) soils near the contaminated area. If the PHC concentrations in the PHC contaminated soils exceed the relevant Tier 1 levels, and the soil organic carbon content is high, then PHC concentrations measured in the background soils can be subtracted from the PHC concentrations measured in the contaminated soils to give an estimate of the actual PHC concentrations. The subtraction should be done without silica gel cleanup on the soil samples. It is important to note that the selected background samples must consist of similar soil to the contaminated samples for the subtraction to be valid; the background samples must also be known to be free of PHC contamination.

Spatial and depth distribution

As part of the environmental investigations at a site, the lateral and vertical extent of PHC contamination needs to be determined. The depth distribution of PHC is typically determined by ensuring that boreholes or test holes extend beneath the PHC contamination. The spatial distribution is typically determined by “stepping out” from impacted test locations until soils with PHC concentrations less than the Tier 1 objectives are encountered in all directions. Professional judgement should be used in selecting sampling locations to provide adequate information to confirm delineation; preferential flow pathways and the direction of groundwater flow should be considered when selecting the sampling locations. Jurisdictions may have requirements for sample spacing to confirm delineation (e.g. BC MOE, 2005).

When dealing with large contaminated areas, or if the source is unknown or not well-defined, it may be advantageous to conduct sampling on a grid pattern, typically using a screening method (see below), followed by more detailed sampling to characterize hot spots and confirm delineation.

It should be noted that, if contamination is encountered within 30 cm of a building slab or within 10 m of a surface water body, a Tier 2 or Tier 3 assessment is required.

Representative Sampling Strategies

Economics and practicality limit the number of samples that can reasonably be submitted for laboratory analyses of PHC concentrations. It is therefore important to ensure that appropriate samples are selected for laboratory analyses.

Soil samples should be collected from a single soil stratum, from a discrete location. For purposes of delineating the vertical or lateral extent of hydrocarbons, samples should not be composited, although composite samples may be acceptable for determining average concentrations of F2 through F4 PHC over a given area. Composite samples generally do not provide meaningful results for F1, since volatile PHC are easily lost during the sample mixing process.

To confirm vertical or lateral delineation of PHC contamination, worst-case samples from the edge of the PHC plume must be analyzed at a laboratory. If the results of these analyses indicate that the PHC concentrations are less than the Tier 1 objectives, then the PHC contamination can normally be presumed to end at or before the sampling location. Soil samples must also be taken from near the source of the contamination to determine the maximum PHC concentrations present. The number of laboratory samples required may be left to professional judgement, though some jurisdictions have specific requirements. BC MOE (2005), for example, suggest that a discrete sample represents 10 m^3 of soil over a depth range of 0.2 m to 1.0 m.

Screening methods (see below) can be used to identify the worst-case sample at a testing location or to provide a preliminary qualitative assessment of the extent of PHC contamination. Screening methods alone, without supporting laboratory analyses, are not sufficient to characterize or delineate PHC contamination from the standpoint of the PHC CWS.

Sampling and preparation methods are detailed in CCME (2001); key points are summarized here:

- samples must be collected by qualified personnel using standard, documented procedures;
- samples should be as undisturbed as possible, and placed in appropriate sampling jars with minimal handling;
- if possible, samples should not be collected from soil exposed to direct sunlight (surface soil may have to be removed prior to sampling);
- sampling jars should be filled with soil (no headspace), properly sealed, cooled to 4^{o}C, and transported to the laboratory as soon as possible;
- all samples must be clearly labelled, including the location or source of the sample, and the sampling date/time; and,
- chain of custody procedures are required when samples may be considered as evidence in an investigation.

Screening Methods

The use of screening methods to qualitatively or semi-quantitatively assess PHC in soil allows environmental investigations to be conducted more cost-effectively and assists with field decision-making. Selected screening methods are briefly discussed in this section; further details and additional methods can be found in other publications (e.g. US EPA, 1997b). Screening methods must be supported with confirmatory laboratory analyses.

Combustible Gas Detectors

Combustible gas detectors are devices capable of measuring hydrocarbon concentrations in air or vapours. They are frequently used as a screening method for PHC in soils by placing a soil sample in an airtight bag or jar with headspace remaining. The sample is generally left for a consistent period of time (typically about 15 minutes to 2 hours), after which the combustible gas detector is used to measure hydrocarbons in the headspace. Combustible gas detectors are relatively easy to use and produce screening results quickly. However, they are only effective at measuring volatile PHC (mainly F1), and therefore only provide meaningful results when the PHC have a high proportion of F1, such as gasoline.

Turbidimetric Method

The turbidimetric screening method (US EPA method 9074) involves extracting hydrocarbons from a small soil sample using a methanol-based solvent. The resulting liquid is placed in a vial, allowed to develop for 10 minutes, and placed in a turbidimeter. The scattering of light passing through the sample is measured, and the result is compared to a standard curve. The method can be used with minimal training. The turbidimetric screening method mainly detects hydrocarbons in the F2 and F3 ranges; volatile hydrocarbons (F1) may be lost in the sample collection and preparation process.

Other Screening Methods

Several other screening methods exist. Examples include the use of various detector tubes or colourimetric tests, field immunoassay tests, portable infrared detectors, and field gas chromatographs. Many of the available field screening methods are specific to individual compounds or types of hydrocarbons, limiting their application. Detailed descriptions of these methods and others can be found in US EPA (1997b).

APPENDIX B: TIER 1 BASIS

B.1 General

Detailed information on the derivation of the Tier 1 levels is provided in the Scientific Rationale (CCME, 2008). This section summarizes the default model parameters used to derive the Tier 1 levels.

B.2 Receptors and Exposure Pathways

The exposure pathways and receptors considered in the derivation of the Tier 1 levels for each land use are summarized in Table B-1. Note that Tier 1 levels were not actually calculated for some of the receptors and exposure pathways due to insufficient available information.

Receptor/Exposure Pathway Combinations Not Considered in Generic Scenarios

Certain receptor/exposure pathways are not considered in the generic scenarios. The receptors and exposure pathways presented in Table B-1 are based on typical scenarios for each type of land use. If receptors or exposure pathways not considered at Tier 1 are present, it is the responsibility of the proponent to identify these and proceed with Tier 2 or Tier 3 as necessary.

B.3 Tier 1 Criteria by Exposure Pathway/Receptor

The Tier 1 criteria for each land use category by exposure pathway/receptor are presented in Tables B-2 and B-3. The lowest number for the land use, considering applicable ground and surface water pathways, is the Tier 1 objective for a site.

B.4 Tier 1 (default) Parameters and Assumptions

The default parameters used to calculate the Tier 1 levels are presented in Tables B-4 through B-9. These include the physical, chemical and toxicological properties of the PHC sub-fractions, receptor characteristics, physical site conditions (such as soil properties) and building characteristics. Procedures for adjusting these parameters at Tier 2 are discussed in Appendix D.

TABLE B-1

LAND-USES, KEY RECEPTORS AND EXPOSURE PATHWAYS

Exposure Pathway	Agriculture	Residential/ Parkland	Commercial	Industrial
Soil Contact	Nutrient cycling[e] Soil invertebrates Crops (plants) Livestock/wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Wildlife [b] Human (toddler)[a]	Nutrient cycling[e] Invertebrates Plants Human (adult)
Soil and Food Ingestion	Herbivores[e] Human (toddler)	(wildlife)[b] Human (toddler)[a]	(wildlife) [b] Human (toddler)[a]	(wildlife) [b] Human (adult)
Groundwater/ Surface Water	Aquatic Life/ Livestock Watering Human (toddler)[a]	Aquatic Life Human (toddler)[a]	Aquatic Life Human (toddler)[a]	Aquatic Life Human (adult)
Indoor Vapour Intrusion	Human (toddler)[a, c]	Human (toddler)[a]	Human (toddler)[a]	Human (adult)
Produce, meat and milk produced on site	Human (toddler)[a, f]	Human (toddler)[a, f] • Produce only		
Off-site migration of Soil/Dust			Human/Eco [d]	Human/Eco [d]

a - Health Canada defines a toddler as a child of age 7 months to 4 years. This age group generally receives the greatest dose per unit body weight and, therefore, represents a critical receptor for human health risk assessment and guidelines development for land uses they may frequent.

b – Wildlife/livestock dermal contact and ingestion data may be particularly important for PHC (e.g., oiling of feathers, etc., although this should be addressed with an initial assessment of the presence of non-aqueous phase liquids - NAPL), but there are unlikely to be sufficient data to develop guidelines that address this exposure pathway

c - An agricultural site may include a farm residence. Subject to jurisdictional policy, the indoor vapour intrusion pathway may be excluded if there is no existing residence or potential for a future residence within 30 m of the contamination.

d - Off-site migration of soil/dust is based on the most sensitive exposure pathway for the surrounding properties.

e – CCME intends that nutrient/energy cycling and (for agricultural land) food ingestion by humans and soil and food ingestion by herbivores be considered; however, sufficient data are not available at this time to support derivation of quantitative soil levels for these pathways.

f - In most cases PHC are not expected to bioaccumulate to high concentrations in produce, meat or milk, though some polycyclic aromatic hydrocarbons (PAH) may bioaccumulate to a limited extent; the available data are currently insufficient to evaluate this pathway on a generic basis

TABLE B-2

PATHWAY-SPECIFIC TIER 1 LEVELS (mg/kg soil) FOR PHC FOR COARSE-GRAINED SURFACE SOILS

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970	380	NA	NA
	Protection of GW for Livestock Watering[2]	5300	14 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	300	2800
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[3]	700	1000	2500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970	380	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	300	2800
	Produce	NC	NC	NC	NC
	Management Limit[3]	700	1000	2500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970	380	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[3]	700	1000	3500	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970	380	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[3]	700	1000	3500	10 000

NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
1 = Assumes surface water body at 10 m from site.
2 = Includes use of dugouts and wells for supply of livestock water.
3 = Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects

TABLE B-3

PATHWAY-SPECIFIC TIER 1 LEVELS (mg/kg soil) FOR PHC FOR FINE-GRAINED SURFACE SOILS

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Protection of GW for Livestock Watering[3]	4200	10 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	1300	5600
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[4]	800	1000	3500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	210	150	1300	5600
	Produce	NC	NC	NC	NC
	Management Limit[4]	800	1000	3500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	2500	6600
	Offsite Migration	NA	NA	19 000	RES
	Management Limit[4]	800	1000	5000	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact	320	260	2500	6600
	Offsite Migration	NA	NA	19,000	RES
	Management Limit[4]	800	1000	5000	10 000

NA = Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded.
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
1 = Assumes site is underlain by groundwater of potable quality in sufficient yield (K of 10^{-4} cm/sec or greater).
2 = Assumes surface water body at 10 m from site.
3 = Generally applicable for this land use as related to use of dugouts and wells for supply of livestock water.

TABLE B-4
PHYSICAL, CHEMICAL AND TOXICOLOGICAL PROPERTIES OF PHC SUB-FRACTIONS

	F1			F2			
	Aliphatic C>6-C8	**Aliphatic C>8-C10**	**Aromatic C>8-C10**	**Aliphatic C>10-C12**	**Aliphatic C>12-C16**	**Aromatic C>10-C12**	**Aromatic C>12-C16**
Tolerable Daily Intake (TDI) (mg/kg/d)[a]	5	0.1	0.04	0.1	0.1	0.04	0.04
Estimated Daily Intake (EDI) (mg/kg/d)[b]	0.02334	0.0103	0.00938	0	0	0	0
Reference Concentration (RfC) (mg/m^3)[a]	18.4	1	0.2	1	1	0.2	0.2
Background Air Conc. (C_a) (mg/m^3)[b]	0.09111	0.03881	0.03745	0	0	0	0
Water Solubility (mg/L)[c]	5.4	0.43	65	0.034	0.00076	25	5.8
Henry's Law Constant (atm-m^3/mol)[c]	1.2	1.9	1.20×10^{-2}	2.9	12.5	3.40×10^{-3}	1.30×10^{-3}
Henry's Law Constant (unitless)[c]	50	80	0.48	120	520	0.14	0.053
Organic Carbon Partition Coefficient (K_{oc}) (mL/g)[c]	$10^{3.6}$	$10^{4.5}$	$10^{3.2}$	$10^{5.4}$	$10^{6.7}$	$10^{3.4}$	$10^{3.7}$
Diffusion Coefficient in Air (cm^2/s)[d]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Absorption Factor for GI Tract (AF_G)[e]	1	1	1	1	1	1	1
Absorption Factor for Skin (AF_D)[e]	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aquatic Life Benchmark (mg/L)[f]	0.0465	0.0076	0.14	0.00118	0.000074	0.096	0.0554
Livestock Water Reference Conc. (mg/L)[g]	53	53	53	49	49	49	49
Half Life in Saturated & Unsaturated Zone (days)[h]	712	712	712	1750	1750	1750	1750
Mass Fraction in Soil[i]	0.55	0.36	0.09	0.36	0.44	0.09	0.11
Mass Fraction in Water[j] - coarse soils	0.605	0.063	0.332	0.024	0.002	0.603	0.371
- fine soils	0.577	0.066	0.357	0.024	0.002	0.603	0.372
Mass Fraction in Soil Vapour[j] - coarse soils	0.854	0.141	0.005	0.767	0.205	0.023	0.005
- fine soils	0.842	0.153	0.005	0.766	0.206	0.023	0.005

a – see Section 3.6 of CCME, 2008
b – see Section 3.7 of CCME, 2008
c – adapted from TPHCWG (Gustafson *et al.*, 1997)
d – recommended by PIWG
e – see Section 3.5.9 of CCME, 2008
f – see Section 4.3.2 of CCME, 2008
g – see Section 4.3.3 of CCME, 2008
h – see Appendices H and I
i – based on typical petroleum product compositions
j – calculated based on soil mass fraction, equilibrium partitioning relationship and default soil properties
NS – not specified

TABLE B-4 (continued)	F3				F4	
	Aliphatic C>16-21	Aliphatic C>21-C34	Aromatic C>16-C21	Aromatic C>21-C34	Aliphatic C>34	Aromatic C>34
Tolerable Daily Intake (TDI) (mg/kg/d)[a]	2	2	0.03	0.03	20	0.03
Estimated Daily Intake (EDI) (mg/kg/d)[b]	0	0	0	0	0	0
Reference Concentration (RfC) (mg/m^3)[a]	NS	NS	NS	NS	NS	NS
Background Air Conc. (C_a) (mg/m^3)[b]	0	0	0	0	0	0
Water Solubility (mg/L)[c]	$2.5x10^{-6}$	NS	0.65	0.0066	NS	NS
Henry's Law Constant ($atm\text{-}m^3/mol$)[c]	118	13500	$3.10x10^{-4}$	$1.61x10^{-5}$	$2.90x10^{6}$	$4.40x10^{-7}$
Henry's Law Constant (unitless)[c]	4900	$5.60x10^{5}$	0.012	$6.7x10^{-4}$	$1.20x10^{8}$	$1.8x10^{-5}$
Organic Carbon Partition Coefficient (K_{oc}) (mL/g)[c]	$10^{8.8}$	10^{13}	$10^{4.2}$	$10^{5.1}$	$10^{18.2}$	$10^{6.25}$
Diffusion Coefficient in Air (cm^2/s)[d]	0.05	0.05	0.05	0.05	0.05	0.05
Absorption Factor for GI Tract (AF_G)[e]	1	1	1	1	1	1
Absorption Factor for Skin (AF_D)[e]	0.2	0.2	0.2	0.2	0.2	0.2
Aquatic Life Benchmark (mg/L)[f]	NS	NS	NS	NS	NS	NS
Livestock Water Reference Conc. (mg/L)[g]	79	79	79	79	42	42
Half Life in Saturated & Unsaturated Zone (days)[h]	NS	NS	NS	NS	NS	NS
Mass Fraction in Soil[i]	0.56	0.24	0.14	0.06	0.8	0.2
Mass Fraction in Water[j] - coarse soils	NS	NS	NS	NS	NS	NS
- fine soils	NS	NS	NS	NS	NS	NS
Mass Fraction in Soil Vapour[j] - coarse soils	NS	NS	NS	NS	NS	NS
- fine soils	NS	NS	NS	NS	NS	NS

a – see Section 3.6 of CCME, 2008
b – see Section 3.7 of CCME, 2008
c – adapted from TPHCWG (Gustafson *et al.*, 1997)
d – recommended by PIWG
e – see Section 3.5.9 of CCME, 2008
f – see Section 4.3.2 of CCME, 2008
g – see Section 4.3.3 of CCME, 2008
h – see Appendices H and I
i – based on typical petroleum product compositions
j – calculated based on soil mass fraction, equilibrium partitioning relationship and default soil properties
NS – not specified (not required for this subfraction)

TABLE B-5
RECEPTOR CHARACTERISTICS

	Toddler [a]	Adult [a]
Body Weight (BW) (kg)	16.5	70.7
Exposure Time (ET) (agricultural)	1	1
Exposure Time (ET) (residential)	1	1
Exposure Time (ET) (commercial) [c]	(10/24)*(5/7)*(48/52)	(10/24)*(5/7)*(48/52)
Exposure Time (ET) (industrial) [c]	(10/24)*(5/7)*(48/52)	(10/24)*(5/7)*(48/52)
Soil Ingestion Rate (SIR) (g/d)	0.08	0.02
Surface Area - hands (SA_{HANDS})(m^2)	0.043	0.089
Surface Area - other (SA_{OTHER}) (m^2)	0.258	0.250
Dermal Loading to Skin (mg/m^2-event)		
Hands (DL_{HANDS})	1000	1000
Surfaces other than hands (DL_{OTHER})	100	100
Exposure Frequency (EF) (events/d)	1	1
Inhalation Rate (IR) (m^3/d)	9.3	15.8
Water Ingestion Rate (IR_W) (L/d)	0.6	1.5

(after CCME, 2006, unless otherwise noted)
a Toddlers are the critical receptors for agricultural, residential and commercial land uses.
b Adults are the critical receptors for industrial land uses.
c Exposure term for direct contact is (5/7)*(48/52)

TABLE B-6
DEFAULT SOIL AND HYDROGEOLOGICAL PARAMETERS

Parameter	Symbol	Soil Type Coarse	Soil Type Fine
Saturated Hydraulic Conductivity (m/y)	K_H	320	32[a]
Hydraulic Gradient	i	0.028	0.028
Recharge (Infiltration rate) (m/y)	I	0.28	0.20
Organic Carbon Fraction (g/g)	foc	0.005	0.005
Soil Bulk Density (g/cm^3)	ρ_b	1.7	1.4
Water Content (Mw/Ms)	M_W/M_S	0.07	0.12
Total Soil Porosity[b]	n	0.36	0.47
Soil Vapour-Filled Porosity[b]	θ_a	0.241	0.302
Soil Moisture-Filled Porosity[b]	θ_w	0.119	0.168
Vapour-Filled Porosity in Foundation Cracks	θ_{a_c}	0.36	0.47
Moisture-Filled Porosity in Foundation Cracks	θ_{w_c}	0	0
Soil Vapour Permeability (cm^2)	k_v	$5x10^{-8}$ [c]	$1x10^{-9}$ [d]

a – all values based on CCME (2006) unless otherwise specified
b – calculated based on soil bulk density and water content
c – based on empirical data on soil gas flow rates into buildings over coarse soils
d – based on expected vapour permeability of silt soils

TABLE B-7
SITE CHARACTERISTICS

Parameter	SYMBOL	VALUE
Contaminant Source Width (m)	Y	10
Contaminant Source Depth (m)	Z	3
Contaminant Source Length (m)	X	10
Distance to Surface Water (m)	x	10
Distance to Potable Water User (m)	x	0
Distance to Livestock Watering (m)	x	0
Distance from Contamination to Building Slab (cm)	L_T	30
Depth to Groundwater (water table) (m)	d	3
Thickness of Unsaturated Soils Beneath Contamination (m)	b	0
Depth of unconfined aquifer (m)	d_a	5
Soil Temperature (K)	T	294
Vapour viscosity (g/cm-s)	μ	0.000173
Adjustment Factor for Vapour Intrusion	AF	10[b]

a – all values based on CCME (2006) unless otherwise specified
b – see discussion in section 3.4.3.2 of CCME, 2008

TABLE B-8
DEFAULT BUILDING CHARACTERISTICS FOR INDOOR INFILTRATION PATHWAY

Parameter	Symbol	Residential Basement	Residential Slab-On-Grade	Commercial Slab-On-Grade
Building Length (cm)	L_B	1225	1225	2000
Building Width (cm)	W_B	1225	1225	1500
Building Area (cm^2)[b]	A_B	$2.7x10^6$	$1.5x10^6$	$3.0x10^6$
Building Height (cm)[c]	H_B	360	360	300
Thickness of Building Foundation (cm)	L_{crack}	11.25	11.25	11.25
Depth Below Grade of Foundation (cm)	Z_{crack}	244	11.25	11.25
Crack Radius (cm)	r_{crack}	0.2	0.2	0.26
Area of Crack (cm^2)	A_{crack}	994.5	994.5	1846
Length of Idealized Cylinder (cm)	X_{crack}	4900	4900	7000
Air Exchanges per Hour (1/h)[d]	ACH	0.5	0.5	0.9
Pressure Differential (g/cm-s^2)[d]	ΔP	40	40	20

a –all values based on CCME (2006) unless otherwise specified
b – includes basement wall area
c – including basement; height of a 2-storey building reduced to account for incomplete mixing of contaminant between storeys (based on US EPA, 2003)
d – see Section 3.4.3.2 of CCME, 2006

TABLE B-9
WATER QUALITY BENCHMARKS FOR ECOLOGICAL EXPOSURE

PHC FRACTION	BENCHMARK FOR AQUATIC LIFE (mg/L)	BENCHMARK FOR LIVESTOCK WATERING (mg/L)
F1	NS	5.3
Aliphatics $C_{>6}$-C_8	0.0465	NS
Aliphatics $C_{>8}$-C_{10}	0.0076	NS
Aromatics $C_{>8}$-C_{10}	0.14	NS
F2	NS	4.9
Aliphatics $C_{>10}$-C_{12}	0.0018	NS
Aliphatics $C_{>12}$-C_{16}	0.000074	NS
Aromatics $C_{>10}$-C_{12}	0.096	NS
Aromatics $C_{>12}$-C_{16}	0.0554	NS
F3	NS	7.9
F4	NS	4.2

NS – not specified

APPENDIX C: TIER 2 ASSESSMENT REQUIREMENTS

C.1 Physical Conditions

Prior to conducting Tier 2 adjustments for a site, more detailed data on the physical conditions at the site are required. Specifically, primary user-adjustable parameters relevant to the pathways active at the site need to be measured:

Source Dimensions

- Site length – the total length of the PHC contaminant plume in the direction parallel to the primary direction of groundwater flow. This is determined based on soil analytical data. Site length is used for the groundwater protection pathways; increased site length reduces the Tier 2 levels.

- Site width – the total width of the PHC contaminant plume in the direction normal to the primary direction of groundwater flow. This is determined based on soil analytical data. Site width is used for the protection of groundwater pathways if there is lateral transport; increased site width reduces the Tier 2 levels. This is not a sensitive parameter in the model.

- Depth to groundwater - measured using groundwater monitoring wells. This is important for the determination of the governing soil texture; the relationship between the depth to groundwater and the depth of the PHC contamination affects the protection of groundwater pathways. Depth to groundwater varies over time, so several measurements are normally necessary.

- Depth to contamination and thickness of contamination – determined from analytical data (potentially supported with screening methods). The depth to contamination affects the vapour inhalation pathway, since an increased separation between the source and receptor will increase the Tier 2 levels. The thickness of contamination, in conjunction with the depth to contamination and depth to groundwater, affects the protection of groundwater pathways, with increased separation between the contamination and groundwater resulting in higher Tier 2 levels.

Hydrological Parameters

- Recharge - defined as precipitation minus runoff and evapotranspiration. Annual precipitation data for a particular region can be obtained from Environment Canada climate normals. Runoff and evapotranspiration are difficult to measure, and are affected by numerous factors; the default values are based on runoff and evapotranspiration accounting for 80% (coarse-grained) or 85% (fine-grained) of total precipitation. If site specific conditions are anticipated to be strongly influential, this parameter may not be considered a primary user adjustable parameter unless defensible site-specific information can be obtained. Jurisdictions may define acceptable recharge values for particular regions. High groundwater recharge decreases the Tier 2 levels.

Hydrogeological and Soil Parameters

- Soil bulk density - determined from mass and volume of an undisturbed sample, or by geophysical methods. This parameter is related to total soil porosity, and, along with water content, affects the moisture-filled porosity. It affects the vapour inhalation pathway, especially as the distance between the source and receptor increases. Bulk density also has an effect on groundwater protection pathways. Increasing soil bulk density generally has a positive effect on Tier 2 levels although, since it also affects contaminant partitioning relationships, the opposite effect can occur for vapour inhalation in some cases if there is very little distance between the source and receptor. Bulk density should be measured for all relevant soil strata, including the contaminated zone for the partitioning relationship, the vadose (unsaturated) zone strata for vapour transport modelling, and in the aquifer for lateral groundwater transport modelling.

- Soil water content (unsaturated zone) - measured by laboratory, by measuring mass before and after oven-drying. Along with bulk density, this parameter affects the moisture-filled porosity of soil. Water content has similar effects on the vapour inhalation and groundwater protection pathways to those of soil bulk density. The moisture-filled porosity used in the models is for the unsaturated zone, and therefore water content data must be collected above the water table. Water content in the contaminated zone influences the partitioning relationship, and water content between the contamination and the building influences vapour transport. It should be noted that water content can vary spatially and with time; sufficient data is required to characterize both spatial and temporal variation in water content. Alternatively, the field capacity of the soil can be used to estimate soil water content.

- Saturated hydraulic conductivity - measured using aquifer pumping tests or slug tests. This parameter affects the groundwater protection pathways. High saturated hydraulic conductivity increases the Tier 2 levels for protection of potable water and livestock watering if there is no offset distance to the receptor, due to greater dispersion and dilution of the PHC. However, it also decreases the Tier 2 levels for protection of aquatic life (and for the other groundwater pathways if an offset distance is used), since PHC are more rapidly transported.

- Hydraulic gradient - determined from the average slope of the groundwater surface, based on measured groundwater elevations across the site. Altering the hydraulic gradient has similar effects to altering the hydraulic conductivity.

- Organic carbon fraction - measured by an acceptable laboratory method (e.g. Leco furnace). This parameter is very important for contaminant partitioning relationships, and has a strong effect on the vapour inhalation and groundwater protection pathways. The higher the organic carbon fraction, the higher the Tier 2 level. This parameter should be measured in the zone of contaminant partitioning (typically near the water table). In cases where the contamination is not in contact with the groundwater and partitioning is occurring above the water table, the organic carbon fraction should also be measured in the saturated zone if lateral groundwater transport is being modelled. It should be measured in uncontaminated soil that is otherwise as similar as possible to the contaminated soil, since the presence of PHC can give a falsely high reading.

Vapour Transport Parameters

- Soil vapour permeability - measured with field pneumatic tests or estimated as a function of hydraulic conductivity, water content and total porosity (US EPA, 1997c). This parameter affects the advective flow component of the vapour inhalation pathway; higher vapour permeability results in lower Tier 2 levels. This parameter should be measured close to the building foundation. Since it is affected by soil water content, sufficient data are required to characterize spatial and temporal variation in soil vapour permeability.

The onus is on the assessor to demonstrate that the data collected are representative of the site; multiple samples are generally necessary to produce a defensible value for Tier 2 adjustments.

In addition to these subsurface characteristics, the distance to any nearby surface water body is necessary for Tier 2 adjustments dealing with the protection against groundwater discharge to the surface water body.

C.2 Contaminant Characterization

At Tier 2, even more so than at Tier 1, it is essential that the depth to contaminated soil is known, as well as the dimensions of the contaminated area: length (parallel to groundwater flow), width (perpendicular to groundwater flow) and thickness. The dimensions of the PHC-contaminated area affect the groundwater protection pathways, with a larger source area decreasing the Tier 2 levels.

Site-specific data on the composition of the PHC fractions can also be used as the basis for Tier 2 adjustment. Most analytical laboratories can provide PHC results in the form of a carbon number histogram, which allows adjustment of the relative proportions of each sub-fraction in the four PHC fractions. Typically, these histograms do not distinguish between aliphatic and aromatic hydrocarbons, so an 80%:20% proportion should be assumed (80% aliphatics and 20% aromatics for each fraction, as per CCME, 2000a). Some analyses, such as a full gas chromatography/mass spectrometry analysis, will provide data on specific compounds, allowing adjustment of the ratio of aliphatics to aromatics. Prior to using site-specific PHC composition data for a Tier 2 adjustment, the proponent must ensure that the composition used conservatively reflects the range of compositions present at the site; in some cases it may be advisable to perform Tier 2 calculations using each analysis available for the site to determine which is the most conservative. Multiple composition analyses are generally required to support a Tier 2 adjustment.

C.3 Point-of-Exposure Measurements

At Tier 2, some jurisdictions may allow measurements of PHC concentrations at locations at or near a point of exposure (POE). These would include measurements made at the actual POE, such as in building air, in potable water wells, or in adjacent surface water bodies as well as at intermediate locations along an exposure or transport route.

Exposure Point Measurements

Concentrations in building air are normally measured using an air sampling pump or vacuum canister. The sample duration (and hence volume) should be set so that the analytical detection limit will be substantially lower than the reference concentrations for the PHC fractions, but high enough that the sampling medium does not become saturated by PHC.

PHC concentrations measured from a potable water well (or, alternatively, directly from the tap) should be collected in clean containers after purging standing water. Samples must be taken under low water flow to ensure volatile PHC are not lost. Surface water samples should be collected from the edge of the surface water body adjacent to the PHC contamination. The analytical results can be compared to target levels for potable water (based on the reference dose, water intake and body weight of human receptors), aquatic life, and/or livestock watering as appropriate.

The advantage of POE measurements is that they remove much of the uncertainty and conservatism involved in modelling the transport of a chemical mixture, instead measuring the concentrations that receptors are actually exposed to. However, the POE concentration may not be at equilibrium with the soil concentration at the time of measurement, and there may be seasonal variation in the PHC concentrations at the POE; therefore, there would likely be a requirement for continued monitoring. Furthermore, POE measurements for a particular building or water well do not necessarily apply if the site is redeveloped or new potable water wells are installed in the future. POE measurements will not normally lead to unconditional site closure, but may be used in conjunction with ongoing remediation or risk management to ensure that immediate health or ecological risks are acceptable.

It should be noted that POE measurements do not provide information about the source of the contamination, and it is possible that the measured concentration may be influenced by other sources. This is of particular concern where tolerable health-based concentrations are likely to be small in relation to background PHC sources, such as in building air where the contribution of building materials, solvents, vehicles, tobacco and consumer products may be significant. For this reason, building air measurements alone are not recommended as a basis for Tier 2 adjustments

Intermediate Exposure Pathway Measurements

Related to POE measurements are measurements of PHC concentrations at intermediate points along transport pathways. The most obvious would be the measurement of PHC in soil vapours beneath a building slab, or measurement of PHC in groundwater in the contaminated area or downgradient (often at the property line). Like POE measurements, these measurements are best used in conjunction with ongoing remediation or risk management, since PHC concentrations in soil vapours or groundwater may not be at equilibrium, and may experience seasonal variation. However, unlike the POE measurements, these values do reflect the source of PHC contamination, and are less likely to include interference from non-petroleum sources.

Measuring the PHC concentrations in soil vapours removes the uncertainty in the partitioning of PHC between adsorbed, dissolved and vapour phases. However, obtaining representative soil vapour samples can be a complex and challenging process, and therefore requires considerable planning and technical expertise when compared to collecting soil samples. The measurement should be performed in vapour well at the point of interest, Guidance on vapour monitoring may vary but generally, samples that are too shallow (e.g. less than 1 meter below the bottom of the building or slab of interest) tend to be unreliable in estimation of actual building concentrations. Alternatively, soil vapours can be measured in the partitioning zone (just above the water table). The samples are collected using a device such as an air sampling pump or a vacuum canister. Multiple sampling points are preferable to a single sampling point, to ensure that the maximum soil vapour concentrations are measured. Several samples collected over time are normally required in order to demonstrate that vapour concentrations at the sampling point are not increasing. At the time of writing, no CCME protocol for soil gas sampling has been developed. Some jurisdictions may develop or adopt protocols; in the absence of a specified protocol, the jurisdiction with authority over the site should be consulted regarding the acceptability of soil vapour measurements and the requirements for soil vapour monitoring programs. The use of soil vapour concentrations at Tier 2 is discussed further in Appendix D.

Likewise, measuring PHC concentrations in groundwater removes the uncertainty in contaminant partitioning, but does not necessarily account for non-equilibrium conditions. Groundwater concentrations can then be used with an appropriate saturated zone transport model (see Appendix D) or compared directly with receptor target levels. As for soil vapours, multiple sampling points and times are generally required.

C.4 Other User-Adjustable Parameters

Several other user-adjustable parameters can also be measured (referred to as secondary Tier 2 adjustable parameters). However, these parameters typically require some form of ongoing management, or else are difficult to measure accurately and reliably. The individual jurisdiction will have discretion as to whether these parameters can be adjusted at Tier 2.

Secondary parameters include building characteristics, some of which are relatively straightforward to measure. However, it should be kept in mind that even easy to measure parameters have been modified to account for other assumptions that the model does not track and these must be taken into account in adjusting any parameter. For instance, building heights have been adjusted to account for incomplete mixing and would not be readily modified without accounting for this factor.

Other building characteristics, such as the air exchange rate, the pressure differential between the building and soil gas, and the area of cracks, are less readily measured and should only be adjusted if a defensible case for a different value can be established. If site-specific building characteristics are used, all potentially affected buildings must be considered. The use of site-specific building characteristics requires ongoing management or restrictions to ensure that future buildings meet the same conditions.

Another user-adjustable parameter is the lateral offset to a vapour inhalation receptor; adjustment of this parameter would require ongoing management or restrictions to ensure that no buildings are later constructed within the assumed lateral offset distance. As noted elsewhere, the vapour transport is not considered to be operative beyond a distance of 30 m, unless there are precluding factors such as preferential migration pathways or a low permeability surface.

Other parameters, such as the depth (thickness) of the unconfined aquifer, are less readily measured and are therefore rarely adjusted at Tier 2.

APPENDIX D: TIER 2 ADJUSTMENT

D.1 Tier 2 Adjustable Parameters

Primary Tier 2 Adjustable Parameters

Primary user-adjustable parameters are parameters used in the calculation of Tier 2 levels for which site-specific data can be readily substituted. These parameters can be readily measured or estimated, and generally do not impose any requirements for future management. The primary user-adjustable parameters, along with typical ranges encountered, are summarized in Table D-1.

Secondary Tier 2 Adjustable Parameters

Jurisdictions may, at their discretion, allow secondary user-adjustable parameters to be modified at Tier 2. These are parameters which are either difficult to measure or estimate, or would impose future management restrictions for the site. The secondary user-adjustable parameters are listed in Table D-2.

D.2 Tier 2 Adjustment Procedures

Following are the equations used to develop Tier 2 levels for the human health exposure pathways. To calculate Tier 2 levels, all relevant exposure pathways must be considered. The Tier 2 level for each fraction is the lowest calculated level of all pathways.

Default values for all parameters in the equations are presented in Appendix B. These values are to be used except for user-adjustable parameters, for which site-specific values may be used. The primary user-adjustable parameters with suggested ranges and the secondary user-adjustable parameters are presented in Tables D-1 and D-2. The influence of the primary Tier 2 adjustable parameters on the resulting Tier 2 levels is shown on Tables D-3 and D-4. All primary user-adjustable parameters are in **bold** type below for ease of reference.

To derive Tier 2 levels for each PHC Fraction, objectives must first be calculated for each individual sub-fraction, for the appropriate Soil Allocation Factor (0.5 for F1 and F2, 0.6 for F3 and 0.8 for F4). The soil allocation factor is 1 for all groundwater protection pathways. Then, the objectives for the sub-fractions must be combined according to their mass fraction within the Fraction, according to the algorithm below:

$$SQG_{Fraction\_i} = \frac{1}{\sum \frac{MF_{subfraction\_j}}{SQG_{subfraction\_j}}}$$

$SQG_{fraction\_i}$	=	soil quality guideline for the Fraction *i* (mg/kg)
$SQG_{subfraction\_j}$	=	soil quality guideline (mg/kg) for each subfraction within Fraction *i* for the appropriate Soil Allocation Factor for Fraction *i*
$\boldsymbol{MF_{subfraction\_j}}$	=	**mass fraction of each subfraction within the Fraction *i***

Note that in addition to the human health and ecological pathways, “upset limits” described in CCME (2000a) must also be considered to account for other hazards associated with PHC, including free product formation, aesthetics considerations and explosion hazard.

Direct Contact Pathway (Soil Ingestion + Dermal Contact)

$$SQG_{DC} = \frac{(TDI - EDI) \times SAF \times BW}{[(AF_G \times SIR) + (AF_D \times \{SA_H DL_H + SA_O DL_O\} EF)] \times ET} + BSC$$

Where:

SQG_{DC}	= soil quality guideline by direct contact (mg/kg)
TDI	= tolerable daily intake (reference dose) (mg/kg-d)
EDI	= estimated daily intake (mg/kg-d)
SAF	= Soil Allocation Factor (unitless)
BW	= body weight (kg)
SIR	= soil ingestion rate (kg/d)
AF_G	= gastrointestinal absorption factor (unitless)
AF_D	= dermal absorption factor (unitless)
SA_H	= surface area of hands (m^2)
SA_O	= surface area of exposed body surfaces other than hands (m^2)
DL_H	= dermal loading of soil to hands (mg/m^2-event)
DL_O	= dermal loading of soil to other skin surfaces (mg/m^2-event)
EF	= exposure frequency (events/d)
ET	= exposure term (unitless) (based on days/week and weeks/year at site; hours/day not considered)
BSC	= background soil concentration (mg/kg)

There are no primary or secondary Tier 2 adjustable parameters in the direct contact pathway equation.

Indoor Infiltration and Inhalation Pathway

Public-domain and commercial software packages are readily available for the calculation of Tier 2 levels for the indoor infiltration and inhalation pathway. The user must ensure that the software used is based on the equations presented above, i.e. Equation 21 presented by Johnson and Ettinger (1991). Some software packages may require modification or “unlocking” to facilitate Tier 2 calculations. For example, some packages are based on a version of the Johnson and Ettinger model with advective flow removed; **advective flow must be considered at Tier 2**.

A version of the Johnson and Ettinger model which considers advective flow has been incorporated into the PHC CWS Tier 2 spreadsheet, available at www.ccme.ca. At the time of writing, this spreadsheet had not been updated for the 2008 PHC CWS, and default model input parameters may therefore not reflect the current defaults.

Details of the calculations are provided below. The equation differs from CCME (2006) in the inclusion of an adjustment factor to account for differences between measured and calculated PHC vapour concentrations. It is up to the jurisdiction as to how the adjustment factor would be used for Tier 2 recalculations. Refer to the jurisdictional authority prior to implementation of the equation.

$$SQG_I = [(RfC - C_a)\{\theta_w + (K_{OC})(f_{OC})(\rho_b) + (H')(\theta_a)\}(SAF)(AF)(DFi)(10^3 g/kg)]/[(H')(\rho_b)(ET)(10^6 cm^3/m^3)] + BSC$$

Where:	SQG_I	= soil quality guideline by indoor infiltration for volatile PHCs using RfC (mg/kg)
	TDI	= tolerable daily intake (reference dose) (mg/kg-d)
	EDI	= estimated daily intake (mg/kg-d)
	RfC	= reference air concentration (mg/m^3)
	C_a	= background indoor/outdoor air concentration (mg/m^3)
	SAF	= Soil Allocation Factor (unitless)
	AF	= Adjustment Factor (unitless)
	θ_w	**= moisture-filled porosity (unitless)**
	θ_a	**= vapour-filled porosity (unitless)**
	K_{OC}	= organic carbon partition coefficient (mL/g)
	f_{OC}	**= fraction organic carbon (g/g)**
	ρ_b	**= dry bulk density (g/cm^3)**
	H'	= unitless Henry's Law Constant = H/RT
	H	= Henry's Law Constant (atm-m^2/mol)
	R	= gas constant (8.2 x 10^{-5} atm-m^2/mol-^{O}K)
	T	= absolute temperature (K)
	DF_i	= dilution factor from soil gas to indoor air (unitless): *see derivation below*
	ET	= exposure term (unitless)
	BSC	= background soil concentration (mg/kg)

Calculation of DF for indoor infiltration pathway:

$$DF_i = \frac{1}{\alpha}$$

DF_i = dilution factor from soil gas concentration to indoor air concentration (unitless)
α = attenuation coefficient
= (contaminant vapour concentration in the building)/(vapour concentration at the contaminant source)

The attenuation coefficient is calculated using the model developed by Johnson and Ettinger (1991). Both advective and diffusive flow into the building are considered for both coarse and fine soils; based on the default parameter values, flow into the building is dominated by advective flow for coarse soils, while both advection and diffusion affect the attenuation factor for fine soils.

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) \exp\left(\frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}}\right)}{\exp\left(\frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}}\right) - 1\right]}$$

D_T^{eff} = effective porous media diffusion coefficient (cm^2/s) – calculated below
A_B = building area exposed to soil, including basement wall area (cm^2)
Q_B = building ventilation rate (cm^3/s) – calculated below
L_T = distance from contaminant source to foundation (cm)
Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s) – calculated below
L_{crack} = thickness of the foundation (cm)
D^{crack} = effective vapour-pressure diffusion coefficient through the crack (cm^2/s) - calculated below
A_{crack} = area of cracks through which contaminant vapours enter the building (cm^2)

$$D_T^{eff} \approx D_a\left(\frac{\theta_a^{10/3}}{n^2}\right)$$

D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm^2/s)
D_a = pure component molecular diffusivities in air (cm^2/s)
θ_a = air-filled porosity (unitless)
n = total soil porosity (unitless)

$$D^{crack} \approx D_a \left(\frac{\theta_{a\_c}^{10/3}}{n_c^{2}} \right)$$

D^{crack} = effective diffusion coefficient through foundation crack (cm^2/s)
D_a = pure component molecular diffusivities in air (cm^2/s)
θ_{a_c} = air-filled porosity of soil-filled foundation crack (unitless)
n_C = total soil porosity in foundation crack (unitless)
Note: soil in foundation cracks is assumed to be dry, so the air-filled porosity is equal to the total porosity in this case. Total porosity is assumed to be equal to that of the underlying soil.

$$Q_B = L_B W_B H_B (ACH) / (3600\ s/h)$$

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})

$$Q_{soil} = \frac{2\pi\ \Delta P\ k_v\ X_{crack}}{\mu \ln\left[\frac{2(Z_{crack})}{r_{crack}}\right]}$$

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

Protection of Groundwater (Potable Groundwater, Aquatic Life and Livestock Watering)

The groundwater model specified in the CCME (2006) protocol (adapted from the BC CSST groundwater model) includes four components:

- Soil/leachate partitioning (DF1)
- Unsaturated zone transport of leachate (DF2)
- Mixing and dilution of leachate at the water table (DF3)
- Lateral groundwater advective/dispersive transport (DF4)

It should be noted that not all of these components will apply in every scenario. Specifically, the unsaturated zone transport (DF2) only applies if the contamination is not in contact with groundwater, and the saturated-zone transport (DF4) only applies if there is a lateral separation between the remediated site and the groundwater receptor; for the development of Tier 1 levels it is assumed that a water well or livestock dugout could be installed at the edge of the contaminant source area (i.e. no offset distance), while a 10 m offset distance to a surface water body is assume for the protection of aquatic life. These distances may be adjusted at Tier 2.

Soil/Leachate Partitioning (DF1)

Partitioning of the contaminant to leachate is evaluated using the standard three-phase equilibrium partitioning model as detailed in Appendix A of CCME (2006).

$$SQG_{GW} = C_L \left\{ K_d + \left(\frac{\theta_w + H'\theta_a}{\rho_b} \right) \right\}$$

SQG_{GW}	=	soil quality guideline for the protection of groundwater (mg/kg) (i.e. potable water, aquatic life or livestock watering)
C_L	=	allowable leachate concentration at source (mg/L) – calculated below
K_d	=	distribution coefficient (cm^3/g) = K_{oc} x f_{oc}
K_{OC}	=	organic carbon partition coefficient (mL/g)
f_{OC}	**=**	**fraction organic carbon (g/g)**
θ_w	**=**	**water filled porosity (unitless)**
H'	=	dimensionless Henry's Law constant = H/RT
H	=	Henry's Law constant (atm-m^3/mol)
R	=	gas constant (8.2 x 10^{-5} atm-m^2/mol-^{O}K)
T	=	absolute temperature (K)
θ_a	**=**	**air-filled porosity (unitless)**
ρ_b	**=**	**soil bulk density in contaminant partitioning zone (g/cm^3)**

Unsaturated Zone Transport (DF2)

$$C_L = {C_z} \Big/ {\exp\left[\frac{b}{2\partial_u} - \frac{b}{2\partial_u}\left(1 + \frac{4\partial_u L_{US}}{v_u}\right)^{1/2} \right]}$$

$$v_u = \frac{I}{\theta_w R_u}; \quad R_u = 1 + \frac{\rho_b}{\theta_w} K_d$$

C_L	=	allowable chemical concentration in leachate at the source (mg/L)
C_z	=	allowable chemical concentration in leachate at the water table (mg/L) calculated below
b	**=**	**thickness of unsaturated zone below the source (m) = d – Z**
d	**=**	**depth from surface to groundwater surface (m)**
Z	**=**	**depth to bottom of contaminated soil (m)**
∂_u	=	dispersivity in the unsaturated zone (m) = 0.1b
L_{US}	=	decay constant for chemical (y^{-1}) in unsaturated zone:

$$L_{US} = \frac{0.6931}{t_{1/2US}}\left(e^{-0.07d}\right)$$

$t_{1/2US}$	=	chemical half-life in unsaturated zone (years)
v_u	=	average linear leachate velocity (m/y)
I	**=**	**infiltration rate (m/y) = precipitation minus runoff and evapotranspiration**
$\boldsymbol{\theta_w}$	**=**	**water-filled porosity (unitless)**
R_u	=	retardation factor in unsaturated zone (unitless)
$\boldsymbol{\rho_b}$	**=**	**soil bulk density in unsaturated zone (g/cm^3)**
K_d	=	distribution coefficient (cm^3/g) = K_{oc} x f_{oc}
K_{OC}	=	organic carbon partition coefficient (mL/g)
$\mathbf{f_{OC}}$	**=**	**fraction organic carbon (g/g)**

Mixing and Dilution at the Water Table (DF3)

The mixing zone unsaturated/saturated equation (below), used to represent dilution of the leachate into groundwater, is based on a mass-balance approach considering movement of the chemical into the groundwater beneath the source (via infiltration of leachate) and away from the source area (via aquifer flow).

The equation is based on the assumption that the chemical is distributed evenly throughout a “mixing zone”. While in reality the concentration of the chemical would not be constant throughout this zone, further vertical mixing would be expected to occur at the point of exposure (water well, dugout or surface water body). Therefore, the mixing zone approach is considered to be a reasonable approximation for purposes of generic guideline development.

$$C_z = C_{gw}\left\{1+\left(\frac{Z_d K_H i}{IX}\right)\right\}$$

C_z	=	allowable chemical concentration in leachate at the water table (mg/L)
C_{gw}	=	allowable chemical concentration in groundwater at the source (mg/L) – calculated below
Z_d	=	average thickness of mixing zone (m) – calculated below

K_H	**=**	**hydraulic conductivity in the saturated zone (m/y)**
i	**=**	**hydraulic gradient (unitless)**
I	**=**	**infiltration rate (m/y) = precipitation minus runoff and evapotranspiration**
X	**=**	**length of source parallel to groundwater flow (m)**

Calculation of average thickness of mixing zone:

$Z_d = r + s$; Z_d cannot exceed d_a

r	=	mixing depth available due to dispersion and diffusion (m)
	=	0.01 X
X	**=**	**length of source parallel to groundwater flow (m)**
s	=	mixing depth available due to infiltration rate and groundwater flow rate (m)

$$s = d_a \left\{ 1 - e^{-\frac{2.178XI}{K_H i d_a}} \right\}$$

d_a	=	depth of unconfined aquifer (m)
I	**=**	**infiltration rate (m/y) = precipitation minus runoff and evapotranspiration**
K_H	**=**	**hydraulic conductivity in the saturated zone (m/y)**
i	**=**	**hydraulic gradient (unitless)**

Lateral Groundwater Transport (DF4)

Note: for a receptor located at the edge of the contaminant source, DF4 = 1 ($C_{gw} = C_w$)

The groundwater model includes the Domenico and Robbins (1984) analytical equation to evaluate lateral transport to a downgradient receptor. The implementation of this model presented below assumes no vertical dispersion downgradient of the source area. This assumption is "realistic" (doesn't significantly affect model results) for situations where the contaminant has mixed through the entire thickness of the aquifer or where there is a relatively large mixing depth and relatively short distance to the receptor, such as the default fine-grained soil scenario, and is conservative in other situations.

The below version of the equation is the steady-state version of the model (i.e. time since release does not need to be considered).

$$C_w(x,y,z,t) = \left(\frac{C_{gw}}{2}\right)\exp\left\{\left(\frac{x}{2\partial_x}\right)\left[1-\left(1+\frac{4L_s\partial_x}{v}\right)^{1/2}\right]\right\}\left\{erf\left[\frac{(y+Y/2)}{2(\partial_y x)^{1/2}}\right]-erf\left[\frac{y-Y/2}{2(\partial_y x)^{1/2}}\right]\right\}$$

$$v = \frac{K_H i}{n_e R_f}; \quad R_f = 1 + \frac{\rho_b}{n} K_d$$

C_w = allowable chemical concentration in water at receptor (mg/L) (i.e. aquatic life guideline, livestock watering RfC); for potable water pathway, calculated as (TDI – EDI)(BW)/IR_W
TDI = tolerable daily intake (mg/kg/d)
EDI = estimated daily intake (mg/kg/d)
BW = body weight (kg)
IR_W = water ingestion rate (L/d)
x = distance from source to receptor (m)
x,y,z = Cartesian coordinates relating source and receptor (m); y, z assumed to be 0
C_{gw} = allowable chemical concentration in groundwater at source (mg/L)
∂_x = longitudinal dispersivity tensor = 0.1x
∂_y = lateral dispersivity tensor = $0.1\partial_x$
L_s = decay constant (y^{-1}) in saturated zone:

$$L_s = \frac{0.6931}{t_{1/2US}}\left(e^{-0.07d}\right)$$

d = depth from surface to groundwater surface (m)
$t_{1/2S}$ = biodegradation half-life (y)
v = velocity of contaminant (m/y)
K_H = hydraulic conductivity in the saturated zone (m/y)
i = hydraulic gradient (unitless)
n = total porosity of soil = 1 - ρ_b/2.65 (unitless)
n_e = effective soil porosity (unitless) = total porosity
Y = source width (m) perpendicular to groundwater flow
R_f = retardation factor (unitless)
ρ_b = soil bulk density in saturated zone (g/cm^3)
K_d = distribution coefficient (cm^3/g) = K_{oc} x f_{oc}
K_{OC} = organic carbon partition coefficient (mL/g)
f_{OC} = fraction organic carbon (g/g)

Offsite Migration Check

The offsite migration check is applied for commercial and industrial sites which may have more sensitive land uses nearby (CCME, 2006).

SQG_{OM} = 14.3 x SQG_A - 13.3 x BSC

where:

SQG_{OM} = soil quality guideline for offsite migration (mg/kg)
SQG_A = governing Tier 1 level for the agricultural land use (mg/kg)
BSC = background soil concentration (mg/kg)

The offsite migration check is not normally adjusted at Tier 2.

D.3 Ecological Soil Contact Pathway at Tier 2

The ecological soil contact pathway levels cannot be adjusted at Tier 2; this requires a more detailed Tier 3 assessment, including site-specific chronic toxicity testing.

Research into bioavailability indices and alternate extraction methods such as cyclodextrin extractions, and how these relate to ecological toxicity, is currently being undertaken. While the dataset is not yet sufficient to allow for the development of a Tier 2 approach, conducting soil analyses with a cyclodextrin analysis prior to proceeding to site-specific toxicity testing may yield valuable information about whether the soils are likely to be toxic to plants and soil invertebrates.

D.4 Management Limits and Other Considerations

The management limits, which include consideration of factors such as free phase formation, fire and explosive hazards, effects on buried infrastructure, aesthetic concerns, and exposure of workers in excavations and trenches, cannot be adjusted or omitted at Tier 2.

Regardless of the results of any Tier 2 adjustment (or compliance of measured concentrations with Tier 1 or Tier 2 limits), the presence of free phase hydrocarbons, aesthetic concerns from PHC contamination, and any observed effects on buried utilities and other infrastructure must be addressed.

D.5 Illustrative Ranges of Tier 2 Objectives

The effects of modifying primary Tier 2 adjustable parameters is illustrated in Tables D-5 through D-16 (coarse-grained soils) and D-17 through D-28 (fine-grained soils). Tier 2 levels were calculated for each pathway by varying the selected parameter from the minimum to the maximum values shown in Table D-1, while holding all other parameters at the default values. Pathways where only a single value is presented for each fraction in the tables are not significantly influenced by the variation of the selected parameter. Ranges shown are the Tier 2 levels calculated at the lowest and highest illustrative values used for the selected parameter. The resulting governing Tier 2 levels (including groundwater protection pathways) are summarized in Tables D-29 and D-30.

D.6 Consideration of Solubility Limits and Raoult's Law

The Tier 1/Tier 2 calculation equations do not include any consideration of water solubility limits or vapour saturation limits. At the discretion of the jurisdiction, it may be permissible to limit calculated dissolved-phase and vapour-phase concentrations based on water solubility and vapour saturation limits. However, it should be noted that the sub-fraction solubility limits included in Table B-4 are estimated values based on correlation of equivalent carbon numbers to measured solubility limits of specific chemicals, and are subject to considerable uncertainty. Calculation of soil risk management objectives for

PHC fractions using solubility limits is also mathematically more complex due to the process of combining sub-fraction results into fractions; "forward-style" calculations where exposure doses are estimated based on specified soil concentrations can more readily incorporate solubility limits.

If water solubility limits and vapour saturation limits are being utilized, the jurisdiction may also allow these values to be adjusted for Raoult's Law if the PHC composition has been adequately characterized.

D.7 Adjustment Based on Point-of-Exposure Measurements

If true point of exposure measurements (i.e. building air, water well, etc.) are made, these can be compared directly with target levels. As for the soil guidelines, the equations are used to calculate values for each sub-fraction, and an inverse weighted average of the sub-fraction values is used as the target level for the fraction.

Building Air

The building air guideline for each sub-fraction is simply the reference concentration, or, where there is no reference concentration:

$$C_{ba} = \frac{(TDI - EDI)(BW)}{IR}$$

C_{ba}	=	allowable concentration in building air (mg/m^3)
TDI	=	tolerable daily intake (reference dose) (mg/kg-d)
EDI	=	estimated daily intake (mg/kg-d)
BW	=	body weight (kg)
IR	=	inhalation rate (m^3/d)

The sub-fraction guidelines are then combined to calculate guidelines for each fraction using the inverse-mass weighted average as above. However, the composition of each fraction in the vapour phase is likely considerably different than the composition of the whole product, due to different affinities of each sub-fraction for the adsorbed, dissolved and vapour phases. Estimated vapour-phase mass fractions are included in Table B-4 for reference, based on equilibrium partitioning calculations; alternatively, site-specific mass fractions in the vapour phase can be used.

Potable Water Source

The guidelines for PHC in potable water are calculated using:

$$C_{DW} = \frac{(TDI - EDI)(BW)}{IR_W}$$

C_{DW} = allowable concentration in potable water (mg/L)
TDI = tolerable daily intake (reference dose) (mg/kg-d)
EDI = estimated daily intake (mg/kg-d)
BW = body weight (kg)
IR_w = water ingestion rate (L/d)

The sub-fraction guidelines are then combined to calculate guidelines for each fraction using the inverse-mass weighted average as above. However, the composition of each fraction in the dissolved phase is likely considerably different than the composition of the whole product, due to different affinities of each sub-fraction for the adsorbed, dissolved and vapour phases. Estimated mass fractions in water are included in Table B-4 for reference, based on equilibrium partitioning calculations; alternatively, site-specific mass fractions in water can be used.

Surface Water (Aquatic Life or Livestock Watering)

The benchmark concentrations for aquatic life and livestock watering are presented in Table B-10. Aquatic life objectives for each sub-fraction should be combined to calculate guidelines for each fraction using the inverse mass-weighted average, as for potable water above.

Intermediate Measurements

Soil Gas Beneath Building Slab

Calculation of PHC guidelines for soil gas beneath the building slab can be approximated by calculating a dilution factor from soil gas to building air (see D.2 above), substituting a small distance (i.e. <1 mm) for L_T. The calculated value of Df_i can then be used in the following equation:

$$C_{sgs} = \frac{(RfC - C_a)(SAF)(DF_i)}{ET}$$

C_{sgs} = soil gas guideline for PHC sub-fraction
RfC = reference air concentration
C_a = background indoor/outdoor air concentration (mg/m^3)
SAF = soil allocation factor (unitless)
DF_i = dilution factor from soil gas to indoor air (unitless):
see derivation in D.2 – Indoor Infiltration and Inhalation Pathway
ET = exposure term (unitless)

or, if a reference concentration is unavailable:

$$C_{sgs} = \frac{(TDI - EDI)(BW)(SAF)(DF_i)}{(ET)(IR)}$$

TDI	=	tolerable daily intake (reference dose) (mg/kg-d)
EDI	=	estimated daily intake (mg/kg-d)
BW	=	body weight (kg)
IR	=	inhalation rate (m^3/d)

Illustrative soil vapour levels are presented in Table D-31 for coarse and fine soils, based on a depth of 1 m below the foundation slab. The sub-fraction levels are combined to calculate Tier 2 levels for each fraction using the inverse mass-weighted average and estimated or measured mass fractions in the vapour phase, as for building air above.

It should be noted that the adjustment factor of 10 described in CCME (2006) does not at this time apply to soil vapour calculations. Some jurisdictions may allow the adjustment factor to be replaced by a biodegradation factor of 10 (for PHC only) if the conditions recommended by Health Canada are met, specifically that there is at least a 4 m separation between the measurement point (and top of the contamination) and the building, and that no more than 80% of the area surrounding the building is paved or otherwise capped (Golder, 2004).

Intermediate Groundwater Monitoring Point

To calculate a guideline for an intermediate groundwater monitoring point (for example, at the property line), use the saturated zone groundwater transport equation presented earlier for the protection of groundwater pathways. The target value for C_w is the appropriate point of exposure guideline (potable water, aquatic life or livestock watering).

Pathway Screening and Associated Limitations/Management Requirements

For some sites, Tier 2 levels may be derived by eliminating pathways that do not apply. However, in most cases this will lead to additional long-term management requirements. Pathways which may be excluded under certain circumstances are as follows:

- The direct contact pathway (soil ingestion and dermal contact) requires direct exposure to soil. Therefore, if the PHC contamination is greater than 1.5 m below grade, these pathways would only apply during construction activities when subsurface soils are exposed. These pathways would be effectively eliminated for a property which is completely paved. The latter scenario would require long-term management to ensure that PHC contaminated surface soils remain covered. Most jurisdictions require the direct contact pathway to be applied for unconditional site closure due to the possibility of soils being excavated and stockpiled at surface.

- Indoor vapour inhalation is applicable for any site with a building. If there are no buildings, the pathway would not have to be considered; however, long-term management would be required to ensure that no buildings are constructed at the site in the future. The pathway is not normally considered operative beyond a distance of

30 m, unless there are precluding factors such as preferential migration pathways or a low permeability surface cap.

- Ecological soil contact, ecological soil ingestion and nutrient cycling may, at the discretion of the jurisdiction, be excluded for certain types of industrial or commercial land if the site is completely paved or capped. Management would be required to ensure that the site remains paved or capped.

- The offsite migration pathway may be excluded for industrial sites where the surrounding land use is also industrial.

Consideration of the protection of groundwater pathways is detailed in the management guidance and in Appendix A.

D.8 Determination of Management Requirements

In some cases, calculation of Tier 2 objectives may result in long-term management requirements, particularly if secondary Tier 2 adjustable parameters are modified. As a general "rule of thumb", if a parameter may change in the future, then there will be a requirement for long-term management if it is adjusted from the Tier 1 default value. Specific management requirements are at the discretion of the jurisdiction, but general guidance is presented below and in Section 5.2 of the guidance.

If management is required due to secondary Tier 2 adjustable parameters being modified, then the management must include control over those parameters. For example, if site-specific building characteristics are used, any future development at the site must comply with the modified parameters. If a set distance to a potable water source is used, then no potable water source can be added closer than the distance used.

Generally, such management requirements would remain in place until the PHC contamination at the site meets either the Tier 1 objectives or an alternate set of Tier 2 objectives without any modification to secondary Tier 2 adjustable parameters.

Long-term management may also be required if point-of-exposure or intermediate measurements are used to protect receptors. In this case, the management requirements will likely require monitoring of the point-of-exposure or intermediate concentrations to ensure that health and ecological risk remain at acceptable levels until the site is remediated to Tier 1 or Tier 2 objectives.

TABLE D-1

PRIMARY TIER 2 ADJUSTABLE PARAMETERS AND ILLUSTRATIVE RANGES

PARAMETER	DEFAULT	ILLUSTRATIVE RANGE
Measured Parameters		
Bulk Density (g/cm^3)	c/g: 1.7 f/g: 1.4	c/g: 1.5 - 1.8 f/g: 1.3 - 1.6
Water Content (M_w/M_s)	c/g: 0.07 f/g: 0.12	c/g: 0.03 – 0.15 f/g: 0.07 - 0.16
Organic Carbon Fraction (g/g)	0.005	c/g: 0.0005 - 0.007 f/g: 0.0005 - 0.03
Soil Vapour Permeability (cm^2)	c/g: $5x10^{-8}$ f/g: 10^{-9}	c/g: 10^{-6} - 10^{-8} f/g: 10^{-8} - 10^{-12}
Saturated Hydraulic Conductivity (m/y)	c/g: 320 f/g: 32	c/g: 32 - 3200 f/g: 0.032 – 32
Recharge (m/y)	c/g: 0.28 f/g: 0.20	0.005 - 0.5
Hydraulic Gradient (unitless)	0.028	0.001 - 0.1
Depth/distance to Contamination (m)[a]	0.3	0 – 10
Thickness of Contamination (m)[b]	3	0.5 - 5
Depth to Groundwater (m)[c]	3	0 – 10
Site Length (m) - parallel to GW flow	10	5 – 30
Site Width (m) - perpendicular to GW flow[b]	10	5 – 30
Distance to nearby surface water (m)[b]	10	0 – 500
Distance to potable water or livestock watering (m)	0	0 – 500
Calculated Parameters		
Effective Porosity	c/g: 0.36 f/g: 0.47	See note d
Moisture-filled Porosity	c/g: 0.119 f/g: 0.168	See note e
Distance from Contamination to Groundwater (m)[b]	0	See note f

c/g – coarse-grained soil
f/g – fine-grained soil
a – distance from the nearest point of the foundation of an occupied buidling
b – parameter only used in the calculation of leaching to groundwater and transport to nearby surface water bodies
c – depth below grade
d – calculated from bulk density, assuming soil specific gravity of 2.65
e – derived from bulk density and water content
f – calculated from depth to contamination, depth to groundwater, and thickness of contamination

TABLE D-2

SECONDARY TIER 2 ADJUSTABLE PARAMETERS

PARAMETER	TIER 1 DEFAULT VALUE	
Site Characteristics		
Distance (lateral or vertical) from PHC contamination to inhalation receptor (m)	0.3	
Annual average soil temperature (K)	294	
Soil/Groundwater Characteristics		
Depth of unconfined aquifer (m)	5	
Building Characteristics		
Building length (cm)	R, A: 1225	C, I: 2000
Building width (cm)	R, A: 1225	C, I: 1500
Building area (cm^2)	R, A: $1.5x10^6$	C, I: $3x10^6$
Building height, including basement (cm)	R, A: 360	C, I: 300
Thickness of building foundation (cm)	11.25	
Distance below grade to idealized cylinder (cm) = depth to bottom of slab	Basement: 244 Slab-on-grade: 11.25	
Air exchanges per hour	R, A: 0.5	C, I: 0.9
Pressure differential ($g/cm \bullet s^2$)	R, A: 40	C, I: 20
Area of cracks (cm^2)	R, A: 994.5	C, I: 1846

A – agricultural land use
R – residential land use
C – commercial land use
I – industrial land use

TABLE D-3
INFLUENCE OF PRIMARY TIER 2 ADJUSTABLE PARAMETERS ON EXPOSURE PATHWAYS
COARSE-GRAINED SOILS

		PARAMETER											
Land use	**Exposure pathway or receptor**	**Soil Vapour Permeability**	**Soil Moisture Content**	**Soil Bulk Density**	**Organic Carbon Fraction**	**Hydraulic Conductivity**	**Recharge Rate**	**Hydraulic Gradient**	**Source Length**	**Depth to Contamination[f]**	**Depth to Groundwater[e]**	**Distance to Receptors[b]**	**Additional Comments**
Agricultural	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	-	-	-	
	Vapour inhalation (slab/grade)	OO	XX	X	XX	-	-	-	-	XX	-	-	
	Vapour inhalation (basement)	OO	XX	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Livestock	-	O	O	XX	XX	OO	XX	O	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Residential	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	-	-	-	
	Vapour inhalation (slab/grade)	OO	XX	X	XX	-	-	-	-	XX	-	-	
	Vapour inhalation (basement)	OO	XX	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Commercial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	XX	-	-	
	Vapour inhalation (slab/grade)	OO	X	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a,g
Industrial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	O	XX	Xc	OO	Xc	O	XX	-	-	
	Vapour inhalation (slab/grade)	OO	X	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	X	X	XX	OO	OO	OO	O	-	-	XX	
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a, g

XX strongly influential; increasing the parameter increases the Tier 2 level
X somewhat influential; increasing the parameter increases the Tier 2 level
OO strongly influential; increasing the parameter decreases the Tier 2 level
O somewhat influential; increasing the parameter decreases the Tier 2 level
\- no influence
a pathway will not normally govern
b may result in land/water use restriction
c significant if lateral transport is considered

d	insufficient data available for Tier 2 modification
e	parameter only has significant influence if unsaturated zone transport occurs
f	parameter only has significant influence if depth to contamination is greater than slab/basement depth
g	**dependent on governing residential pathway**

TABLE D-4
INFLUENCE OF PRIMARY TIER 2 ADJUSTABLE PARAMETERS ON EXPOSURE PATHWAYS
FINE-GRAINED SOILS

Land use	Exposure pathway or receptor	*PARAMETER* Soil Vapour Permeability	Soil Moisture Content	Soil Bulk Density	Organic Carbon Fraction	Hydraulic Conductivity	Recharge Rate	Hydraulic Gradient	Source Length	Depth to Contamination[f]	Depth to Groundwater[e]	Distance to Receptors[b]	Additional Comments
Agricultural	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	Oc	XX	Oc	-	-	-	
	Vapour inhalation (slab/grade)	OO	O	X	XX	-	-	-	-	X	-	-	
	Vapour inhalation (basement)	OO	O	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Livestock	-	O	O	XX	XX	OO	XX	OO	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Residential	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhalation (slab/grade)	OO	O	X	XX	-	-	-	-	X	-	-	
	Vapour inhalation (basement)	OO	O	X	XX	-	-	-	-	-	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
Commercial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhalation (slab/grade)	OO	O/X	X	XX	-	-	-	-	X	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a,g
Industrial	Direct Exposure	-	-	-	-	-	-	-	-	-	-	-	a
	Drinking Water	-	-	-	XX	XX	O	XX	O	-	-	-	
	Vapour inhalation (slab/grade)	OO	O/X	X	XX	-	-	-	-	X	-	-	
	Aquatic life	-	-	-	XX	-	-	OO	-	-	-	XX	a
	Eco soil contact	-	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	-	a, g

XX strongly influential; increasing the parameter increases the Tier 2 level
X somewhat influential; increasing the parameter increases the Tier 2 level
OO strongly influential; increasing the parameter decreases the Tier 2 level
O somewhat influential; increasing the parameter decreases the Tier 2 level
\- no influence
a pathway will not normally govern
b may result in land/water use restriction

c	significant if lateral transport is considered
d	insufficient data available for Tier 2 modification
e	parameter only has significant influence if unsaturated zone transport occurs
f	parameter only has significant influence if depth to contamination is greater than slab/basement depth
g	dependent on governing residential pathway

TABLE D-5

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS DEFAULT SCENARIO

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	970	380	NA	NA
	Protection of GW for Livestock	5300	14000	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-6

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS VAPOUR PERMEABILITY RANGING FROM 10^{-8} cm^2 TO 10^{-6} cm^2

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 9**	**96 – 46**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**20 – 5**	**110 – 26**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Protection of GW for Livestock	5300	14000	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 9**	**96 – 46**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**20 – 5**	**110 – 26**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**180 – 50**	**970 – 250**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**180 – 50**	**970 – 250**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-7

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS MOISTURE CONTENT RANGING FROM 0.03 g/g TO 0.15 g/g

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 150**	**120 – 820**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**30 – 100**	**180 – 570**	**NA**	**NA**
	Protection of GW for FAL	**980-950**	**380**	**NA**	**NA**
	Protection of GW for Livestock	**5500 – 4800**	**14000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 150**	**120 – 820**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**30 – 100**	**180 – 570**	**NA**	**NA**
	Protection of GW for FAL	**980-950**	**380**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**300 – 950**	**1600 – 5400**	**NA**	**NA**
	Protection of GW for FAL	**980-950**	**380**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**300 – 950**	**1600 – 5400**	**NA**	**NA**
	Protection of GW for FAL	**980-950**	**380**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-8

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS SOIL BULK DENSITY RANGING FROM 1.5 g/cm^3 TO 1.8 g/cm^3

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 – 230**	**320**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 30**	**130 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**40**	**180 – 210**	**NA**	**NA**
	Protection of GW for FAL	**710 – 1100**	**300 - 420**	**NA**	**NA**
	Protection of GW for Livestock	**5800 – 5100**	**14000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 – 230**	**320**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**20 – 30**	**130 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**40**	**180 – 210**	**NA**	**NA**
	Protection of GW for FAL	**710 – 1100**	**300 - 420**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**240 – 230**	**320**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**310 – 340**	**1600 – 1900**	**NA**	**NA**
	Protection of GW for FAL	**710 – 1100**	**300 - 420**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**240 – 230**	**320**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**310 – 340**	**1600 – 1900**	**NA**	**NA**
	Protection of GW for FAL	**710 – 1100**	**300 - 420**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-9

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS ORGANIC CARBON FRACTION RANGING FROM 0.0005 g/g TO 0.007 g/g

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**28 – 330**	**33 – 440**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**5 – 40**	**16 – 200**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**6 – 50**	**21 – 270**	**NA**	**NA**
	Protection of GW for FAL	**4 – 3800**	**3.6 - 1100**	**NA**	**NA**
	Protection of GW for Livestock	**1100 – 7100**	**1500 – 19000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**28 – 330**	**33 – 440**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**5 – 40**	**16 – 200**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**6 – 50**	**21 – 270**	**NA**	**NA**
	Protection of GW for FAL	**4 – 3800**	**3.6 - 1100**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**28 – 330**	**33 – 440**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**50 – 430**	**190 – 2400**	**NA**	**NA**
	Protection of GW for FAL	**4 – 3800**	**3.6 - 1100**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**28 – 330**	**33 – 440**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**50 – 430**	**190 – 2400**	**NA**	**NA**
	Protection of GW for FAL	**4 – 3800**	**3.6 - 1100**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-10

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS HYDRAULIC CONDUCTIVITY RANGING FROM 32 m/y to 3200 m/y

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**160 – 450**	**210 – 600**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**RES – 30**	**RES – 62**	**NA**	**NA**
	Protection of GW for Livestock	**3500 - 10000**	**9200 - 26000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**160 – 450**	**210 – 600**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**RES – 30**	**RES – 62**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**160 – 450**	**210 – 600**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**RES – 30**	**RES – 62**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**160 – 450**	**210 – 600**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**RES – 30**	**RES – 62**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-11

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS GROUNDWATER RECHARGE RANGING FROM 0.005 m/y TO 0.5 m/y

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**1500 – 220**	**2000 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**5700 – 900**	**2300 – 350**	**NA**	**NA**
	Protection of GW for Livestock	**RES – 4900**	**RES – 13000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**1500 – 220**	**2000 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**5700 – 900**	**2300 – 350**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**1500 – 220**	**2000 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**5700 – 900**	**2300 – 350**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**1500 – 220**	**2000 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**5700 – 900**	**2300 – 350**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-12

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS HYDRAULIC GRADIENT RANGING FROM 0.001 TO 0.1

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**110 – 300**	**150 – 410**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**RES – 68**	**RES – 77**	**NA**	**NA**
	Protection of GW for Livestock	**2500 – 6800**	**6500 – 18000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**110 – 300**	**150 – 410**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**RES – 68**	**RES – 77**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**110 – 300**	**150 – 410**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**RES – 68**	**RES – 77**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**110 – 300**	**150 – 410**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**RES – 68**	**RES – 77**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-13

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS SITE LENGTH RANGING FROM 5 m TO 30 m

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 – 220**	**320 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**990 – 900**	**380 – 350**	**NA**	**NA**
	Protection of GW for Livestock	**5400 – 4900**	**14000 – 13000**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 – 220**	**320 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**990 – 900**	**380 – 350**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**240 – 220**	**320 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**990 – 900**	**380 – 350**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**240 – 220**	**320 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**990 – 900**	**380 – 350**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-14

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SOILS DEPTH/DISTANCE TO CONTAMINATION RANGING FROM 30 cm TO 10 m BELOW GRADE

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**30 – 300**	**150 – 1600**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**40 – 150**	**190 – 800**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Protection of GW for Livestock	5300	14000	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**30 – 300**	**150 – 1600**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**40 – 150**	**190 – 800**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**320 – 1800**	**1700 – 9600**	**NA**	**NA**
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	**NA**	**NA**	**4300 – NA**	**RES**
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	240	320	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	320 – 1800	1700 – 9600	NA	NA
	Protection of GW for FAL	970	380	NA	NA
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	**NA**	**NA**	**4300 – NA**	**RES**

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-15

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS DEPTH TO GROUNDWATER[a] RANGING FROM 3 m TO 10 m

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 - RES**	**320 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**970 – RES**	**380 - RES**	**NA**	**NA**
	Protection of GW for Livestock	**5300 - RES**	**14000 - RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 - RES**	**320 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**970 – RES**	**380 - RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**240 - RES**	**320 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**970 – RES**	**380 - RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**240 - RES**	**320 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**970 – RES**	**380 - RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.

NA – pathway not applicable for PHC fraction.
[a] varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-16

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN COARSE-GRAINED SURFACE SOILS DISTANCE TO GROUNDWATER RECEPTORS[a] RANGING FROM 0 m TO 500 m

LAND USE	**PATHWAY**	**F1 (C_6 - C_{10})**	**F2 ($C_{>10}$ - C_{16})**	**F3 ($C_{>16}$ - C_{34})**	**F4 ($C_{>34}$ - C_{50})**
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**240 – RES**	**320 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**4.2 – RES**	**5.3 – RES**	**NA**	**NA**
	Protection of GW for Livestock	**5300 – RES**	**14000 – RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	240 – RES	320 – RES	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Protection of GW for FAL	**4.2 – RES**	**5.3 – RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	300	2800
	Management Level	700	1000	2500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**240 – RES**	**320 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**4.2 – RES**	**5.3 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**240 – RES**	**320 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	320	1700	NA	NA
	Protection of GW for FAL	**4.2 – RES**	**5.3 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	1700	3300
	Management Level	700	1000	3500	10000
	Offsite Migration	NA	NA	4300	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.

[a] distance to surface water (FAL), potable water user and livestock watering.
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-17

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS DEFAULT SCENARIO

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	4200	10000	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-18

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS VAPOUR PERMEABILITY RANGING FROM 10^{-12} cm^2 TO 10^{-8} cm^2

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**930 – 20**	**4800 – 87**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**930 – 20**	**4700 – 100**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	4200	10000	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**930 – 20**	**4800 – 87**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**930 – 20**	**4700 – 100**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**5500 – 180**	**28000 – 930**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**5500 – 180**	**28000 – 930**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-19

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS MOISTURE CONTENT RANGING FROM 0.07 g/g TO 0.16 g/g

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**620 – 600**	**3100**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**730 – 700**	**3600 – 3700**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**4400 – 4000**	**10000**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**620 – 600**	**3100**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**730 – 700**	**3600 – 3700**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4700 – 4500**	**23000 – 24000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4700 – 4500**	**23000 – 24000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-20

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS SOIL BULK DENSITY RANGING FROM 1.3 g/cm^3 TO 1.6 g/cm^3

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**590 – 660**	**2900 – 3500**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**680 – 790**	**3400 – 4200**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**4400 – 3800**	**10000**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**590 – 660**	**2900 – 3500**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**680 – 790**	**3400 – 4200**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4300 – 5200**	**21000 – 28000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4300 – 5200**	**21000 – 28000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-21

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS ORGANIC CARBON FRACTION RANGING FROM 0.0005 TO 0.03 g/g

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**22 – 1000**	**25 – 1400**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**120 – 3200**	**360 – 18000**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**140 – 3700**	**420 – 22000**	**NA**	**NA**
	Protection of GW for FAL	**140 – RES**	**30 – RES**	**NA**	**NA**
	Protection of GW for Livestock	**920 – 20000**	**1100 - RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**22 – 1000**	**25 – 1400**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**120 – 3200**	**360 – 18000**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**140 – 3700**	**420 – 22000**	**NA**	**NA**
	Protection of GW for FAL	**140 – RES**	**30 – RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**22- 1000**	**25 – 1400**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**890 – 24000**	**2700 – RES**	**NA**	**NA**
	Protection of GW for FAL	**140 – RES**	**30 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**22 – 1000**	**25 – 1400**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	**890 – 24000**	**2700 – RES**	**NA**	**NA**
	Protection of GW for FAL	**140 – RES**	**30 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-22

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS HYDRAULIC CONDUCTIVITY RANGING FROM 0.032 m/y to 32 m/y[a]

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**71 – 170**	**95 – 230**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**1700 – 4200**	**4200 – 10000**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**71 – 170**	**95 – 230**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**71 – 170**	**95 – 230**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**71 – 170**	**95 – 230**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.
[a] – a hydraulic conductivity less than 32 m/y may result in insufficient yield for a domestic water well or livestock water supply. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-23

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS GROUNDWATER RECHARGE RANGING FROM 0.005 m/y TO 0.5 m/y

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**350 – 130**	**470 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**8500 – 3200**	**20000 – 7600**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**350 – 130**	**470 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**350 – 130**	**470 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**350 – 130**	**470 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-24

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS HYDRAULIC GRADIENT RANGING FROM 0.001 TO 0.1

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**77 – 220**	**100 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	**RES – 13000**	**RES – 3400**	**NA**	**NA**
	Protection of GW for Livestock	**1900 – 5300**	**4500 – 13000**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**77 – 220**	**100 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	**RES – 13000**	**RES – 3400**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**77 – 220**	**100 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	**RES – 13000**	**RES – 3400**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**77 – 220**	**100 – 290**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	**RES – 13000**	**RES – 3400**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-25

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS SITE LENGTH RANGING FROM 5 m TO 30 m

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**200 – 120**	**260 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**4800 – 3000**	**12000 – 7300**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**200 – 120**	**260 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**200 – 120**	**260 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**200 – 120**	**260 – 170**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-26

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SOILS DEPTH/DISTANCE TO CONTAMINATION RANGING FROM 30 cm TO 10 m BELOW GRADE[a]

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**610 – 840**	**3100 – 4300**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**710 – 810**	**3600 – 4100**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	4200	10000	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**610 – 840**	**3100 – 4300**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**710 – 810**	**3600 – 4100**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4600 – 5800**	**23000 – 30000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	**NA**	**NA**	**19000 – NA**	**RES**
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	170	230	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**4600 – 5800**	**23000 – 30000**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000 – NA	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-27

ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS DEPTH TO GROUNDWATER[a] RANGING FROM 3 m TO 10 m

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**170 – RES**	**230 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Protection of GW for Livestock	**4200 – RES**	**10000 - RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	170 – RES	230 - RES	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	**610**	**3100**	**NA**	**NA**
	Vapour Inhalation (indoor, basement)	**710**	**3600**	**NA**	**NA**
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**170 – RES**	**230 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**170 – RES**	**230 - RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	RES	RES	NA	NA
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.

NA – pathway not applicable for PHC fraction.
[a] varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-28
ILLUSTRATIVE SOIL QUALITY GUIDELINES (mg/kg) FOR PHC IN FINE-GRAINED SURFACE SOILS DISTANCE TO GROUNDWATER RECEPTORS[a] RANGING FROM 0 m TO 500 m

LAND USE	PATHWAY	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Agricultural	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**170 – RES**	**230 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	3.3 – RES	3.9 – RES	NA	NA
	Protection of GW for Livestock	4200 – RES	10000 – RES	NA	NA
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Residential	Direct Exposure (Combined)	12000	6800	15000	21000
	Protection of Potable GW	**170 – RES**	**230 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Protection of GW for FAL	**3.3 – RES**	**3.9 – RES**	**NA**	**NA**
	Ecological Soil Contact	210	150	1300	5600
	Management Level	800	1000	3500	10000
Commercial	Direct Exposure (Combined)	19000	10000	23000	RES
	Protection of Potable GW	**170 – RES**	**230 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	**3.3 – RES**	**3.9 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES
Industrial	Direct Exposure (Combined)	RES	RES	RES	RES
	Protection of Potable GW	**170 – RES**	**230 – RES**	**NA**	**NA**
	Vapour Inhalation (indoor, slab-on-grade)	4600	23000	NA	NA
	Protection of GW for FAL	**3.3 – RES**	**3.9 – RES**	**NA**	**NA**
	Ecological Soil Contact	320	260	2500	6600
	Management Level	800	1000	5000	10000
	Offsite Migration	NA	NA	19000	RES

RES – Residual PHC formation. Calculated value exceeds 30 000 mg/kg and solubility limit for PHC fraction.
NA – pathway not applicable for PHC fraction.

[a] distance to surface water (FAL), potable water user and livestock watering. .
Values in **bold** denote scenarios that are significantly different from the default case.

TABLE D-29
SUMMARY OF ILLUSTRATIVE EFFECTS OF SELECTED TIER 2 ADJUSTMENTS
COARSE-GRAINED SOILS (mg/kg)[a]

PARAMETER AND RANGE	LAND USE	F1 $(C_6 - C_{10})$	F2 $(C_{>10} - C_{16})$	F3 $(C_{>16} - C_{34})$	F4 $(C_{>34} - C_{50})$
Default Values	A	30	150	300	2800
	R	30	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Vapour Permeability Ranging from 10^{-8} cm^2 to 10^{-6} cm^2	A	20 – 5 [c]	96 – 26 [b, c]	300	2800
	R	20 – 5 [c]	96 – 26 [b, c]	300	2800
	C	180 – 50 [c]	260 – 250 [b]	1700	3300
	I	180 – 50 [c]	260 – 250 [b]	1700	3300
Moisture Content Ranging from 0.03 g/g to 0.15 g/g	A	20 – 100 [b]	120 – 150 [b]	300	2800
	R	20 – 100 [b]	120 – 150 [b]	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Soil Bulk Density Ranging from 1.5 g/cm^3 to 1.8 g/cm^3	A	20 – 30	130 – 150 [b]	300	2800
	R	20 – 30	130 – 150 [b]	300	2800
	C	240 – 230	260	1700	3300
	I	240 – 230	260	1700	3300
Organic Carbon Fraction Ranging from 0.0005 g/g to 0.007 g/g	A	4.7 – 40 [b]	3.9 – 150 [b]	300	2800
	R	4.7 – 40 [b]	3.9 – 150 [b]	300	2800
	C	4.7 – 320 [b]	3.9 – 260 [b]	1700	3300
	I	4.7 – 320 [b]	3.9 – 260 [b]	1700	3300
Hydraulic Conductivity Ranging from 32 m/y to 3200 m/y	A	30	150 – 67 [b]	300	2800
	R	30	150 – 67 [b]	300	2800
	C	160 – 36 [b, c]	210 – 67 [b, c]	1700	3300
	I	160 – 36 [b, c]	210 – 67 [b, c]	1700	3300
Groundwater Recharge Ranging from 0.005 m/y to 0.5 m/y	A	30	150	300	2800
	R	30	150	300	2800
	C	320 – 220 [b]	260	1700	3300
	I	320 – 220 [b]	260	1700	3300
Hydraulic Gradient Ranging from 0.001 to 0.1	A	30	150 – 94 [b]	300	2800
	R	30	150 – 94 [b]	300	2800
	C	110 – 97 [b, c]	150 – 94 [b, c]	1700	3300
	I	110 – 97 [b, c]	150 – 94 [b, c]	1700	3300
Site Length Ranging from 5 m to 30 m	A	30	150	300	2800
	R	30	150	300	2800
	C	240 – 220	260	1700	3300
	I	240 – 220	260	1700	3300
Depth/Distance to Contamination Ranging from 0 m to 10 m Below Grade[d]	A	30 – 150 [b]	150	300	2800
	R	30 – 150 [b]	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Depth to Groundwater[e] Ranging from 3 m to 10 m	A	30	150	300	2800
	R	30	150	300	2800
	C	240	260	1700	3300
	I	240	260	1700	3300
Distance to Groundwater Receptors[f] Ranging from 0 m to 500 m	A	4.2 – 30 [b]	5.3 – 150 [b]	300	2800
	R	4.2 – 30 [b]	5.3 – 150 [b]	300	2800
	C	4.2 – 320 [b]	5.3 – 260 [b]	1700	3300
	I	4.2 – 320 [b]	5.3 – 260 [b]	1700	3300

a – all results assume that all pathways are active, including groundwater and surface water pathways
b – governing pathway changes

c – both ends of range are less than default value, due to parameter having opposite effects on the protection of potable groundwater and the protection of groundwater for aquatic life pathways
d – minimum 30 cm separation between contamination and building foundation assumed
e – varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m
f – distance to surface water (FAL), potable water user and livestock watering

A – agricultural R – residential C – commercial I – industrial

TABLE D-30

SUMMARY OF ILLUSTRATIVE EFFECTS OF SELECTED TIER 2 ADJUSTMENTS FINE-GRAINED SOILS (mg/kg)[a, b]

PARAMETER AND RANGE	LAND USE	F1 (C_6 - C_{10})	F2 ($C_{>10}$ - C_{16})	F3 ($C_{>16}$ - C_{34})	F4 ($C_{>34}$ - C_{50})
Default Values	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Vapour Permeability Ranging from 10^{-12} cm^2 to 10^{-8} cm^2	A	170 – 20 [b]	150 – 87 [b]	1300	5600
	R	170 – 20 [b]	150 – 87 [b]	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Moisture Content Ranging from 0.07 g/g to 0.16 g/g	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Soil Bulk Density Ranging from 1.3 g/cm^3 to 1.6 g/cm^3	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Organic Carbon Fraction Ranging from 0.0005 g/g to 0.03 g/g	A	22 – 210 [b]	25 – 150 [b]	1300	5600
	R	22 – 210 [b]	25 – 150 [b]	1300	5600
	C	22 – 320 [b]	25 – 260 [b]	2500	6600
	I	22 – 320 [b]	25 – 260 [b]	2500	6600
Hydraulic Conductivity Ranging from 0.032 m/y to 32 m/y[c]	A	71 – 170	95 – 150 [b]	1300	5600
	R	71 – 170	95 – 150 [b]	1300	5600
	C	71 – 170	95 – 230	2500	6600
	I	71 – 170	95 – 230	2500	6600
Groundwater Recharge Ranging from 0.005 m/y to 0.5 m/y	A	210 – 130 [b]	150	1300	5600
	R	210 – 130 [b]	150	1300	5600
	C	320 – 130 [b]	260 – 170 [b]	2500	6600
	I	320 – 130 [b]	260 – 170 [b]	2500	6600
Hydraulic Gradient Ranging from 0.001 to 0.1	A	77 – 210 [b]	100 – 150 [b]	1300	5600
	R	77 – 210 [b]	100 – 150 [b]	1300	5600
	C	77 – 220	100 – 260 [b]	2500	6600
	I	77 – 220	100 – 260 [b]	2500	6600
Site Length Ranging from 5 m to 30 m	A	200 – 120	150	1300	5600
	R	200 – 120	150	1300	5600
	C	200 – 120	260 – 170	2500	6600
	I	200 – 120	260 – 170	2500	6600
Depth/Distance to Contamination Ranging from 0 m to 10 m Below Grade[d]	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Depth to Groundwater[e] Ranging from 3 m to 10 m	A	170	150	1300	5600
	R	170	150	1300	5600
	C	170	230	2500	6600
	I	170	230	2500	6600
Distance to Groundwater Receptors[f] Ranging from 0 m to 500 m	A	3.3 – 210 [b]	3.9 – 150 [b]	1300	5600
	R	3.3 – 210 [b]	3.9 – 150 [b]	1300	5600
	C	3.3 – 320 [b]	3.9 – 260 [b]	2500	6600
	I	3.3 – 320 [b]	3.9 – 260 [b]	2500	6600

a – all results assume that all pathways are active, including groundwater and surface water pathways
b – governing pathway changes
c – hydraulic conductivity of less than 32 m/y may result in insufficient yield for a domestic water well or livestock water supply
d – minimum 30 cm separation between contamination and building foundation assumed
e – varying the depth to groundwater from 3 m to 10 m results in a depth from contamination to groundwater of 0 m to 7 m
f – distance to surface water (FAL), potable water user and livestock watering
A – agricultural R – residential C – commercial I – industrial

TABLE D-31
ILLUSTRATIVE SOIL VAPOUR LEVELS
(mg/m^3)[a]

		F1	F2
Coarse Soils	Agricultural	5600	1100
	Residential	5600	1100
	Commercial	50 000	10 000
	Industrial	50 000	10 000
Fine Soils	Agricultural	66 000	14 000
	Residential	66 000	14 000
	Commercial	490 000	110 000
	Industrial	490 000	110 000

a – based on a minimum depth of 1 m below the building foundation, default soil properties, and the vapour phase mass fractions summarized in Table B-4

APPENDIX E: ROLE OF PROBABILISTIC RISK ASSESSMENT

E.1 Introduction

Human health and ecological risk assessments may be carried out using deterministic or probabilistic methods. Deterministic methods involve the use of a single "point estimate" value for each input assumption and the completion of a single computational process to yield a point estimate of risk or remedial objective (Richardson, 1996). Input parameters may be mean values, worst case estimates or values representative of "reasonable maximum exposure" conditions. In probabilistic methods, key input assumptions are assigned probability distributions, and a form of Monte Carlo simulation is conducted whereby multiple iterations of the computational process are conducted using parameters randomly sampled from the defined input distributions. The results of the simulations generate a probability distribution of the output variable (risk or remedial objective) from which basic statistical information can be obtained. The results represent a measure of the variability in the risk estimate or remedial objective arising from uncertainty or natural variability in the input assumptions (Richardson, 1996).

While probabilistic methods have been used for guideline development by certain jurisdictions the PHC CWS Tier 1 values were developed deterministically in accordance with available protocols (CCME 1996a, 2006) and with Canadian federal regulatory practice. Probabilistic methods are becoming increasingly widely used in Canada for site-specific risk assessment, particularly for human health assessment, although no detailed guidance for the incorporation of the results of probabilistic risk assessment into regulatory decision making has been established. The provision of specific guidance for probabilistic analysis, like site-specific risk assessment, is beyond the scope of this document. However, the purpose of this section is to highlight certain aspects of each method and discuss some of the differences, such that the user may apply and interpret the results of the approach in the appropriate context.

E.2 Deterministic Assessment and the Development of PHC CWS Tier 1 Levels

Risk assessments carried out for regulatory purposes in Canada have traditionally employed mean values of key variables, particularly those related to human exposure factors or receptor characteristics, in order to determine the approximate average or 'typical' level of exposure or risk to the population. In the United States, on the other hand, deterministic risk assessments historically made use of near-worst case assumptions. The potential for over-conservatism resulting from the compounding of near-worst-case assumptions has been one of the driving factors in the trend towards probabilistic risk assessment in the last five years. Risk assessments used for the development of guidelines such as remediation objectives are often intended to be applicable to a broad range of site conditions, in order to be applicable to a majority of sites, while still being based on average levels of human exposure. As a result, deterministic risk assessments do not necessarily apply consistent degrees of conservatism, and the level of protection is therefore not always quantifiable.

The Tier 1 levels of the PHC CWS were developed using deterministic application of the algorithms and models described in the Scientific Rationale (CCME, 2000a) and Appendix C. Single point estimate values were used for all input variables, although the basis for the selection of the values varied between different categories of input parameters. Human exposure factors are average values, being taken for the most part as the means of the distributions compiled by Richardson (1997). Physical site conditions, mainly soil and groundwater parameters, tend towards the more conservative end of the range of possible values but are not necessarily worst case values. Building details, applicable to the indoor vapour inhalation pathway, are typical values for given building types. For ecological exposure, the modeling of indirect pathways makes use of conservative assumptions regarding physical conditions and fate and transport. Direct ecological exposure, and toxicity for both direct and indirect exposure, are based where possible on lower quartile or median effects data in accordance with CCME protocol (CCME 1996a, 2006).

The logic behind the use of conservative values for physical site conditions is that the resulting Tier 1 objectives are likely to be protective at a large majority of sites. Furthermore, the opportunity for site-specific adjustments at Tier 2 provides a means of reducing the uncertainty and conservatism in the generic objectives when applied to a set of known conditions. The resulting objectives are thus based on a reasonable exposure scenario that is protective for the environmental pathways of concern at the site in question, albeit combined with conservative toxicity parameters.

E.3 Probabilistic Assessment

In probabilistic risk assessment, probability distributions are used to represent parameters that have significant variability or uncertainty. For example, human exposure factors such as body weight, inhalation rate etc., can be described by probability density functions for the population as a whole or for subgroups thereof. Also, physical site parameters in which there is uncertainty can be expressed in terms of probability distributions. However, the distributions used for site-specific risk assessment would be different from those used to represent variation between sites in the derivation of generic objectives. In the former case the distribution would be used to describe variability across a site and/or uncertainty in the measurement of key parameters.

One of the major benefits of probabilistic risk assessment, from a regulatory perspective, is that remediation objectives can be established that are likely to be protective in a defined percentage of cases. For example, remediation guidelines may be based on the 90th percentile of the risk distribution, or the 10th percentile remedial objective corresponding to the target level of risk. The selection or acceptance of an appropriate percentile, and hence level of protection, would normally be a jurisdictional issue. The use of mean values for exposure factors in the derivation of the deterministic Tier 1 PHC CWS values would be equivalent to the use of the mean of the probability distribution of risk, if the latter was primarily a function of variability in exposure factors.

E.4 Application of Probabilistic Risk Assessment at Tiers 2 and 3

Probabilistic risk assessment is not advocated at Tier 2, for a number of reasons. First, the concept of a Tier 2 adjustment is the substitution of one or more site-specific parameters into the algorithm or model used in the derivation of Tier 1. The process is intended to be simple and transparent. Probabilistic assessment is not amenable to the establishment of a "calculation trail" leading to the derived objective, and thus could obscure the Tier 2 adjustment process.

Furthermore, the parameters incorporated in Tier 1, both adjustable and non-adjustable at Tier 2, are already expressed as single point values, and redefining them as distributions is not envisioned at this stage. Finally, the level of protection (i.e. mean or average exposure) has to be the same; thus a result based on the mean of a probabilistic distribution would not deviate significantly from one based on deterministic analysis.

The use of a probabilistic approach for site-specific risk assessment at Tier 3 may offer some important advantages. For instance, since one purpose of a site-specific risk assessment is to increase the accuracy of exposure estimates, explicit consideration of uncertainty in some parameters will offset the need for conservatism. An example of this is that with sufficient soil sampling and analysis, a statistical description of soil PHC concentrations may be used instead of a worst case or maximum value.

Another advantage is that a probability distribution of risk can be useful with respect to cost-benefit analysis of risk management options, such as in evaluating the increase in level of protection associated with a reduction in PHC concentration, or in assessing the value of additional site information in reducing uncertainty. Furthermore, different subpopulations and health or ecological protection goals may be considered where ongoing management at Tier 3 is contemplated. Probabilistic risk assessment can also provide useful insight for the purpose of risk communication.

Therefore probabilistic risk assessment is considered viable at Tier 3 and would be accommodated within the PHC CWS framework. To obtain a representative probabilistic estimate of risk, or derivation of a remedial objective, all key variables should be assigned representative distributions where appropriate. In some cases this may result in greater conservatism with respect to a parameter than if a single point estimate were used, but the overall variation in risk would take into account the variability of all influential parameters. Some jurisdictions may not accept probabilistic treatment of toxicity values. Correlated variables should be linked in the probabilistic analysis. Ultimately, the application of probabilistic risk assessment to Tier 3 risk management will require approval and acceptance of the jurisdiction, particularly with respect to the interpretation of the assessment and level of protection implied.

Guidance for conducting probabilistic risk assessment may be found elsewhere (e.g. US EPA, 2001; Health Canada, 2006).