INTRODUCTION

In 2006, the Canadian Council of Ministers of the Environment (CCME) published a revised and updated version of A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME 2006). The following is a brief summary of the revised document.

Canadian Soil Quality Guidelines

Interim Canadian environmental quality criteria for contaminated sites were established by CCME for defined land uses by adopting existing criteria for soil and water used by various jurisdictions in Canada (see CCME 1991). Many of the interim criteria for soil were based on professional judgment, and have since been revised based on current scientific information using the procedures described in the original version of the soil protocol (CCME 1996a). The new Canadian soil quality guidelines (as they are now called, instead of criteria) have been derived specifically for protection of the ecological receptors in the environment and/or for the protection of human health associated with the identified land uses.

The use and interpretation of the terms guidelines, objectives, and standards vary among different agencies and countries. CCME publications about the National Contaminated Sites Remediation Program prior to 1996 used the term soil criteria. This term has since been replaced by guidelines for consistency with other environmental media (water, sediments, etc.). For the purpose of this document, these terms are defined as follows:

Canadian Environmental Quality Guidelines
Canadian Council of Ministers of the Environment, 2007
PROTOCOL SUMMARY

Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health

Guidelines - Numerical limits or narrative statements recommended to support and maintain designated uses of the soil environment.

Objectives - Numerical limits or narrative statements established to protect and maintain designated uses of the soil environment at a particular site.

Standards - Guidelines or objectives recognized in enforceable environmental control laws of one or more levels of government.

What is the Soil Protocol?

The soil protocol was originally developed by the Subcommittee on Environmental Quality Guidelines for Contaminated Sites, and subsequently revised and updated by the Soil Quality Guidelines Task Group, to provide a method for replacing the interim remediation criteria for soil with scientifically defensible generic guidelines accounting for both scientific and management considerations. It provides stakeholders (i.e., the public, industry, and regulatory agencies) with the basic concepts and methods employed in generic guideline development (CCME 2006).

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

It is recognized that contaminants are likely to occur in mixtures. However, not enough is known about most contaminant mixtures at this time to routinely consider them in the guideline derivation process, though some guidelines have been developed for commonly-occurring mixtures of chemicals with closely related physical-chemical properties and toxicology.

Guiding Principles

Soil is a complex heterogeneous medium consisting of variable amounts of minerals, organic matter, water, and air that is capable of supporting organisms, including plants, bacteria, fungi, protozoans, invertebrates, and other animal life. Ideally, soil at the guideline levels will provide a healthy functioning ecosystem capable of sustaining the current and likely future uses of the site by ecological receptors and humans.

Protecting the Environment

To protect the terrestrial ecosystem, the derivation process outlined in the soil protocol considers the adverse effects resulting from direct contact exposure to soil-based contaminants as well as those resulting from ingestion of contaminated soil and food. Indirect exposure via use of contaminated groundwater for agricultural purposes and migration to nearby surface water bodies are also considered, as is the migration of contaminants to more sensitive nearby properties due to wind and water erosion. Potential exposure pathways, receptor arrays, and exposure scenarios are assumed for major land uses. Based on these exposure scenarios, ecological receptors that sustain the primary activities for each land use category are identified.

A literature review is conducted to determine the environmental fate and behaviour of the contaminant as well as its toxicity in soil. A standard procedure is used to derive an effects-based soil quality guideline for soil-dependent organisms (i.e., invertebrates, plants and microbes) from acceptable toxicity data. For higher trophic level consumers (i.e., livestock and terrestrial wildlife), pathways have been identified to derive environmental quality guidelines that consider the ingestion of contaminated soil and food. Groundwater pathways are evaluated by modelling the partitioning of contaminants into soil pore water and subsequent dilution in a groundwater aquifer; lateral transport is also considered in the case of transport to nearby surface water.

Protecting Human Health

Human health soil quality guidelines provide concentrations of contaminants in soil at or below which no appreciable human health risk is expected. To protect human health, derivation processes for threshold and non-threshold toxicants (i.e., carcinogens or germ cell mutagens) are differentiated, taking into account daily background exposure from air, water, soil, food, and consumer products. Indirect exposure pathways resulting from contaminated soils, such as contaminated groundwater, contaminated meat, milk, and produce, infiltration into indoor air, and wind erosion resulting in deposition on neighbouring property are also considered during the derivation of human health guidelines. These
indirect exposure pathways are evaluated conservatively by applying simplified transport and redistribution models using generic site characteristics in a variety of site conditions.

Key components of the risk-based generic human health guidelines include an assessment of multimedia background exposure unrelated to contaminated sites and a generic human exposure scenario relevant to each land use. In the multimedia exposure assessment, total background exposure by all sources (i.e., air, water, food, soil, and consumer products when appropriate) and all exposure routes (i.e., inhalation, ingestion, and skin absorption) is estimated. The human health soil quality guidelines are established after accounting for this background exposure to ensure that the total tolerable contaminant intake is not exceeded.

**Land Use**

Generic guidelines are derived to protect human and key ecological receptors that sustain normal activities on four land use categories: agricultural, residential/parkland, commercial, and industrial. Generic land use scenarios are envisioned for each category based on how the land is used and on how sensitive and dependent the activity is on the land. Sensitivity to contamination increases among ecological or human health components most dependent on land use activities (i.e., agricultural and residential/parkland).

The definition of each land use accommodates generic conditions and puts boundaries on the receptors and exposure pathways considered in guideline derivation for that land use. The four defined land uses are as follows:

- **agricultural** — where the primary activity is growing crops or tending livestock and includes agricultural land providing habitat for resident and transitory wildlife as well as native flora, as well as farm residences;
- **residential/parkland** — where the primary activity is residential or recreational activity; parkland is defined as a buffer zone between areas of residency and campground areas, and excludes wild lands such as national or provincial parks;
- **commercial** — where the primary activity is commercial (e.g., shopping mall), not residential or manufacturing and does not include zones where food is grown;
- **industrial** — where the primary activity involves the production, manufacture, or construction of goods, and public access to the property is restricted.

Key biological receptors and exposure pathways were identified for each land use to protect soil quality and maintain activities performed on these lands. Recognizing differences in analyzing human health and ecological issues, soil quality guidelines for each chemical are developed for both ecological and human receptors. For each of the four land uses, to protect both human health and the environment, the most protective guideline is chosen as the soil quality guideline.

**Soil Type**

The protocol recognizes that contaminant fate and transport, as well as bioavailability, are dependent to varying degrees on soil texture, moisture content and other factors. To minimize the uncertainty in guideline derivation introduced by soil variability, the protocol considers two generic soil types: coarse-textured soils (sand and gravel), defined as soils with a median grain size of 75 microns or greater, and fine-textured soils (silt and clay), defined as soils with a median grain size less than 75 microns.

Where there are sufficient data available, separate guidelines are developed for both coarse and fine-textured soils.

**USE OF CANADIAN SOIL QUALITY GUIDELINES**

Canadian soil quality guidelines derived using the soil protocol replace corresponding interim environmental quality criteria for contaminated sites (CCME 1991), if applicable. This set of guidelines represents “clean down to levels” at contaminated sites and not “pollute up to levels” for less contaminated sites. Like the interim criteria, these effects-based guidelines are for contaminated site assessment and remediation and should not be used to manage pristine sites or directly evaluate soil amendments prior to their addition to soil. The new generic guidelines are intended to provide a high level of protection for designated land uses and are considered broadly applicable to Canadian soils (CCME 2006).

Canada has adopted a three-tiered approach for dealing with contaminated site assessment and remediation (Figure 1). The first tier is the direct adoption of Canadian soil quality guidelines. However, the fact that some sites might present particular conditions (e.g., high natural background concentrations, complex mixtures of contaminants, or unusual exposure scenarios) must also be considered. For these sites, the second tier allows limited
modification of Canadian soil quality guidelines by setting site-specific objectives (CCME 1996b). Finally, the third tier uses risk assessment procedures to establish remediation objectives at contaminated sites on a site-specific basis (CCME 1996c).

ENVIRONMENT

The guideline derivation process focuses on the effects of chemical stressors on the biotic component of a terrestrial ecosystem. Specifically, it evaluates the potential for adverse effects to occur from exposures to soil-based contaminants at point-of-contact or by indirect means (i.e., food chain transfer, contamination of groundwater or surface water, or offsite migration). Adverse effects data may come in a variety of forms, ranging from data collected in the field (e.g., mesocosm studies) to single species tests performed in the laboratory (i.e., using bioassays). Specific land uses are studied, and guidelines based on the availability of terrestrial toxicity information are developed.

Level of Ecological Protection and Relevant Endpoints

The level of protection provided by the guidelines depends on the protection goals sought for individual land use categories. Therefore, for agricultural and residential/parkland land uses, it is necessary to achieve a level of ecological functioning that sustains the primary activities associated with these land uses.

On commercial and industrial lands, the primary land use activities are not directly dependent on the need to sustain a high level of ecological processes. The same key ecological receptors and endpoints examined for agricultural and residential/parkland land uses are also examined for commercial and industrial land uses. However, the level of protection for commercial and industrial land uses is reduced to correspond with the lower protection levels required by these land use categories.

Despite the different levels of protection, an important common principle exists for all land use categories. The level of ecological protection provided by the soil quality guidelines ensures that the remediated land has the potential to support most activities likely to be associated with each land use.

In developing Canadian environmental soil quality guidelines (SQG), only the endpoints related to the “direct effects” of chemical stressors to receptors are examined, and these do not account for the “indirect effects” (e.g., avoidance of polluted food items) that may occur from sublethal exposures. In terrestrial toxicity testing, most studies have focused on mortality (LC50) as a short-term endpoint and on reproduction, growth, development, behaviour, activity, lesions, physiological changes, respiration, nutrient cycling, contribution to decomposition, genetic adaptation, and physiological acclimatization as long-term, sublethal endpoints such as the effective concentration 50 (EC50), no observed effects concentration (NOEC), and lowest observed effects concentration (LOEC) (SECOFASE 1993). In recent years, more data have become available using regression-based endpoints (e.g., ECx), including endpoints for low-level effects such as the EC20 or EC25.
Environmental soil quality guidelines rely on sensitive measurement endpoints for key receptors that act as “predictive sentinel species”. Extrapolation to assessment endpoints is therefore restricted to the population level, since single species measurements of endpoint data are used in guideline derivations. Information from laboratory studies must involve endpoints critical to the maintenance of a species, such as mortality, reproduction, and growth, which are required to complete a normal life cycle and to produce viable offspring. Studies showing damage or visible injury to ornamental plants are also considered, since the healthy appearance of these plants is of importance to many property owners. Guidelines are, when possible, based on long-term toxicity tests following standard methodologies, rather than less-sensitive acute exposure tests; uncertainty factors may be required if short-term tests are used.

**Exposure Pathways and Key Receptors According to Land Use**

The maintenance of primary ecological functions is usually required for most land use activities (except some commercial and industrial processes). The receptor and exposure scenarios for agricultural, residential/parkland, commercial, and industrial land uses are shown in Table 1. Additional land uses are possible, and may be specified by CCME or regulatory jurisdictions or addressed on a site-specific basis.

<table>
<thead>
<tr>
<th>Route of Exposure</th>
<th>Agricultural</th>
<th>Residential/ Parkland</th>
<th>Commercial</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and Food Ingestion</td>
<td>Herbivores, Secondary and Tertiary Consumers*</td>
<td>Herbivores*, Secondary and Tertiary Consumers*</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Ingestion of Contaminated Water</td>
<td>Livestock</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Contact with Contaminated Water</td>
<td>Freshwater Life, Crops (irrigation)</td>
<td>Freshwater Life</td>
<td>Freshwater Life</td>
<td>Freshwater Life</td>
</tr>
</tbody>
</table>

Note: *a – Herbivores (residential/parkland) and Secondary and Tertiary Consumers (agricultural and residential/parkland) are considered for substances that bioaccumulate and/or biomagnify.
Agricultural Land Use

Although agricultural land use varies, the development of SQG_E must protect key receptors that permit or maintain crop growth and livestock production against adverse effects. Protection must also be offered to resident and transitory wildlife and native flora because in some areas (e.g., agroecosystems) this may be the only viable habitat for these organisms.

Sufficient toxicological information exists to consider soil contact by microbes (and their effect on nutrient cycling), soil invertebrates (e.g., decomposers), crops and plants (e.g., seeds and roots) in the derivation of soil guidelines for the protection of crop and plant growth. Root uptake and accumulation of contaminants by crops grown on site and used as feed or by native flora used as pasture must also be examined when they relate to livestock and wildlife ingestion scenarios. For substances which may biomagnify in the food chain, ingestion by secondary and tertiary consumers is also evaluated.

Groundwater and surface water exposure pathways are evaluated based on groundwater modelling and published water quality guidelines. In the absence of published water quality guidelines, target concentrations in groundwater may be derived based on available toxicological data.

Residential/Parkland Land Use

The development of SQG_E for residential/parkland land use, like that for agricultural land use, must ensure that the soil is capable of sustaining soil-dependent species and does not adversely affect wildlife from direct soil contact. The soil guidelines must also be protective of freshwater life in nearby surface water bodies. Uptake into the food chain is also considered for substances which may biomagnify.
Commercial and Industrial Land Use

Commercial and industrial land use SQG_E will be derived for direct soil contact by soil-dependent biota and wildlife and will offer the same level of protection for both land activities. Consequently, the same SQG_E will be provided for both commercial and industrial land uses.

On commercial and industrial lands, activities may not rely on key ecological receptors to the same degree as agricultural and residential/parkland land uses. Therefore, SQG_E developed for commercial and industrial land use will not offer the same level of protection from adverse effects as those for agricultural and residential/parkland land uses. Protection of freshwater life in nearby surface water bodies is considered for the commercial and industrial guidelines, as is potential migration of contaminated soil to more sensitive neighbouring properties.

Derivation of Environmental Soil Quality Guidelines

The general process for deriving SQG_E is summarized in Figure 2. For each contaminant, an extensive literature search of all published and non-proprietary data is conducted to obtain information on physical and chemical properties, sources and emissions, distribution in the environment, environmental fate and behaviour, short- and long-term toxicity, and existing guidelines, standards, and criteria.

Because the quality of soil toxicity information is variable, toxicological data obtained from the literature are screened to ensure that studies selected will provide scientifically verified information. Candidate data are screened to determine if they can be used in the derivation of SQG_E. Acceptable data are referred to as “selected”, whereas other data are referred to as “consulted”. All the information regarding the ecological toxicity data for a specific chemical can be found in the supporting documents available from either the National Guidelines and Standards Office of Environment Canada or CCME.

After compilation, review, and evaluation of the available information, selected data fulfilling the minimum toxicological data requirements specified for each of the procedures are used to derive SQG_E. Minimum data requirements are designed to ensure guidelines are derived based on effects data from a variety of organisms (CCME 2006). In situations where there is a strong weight of evidence to suggest that the minimum data requirements do not apply, professional judgment may be used to derive an SQG_E based on a single class of organism (e.g., when scientific evidence suggests that a single organism group is the most threatened).

Soil Quality Guidelines for Soil Contact

The following section summarizes the methods for deriving environmental soil quality guidelines that apply to all four land uses and that are based on soil contact by soil-dependent organisms. For more details on these derivation methods, see the soil protocol (CCME 2006). The derivation methods for soil quality guidelines for soil contact (SQG_SC) are presented in order of preference. When minimum data are not available for a particular method, a measure of conservatism is added to each subsequent method to account for the inherent uncertainties of deriving guidelines from a less preferable data set. Uncertainty factors may also be applied in some cases if available toxicity data reflect mainly low bioavailability conditions. An overview of the derivation procedure for SQG_SC is provided in Figure 3.

Weight of Evidence Method

The weight of evidence method is a modification of an approach used for calculating sediment quality guidelines for the National Status and Trends Program (Long and Morgan 1990) and an approach proposed by CCME (CCME 1995) for deriving Canadian sediment quality guidelines. These methods use a percentile of the effects data set, or combined effects and no effects data set, to estimate a concentration in the sediment expected to cause no adverse biological effects. The approach was further refined during the development of the Canada-Wide Standard for Petroleum Hydrocarbons in Soil (CCME, 2001), utilizing EC_X endpoints instead of effects and no effects data.

The preferred approach is to use the 25th percentile of the compiled EC_{25} effects-endpoints data distribution (the “estimated species sensitivity distribution - 25th percentile, or ESSD_{25}), which is then divided by an uncertainty factor in order to derive the threshold effects concentration (TEC) for agricultural and residential/parkland land uses. The 50th percentile of the EC_{25} data distribution is selected as the effects concentration low (ECL) for commercial and industrial land uses.

The TEC represents the concentration of a contaminant in soil at which only minimal effects on ecological function would be observed, and is considered to be an appropriate level of protection for guidelines for the agricultural and
residential/parkland land uses. The ECL represents a concentration of a contaminant in soil at which only a low level of adverse effects would be expected to occur in less than half of the species in the terrestrial community; this is considered to be an appropriate level of protection for commercial and industrial land uses.

In the event that EC<sub>25</sub> values cannot be determined for a sufficient number of toxicity studies, but all other data requirements of the weight-of-evidence approach are met (CCME 2006), then the available “effects” and “no observed effects” data can be compiled. The 25<sup>th</sup> percentile of the combined effects and no observed effects data is chosen as the ESSD<sub>25</sub>, which is divided by an uncertainty factor to derive the TEC. The 50<sup>th</sup> percentile of the data distribution of effects and no observed effects data is selected as the ECL.

**Lowest-Observed-Effect Concentration Method**

When the minimum data requirements for the weight of evidence method cannot be met, the TEC for agricultural and residential/parkland land uses is derived by extrapolating from the lowest available LOEC divided by an uncertainty factor (if needed). In this method, the TEC is estimated to be somewhere below the lowest reported LOEC.

For commercial and industrial land uses, the LOEC method is slightly modified in order to account for the lower level of protection. Therefore, the ECL is derived using the geometric mean of the available LOEC data.

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**Figure 3: Procedure for Deriving Soil Quality Guidelines for Soil Contact for Agricultural and Residential/Parkland Land Use**

- PRGSC

Where: ESSD<sub>25</sub> = 25th percentile of estimated species sensitivity distribution, TEC = Threshold Effects Concentration, LOEC = Lowest Observed Effect Concentration, LC<sub>50</sub> = Median Lethal Concentration, EC<sub>50</sub> = Median Effects Concentration.
Median Effects Method

Alternatively, if the minimum data requirements cannot be met for the weight of evidence and LOEC methods, the TEC for agricultural and residential/parkland land uses is derived by extrapolating from the lowest available EC_{50} or LC_{50} using an uncertainty factor ranging from 5 to 10. In this method, the TEC is estimated in the region of predominantly no effects in the data distribution.

The median effects method is not recommended for guideline derivation for commercial and industrial land uses. Because uncertainty factors are not applied at the point of departure from the effects distribution, the ECL would therefore be estimated at a level of median effects, which is contrary to the level of protection desired at the level of the ECL.

Insufficient Data for Soil Contact Guideline Derivation

If minimum data requirements for the above methods cannot be met, then there is insufficient information to develop an SQG_{Fc} and, consequently, a final SQG_{F}. Data gaps will be identified for further research. It may be possible to develop a provisional SQG_{F}, as discussed under the Derivation of the Final Soil Quality Guidelines.

Developing Soil Quality Guidelines for the Protection of Nutrient and Energy Cycling

Soil processes such as decomposition, respiration and organic nutrient cycles are important components of the ecological function of soil. These processes may be affected by the presence of contaminants, and therefore should be considered in the development of soil quality guidelines.

CCME (2006) outlines the procedures for determining the soil quality guideline for the protection of nutrient and energy cycling (SQG\textsubscript{NEC}), which are very similar to those applied for the SQG_{Fc}. Since data are expected to be limited for this pathway, the SQG\textsubscript{NEC} is incorporated as a check mechanism; professional judgement should be used to decide whether the SQG\textsubscript{NEC} is applied when determining the SQG_{F}.

Derivation of Soil Quality Guidelines for Soil and Food Ingestion

The procedure for deriving soil quality guidelines for soil and food ingestion (SQG\textsubscript{I}) by grazing livestock and wildlife is used for agricultural land use, and, if the contaminant may biomagnify, for residential land use. This procedure also accounts for the consumption of contaminated forage via the accumulation of contaminants in the food chain. Exposure of secondary and tertiary consumers via the food chain is considered for substances which may biomagnify. Soil type does not normally affect guidelines developed for this pathway.

Determining the Daily Threshold Effect Dose

The first step in determining the daily threshold effect dose (DTED) for each applicable trophic level (primary, secondary and tertiary consumers) is to determine the species considered to be most at threat from contaminated soil and food ingestion. The most threatened species has the lowest ratio of reported LOAEL to dry matter ingestion rate (expressed as food ingested per kg body weight per day), considering a minimum of three studies. If minimum data requirements cannot be met when determining the DTED, then no SQG\textsubscript{I} shall be set.

The DTED is established by applying an uncertainty factor to the LOAEL for the most threatened species. Information is then gathered on the bioavailability and bioconcentration factor specific to the contaminant. The information gathered is used to calculate the SQG\textsubscript{I} as detailed in CCME (2006).

Calculation of Guidelines for Soil and Food Ingestion

Soil quality guidelines based on soil and food ingestion for primary consumers are calculated using the following equation:

\[
SQG_{Ic} = \frac{0.75 \times DTED_{Ic} \times BW_{Ic}}{(SIR_{Ic} \times BF) + (FIR_{Ic} \times BCF_{I})}
\]

where

- DTED\textsubscript{Ic} = daily threshold effects dose for primary consumer (mg·kg\textsuperscript{-1}·d\textsuperscript{-1})
- BW\textsubscript{Ic} = body weight of primary consumer (kg)
- SIR\textsubscript{Ic} = soil ingestion rate for primary consumer (kg·d\textsuperscript{-1})
FIR_{1C} = \text{food ingestion rate for primary consumer (kg·d}^{-1}\text{)}
BF = \text{bioavailability factor for soil}
BCF_1 = \text{bioconcentration factor in food of primary consumer (unitless)}

Calculations for secondary and tertiary consumers are performed using similar equations, as detailed in CCME (2006).

**Derivation of Soil Quality Guidelines for the Protection of Freshwater Life**

Contamination present in soil can migrate to groundwater. If there are surface water bodies (streams, rivers, lakes, etc.) nearby, then life in these surface water bodies may be affected by the contamination, particularly if there is a permeable aquifer connecting the contamination with the surface water body. The soil quality guideline for the protection of freshwater life (SQG_{FL}) is calculated using a groundwater dilution and transport model, as detailed in CCME (2006). A brief summary of the calculations is provided in Appendix A. This pathway is applied for all land uses, and the calculated guideline is independent of land use, though this pathway may be eliminated on a site-specific basis if there are no surface water bodies in the vicinity.

**Derivation of Soil Quality Guidelines for the Protection of Livestock Watering and Irrigation Water**

Contamination that migrates to groundwater may affect the water quality in dugouts or water wells used for livestock watering or crop irrigation. Therefore, soil quality guidelines for the protection of livestock watering (SQG_{LW}) and irrigation water (SQG_{IR}) are calculated for agricultural land use, using the procedure detailed in CCME (2006) and summarized in Appendix A.

**Derivation of Soil Quality Guidelines for Offsite Migration**

In deriving soil quality guidelines for commercial and industrial sites, SQGTG uses an exposure scenario which considers contact of ecological receptors with on-site soil only. However, wind and water erosion of soil and subsequent deposition can transfer contaminated soil from one site to another. In order to ensure that remediated commercial and industrial properties do not pose a risk to more sensitive properties nearby, the SQG_{OM-E} is determined as detailed in CCME (2006) and summarized in Appendix C, and applied as a check mechanism for commercial and industrial sites.

**Derivation of the Final Environmental Soil Quality Guidelines**

**Agricultural Land Use**

The SQG_E for each soil type (coarse-grained and fine-grained) is the lowest of the values calculated for all exposure pathways applicable for the contaminant (i.e., the lowest of the SQG_{SC}, SQG_{I}, SQG_{FL}, SQG_{LW} and SQG_{IR}). If there are insufficient data to evaluate all of the applicable pathways, the SQG_E can still be determined so long as the SQG_{SC} has been calculated; if the substance is known to biomagnify, the SQG_{I} is also required. If data are not available to derive the SQG_{SC} (or, for substances that biomagnify, the SQG_{I}), then no SQG_E shall be set, since it is assumed that these guidelines represent exposures by the most likely critical pathways. In this situation, data gaps will be identified for further research.

**Residential/Parkland Land Use**

For contaminants which do not bioaccumulate and/or biomagnify, the lower of the SQG_{SC} and SQG_{FL} for each soil type is used as the SQG_E for residential/parkland land use. For contaminants which bioaccumulate or biomagnify, the lower of the SQG_{SC}, SQG_{FL} and SQG_{I} is used as the SQG_E. The SQG_{SC} is a required pathway, and the SQG_E cannot be set if this pathway cannot be evaluated. If the substance is known to biomagnify, the SQG_{I} is also required. If no guideline can be set, then data gaps will be identified for further research.

**Commercial and Industrial Land Use**

The lower of the SQG_{SC} and the SQG_{FL} for each soil type is used as the SQG_E for commercial and industrial land use. The guideline may also be modified by the SQG_{OM-E}. If the SQG_{SC} cannot be determined, no guideline can be set, and data gaps will be identified for further research.

**HUMAN HEALTH**

The steps employed to derive Canadian soil quality guidelines based on human health are similar to those used for site-specific risk assessment and require that several basic assumptions be made in lieu of site-specific information. For a specified land use, a generic exposure
scenario was defined that details a sensitive receptor (toddler or adult), the reference characteristics of that receptor (weight, amount of soil and water ingested daily, exposure duration, etc.), and specific pathways of exposure.

Development of human health soil quality guidelines (SQG\textsubscript{HH}) involves consideration of a variety of potential exposure pathways: direct soil exposure (soil ingestion, dermal contact with soil, and inhalation of soil particulate), migration of soil contaminants into groundwater used for drinking water, and volatilization of contaminants into indoor air. Two additional “check mechanisms”, which may or may not be used to adjust the SQG\textsubscript{HH}, depending on professional judgement, are also evaluated: exposure from ingestion of food grown on contaminated soils, and offsite migration of contamination via wind and water erosion.

Input values for exposure variables depend on the assumptions for each land use scenario, as well as the soil type (coarse or fine-textured), and are summarized in CCME (2006).

Guiding Principles for Human Health Soil Quality Guidelines

The following guiding principles are retained for the derivation of generic SQG\textsubscript{HH} protective of human health in Canada.

1. There should be no appreciable risk to humans from a contaminated site. For each specified land use, there should be no restrictions as to the extent or nature of the interaction with the site. All activities normally associated with the intended land use should be free of any appreciable health risk.

2. Guidelines are based on defined, representative situations. Deriving numerical guidelines necessitates defining specific scenarios within which the exposure likely to arise on the site can be predicted with some degree of certainty.

3. Guidelines are derived by considering exposure through all relevant pathways. The total exposure from soil, air, water, and food is considered in the development of guidelines.

4. A critical human receptor is identified for each land use. To ensure that the guidelines do not limit the application of a site within the intended land use category, the defined exposure scenarios are usually based on the most sensitive receptor to the chemical, and the most critical health effect.

5. Guidelines should be reasonable, workable and usable. Guidelines are developed by applying scientifically derived information, backed by professional judgement where data gaps occur. Occasionally, defined exposure-based procedures produce numerical guidelines either far below background levels of contamination occurring naturally in the soil, or below practical quantitation limits. When this occurs, guidelines cannot be below background levels, and provisional guidelines should be established based on background soil concentrations.

Investigation of Contaminant Toxicology

Toxic effects from exposure to environmental contaminants may be classified as organ-specific, neurological/behavioural, reproductive/developmental, immunological, carcinogenic, and mutagenic. These effects can be manifested at the biochemical, cellular, histopathological, and morphological levels. Effects vary, depending on the dosage, route of exposure (e.g., ingestion, inhalation, or dermal contact), frequency and/or duration of exposure, species (and strain in the case of some organisms), physiological state, sex, and age of the exposed population. Toxicological effects from exposure to chemical substances may be brief or prolonged, reversible or irreversible, immediate or delayed.

Hazard assessment determines the health effect potentially attributable to a contaminant (e.g., carcinogenic, hepatotoxic, or teratogenic) and estimates the reference dose believed to be associated with a defined level of incidence of that effect in the population. For a threshold substance, exposure less than the reference dose should pose a zero probability of incidence of an adverse effect in the population. For a non-threshold substance (i.e., a carcinogen or a germ cell mutagen), the critical risk-specific dose is defined for risk levels. If both threshold and non-threshold toxicity reference values have been published, it may be necessary to evaluate both endpoints separately, as their relative sensitivity may vary with different exposure routes and scenarios.

Threshold Contaminants

Where possible, a concentration (or dose) of a chemical substance that does not produce any adverse effect (i.e., NO(A)EL) for the critical endpoint is identified, usually
from toxicological studies involving experimental animals, but sometimes from epidemiological studies of human populations. If a value for the NO(A)EL cannot be ascertained, a LO(A)EL is used, accounting for the critical effect.

Uncertainty factors are applied to the NO(A)EL or LO(A)EL to derive a tolerable daily intake (TDI) to which a person can be exposed daily over a lifetime without deleterious effect. Ideally, the NO(A)EL is derived from a lifetime (i.e., chronic) exposure study involving the most sensitive or relevant species or the most sensitive subpopulation (e.g., developmental studies) in which the route of administration in animal studies is similar to that by which humans are principally exposed. Relevant species are determined, where possible, based on data on species differences in pharmacokinetic parameters or mechanism of action.

TDIs are not generally developed on data from acute or short-term studies unless effects in longer-term studies are expected to be similar. Occasionally, TDIs are based on data from subchronic studies in the absence of available information from adequately designed and conducted chronic toxicity studies; an additional factor of uncertainty is included in this case. In some cases, where toxicity studies using the route of exposure by which humans are principally exposed cannot be identified, a NO(A)EL or LO(A)EL from a bioassay by another route of exposure may be used where appropriate, incorporating relevant pharmacokinetic data.

Non-threshold Contaminants

For non-threshold contaminants (currently restricted to mutagenesis and genotoxic carcinogenesis), some probability of harm to human health at any level of exposure is assumed. Consequently, it is not possible to determine a dose below which adverse effects do not occur. Therefore, mathematical models are used to extrapolate data on the exposure– or dose–response relationship derived from experimental studies in animal species or epidemiological studies (generally in workers) in order to estimate the cancer risk for concentrations to which the general population is exposed.

Wherever possible, and if considered appropriate by Health Canada, information on pharmacokinetics, metabolism, and mechanisms of carcinogenicity and mutagenicity is incorporated into the quantitative estimates of potency derived, particularly from studies in animals (to provide relevant scaling of potency for human populations).

Human exposure to non-threshold toxicants should be reduced to the lowest levels deemed reasonably feasible. Health Canada has determined the reference dose as the TDI for threshold substances and risk-specific doses (RSDs) associated with risks of $10^{-4}$, $10^{-5}$, $10^{-6}$, and $10^{-7}$ for non-threshold substances. $\text{SQG}_{\text{HH}}$s for non-threshold substances in Canadian soils are derived with a level of risk of both $10^{-5}$ and $10^{-6}$ for incremental risk from soil, consistent with the risk levels accepted by most Canadian regulatory jurisdictions.

**Estimated Daily Intake**

Canadians are exposed to background contamination in the air, soil, food, water and, in some cases, consumer products, which is quantified by the estimated daily intake (EDI) for a particular contaminant. The EDI estimates exposures via all known or suspected routes (inhalation, ingestion, and dermal contact). Because background exposure is present at all times, risks posed by a contaminated site must be determined in addition to this background exposure.

Where appropriate, information on concentrations of contaminants in specific localities may also be used to estimate background exposure of some high exposure subgroups in the general population. Relevant data on the duration and frequency of exposure as well as on the behaviour and activity patterns of individuals are also considered in the development of estimates of background exposure of the general population.

**Assumptions**

**About Exposure Scenarios**

$\text{SQG}_{\text{HH}}$s are based on a chronic exposure scenario (i.e., lifetime exposure to a remediated site). This conservative assumption helps ensure that no limitations will exist within the defined land use. Setting soil quality guidelines begins by working backward from the TDI or from the critical RSD for a contaminant through appropriate direct soil exposure pathways to a land use generic soil concentration.

The defined exposure scenario used in deriving the generic soil quality guidelines may not be appropriate for a particular site to be remediated. In such cases (e.g., camping sites), further guidance to allow modification of the generic guidelines within limits, through the setting of
site-specific objectives, has been developed and is presented in CCME (1996b).

**Threshold Contaminants**

No single medium should deplete the entire TDI or even the entire residual tolerable daily intake (RTDI). The RTDI is the difference between the TDI and the EDI (RTDI = TDI - EDI). Because people are exposed to five primary media (i.e., air, water, soil, food, and consumer products), 20% of the RTDI is, in the majority of cases, apportioned to each of these five media. Therefore, 20% of the RTDI accounts for soils when deriving soil remediation guidelines, allowing for 80% of the remaining tolerable incremental exposure to be reserved for other media. If defensible contaminant-specific data demonstrate that a contaminant does not occur in a given exposure medium, the RTDI may be distributed among the applicable media as detailed in CCME (2006).

**Non-threshold Contaminants**

In theory, low levels of background exposure occur for many carcinogens. However, the TDI and tolerable incremental exposure cannot be determined for carcinogens, as some level of risk is assumed to exist at any level of exposure other than zero. Therefore, Canadian environmental quality guidelines are derived based on an incremental risk (above background) of both \(10^{-5}\) and \(10^{-6}\) from remediated soils at the guideline concentration, consistent with the risk levels accepted by most Canadian regulatory jurisdictions.

**About Pathways, Receptors, and Land Uses**

The physical and chemical properties of a contaminant will determine its environmental fate and exposure pathways to humans. For example, the dermal exposure pathway will be of importance for lipophilic contaminants, which can readily cross the epidermal layer of the skin. Similarly, contaminants with a high vapour pressure, likely to volatilize from soil to air, are extremely important in the respiratory pathway.

Soil exposure pathways can result from direct or indirect exposure to soil. Direct exposure pathways include ingestion of soil/dust, dermal uptake of contaminants in contact with the skin, and inhalation of soil particles into the lungs.

The first step in the derivation of an SQG\(_{\text{HH}}\) considers all direct soil exposure pathways to obtain a direct human soil quality guideline (SQG\(_{\text{DH}}\)).

The second step in the derivation of an SQG\(_{\text{HH}}\) is the consideration of indirect soil exposure pathways based on simplified models using conservative generic input values for site-specific characteristics. The following indirect pathways are considered: contamination of groundwater used as potable water (Appendix A), contamination of

**Table 2. Receptors and exposure pathways considered in the derivation of human health soil quality guidelines.**

<table>
<thead>
<tr>
<th>Route of exposure</th>
<th>Agriculture</th>
<th>Residential/ parkland</th>
<th>Commercial</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive receptor</td>
<td>Toddler(^*)</td>
<td>Toddler(^*)</td>
<td>Toddler(^*)</td>
<td>Adult</td>
</tr>
<tr>
<td></td>
<td>Adult(^†)</td>
<td>Adult(^†)</td>
<td>Adult(^†)</td>
<td></td>
</tr>
<tr>
<td>Exposure period</td>
<td>24 hours per day, 365 days per year</td>
<td>24 hours per day, 365 days per year</td>
<td>10 hours per day, 5 days per week, 48 weeks per year</td>
<td>10 hours per day, 5 days per week, 48 weeks per year</td>
</tr>
<tr>
<td>Direct soil exposure pathways</td>
<td>Ingestion</td>
<td>Ingestion</td>
<td>Ingestion</td>
<td>Ingestion</td>
</tr>
<tr>
<td></td>
<td>Dermal contact</td>
<td>Dermal contact</td>
<td>Dermal contact</td>
<td>Dermal contact</td>
</tr>
<tr>
<td></td>
<td>Inhalation</td>
<td>Inhalation</td>
<td>Inhalation</td>
<td>Inhalation</td>
</tr>
<tr>
<td>Indirect soil exposure pathways</td>
<td>Groundwater</td>
<td>Groundwater</td>
<td>Groundwater</td>
<td>Groundwater</td>
</tr>
<tr>
<td></td>
<td>Indoor air</td>
<td>Indoor air</td>
<td>Indoor air</td>
<td>Indoor air</td>
</tr>
<tr>
<td></td>
<td>Produce, meat and milk ingestion</td>
<td>Backyard produce</td>
<td>Off-site migration</td>
<td>Off-site migration</td>
</tr>
</tbody>
</table>

\(^*\) Threshold contaminant.  
\(^†\) Non-threshold contaminant.
indoor air via volatilization into basements (Appendix B), off-site migration of soil/dust (Appendix C), and contamination of produce, milk, and meat from on site (Appendix D). The actual inclusion of each pathway in the guideline derivation equation is based on the quality of the scientific evidence that a pathway is contributing to exposure. For cases where exposure pathways have been excluded, this decision will be reassessed as new scientific data become available.

The choice of sensitive receptors is linked to land use considerations, and guidelines are developed for the four defined land uses. The most sensitive human receptor is chosen to represent the occupant or user for each land use, and the exposure period (i.e., the frequency, duration, and intensity of the exposure assumed for the land use) is defined as presented in Table 2.

In the case of non-threshold substances, hazard is necessarily assessed for an adult, as exposure is assumed to be continuous over 70 years. However, for threshold substances, exposure is averaged over, and TDI measured against, the most sensitive life stage, which is the toddler stage (6 months to 4 years) for all land uses except industrial, where public access is restricted and toddlers are assumed not to be present.

### Derivation of Direct Contact Human Health Soil Quality Guidelines

#### Direct Contact Soil Quality Guidelines for Threshold Substances

The SQG\textsubscript{DH} for threshold substances are calculated using the following equation:

\[
\text{SQG}_{\text{DH}} = \frac{(\text{TDI} - \text{EDI}) \times \text{SAF} \times \text{BW} + \text{BSC}}{[(\text{AF}_G \times \text{SIR}) + (\text{AF}_L \times \text{IR}_S) + (\text{AF}_S \times \text{SR} \times \text{ET}_2)] \times \text{ET}_1}
\]

where

- \(\text{SQG}_{\text{DH}}\) = direct human health soil quality guideline (mg kg\textsuperscript{-1})
- \(\text{TDI}\) = tolerable daily intake (mg kg\textsuperscript{-1} bw per day)
- \(\text{EDI}\) = estimated daily intake (multimedia exposure assessment) (mg kg\textsuperscript{-1} per day)
- \(\text{SAF}\) = soil allocation factor (unitless)
- \(\text{BW}\) = body weight (kg)
- \(\text{BSC}\) = background soil concentration (mg kg\textsuperscript{-1})
- \(\text{AF}_G\) = relative absorption factor for gut (unitless)
- \(\text{AF}_L\) = relative absorption factor for lung (unitless)
- \(\text{AF}_S\) = relative absorption factor for skin (unitless)
- \(\text{SIR}\) = soil ingestion rate (kg d\textsuperscript{-1})
- \(\text{IR}_S\) = soil inhalation rate (kg d\textsuperscript{-1})
- \(\text{SR}\) = soil dermal contact rate (kg d\textsuperscript{-1})
- \(\text{ET}_1\) = exposure term 1 (unitless) – days per week/7 x weeks per year/52
- \(\text{ET}_2\) = exposure term 2 (unitless) – hours per day/24

While for most chemicals the three direct contact pathways (soil ingestion, dermal contact and particulate inhalation) are combined, if the mechanisms of toxicity are different and separate toxicity reference values have been published for oral, dermal and/or inhalation exposures, the pathways may be evaluated separately as detailed in CCME (2006).

The soil inhalation rate is defined as the amount of respirable soil particles inhaled in a day. The soil dermal contact rate is the amount of soil adhering to the skin in a day. The soil ingestion rate refers to the amount of soil ingested on a daily basis. Relative absorption factors may be required where the critical toxicity study used in developing the NO(A)EL employed an absorbed dose rather than an administered dose, or where the critical toxicity study has employed a different medium than that under investigation. Then soil ingestion, dermal contact, and inhalation rates are multiplied by corresponding relative absorption factors (AF), when these data are available.

The exposure term is the ratio of the defined exposure period for each land use to the maximum exposure period (24 hours per day × 365 days per year). Exposure via soil ingestion and dermal contact is assumed to occur as a result of discrete exposure events, and not at a constant rate over the day; therefore the hours per day exposed are not considered for these pathways (only days per year are considered).

### Soil type does not normally affect direct contact pathways.

#### Direct Contact Soil Quality Guidelines for Non-threshold Substances

If the chemical is identified as a non-threshold substance, then the guideline will be derived using a critical RSD based on incremental risks from soil exposure of both 10\textsuperscript{-5} and 10\textsuperscript{-6}. The use of other critical risk levels can easily be accommodated at a site-specific objective level. The SQG\textsubscript{DH} for non-threshold substances is established as follows:
\[ \text{SQG}_{\text{DH}} = \frac{\text{RSD} \times \text{BW}}{[(\text{AF}_G \times \text{SIR}) + (\text{AF}_L \times \text{IR}_S) + (\text{AF}_S \times \text{SR})] \times \text{ET}} + \text{BSC} \]

where

- \( \text{SQG}_{\text{DH}} \) = direct human health soil quality guideline (mg\(\cdot\)kg\(^{-1}\))
- \( \text{RSD} \) = risk specific dose (mg\(\cdot\)kg\(^{-1}\) per day)
- \( \text{BW} \) = body weight (kg)
- \( \text{BSC} \) = background soil concentration (mg\(\cdot\)kg\(^{-1}\))
- \( \text{AF}_G \) = relative absorption factor for gut (unitless)
- \( \text{AF}_L \) = relative absorption factor for lung (unitless)
- \( \text{AF}_S \) = relative absorption factor for skin (unitless)
- \( \text{SIR} \) = soil ingestion rate (kg\(\cdot\)d\(^{-1}\))
- \( \text{IR}_S \) = soil inhalation rate (kg\(\cdot\)d\(^{-1}\))
- \( \text{SR} \) = soil dermal contact rate (kg\(\cdot\)d\(^{-1}\))
- \( \text{ET} \) = exposure term (unitless) = 1

The adult is the receptor when considering lifetime cancer risk. Absorption factors may be required when the critical toxicity study used in developing the cancer slope factor has used an absorbed dose rather than an administered dose. Absorption factors may also be required when the critical toxicity study employed a different medium in developing the cancer slope factor than that under investigation. Then soil ingestion, dermal contact, and inhalation rates are multiplied by corresponding relative absorption factors (AF), when these data are available. The exposure term is the ratio of the defined exposure period for each land use to the maximum exposure period (24 hours per day \(\times\) 365 days per year).

Soil type does not normally affect direct contact pathways.

**Indirect Soil Contaminant Exposure**

The following modelling procedures were developed to ensure that the final generic soil quality guideline will not lead to excessive migration of a soil contaminant to another medium, (e.g., air, water, and food). These indirect exposure pathways and management adjustment factors add a level of protectiveness to the generic guidelines, which permits their use at a very broad range of sites within a land use category, but which may not be required or applicable to every site. These pathways are further discussed in the appendices. The primary indirect exposure pathways are the migration of soil contaminants into groundwater used as drinking water (Appendix A) and the volatilization of soil contaminants into indoor air (Appendix B). The other two mechanisms are check mechanisms. The term check mechanisms refers to the necessarily imprecise nature of those models using conservative point estimates, based on data and professional judgment, for generic input values; as a result, professional judgement should be used to determine whether the \( \text{SQG}_{\text{HH}} \) is adjusted by these pathways. These two check mechanisms are for the off-site migration of contaminants from commercial and industrial sites to more sensitive neighbouring properties (Appendix C) and for exposure from ingestion of food grown on contaminated soils (Appendix D).

If data requirements for one or more applicable pathways cannot be met, a provisional guideline can still be developed, as discussed under Derivation of the Final Soil Quality Guidelines.

**Derivation of the Final Human Health Soil Quality Guidelines**

**Agricultural Land Use**

The direct human health soil quality guideline (\( \text{SQG}_{\text{DH}} \)) is calculated, as are the guidelines for indirect exposure to soil contaminants via infiltration of volatile compounds into indoor air (\( \text{SQG}_{\text{IAQ}} \)), protection of potable groundwater (\( \text{SQG}_{\text{PW}} \)) and ingestion of produce, meat, and milk produced on-site (\( \text{SQG}_{\text{FI}} \)). The final \( \text{SQG}_{\text{HH}} \) is set at the lowest value of the applicable soil quality guidelines. This ensures that the final \( \text{SQG}_{\text{HH}} \) is protective of all these potential contaminant media transfer pathways.

**Residential/Parkland Land Use**

The direct human health soil quality guideline (\( \text{SQG}_{\text{DH}} \)) is calculated; the \( \text{SQG}_{\text{IAQ}} \) and \( \text{SQG}_{\text{PW}} \) are calculated as well and the final \( \text{SQG}_{\text{HH}} \) is set as the lowest of the values generated.

For residential properties with backyard gardens, the check mechanisms for contamination of produce grown on-site is calculated and presented in the contaminant assessment document for possible use as a site-specific objective. If the contaminant biomagnifies, the \( \text{SQG}_{\text{FI}} \) is a required pathway and can therefore adjust the \( \text{SQG}_{\text{HH}} \).

**Commercial and Industrial Land Uses**

The direct human health soil quality guideline (\( \text{SQG}_{\text{DH}} \)) is calculated; as with residential land use, the \( \text{SQG}_{\text{IAQ}} \) and \( \text{SQG}_{\text{PW}} \) are also calculated, and the \( \text{SQG}_{\text{HH}} \) is set as the
lowest of the values. The procedure for checking off-site migration via wind and water erosion from a commercial or industrial site to adjacent more sensitive land use (SQG_{OM-HH}) is then applied as a check mechanism to determine the final SQG_{HH}.

**DERIVATION OF THE FINAL SOIL QUALITY GUIDELINES**

**Final Guideline Derivation**

The final recommended soil quality guideline (SQG_{F}) protects both environmental and human health. The lower of the two guidelines obtained through the derivation of the SQG_{E} and the SQG_{HH}, will be recommended as the SQG_{F} for each land use category and soil type (if applicable), subject to the restrictions discussed in the section below. An overview of the entire guideline derivation process outlining the major steps leading to derivation of the SQG_{F}, is illustrated in Figure 4.

**Provisional Guidelines**

In order for a final soil quality guideline to be developed, guidelines for certain required pathways (see Section 8 in Part B and Section 6 in Part C of CCME 2006) must be calculated, and the data requirements for each of these required pathways must be met. In some cases, though, it may not be possible to calculate a guideline for a particular pathway, or it may not be possible to completely meet the data requirements for the calculation of a pathway.

However, literature searches often yield data that do not meet the requirements of the soil protocol, but still provide useful toxicity information. Also, toxicity tests using standard methodologies may produce data that do not meet the regular quality standards defined by toxicologists, due to difficulties in handling and evaluating certain substances such as volatile organic chemicals in the context of a soil contact test, for example.

While acknowledging the need for toxicity and exposure data of the highest quality, it is considered to be better to establish a guideline based on incomplete data than to not establish a risk-based guideline. In these cases, the SQG_{E} and SQG_{HH} are determined, but are designated as “Provisional Guidelines” to reflect the uncertainty and data gaps in the guideline development. A guideline will also be designated as a Provisional Guideline if the EDI exceeds the TDI. If either the SQG_{E} or SQG_{HH} are provisional, then the SQG_{F} is also considered to be a provisional guideline.

The guiding principles for calculating the soil quality guidelines are still followed when developing provisional guidelines. However, since data requirements are relaxed, the following principles are followed:

- be precautionary; use higher safety factors where degree of uncertainty is high;
- keep in mind that provisional environmental soil quality guidelines for agricultural and residential/parkland land uses are intended to approximate no appreciable effect levels while those for commercial and industrial land uses allow for a low level of effects;
- keep in mind that provisional human health soil quality guidelines are intended to result in no appreciable risk to humans for all activities associated with the intended land use;
- be consistent with the spirit of the protocol.

If the provisional SQG_{F} is higher than an existing guideline, such as a 1991 interim soil criterion (if applicable), the previously existing guideline is retained as the SQG_{F}.

**Considerations Other Than Toxicity**

Contaminants may have adverse effects in addition to producing toxic responses in human and ecological receptors. These may include aesthetic concerns (e.g., odours), explosive hazards, free-phase liquid formation, or damage to utilities and infrastructure.

If there is evidence that a contaminant may cause significant environmental effects beyond toxicity to human and ecological receptors, then this evidence is evaluated. A soil quality guideline for management considerations (SQG_{M}) is developed to reflect any additional concerns associated with the contaminant.

There may be considerable uncertainty in the development of the SQG_{M}, and for some concerns associated with contaminants only a qualitative evaluation may be possible. Therefore, professional judgement is used to determine whether the SQG_{F} should be adjusted based on the SQG_{M}.
Evaluation against Plant Nutritional Requirement, Geochemical Background, and Practical Quantitation Limits

Guidelines should be reasonable, workable, and usable. Guidelines are developed by applying scientifically derived information, backed by professional judgment where data gaps occur. Occasionally, defined exposure-based procedures produce numerical guidelines that conflict either with plant nutritional requirements or geochemical background. When a conflict of this type occurs, guidelines must be adjusted as described below.

Some chemicals (e.g., copper and zinc) considered hazardous at high levels also provide minimum nutritional requirements for the maintenance of plant growth at lower levels. The SQG\textsubscript{F} determined for these chemicals may fall below the nutritional requirements. For agricultural and residential/parkland land uses, maintenance of nutritional requirements is critical to sustaining the primary activity on these lands (i.e., growing crops, grass, and trees). Accordingly, the SQG\textsubscript{F} for these land use categories is compared to minimum plant nutritional requirements. If the SQG\textsubscript{F} is below acceptable minimum plant nutritional requirement levels, then insufficient nutritional requirements for plant growth may result at the value of the SQG\textsubscript{F}. The SQG\textsubscript{F} should therefore default to the soil concentration required for minimum plant nutrition. This value is not applied to the commercial or industrial land use categories because it is anticipated that the resulting SQG\textsubscript{F} will be above plant nutritional requirements.

Where applicable, the SQG\textsubscript{F} should also be compared to an acceptable geochemical background soil concentration to ensure the final value is not below background levels. Where the SQG\textsubscript{F} is below the accepted geochemical background soil concentration, the accepted background concentration replaces the SQG\textsubscript{F} generated using this soil protocol.

Finally, a candidate SQG\textsubscript{F} for a given substance should be checked against the current practical quantitation limit achievable in Canada. Where the candidate SQG\textsubscript{F} is below the limit of practical quantitation (generally 5 times the analytical detection limit), a footnote should be added to the SQG\textsubscript{F} stating “laboratories may not be able to reliably measure concentrations of this magnitude”. The SQG\textsubscript{F} should not be adjusted based on the practical quantitation limit, however.

Because guidelines are based primarily on biological effects, and background exposures are, wherever possible, incorporated into the procedures, it is anticipated that very few candidate SQG\textsubscript{F} will require adjustment. Where any of the three evaluation procedures described above result in modification of a candidate SQG\textsubscript{F}, this condition will be noted in the assessment document for the substance.
Figure 4: Overview of Steps Leading to Derivation of a Final Soil Quality Guideline

References


Appendix A
Evaluation of Groundwater Exposure Pathways

Soil contamination can lead to groundwater contamination. Canadian soil quality guidelines are designed to prevent unacceptable transfers of contaminants to groundwater systems. Specifically, the protection of groundwater beneath a remediated site used for drinking water by humans or for agricultural purposes (livestock watering or irrigation water) is considered, as is the protection of freshwater life in nearby surface water bodies hydraulically connected to groundwater beneath the remediated site.

The groundwater pathways are applicable to non-dissociating organic contaminants and to some ionizing organic compounds provided that sorption of the dissociated and non-dissociated forms can be simply described, as in the case of weak organic acids. These pathways are not applicable to metals on a generic basis because partitioning of metal contaminants between sorbed and dissolved forms in soils is complex and affected by many site-specific parameters; potential effects of metals on groundwater systems should be evaluated on a site-specific basis.

Partitioning of Contaminants Between Soil and Soil Water

Partitioning of contaminants between soil and soil water can be described by the following equation:

\[ C_s = K_d \times C_{sw}^{1/n} \]

where

- \( C_s \) = concentration in soil
- \( C_{sw} \) = concentration in soil water
- \( K_d \) = distribution coefficient
- \( n \) = empirical constant

For most non-dissociating organic compounds, \( n = 1 \). For these compounds, \( K_d \) can be estimated as the product of the organic carbon partitioning coefficient (\( K_{oc} \)) and the organic carbon fraction of the soil (\( f_{oc} \)).

For certain dissociating organic compounds, such as weak organic acids, \( K_d \) can be estimated as:

\[ K_d = K_{oc} \times F_{oc} \times Q \]

where \( Q \) is the proportion of the substance in non-ionized form. \( Q \) can be determined from the equilibrium acidity expression:

\[ Q = 1/(1 + K_a[H^+]) \]

where \( K_a \) is the acidity constant for the contaminant.

Calculation of Soil Quality Guidelines for the Protection of Groundwater

The groundwater pathways are addressed using a groundwater model developed by the British Columbia Contaminated Sites Soil Taskgroup (CSST), based on the US EPA (1996) Soil Screening Guidance and using saturated groundwater transport equations developed by Domenico and Robbins (1985). The model is based on one-dimensional groundwater flow, and incorporates a variety of mechanisms including dispersion, biodegradation, adsorption-desorption, and dilution of leachate into groundwater.

The groundwater protection guidelines are calculated using the following equations:

Soil/Leachate Partitioning

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

where

\( SQG_{GW} \) = soil quality guideline for the protection of groundwater (mg kg\(^{-1}\)) (i.e., \( SQG_{PW}, SQG_{FL}, SQG_{IR}, SQG_{LW} \))

\( C_L \) = allowable leachate concentration at source (mg L\(^{-1}\)) – calculated below

\( K_d \) = distribution coefficient (cm\(^3\) g\(^{-1}\))

\( \theta_w \) = water filled porosity (unitless)

\( H' \) = dimensionless Henry’s Law constant = \( H \times 42.32 \)

\( H \) = Henry’s Law constant (atm-m\(^3\) mol\(^{-1}\))

\( \theta_a \) = air-filled porosity (unitless)

\( \rho_b \) = soil bulk density in contaminant partitioning zone (g-cm\(^{-3}\))

Mixing Zone Unsaturated/Saturated

\[ C_{L} = C_{gw} \left[ 1 + \left( \frac{Z_d K_H}{IK} \right) \right] \]

where

\( C_{L} \) = allowable chemical concentration in leachate (mg L\(^{-1}\))
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\[ v = \frac{K_H i}{n_x R_f} \]
\[ R_f = 1 + \frac{\rho_b}{n} K_d \]

\[ C_w = \text{allowable chemical concentration in water at receptor (mg⋅L}^{-1}\text{) (i.e., drinking water guideline, freshwater life guideline, irrigation water guideline, livestock watering guideline as appropriate)} \]
\[ x = \text{distance from source to receptor (m)} \]
\[ x, y, z = \text{Cartesian coordinates relating source and receptor (m); } y, z \text{ assumed to be 0} \]
\[ t = \text{time since contaminant release (years)} \]
\[ C_{gw} = \text{allowable chemical concentration in groundwater at source (mg⋅L}^{-1}\text{)} \]
\[ \beta_x = \text{longitudinal dispersivity tensor} = 0.1x \]
\[ \beta_y = \text{lateral dispersivity tensor} = 0.1\beta_k \]
\[ L_x = \text{decay constant (y}^{-1}\text{) in saturated zone:} \]
\[ L_x = \frac{0.693}{\sqrt{2\pi/t_{1/2}}} \left( e^{-0.07d} \right) \]
\[ d = \text{depth from surface to groundwater surface (m)} \]
\[ t_{1/2S} = \text{biodegradation half-life (y)} \]
\[ v = \text{velocity of contaminant (m⋅y}^{-1}\text{)} \]
\[ K_H = \text{hydraulic conductivity in the saturated zone (m⋅y}^{-1}\text{)} \]
\[ i = \text{hydraulic gradient (unitless)} \]
\[ n = \text{total porosity of soil} = 1 - \rho_b/2.65 \text{ (unitless)} \]
\[ n_e = \text{effective soil porosity (unitless)} \]
\[ Y = \text{source width (m) perpendicular to groundwater flow} \]
\[ R_f = \text{retardation factor (unitless)} \]
\[ \rho_b = \text{soil bulk density in saturated zone (g⋅cm}^{-3}\text{)} \]
\[ K_d = \text{distribution coefficient (cm}^{-2}⋅\text{g}^{-1}\text{)} \] - see above

Further details regarding the application of the groundwater model are presented in CCME (2006).

**References**


Appendix B

Migration of Contaminated Vapours into Buildings

Volatile organic compounds can migrate from soil into the basements of buildings. For these compounds, inhalation of indoor vapours is often the dominant exposure pathway.

Vapours may be released from soil to the outside air at the ground surface, in addition to entering buildings. However, since buildings are enclosed spaces (and therefore have less air circulation than the outdoors), and buildings are often under-pressured due to heating (resulting in pressure-driven movement of soil gas into the building), migration of vapours into buildings poses a much greater health risk than migration of vapours to the outdoors.

Processes involved in the migration of vapours into buildings include:

- Partitioning of contaminants into soil gas (see Appendix A of CCME 2006).
- Diffusion of vapour-phase contaminants through soil to the building slab.
- Advective flow of soil gas into a building due to pressure differences between the building and the external atmosphere.
- Diffusion of contaminants through soil-filled cracks in the building foundation.

Johnson and Ettinger (1991) provided one of the first screening level models to assess potential risks posed by the indoor infiltration of volatile contaminants emanating from soil and/or groundwater, and it has become a widely accepted work in this area.

Guidelines for the protection of indoor air quality can be calculated using the equations below:

**Threshold chemicals:**

\[ SQG_{IAQ} = [(TC - C_{bg}) \theta_a + (K_{OC}) f_{OC}(\rho_b) + (H')(\theta_w)]/(\rho_b)(\theta_a)(ET)(10^6 \text{ cm}^3 / \text{ m}^3)] + BSC \]

**Non-threshold chemicals:**

\[ SQG_{IAQ} = [(RSC) \theta_a + (K_{OC}) f_{OC}(\rho_b) + (H')(\theta_w)]/(\rho_b)(\theta_a)(ET)(10^6 \text{ cm}^3 / \text{ m}^3)] + BSC \]

Where:

- \( SQG_{IAQ} \) = soil quality guideline for the protection of indoor air quality
- \( TC \) = tolerable concentration or reference concentration (mg·m\(^{-3}\))
- \( RSC \) = risk-specific concentration
- \( C_{bg} \) = background indoor/outdoor air concentration (mg·m\(^{-3}\))
- \( SAF \) = soil allocation factor (unitless)
- \( BW \) = body weight (kg)
- \( \theta_a \) = vapour-filled porosity (unitless) = effective porosity (n) – moisture-filled porosity
- \( \theta_w \) = moisture-filled porosity (unitless)
- \( n \) = soil porosity (unitless)
- \( K_{OC} \) = organic carbon partition coefficient (mL·g\(^{-1}\))
- \( f_{OC} \) = soil organic carbon fraction in contaminant partitioning zone (g carbon per g soil)
- \( \rho_b \) = soil dry bulk density in contaminant partitioning zone (g·cm\(^{-3}\))
- \( H' \) = unitless Henry’s Law Constant = \( H/RT \)
- \( H \) = Henry’s Law Constant (atm·m\(^3\)·mol\(^{-1}\))
- \( R \) = gas constant (8.2 x 10\(^{-5}\) atm·m\(^3\)·mol\(^{-1}\)·K\(^{-1}\))
- \( T \) = annual average soil 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\(^{-1}\))

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)
- \( \alpha \) = attenuation coefficient
  = (contaminant vapour concentration in the building)/(vapour concentration at the contaminant source)

\[ D_{T,\text{eff}}^\text{crack} \approx D_a \left( \frac{\theta_a^{1/3}}{n^2} \right) \]

- \( D_{T,\text{eff}}^\text{crack} \) = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm\(^2\)⋅s\(^{-1}\))
- \( D_a \) = pure component molecular diffusivities in air (cm\(^2\)⋅s\(^{-1}\))
- \( \theta_a \) = vapour-filled porosity (unitless)
- \( n \) = total soil porosity (unitless)

\[ Q_b = \frac{L_B W_B H_B (ACH)}{3600 \text{ s/h}} \]

- \( Q_b \) = building ventilation rate (cm\(^3\)⋅s\(^{-1}\))
- \( L_B \) = building length (cm)
- \( W_B \) = building width (cm)
- \( H_B \) = building height, including basement (cm)
- \( ACH \) = air exchanges per hour (h\(^{-1}\))

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

- \( Q_{\text{soil}} \) = volumetric flow rate of soil gas into the building (cm\(^3\)⋅s\(^{-1}\))
- \( \Delta P \) = pressure differential (g⋅cm\(^{-1}\)⋅s\(^{-2}\))
- \( k_v \) = soil permeability to vapour flow (cm\(^2\))
- \( X_{\text{crack}} \) = length of idealized cylinder (cm)
- \( \mu \) = vapour viscosity (g⋅cm\(^{-1}\)⋅s\(^{-1}\))
- \( Z_{\text{crack}} \) = distance below grade to idealized cylinder (cm)
- \( r_{\text{crack}} \) = radius of idealized cylinder (cm)

\[ \alpha = \frac{\left( D_{T,\text{eff}}^\text{crack} A_B \right) \exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{T,\text{eff}}^\text{crack} A_{\text{crack}}} \right)}{\exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{T,\text{eff}}^\text{crack} A_{\text{crack}}} \right) + \left( \frac{D_{T,\text{eff}}^\text{crack} A_B}{Q_b L_T} \right) + \left( \frac{D_{T,\text{eff}}^\text{crack} A_B}{Q_b L_T} \right) \exp \left( \frac{Q_{\text{soil}} L_{\text{crack}}}{D_{T,\text{eff}}^\text{crack} A_{\text{crack}}} \right) - 1} \]
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\[ D_{T}^{\text{eff}} = \text{effective porous media diffusion coefficient (cm}^2\cdot\text{s}^{-1}) \]
\[ A_B = \text{building area (cm}^2) \]
\[ Q_B = \text{building ventilation rate (cm}^3\cdot\text{s}^{-1}) \]
\[ L_T = \text{distance from contaminant source to foundation (cm)} \]
\[ Q_{\text{soil}} = \text{volumetric flow rate of soil gas into the building (cm}^3\cdot\text{s}^{-1}) \]
\[ L_{\text{crack}} = \text{thickness of the foundation (cm)} \]
\[ D_{\text{crack}} = \text{effective vapour-pressure diffusion coefficient through the crack (cm}^2\cdot\text{s}^{-1}) \]
\[ A_{\text{crack}} = \text{area of cracks through which contaminant vapours enter the building (cm}^2) \]

**References**


Appendix C
Off-site Migration Check Calculations

Soil quality guidelines for commercial and industrial sites consider on-site exposure only. However, wind and water erosion of soil and subsequent deposition can transfer contaminated soil from one property to another. The off-site migration check has been developed to address the possibility of subsequent movement of soil from a commercial or industrial property to a more sensitive adjacent property (CCME 2006).

The universal soil loss equation and the wind erosion equation are used to estimate the transfer of soil to an adjacent property (CCME 2006). It is possible to calculate the concentration ($C_i$) in the eroded soil from the commercial or industrial site that will increase the contaminant concentration in the receiving soil to equal the agricultural guideline within a specified period of time. If the guideline for commercial or industrial sites is above $C_i$, then more sensitive land adjacent to a commercial or industrial property could become unacceptably contaminated via erosion and off-site deposition. The following equation has been derived to allow the calculation of soil quality guidelines for off-site migration (see CCME 2006 for derivation):

$$\text{SQG}_{OM} = 14.3 \times \text{SQG}_A - 13.3 \times \text{BSC}$$

where

$\text{SQG}_{OM}$ = soil quality guideline for offsite migration (mg·kg$^{-1}$)
$\text{SQG}_A$ = soil quality guideline for agricultural land use (mg·kg$^{-1}$)
$\text{BSC}$ = background concentration of contaminant in the receiving soil (mg·kg$^{-1}$)

The environmental soil quality guideline for offsite migration ($\text{SQG}_{OM,E}$) is calculated using the $\text{SQG}_E$ for the agricultural land use; the human health soil quality guideline for offsite migration ($\text{SQG}_{OM,HH}$) is calculated using the $\text{SQG}_{HH}$ for the agricultural land use.

Reference

Appendix D

Human Food Consumption Check Calculations

Humans can be indirectly exposed to contaminants in soil through food chain contamination of produce, meat, and milk. Soil quality guidelines should be adjusted to avoid an unacceptable contribution to the total daily intake of contaminants via homegrown produce, meat, and milk (CCME 2006).

The concentration estimated to occur in food as a result of soils at the guideline concentration must be less than the maximum residue limit (MRL) for each chemical published under the Food and Drug Act. In addition, the total daily intake estimated using the food consumption check must not exceed the total background exposure from food (i.e., estimated daily intake [EDI]) by more than 20% of the difference between the tolerable daily intake (TDI) and the EDI, for non-carcinogens. For carcinogens, the total contaminant intake must not exceed the risk-specific dose (RSD) for a specified cancer risk.

Residential Setting

For residential land use, an estimated 10% of all fruits and vegetables consumed are homegrown whereas neither milk nor meat is produced. Thus, human intake of contaminants resulting from consumption of backyard produce can be defined as:

\[
I_p = \frac{\left( P_h \times P_c \times B_r \times SQG_{HH} \right) + \left[ \left( 1 - P_h \right) \times P_c \times P_r \right]}{BW}
\]

where
- \( I_p \) = total intake of contaminants from produce (mg·kg\(^{-1}\) per day)
- \( P_h \) = percent of homegrown produce for residential land use (10%)
- \( P_c \) = produce consumption rate (kg·d\(^{-1}\))
- \( B_r \) = bioconcentration factor for produce
- \( SQG_{HH} \) = human health soil quality guideline for residential/parkland land use (mg·kg\(^{-1}\))
- \( P_r \) = average contaminant concentration in retail produce (mg·kg\(^{-1}\))
- \( BW \) = body weight of receptor (toddler for noncarcinogens, adult for carcinogens)

When a bioconcentration factor for produce is not available for a specific contaminant, the following equation can be used to evaluate \( B_r \) for organic contaminants (Travis and Arms 1988):

\[
\log B_r = 1.59 - 0.58 \log K_{ow}
\]

Then, the total contaminant intake from food (\( T_{res} \)) for residential/parkland land use must be calculated using the following equation:

\[
T_{res} = T_f - I_{bp} + I_p
\]

where
- \( T_f \) = total estimated background intake of contaminants from food
- \( I_{bp} \) = background intake of contaminants from produce consumption

For noncarcinogen contaminants, if \( T_{res} > 0.2 \) (TDI - EDI) + \( T_f \), the contaminant exposure from backyard produce should be evaluated on a site-specific basis since the percentage of homegrown produce is highly variable. For carcinogen contaminants, \( T_{res} \) should not exceed the RSD for the applicable cancer risk level (CCME 2006). The soil quality guideline should be modified accordingly.

Agricultural Setting

For agricultural land use, an estimated 50% of all fruits and vegetables, 50% of the meat, and 100% of the milk consumed are produced on site. Thus, human intake of contaminants resulting from consumption of produce must be recalculated (\( I_p' \)) using the 50% value and added to the intake of contaminants resulting from the consumption of meat and milk, which can be calculated as follows:

for meat:

\[
I_b = \frac{\left( M_h \times M_c \times B_p \times SQG_{HH} \right) + \left[ \left( 1 - M_h \right) \times M_c \times M_r \right]}{BW}
\]

where
- \( I_b \) = total intake of contaminants from beef (mg·kg\(^{-1}\) per day), assumed beef is the major type of ingested meat originating from grazing animals
- \( M_h \) = percent of meat home produced
- \( M_c \) = meat consumption rate (kg·d\(^{-1}\))
- \( B_p \) = biotransfer factor for beef

When a biotransfer factor for produce is not available for a specific contaminant, the following equation can be used to evaluate \( B_p \) for organic contaminants (Travis and Arms 1988):
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SQG_{HH} = human health soil quality guideline for agricultural land use (mg kg^{-1})

M_r = average contaminant concentration in retail beef (mg kg^{-1})

BW = body weight of receptor (toddler for noncarcinogens, adult for carcinogens)

When a biotransfer factor for beef is not available for a specific contaminant, the following equation can be used to evaluate B_p for organic contaminants (Travis and Arms 1988):

\[
\log B_p = 7.6 + \log K_{ow}
\]

for milk: \[
I_m = \frac{((MK_h \times MK_e \times B_m \times SQG_{HH}) + [(1 - MK_h) \times MK_e \times MK_r])}{BW}
\]

where

I_m = total intake of contaminants from milk (mg kg^{-1} per day)

MK_h = percent of milk home produced

MK_e = milk consumption rate (kg d^{-1})

B_m = biotransfer factor for milk

SQG_{HH} = human health soil quality guideline for agricultural land use (mg kg^{-1})

MK_r = average contaminant concentration in retail milk (mg kg^{-1})

BW = body weight of receptor (toddler for noncarcinogens, adult for carcinogens)

When a bioconcentration factor for milk is not available for a specific chemical, the following equation can be used to evaluate B_m for organic contaminants (Travis and Arms 1988):

\[
\log B_m = -8.1 + \log K_{ow}
\]

Then, the total contaminant intake from food (T_{ag}) for agricultural land use can be calculated:

\[
T_{ag} = T_f - I_{bp} - I_{bb} - I_{bm} + I_p + I_b + I_m
\]

where

T_f = total estimated background intake of contaminants from food

I_{bp} = background intake of contaminants from produce consumption

I_{bb} = background intake of contaminants from meat consumption

I_{bm} = background intake of contaminants from milk consumption

For noncarcinogen contaminants, T_{ag} should not be greater than 0.2(TDI - EDI) + T_c. For carcinogen contaminants, T_{ag} should not exceed the RSD for the applicable cancer risk level (CCME 2006). Based on the above intake rates, soil quality guidelines for the food ingestion pathway can therefore be calculated using the following equations:

For threshold chemicals:

\[
SQG_{si} = \frac{(TDI - EDI) \times BW \times SAF}{(BSC)}
\]

For non-threshold chemicals:

\[
SQG_{si} = \frac{RSD \times BW}{(BSC)}
\]

where:

TDI = tolerable daily intake (mg kg^{-1} bw per day)

EDI = estimated daily intake (multimedia exposure assessment) (mg kg^{-1} per day)

RSD = risk-specific dose (mg kg^{-1} bw per day)

SAF = soil allocation factor (unitless)

BSC = background soil concentration (mg kg^{-1})

References


Reference listing:


For further scientific information, contact:

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