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

PROTOCOL SUMMARY

Summary of A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME 1996a)

Contents

INTRODUCTION

In 1996, the Canadian Council of Ministers of the Environment (CCME) published *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996a). The following is a brief summary and updating of that document.

Canadian Soil Quality Guidelines

Interim Canadian environmental quality criteria for contaminated sites were established by the 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 are not scientifically defensible, however, and have been revised based on current scientific information using the procedures described in the soil protocol (CCME 1996a). The new set of 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 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. Previous CCME publications about the

National Contaminated Sites Remediation Program used the term *soil criteria*. This term will now be replaced by *guidelines* for consistency with other environmental media (water, sediments, etc.). For the purpose of this document, these terms are defined as follows:

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 developed by the Subcommittee on Environmental Quality Guidelines for Contaminated Sites 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 1996a).

The guidelines are revised on a substance-by-substance basis 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 for the environmental guidelines and from Health Canada for the human health component of the guidelines.

It is recognized that contaminants are likely to occur in mixtures. However, not enough is known about contaminant mixtures at this time to consider them in the guideline derivation process. Human health guidelines theoretically apply to the practical depth (i.e., 0–5 cm from the surface) for direct soil exposure and to a greater depth (>5 cm) for potential indirect exposure routes (to prevent groundwater contamination or infiltration of contaminants into indoor air).

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. 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.

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 nonthreshold toxicants are differentiated, taking into account daily background exposure from air, water, soil, food, and consumer products. Indirect exposure routes resulting from contaminated soils, such as contaminated groundwater, contaminated meat, milk, and produce, contaminated produce from private gardens, 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 routes 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 pathways (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;
- 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.

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 recommended soil quality guideline.

USE OF CANADIAN SOIL QUALITY GUIDELINES

Canadian soil quality guidelines derived using the soil protocol will replace the interim environmental quality criteria for contaminated sites (CCME 1991). This new 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. 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 1996a).

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). 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).

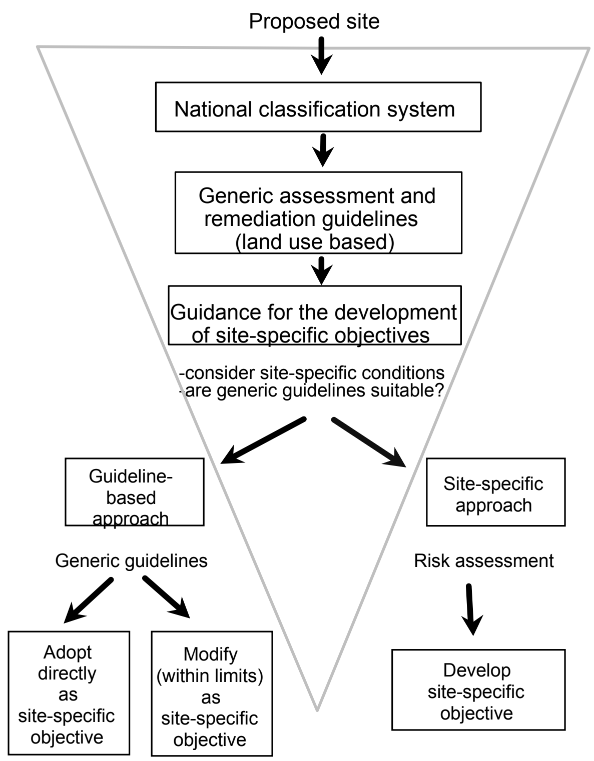


Figure 1. National framework for contaminated site assessment and remediation.

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_Es), 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 (LC_{50}) as a short-term endpoint and on reproduction, growth, development, behaviour, activity, lesions, physiological changes, respiration, nutrient cycling, contribution to decomposition, genetical adaption, and physiological acclimatization as long-term, sublethal endpoints (EC_{50}, NOEC, and LOEC) (SECOFASE 1993).

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.

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.

Agricultural Land Use

Although agricultural land use varies, the development of SQG_Es must protect key receptors that permit or maintain crop growth and livestock production against adverse effects. Protection must also be offered to resident and

Table 1. Receptors and exposure pathways considered in the derivation of environmental soil quality guidelines.

Land use	Soil quality guidelines for soil contact (SQG_{SC})	Soil quality guidelines for soil and food ingestion (SQG_{I})
Agriculture	Soil nutrient cycling processes Soil invertebrates Crops/plants Livestock/wildlife	Herbivores
Residential/ parkland, commercial, and industrial	Soil nutrient cycling processes Soil invertebrates Plants Wildlife	Not applicable

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.

Residential/Parkland Land Use

The development of SQG_Es 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.

Commercial and Industrial Land Use

Commercial and industrial land use SQG_Es 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, only one SQG_E will be provided for commercial and industrial land use.

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_Es 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.

Derivation of Environmental Soil Quality Guidelines

The general process for deriving SQG_Es is summarized in Figure 2. For each contaminant, an extensive literature search of all published and nonproprietary 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_Es. Acceptable data are referred to as "selected",

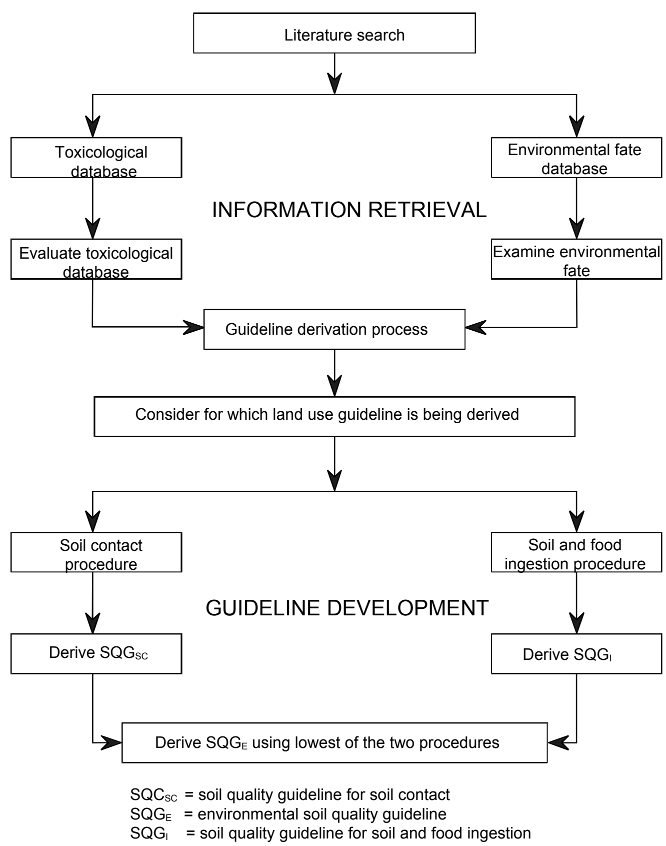


Figure 2. Overall procedure for the derivation of environmental soil quality guidelines.

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 at the Guidelines Division, Environmental Quality Branch, Environment Canada.

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_Es. Minimum data requirements are designed to ensure guidelines are derived based on effects data from a variety of organisms (CCME 1996a). 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 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 1996a). The derivation methods for soil quality guidelines for soil contact (SQG_{SC}s) 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. An overview of the derivation procedure for SQG_{SC}s 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 the 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.

For agricultural and residential/parkland land uses, the 25th percentile of the effects and no effects data distribution is chosen as the "no potential effects range" (NPER). The NPER represents a point estimate in the

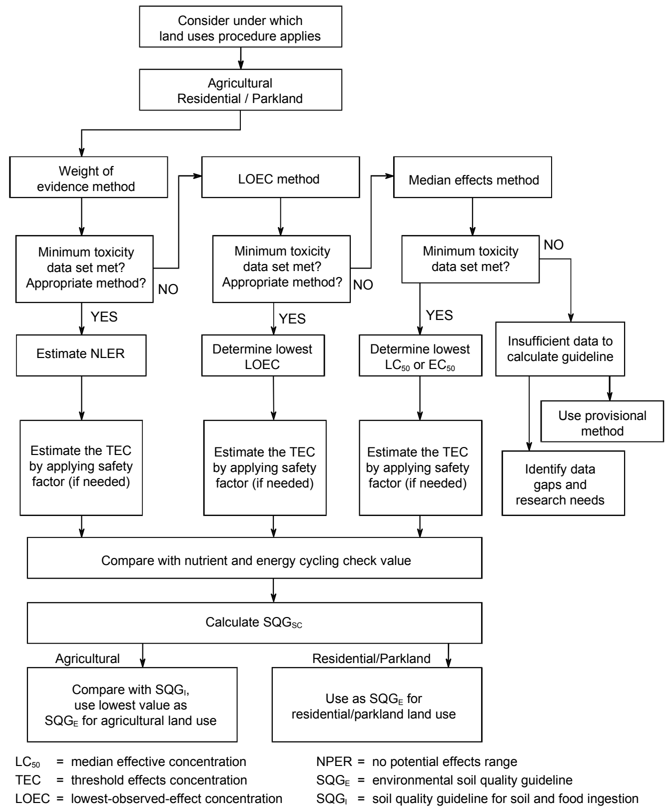


Figure 3. Procedure for the derivation of environmental soil quality guidelines for soil contact for agricultural and residential/parkland land uses.

distribution below which the proportion of definitive effects data (EC_X, LC_X) do not exceed acceptable levels (25%). Definitive effects data below the NPER are minimal effects concentrations that overlap the range of LOECs and NOECs used to determine the NPER. Norenberg-King (1988) used a 25% effect level as an estimate of the minimal effect level. An uncertainty factor is then applied to NPER in order to derive the threshold effects concentration (TEC) for agricultural and residential/parkland land uses.

For commercial and industrial land uses, the 25th percentile of the effects only data distribution is selected as the effects concentration low (ECL). At this level, some effects are expected to occur, but not at the level of median lethality in the population.

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.

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_{SC} and, consequently, a final SQG_{E}. Data gaps will be identified for further research.

Using Nutrient and Energy Cycling Data in the Derivation of Soil Quality Guidelines for Soil Contact

Once the TEC (or ECL) is calculated, it is compared with the microbial value derived using the nutrient and energy cycling check for selected microbial processes as described in CCME (1996a). If the microbial value is lower than the TEC (or ECL) calculated using any of the soil contact methods, microbial nutrient and energy cycling processes may experience adverse effects at the level of the TEC (or ECL). In this case, the geometric mean of the microbial and TEC (or ECL) values is selected as the SQG_{SC}. The geometric mean is used, assuming that the data are log-normally distributed. However, if the TEC (or ECL) is lower than the microbial value, then the TEC (or ECL) is considered to be protective of microbial nutrient and energy cycling processes and is adopted directly as the SQG_{SC}.

Derivation of Soil Quality Guidelines for Soil and Food Ingestion

The procedure for deriving soil quality guidelines for soil and food ingestion (SQG_{I}) by grazing livestock and wildlife is used only for agricultural land use. This procedure also accounts for the consumption of contaminated forage via the accumulation of contaminants in the food chain. Because this procedure is limited to a herbivore food chain, chemicals that bioaccumulate in the tissues of plants and that can be transferred in the food chain are of primary importance.

Determining the Daily Threshold Effect Dose

The first step in determining the daily threshold effect dose (DTED) is to determine the species considered to be most at threat from contaminated soil and food ingestion. The most threatened species has the lowest reported LOAEL, considering a minimum of three studies. If minimum data requirements cannot be met when determining the DTED, then no SQG_{I} shall be set.

Once the DTED is established, information is gathered on the body weight, the rate of soil ingestion, and the rate of food ingestion for the most sensitive species as well as information on bioavailability and bioconcentration factor specific to the contaminant. The information gathered is used to calculate the SQG_{I} as detailed in CCME (1996a).

Derivation of the Final Environmental Soil Quality Guidelines

Agricultural Land Use

Two procedures (i.e., SQG_{SC} and SQG_{I}) are used to derive SQG_{E}s for agricultural land use. The final SQG_{E} for agricultural land use is derived by selecting the lower of the SQG_{SC} and the SQG_{I}. If data are not available to derive an SQG_{I}, then the SQG_{SC} shall be determined as the SQG_{E}. In this case, it is assumed that the SQG_{SC} for soil-dependent biota is a more sensitive measure of ecological effects than a guideline for ingestion by wildlife and livestock and can be used to represent these pathways. However, if data are not available to derive an SQG_{SC}, then no SQG_E shall be set using only the SQG_I. In this situation, it is assumed that these guidelines cannot represent exposures to soil-dependent biota.

Residential/Parkland Land Use

The SQG_{SC} is used as the SQG_E for residential/parkland land use. If no guideline can be set, then data gaps will be identified for further research.

Commercial and Industrial Land Use

The SQG_{SC} is used as the SQG_E for commercial and industrial land uses. If no guideline can be set, then data gaps will be identified for further research.

Provisional Method for Environmental Soil Quality Guidelines

Limitations in the availability of high quality soil toxicity data may hinder the derivation of SQG_Es because the methods described above are all limited by minimum data requirements. However, literature searches often yield data that do not meet the requirements of the soil protocol, but still provide some 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 data of the highest quality, it is the opinion of the Subcommittee on Environmental Quality Guidelines for Contaminated Sites that guidelines based on limited toxicity information are still more practical and scientifically defensible than the absence of guidelines or than guidelines that are not risk-based. Thus, a provisional method for deriving SQG_Es was proposed. The guidelines derived using this method are called “provisional” to clearly indicate that the underlying data do not meet the requirements of the soil protocol and that there is an urgent need for additional research. Also, given the increased uncertainty surrounding provisional SQG_Es, such provisional guidelines may not be used to raise existing criteria or guidelines, such as the interim criteria (CCME 1991), but only to lower them if the provisional value indicates that the existing criteria or guidelines are not adequately protective.

The guiding principles described in the soil protocol were followed while applying relaxed data requirements in order to allow the derivation of provisional SQG_Es. When the data requirements of one of the previously described derivation methods were met, SQG_Es were derived. However, when the available data did not meet those requirements, professionnal judgment was used to evaluate the available information and to recommend a provisional SQG_E. The derivation of provisional SQG_Es was directed by the following landmarks:

- be precautionary; use higher safety factors where degree of uncertainty is high;
- use soil contact data for plants and invertebrates preferentially over mammalian data, equilibrium partitioning data, or other data;
- rely on equilibrium partitioning data only to justify additional safety factors and to assist in professional judgment;
- use microbial data as a check mechanism; follow the method described in the soil protocol (use the geometric mean of the soil contact number and the microbial value where the microbial value is lower);
- keep in mind that provisional SQG_Es for agricultural and residential/parkland land uses are intended to approximate no appreciable effect levels where those for commercial and industrial land uses allow for a low level of effects;
- be consistent with the spirit of the soil protocol (CCME 1996a).

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 (child or adult), the reference characteristics of that receptor (weight, amount of soil and water ingested daily, exposure duration, etc.), and specific pathways of exposure. Few distinctions have been made for differing soil type, differing soil chemical, or physical composition, all of which might be incorporated at a site-specific objective level.

Development of human health soil quality guidelines (SQG_{HH}s) is done in two steps. The first step involves derivation of a preliminary soil quality guideline using direct soil exposure pathways (soil ingestion, soil dermal contact, and inhalation of soil particulate). The input values for exposure variables depend on the assumptions for each land use scenario and include the choice of sensitive human receptor, exposure duration, frequency, and intensity.

The second step involves check mechanisms that attempt to quantify and respond to cross-media transfer of soil contaminants. These checks ensure that preliminary generic soil quality guidelines do not lead to unacceptable exposures from other media. Assumptions have been made about certain generic site conditions, and simplified models have been deliberately chosen to describe the involved mechanisms in order to limit the need for additional assumed values.

Guiding Principles for Human Health Soil Quality Guidelines

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

- Soil should pose no appreciable risk to humans for all activities associated with the intended land use. Furthermore, there should be no restrictions as to the extent or nature of the interaction with the site for each specified land use.
- Guidelines are based on defined specific scenarios within which the exposure likely to arise on the site can be predicted with some degree of certainty.
- Guidelines are derived by considering exposure through all relevent pathways (soil, air, water, and food).
- A critical human receptor is identified for each land use, and the defined exposure scenarios are usually based on the most sensitive receptor to the chemical and the most critical health effect.
- Guidelines are developed by applying scientifically derived information, backed by professional judgment where data gaps occur.

Investigation of Contaminant Toxicology

Toxic effects from exposure to environmental contaminants may be classified as organ-specific, neurological/ behaviourial, 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 nonthreshold substance (i.e., a carcinogen or a germ cell mutagen), the critical risk-specific dose is defined for a risk level of 1 in 1 million.

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.

Nonthreshold Contaminants

For nonthreshold 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 nonthreshold 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 nonthreshold substances. However, SQE_{HH}s for nonthreshold substances in Canadian soils are derived with a level of risk of 10^{-6} for incremental risk from soil.

Estimated Daily Intake

Canadians are exposed to background contamination in the air, food, and water, 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 are also considered in the development of estimates of background exposure of the general population.

Assumptions

About Exposure Scenarios

SQE_{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 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.

Nonthreshold 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 of 1×10^{-6} from remediated soils at the guideline concentration. The uses of different incremental risk levels can be calculated and incorporated into the development of a site-specific objective, subject to the approval of the jurisdictional authority (CCME 1996b).

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 prime 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_{HH} considers all direct soil exposure pathways to obtain a preliminary soil quality guideline ($PSQG_{HH}$). 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 second step in the derivation of an SQG_{HH} is the consideration of indirect soil exposure pathways through the use of check mechanisms based on simplified models using conservative generic input values for site-specific characteristics. The resulting values of the checks are compared to the $PSQG_{HH}$ in order to define the final SQG_{HH}. The following indirect pathways are considered: contamination of groundwater used as drinking water (Appendix A), contamination of 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 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 nonthreshold 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 TDIs measured against, the most sensitive life stage, which is the toddler stage (6 months to 4 years).

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

Route of exposure	Agriculture	Residential/ parkland	Commercial	Industrial
Sensitive receptor	Child* Adult†	Child* Adult†	Child* Adult†	Child* Adult†
Exposure period	24 hours per day, 365 days per year	24 hours per day, 365 days per year	10 hours per day, 5 days per week, 48 weeks per year	10 hours per day, 5 days per week, 48 weeks per year
Direct soil exposure pathways	Ingestion Dermal contact Inhalation	Ingestion Dermal contact Inhalation	Ingestion Dermal contact Inhalation	Ingestion Dermal contact Inhalation
Indirect soil exposure pathways	Groundwater Indoor air Backyard produce	Groundwater Indoor air	Groundwater Indoor air	Groundwater Indoor air Off-site migration

*Threshold contaminant.
†Nonthreshold contaminant.

Derivation of Preliminary Human Health Soil Quality Guidelines

Preliminary Soil Quality Guidelines for Threshold Substances

The $PSQG_{HH}$s for threshold substances are calculated using the following equation:

$$PSQG_{HH} = \frac{(TDI - EDI) \times SF \times BW}{[(AF_I \times IR) + (AF_D \times DR) + (AF_S \times SR)] \times ET} + BSC$$

where

$PSQG_{HH}$ = preliminary human health soil quality guideline (mg·kg^{-1})
TDI = tolerable daily intake (mg·kg^{-1} bw per day)
EDI = estimated daily intake (multimedia exposure assessment) (mg·kg^{-1} per day)
SF = soil allocation factor (unitless)
BW = body weight (kg)
BSC = background soil concentration (mg·kg^{-1})
AF_I = absorption factor for gut (unitless)
AF_D = absorption factor for lung (unitless)
AF_S = absorption factor for skin (unitless)
IR = soil ingestion rate (kg·d^{-1})
DR = soil inhalation rate (kg·d^{-1}
SR = soil dermal contact rate (kg·d^{-1})
ET = exposure term (unitless)

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 contacting the skin in a day. The soil ingestion rate refers to the amount of soil ingested on a daily basis. 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 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).

Preliminary Soil Quality Guidelines for Nonthreshold Substances

If the chemical is identified as a nonthreshold substance, then the guideline will be derived using a critical RSD based on an incremental risk from soil exposure of 10^{-6}. The use of other critical risk levels can easily be accommodated at a site-specific objective level. The $PSQG_{HH}$ for nonthreshold substances is established as follows:

$$PSQG_{HH} = \frac{RSD \times BW}{[(AF_I \times IR) + (AF_D \times DR) + (AF_S \times SR)] \times ET} + BSC$$

where

$PSQG_{HH}$ = preliminary human health soil quality guideline (mg·kg^{-1})
RSD = risk specific dose (mg·kg^{-1} per day)
BW = body weight (kg)
BSC = background soil concentration (mg·kg^{-1})
AF_I = absorption factor for gut (unitless)
AF_D = absorption factor for lung (unitless)
AF_S = absorption factor for skin (unitless)
IR = soil ingestion rate (kg·d^{-1})
DR = soil inhalation rate (kg·d^{-1})
SR = soil dermal contact rate (kg·d^{-1})
ET = exposure term (unitless)

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 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).

Indirect Soil Contaminant Exposure

The following check 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 check mechanisms and 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 check mechanisms are further discussed in the appendixes, which also include the variables used for the different chemicals in the checks. The first two check mechanisms for indirect exposures are the migration of soil contaminants into groundwater (Appendix A) and the volatilization of soil contaminants into indoor air (Appendix B). The other two check mechanisms are called management adjustment factors (MAFs). The term MAFs refers to the necessarily imprecise nature of those models using conservative point estimates, based on data and professional judgment, for generic input values. These two MAFs are for the off-site migration of contaminants from industrial sites to more sensitive neighbouring properties (Appendix C) and for exposure from ingestion of food grown on contaminated soils (Appendix D).

Derivation of the Final Human Health Soil Quality Guidelines

Agricultural Land Use

First, the $PSQG_{HH}$ is calculated. For agricultural land use, the check mechanisms for indirect exposure to soil contaminants via ingestion of groundwater, infiltration of volatile compounds into indoor air, and ingestion of produce, meat, and milk produced on-site are all calculated. If these calculations indicate an unacceptable exposure, the final SQG_{HH} is set at the lowest value generated by the check procedures. This ensures that the final SQG_{HH} is protective against all these potential contaminant media transfer pathways. If the check mechanisms indicate acceptable exposures, then the final SQG_{HH} is set at the level of the $PSQG_{HH}$.

Residential/Parkland Land Use

First, the $PSQG_{HH}$ is calculated. For residential/parkland land use, check mechanisms for indirect exposure to soil contaminants via ingestion of groundwater and infiltration of volatile contaminants into indoor air are calculated. If these calculations indicate an unacceptable exposure for the $PSQG_{HH}$, then the final SQG_{HH} is set at the lower of the values generated by these checks. If the check mechanisms indicate acceptable exposures, then the final SQG_{HH} is set at the level of the $PSQG_{HH}$.

For residential properties with backyard gardens, the check mechanisms for contamination of produce grown on site is calculated and presented in the supporting document for possible use as a site-specific objective.

Commercial Land Use

First, the $PSQG_{HH}$ is calculated. For commercial land use, check mechanisms for indirect exposure to soil contaminants via ingestion of groundwater, and infiltration of volatile contaminants into indoor air are calculated. If these modelling procedures indicate an unacceptable exposure for the $PSQG_{HH}$, then the final SQG_{HH} is set at the lower of the values generated by these two models. If the check mechanisms indicate acceptable exposures, then the final SQG_{HH} is set at the level of the $PSQG_{HH}$.

Industrial Land Use

First, the $PSQG_{HH}$ is calculated. As with commercial land use, the check mechanisms for indirect exposure via ingestion of groundwater and infiltration of volatile contaminants into indoor air are applied to the $PSQG_{HH}$ for industrial land use. Where unacceptable exposures are found using these modelling procedures, the $PSQG_{HH}$ for industrial land use is set at the lower of the values generated by these check mechanisms. Where acceptable exposures are found, the original $PSQG_{HH}$ is used. The procedure for checking off-site migration via wind and water erosion from an industrial site to an adjacent more sensitive land use is then applied as an MAF to determine the final SQG_{HH}.

The $PSQG_{HH}$, which has been modified to ensure protection of human health with respect to the check mechanisms, becomes the recommended SQG_{HH}. Appropriate annotations will accompany any SQG_{HH} that is based on a modified $PSQG_{HH}$.

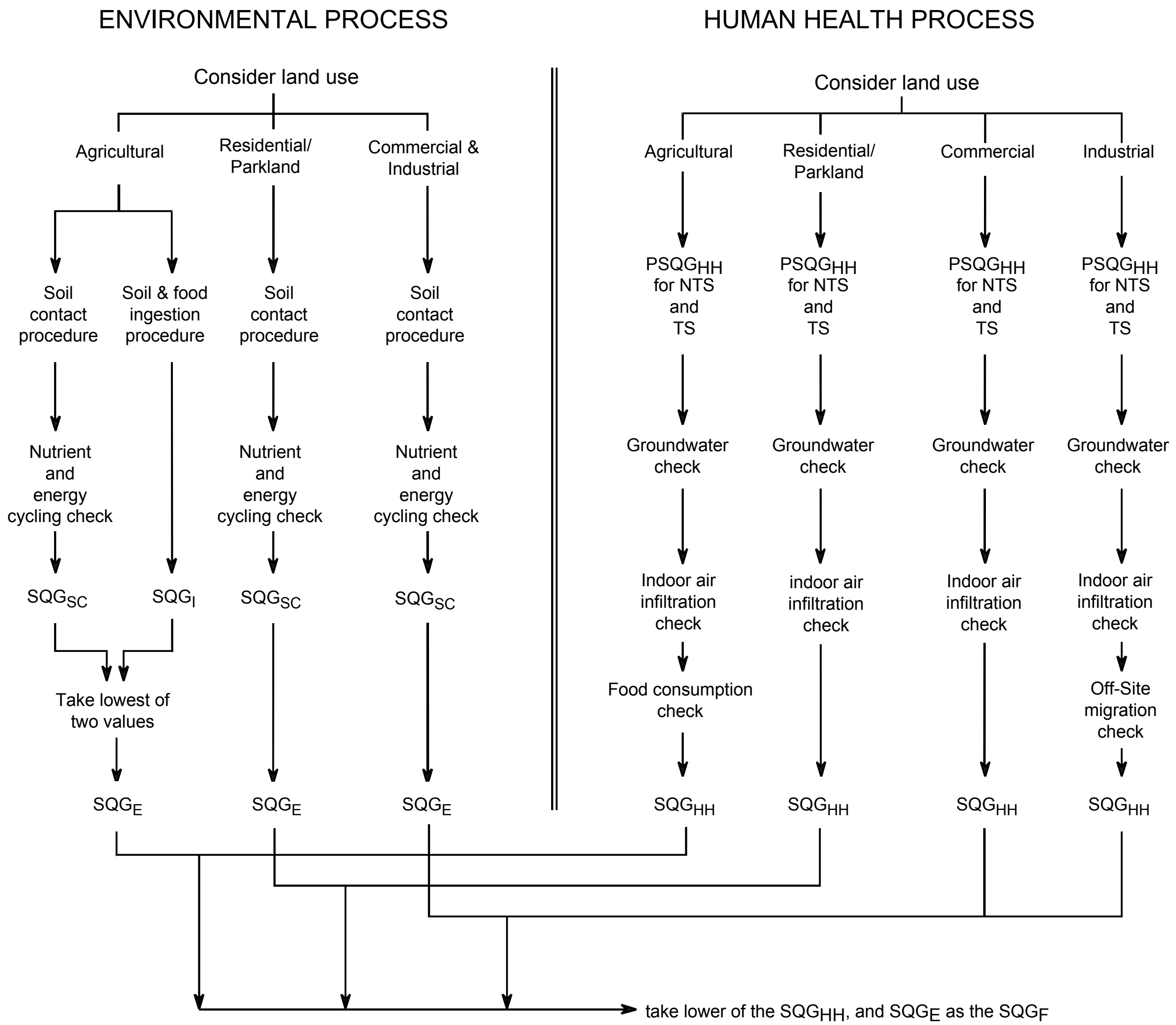
DERIVATION OF THE FINAL SOIL QUALITY GUIDELINES

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 in each land use category, 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.

Evaluation against Plant Nutritional Requirement, Geochemical Background, and Analytical Detection Limits

Guidelines should be reasonable, workable, and usable. Guidelines are developed by applying scientifically derived information, backed by professional judgment



SQG_{SC} = soil quality guideline for soil contact
SQG_{I} = soil quality guideline for soil and food ingestion
SQG_{E} = environmental soil quality guideline
$PSQG_{HH}$ = preliminary human health soil quality guideline
SQG_{HH} = human health soil quality guideline
SQG_{F} = final soil quality guideline
TS = threshold substance
NTS = nonthreshold substance

Figure 4. Overview of the derivation process for the final recommended soil quality guideline.

where data gaps occur. Occasionally, defined exposure-based procedures produce numerical guidelines that conflict either with plant nutritional requirements, geochemical background, or analytical detection limits. 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_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_F for these land use categories is compared to minimum plant nutritional requirements. If the SQG_F is below acceptable minimum plant nutritional requirement levels, then insufficient nutritional requirements for plant growth may result at the value of the SQG_F. The SQG_E 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_F will be above plant nutritional requirements.

Where applicable, the SQG_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_F is below the accepted geochemical background soil concentration, the accepted background concentration replaces the SQG_F generated using this soil protocol.

Finally, a candidate SQG_F for a given substance must be checked against the best analytical detection limit currently achievable in Canada for soils. Where the candidate SQG_F is below the analytical detection limit, the SQG_F shall be set at the detection limit.

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_Fs will require adjustment. Where any of the three evaluation procedures described above does result in modification of a candidate SQG_F, this condition will be noted in the assessment document for the substance.

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Appendix A
Groundwater Check Calculations for Benzo*(a)*pyrene, Pentachlorophenol, Phenol, Toluene, and Xylenes

Soil contamination can lead to groundwater contamination. Canadian soil quality guidelines are designed to prevent unacceptable transfers of contaminants to groundwater systems through the groundwater check (CCME 1996). This check assumes that an aquifer underlying a remediated site may be used by humans as a drinking water source.

The groundwater check is applicable to nondissociating organic contaminants and to some ionizing organic compounds provided that sorption of the dissociated and nondissociated forms can be simply described, as in the case of weak organic acids. It is not applicable to metals because partitioning of metal contaminants between sorbed and dissolved forms in soils is complex and affected by many site-specific parameters.

Nondissociating Organic Contaminants

Equilibrium partitioning isotherms effectively describe the behaviour of nondissociating organic contaminants in soils. Thus, the total contaminant concentration in soil at which the contaminant concentration in the pore water is equal to the drinking water guideline concentration can be calculated. However, pore water will ultimately drain to groundwater, where dilution will occur. Therefore, the soil concentration is multiplied by a generic dilution factor, which has been set at 50 (CCME 1996). Hence,

$$Y = DF \times C_w(K_{oc} \times f_{oc} + \theta_m)$$

where

- Y = total contaminant concentration in soil at equilibrium with pore water at the drinking water guideline concentration ($mg \cdot kg^{-1}$)
- DF = dilution factor (50)
- C_w = drinking water guideline concentration ($mg \cdot L^{-1}$)
- θ_m = mass moisture content ($L \cdot kg^{-1}$)
- K_{oc} = organic carbon partitioning coefficient ($L \cdot kg^{-1}$), calculated as $0.41 \times K_{ow}$, where K_{ow} is the octanol–water partition coefficient
- f_{oc} = organic fraction of dry soil ($g \cdot g^{-1}$) (default: 0.003)

Dissociating Organic Contaminants

The preceding equation may be extended to dissociating organic contaminants if the soil pH, the acidity constant of the contaminant, and the partition coefficient of the nondissociated form are taken into consideration. The equation would then become

$$Y = DF \times C_w (K_{oc}' \times f_{oc} \times Q_{env} + \theta_m) \quad (1)$$

where

- K_{oc}' = organic carbon-normalized coefficient for the nondissociated form
- Q_{env} = proportion of the nondissociated form at environmental pH

K_{oc}' is calculated as described in the following equation (Mackay et al. 1992–1995), using the octanol–water partition coefficient for the nondissociated form (K_{ow}'):

$$K_{oc}' = 0.41 \times K_{ow}' \quad (2)$$

The K_{ow}' is obtained by modifying the octanol–water partition coefficient for total contaminant (K_{ow}) so that it takes into account only the nondissociated fraction. Since the dissociated fraction depends on pH, the modification can be made by applying the following equation, where K_a is the acidity constant of the contaminant and where $[H^+]_{exp}$ is the concentration of H^+ ions in solution at the pH to which the K_{ow} was experimentally determined:

$$K_{ow}' = K_{ow} \times (1 + K_a / [H^+]_{exp}) \quad (3)$$

Q_{env} is calculated using the following equation, where $[H^+]_{env}$ is the concentration of H^+ ions in solution at environmental pH:

$$Q_{env} = 1 / (1 + K_a / [H^+]_{env}) \quad (4)$$

By combining equations 1 to 4 we obtain:

$$Y = DF \times C_{wa} [0.41 \text{ x } K_{ow} \times (1 + K_a / [H^+]_{exp}) \times f_{oc} \times 1 / (1 + K_a / [H^+]_{env}) + \theta_m]$$

Therefore, the following chemicals were eligible for groundwater check calculations using the specific variables indicated in the table below. Results of calculations are also provided.

Maximum allowable concentrations (Y) of contaminants in soil to ensure the protection of groundwater.

Contaminant	Canadian drinking water guideline ($mg \cdot L^{-1}$)	Log K_{ow}*	K_a (pK_a)*	Y ($mg \cdot kg^{-1}$)
Nondissociating				
Benzo*(a)*pyrene	0.00001	6.04	NA	0.67
Phenol	0.560 (provisional)	1.46	NA	3.79
Toluene	0.024	2.69	NA	0.84
Xylenes	0.300	3.20 †	NA	30.74
Dissociating				
Pentachlorophenol	0.060	5.05‡	1.99×10^{-5} (4.7)§	7.55

Notes: log K_{ow} = log of the n-octanol–water partition coefficient; pK_a = log of the dissociation or acidity constant; Y = maximum allowable contaminant concentration in soil for protection of groundwater; NA = not applicable.
*Values from Mackay et al. (1992–1995) unless indicated otherwise.
†Value for the most prevalent isomer, *m*-xylene.
‡Value from Shui et al. (1994).
§Value from Crosby et al. (1981).

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Appendix B
Indoor Air Check Calculations for Benzo*(a)*pyrene, Pentachlorophenol, and Phenol

Volatile organic compounds can migrate from soil into the basements of buildings. The present check applies to volatile compounds and attempts to ensure that the guidelines proposed will not pose a potential risk of indoor air contamination.

The concentration of volatile compounds in the soil gas (air) can be estimated with the following equation:

$$C_{sg} = (1000 \times C_s \times H) / (K_{oc} \times f_{oc} \times R \times T)$$

where

C_{sg} = contaminant concentration in soil gas ($mg \cdot m^{-3}$)
C_s = contaminant concentration in soil, set equal to soil quality guideline ($mg \cdot kg^{-1}$)
H = Henry's law constant (atm∀$m^{-3} \cdot mol^{-1}$)
K_{oc} = organic carbon partitioning coefficient ($L \cdot kg^{-1}$), calculated as $0.41 \times K_{ow}$, where K_{ow} is the octanol–water partition coefficient
f_{oc} = organic fraction of dry soil ($g \cdot g^{-1}$) (default: 0.003)
R = gas constant (8.20×10^{-5} atm∀$m^{-3} \cdot mol^{-1}$ K)
T = absolute temperature (K) (default: 294)

Once in the gas phase, volatile organic compounds migrate into basements via diffusion and barometric pressure differentials between the soil gas and the indoor air. The dilution factor from soil gas to indoor air is 10 000 (CCME 1996). Therefore, dividing the estimated soil gas concentration (C_{sg}) for a volatile organic compound by 10 000 provides an estimated upper limit on the expected indoor air concentration. The indoor air concentration (C_{sg}/10 000) resulting from the soil guideline for volatile organic compounds should not exceed 20% of the inhalation reference dose for threshold contaminants; for nonthreshold contaminants it should not exceed an estimated incremental cancer incidence of 1 in 1 000 000. If the resulting indoor air concentration (C_{sg}/10 000) is too high, an acceptable soil concentration (C_s') can be back-calculated using the equation below:

$$C_s' = (0.20 \times TDI_i \times BW \times K_{oc} \times f_{oc} \times R \times T \times 10\,000) / (IR \times H)$$

where

TDI_i = tolerable daily intake by inhalation ($mg \cdot kg^{-1}$ bw per day)

Table B-1. Specific variables used in the indoor air check.

Contaminant	TDI_i* ($mg \cdot kg^{-1}$ bw per day)	Child EDI_i ($mg \cdot kg^{-1}$ bw per day)	Adult EDI_i ($mg \cdot kg^{-1}$ bw per day)	H† ($atm \cdot m^{-3} \cdot mol^{-1}$)	log K_{ow}
Benzo*(a)*pyrene‡	1.64×10^{-7}	NA	NA	4.5×10^{-7}	6.04
Pentachlorophenol	0.003 (provisional)	3.25×10^{-6}	2.78×10^{-6}	7.8×10^{-7}	5.05§
Phenol	0.060	4.6×10^{-5}	3.9×10^{-5}	5.3×10^{-7}	1.46

Notes:
TDI_i = Tolerable daily intake by inhalation; EDI_i = Estimated daily intake by inhalation; H = Henry's law constant; log K_{ow} = log of the n-octanol-water partition coefficient.
*Value identical to the oral TDI (MMEDE 1994).
†Values from Mackay et al. (1992–1995), converted from Pa to atm using a factor of 9.8692×10^{-6}.
‡Nonthreshold contaminant: inhalation slope factor taken from USEPA (1991) to obtain TDI_i.
§Value from Shui et al. (1994).

BW = body weight of receptor (13-kg child for noncarcinogens, 70-kg adult for carcinogens)
IR = inhalation rate (using a 13-kg child for noncarcinogens and a 70-kg adult for carcinogens [$L \cdot d^{-1}$]).

Therefore, the indoor air check was done for the following eligible chemicals using the specific variables indicated in Table B-1.

The preliminary soil quality guidelines and the calculation results are as follows:

Table B-2. Maximum allowable concentrations of contaminants in soil to protect the air quality in buildings on site.

Contaminant	Residential/ parkland (C_s')	Commercial (C_s')*	Industrial (C_s')*
Benzo*(a)*pyrene	357	357	357
Pentachlorophenol	66 470	241 951	283 264
Phenol	503	1 831	2 144

Note: C_s' = Back-calculated soil concentration resulting in an intake equal to 20% of TDI.

*Values calculated with a time apportionment factor of 3.64, representing an exposure of 10 hours per day, 5 days per week, 48 weeks per year.

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Appendix C
Off-site Migration Check Calculations for As, B(a)P, Cd, Cr, Cu, Cyanide, Pb, Pentachlorophenol, Phenol, Tetrachloroethylene, Toluene, and Xylene

Soil quality guidelines for 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 an industrial property to an adjacent residential property (CCME 1996).

The universal soil loss equation and the wind erosion equation are used to estimate the transfer of soil to an adjacent property (CCME 1996). It is possible to calculate the concentration (C_i) in the eroded soil from the industrial site that will increase the contaminant concentration in the receiving soil to equal the residential/parkland guideline within a specified period of time. If the guideline for industrial sites is above C_i, then residential land adjacent to an industrial property could become unacceptably contaminated via erosion and off-site deposition. The following equation has been derived to allow the calculation of C_i:

$$C_i = \{D_m \times C_m - [(D_m - D_d) \times BSC]\} / D_d$$

where

C_i = concentration of contaminant in eroded soil ($mg \cdot kg^{-1}$)
D_m = depth of mixing, (default 2 cm)
C_m = concentration of contaminant in receiving soil after mixing, set equal to the soil quality guideline for residential/parkland land use ($mg \cdot kg^{-1}$)
D_d = depth of deposited material before mixing: 0.14 cm (assuming a deposition rate of 13.9 $t \cdot ha^{-1}$ and a bulk density for the eroded material of 1 $t \cdot m^{-3}$)
BSC = background concentration of contaminant in the receiving soil ($mg \cdot kg^{-1}$)

The off-site migration check was done for the following chemicals using the specific variables indicated in the following table. Calculation results are also given.

Reference

CCME (Canadian Council of the Ministers of Environment). 1996. A protocol for the derivation of environmental and human health soil quality guidelines. CCME, Winnipeg.

Maximum allowable concentrations (C_i) of contaminants in soil of industrial sites for the protection of residential/parkland properties.

Contaminant	SQG_{HH} for residential/ parkland land use ($mg\cdot kg^{-1}$)	Background soil concentration ($mg\cdot kg^{-1}$)	Calculated C_i ($mg\cdot kg^{-1}$)	$PSQG_{HH}$ for industrial land use* ($mg\cdot kg^{-1}$)
Arsenic (inorganic)†	12†	10	38.78	12†
Benzo*(a)*pyrene‡	1.5	0.113	20.07	1.5
Cadmium (inorganic)	14.1	0.8	192	2090
Chromium (total)	218	62	2307	6687
Copper	1127	22	15921	20406
Cyanide (free)	29.4	0.02	422	2307
Lead	142.9	98	744	8201
Pentachlorophenol	93	0.007	1338	7542
Phenol	1939	0.027	27899	152396
Tetrachloroethylene	0.15	0.00018	2.11	0.62
Toluene	13.9	0.00026	200	59.36
Xylenes	4.6	0.00018	66.19	19.95

Notes: $PSQG_{HH}$ = preliminary human health soil quality guideline; SQG_{HH} human health soil quality guideline.

*Guidelines have been calculated with a time apportionment factor of 3.64, representing an exposure of 10 hours per day, 5 days per week, 48 weeks per year.
†Treated as a nonthreshold contaminant. SQG_{HH} represents incremental risk-specific guidelines.
‡Nonthreshold contaminant.

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 1996).

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. If no MRL is available, then the total daily intake estimated using the backyard produce 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 noncarcinogens. 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:

$$I_p = \{(P_h \times P_c \times B_v \times SQG_{HH}) + [(1 - P_h) \times P_c \times P_r]\} / BW$$

where

I_p = total intake of contaminants from produce ($mg{\cdot}kg^{-1}$ per day)
P_h = percent of homegrown produce for residential land use (10%)
P_c = produce consumption rate (0.125 $kg{\cdot}d^{-1}$ for noncarcinogens [child], 0.250 $kg{\cdot}d^{-1}$ for carcinogens [adult])
B_v = bioconcentration factor for produce
SQG_{HH} = human health soil quality guideline for residential/parkland land use ($mg{\cdot}kg^{-1}$)
P_r = average contaminant concentration in retail produce ($mg{\cdot}kg^{-1}$)
BW = body weight of receptor (13-kg child for noncarcinogens, 70-kg 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_v for organic contaminants (Travois and Arms 1988):

$$\log B_v = 1.59 - 0.58 \log K_{ow}$$

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 associated with a cancer risk of 10^{-6} (CCME 1996). 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: $$I_b = \{(M_h \times M_c \times B_p \times SQG_{HH}) + [(1 - M_h) \times M_c \times M_r]\} / BW$$

where

I_b = total intake of contaminants from beef ($mg{\cdot}kg^{-1}$ 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 (0.060 $kg{\cdot}d^{-1}$ for noncarcinogens [child], 0.135 $kg{\cdot}d^{-1}$ for carcinogens [adult])
B_p = bioconcentration factor for beef
SQG_{HH} = human health soil quality guideline for agricultural land use ($mg{\cdot}kg^{-1}$)
M_r = average contaminant concentration in retail beef ($mg{\cdot}kg^{-1}$)
BW = body weight of receptor (13-kg child for noncarcinogens, 70-kg adult for carcinogens)

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

$$\log B_p = 7.6 + \log K_{ow}$$

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

where

I_m = total intake of contaminants from milk ($mg{\cdot}kg^{-1}$ per day)
MK_h = percent of milk home produced
MK_c = milk consumption rate (0.670 $kg{\cdot}d^{-1}$ for noncarcinogens [child], 0.283 $kg{\cdot}d^{-1}$ for carcinogens [adult])
B_m = bioconcentration factor for milk
SQG_{HH} = human health soil quality guideline for agricultural land use ($mg{\cdot}kg^{-1}$)
MK_r = average contaminant concentration in retail milk ($mg{\cdot}kg^{-1}$)
BW = body weight of receptor (13-kg child for noncarcinogens, 70-kg 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_v for organic contaminants (Travois 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_f. For carcinogen contaminants, T_{ag} should not exceed the RSD associated with a cancer risk of 10^{-6} (CCME 1996). The soil quality guideline should be modified accordingly.

References

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