Eco-SSL
Ecological Soil Screening Levels

Attachment 1-1

Guidance for Developing Ecological Soil Screening Levels (Eco-SSLs)

Review of Existing Soil Screening Benchmarks

OSWER Directive 92857-55

November 2003

A CRITICAL REVIEW OF METHODS

for

DEVELOPING ECOLOGICAL SOIL QUALITY GUIDELINES AND CRITERIA

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EXECUTIVE SUMMARY

In support of the U.S. Environmental Protection Agency (USEPA) development of soil criteria referred to as Ecological Soil Screening Level to screen contaminated sites, methods used elsewhere to develop similar criteria were reviewed. Technical guidance documents from Europe (most notably, The Netherlands), Australia, Canada (Federal), British Columbia, and Oak Ridge National Laboratory were examined. None of the U.S. states have distinct methods. Technical staff in each of the countries were also consulted. In addition, USEPA methods for development of water and sediment criteria were reviewed.

Three generic methods have been used to set protective soil concentrations throughout the world.

- Type 1 selects the lowest reported toxicity value and divides by an assessment (safety) factor.
- Type 2 arrays all reported values in a statistical distribution and selects a particular percentile.
- Type 3 ranks all reported soil concentrations from lowest to highest and chooses the upper boundary such that no toxic effects are known to occur at lower concentrations; however, higher concentrations do not always cause toxicity.

The final goal of all environmental protection values, regardless of media, is protection while being reasonable. How issues such as level of protection, use of assessment factors, background levels, and minimum data requirements are addressed varies with jurisdictions, which in turn affects the final values. Compilation of soil protection values revealed substantial differences among the various jurisdictions. Generally, the different values were drawn from the same world-wide body scientific studies. Therefore the differences among these jurisdictions primarily reflect differences in policy, rather than technical rigor or quality of the underlying science.

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ABBREVIATIONS

ACR	**A**cute to **C**hronic **R**atio
BCF	**B**ioconcentration **F**actor
BCME	**B**ritish **C**olumbia **M**inistry of **E**nvironment, **L**ands, and **P**arks
BW	**B**ody **W**eight
CCME	**C**anadian **C**ouncil of **M**inisters of the **E**nvironment
EC	**E**uropean **C**ommunity
EC_{10}	**E**ffect **C**oncentration for **10**% of the test organisms
EC_{50}	**E**ffect **C**oncentration for **50**% of the test organisms
Eco-SSL	**E**cological **S**oil **S**creening **L**evel
EIL	**E**nvironmental **I**mpact **L**evel
ER-H	**E**ffects **R**ange **– H**igh
ER-L	**E**ffects **R**ange **- L**ow
ER-M	**E**ffects **R**ange - **M**edium
LC_{50}	**L**ethal **C**oncentration for **50**% of the test animals
LOAEC	**L**owest **O**bservable **A**dverse **E**ffect **C**oncentration
MOEE	**M**inistry of **E**nvironment and **E**nergy (Ontario)
MPC	**M**aximum **P**ermissible **C**oncentration
NOAA	**N**ational **O**ceanographic and **A**tmospheric **A**dministration
NOAEC	**N**o **O**bservable **A**dverse **E**ffect **C**oncentration
NPER	**N**o **P**otential **E**ffects **R**ange
ORNL	**O**ak **R**idge **N**ational **L**aboratory
PNEC	**P**redicted **N**o **E**ffect **C**oncentration
QSAR	**Q**uantitative **S**tructure **A**ctivity **R**elationship
SETAC	**S**ociety of **E**nvironmental **T**oxicology and **C**hemistry
TEC	**T**hreshold **E**ffects **C**oncentration
USEPA	**U**nited **S**tates **E**nvironmental **P**rotection **A**gency

GLOSSARY

Acute Toxicity: A short-term exposure to a contaminant in a medium and usually at concentrations high enough to induce an effect rapidly.[1]

Assessment Factors: A number applied to the toxicity value of a chemical in a situation with little data to provide an assumed safe value in the ecosystem. Also called: application factors, uncertainty factors, or safety factors.

Background Concentration: A representative ambient level for a chemical in soil or water.[1]

Benchmark Values: Concentrations related to thresholds sometimes used in Risk Quotients.

Bioaccumulation: Defined by the USEPA to be terrestrial rates of uptake of contaminants from the environment.

Bioconcentration Factor (BCF): The ratio of the chemical concentration in an organisms to the concentration in the media. However, the USEPA defines bioconcentration as only a concentration of chemical absorbed through gills from an aquatic environment.

Biomagnification: As tissue concentrations of accumulated chemical compounds are passed up trophic levels, the tissue residue concentrations increase systematically as trophic level increases.[1]

Chronic Continuous Criterion: A USEPA water quality value that is the highest concentration of a pollutant that can be continuously maintained in a water body without unacceptably affecting aquatic organisms or beneficial uses.

Chronic Maximum Concentration: A value for the USEPA that my be exceeded for a few hours once every three years, set at half of the Final Acute Value.

Chronic Toxicity: Long-term exposure (weeks to years) to a contaminant in a medium, often includes reproduction or the full life cycle of the organism.[1]

Cofauna: Australian term for animals not directly associated with an area of contamination, but may be affected by impact (i.e., indirect effects) or by offsite migration of the contaminant.

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[1] Adapted from CCME 1996(a)

Criteria: Concentrations of contaminants in environmental media that may not be exceeded; legally enforceable and subject to fine or other regulatory action should exceedences occur.

Critical Limits: A threshold value where harmful effects occur used in RIVM (The Netherlands) Guidelines. Also called: Maximum Permissible Concentration or Maximum Allowable Concentration.

Critical Loads: A threshold amount of material that can be present without causing harm to terrestrial organisms within the context of the specific soil chemistry that is used in RIVM (The Netherlands) Guidelines.

Ecological Soil Screening Level (Eco-SSL): Soil concentrations protective of terrestrial organisms; unacceptable adverse effects should not occur to ecological receptors at or below this value. Also called: critical loads, precautionary soil values, or soil quality objectives.

Ecotox Thresholds: A screening value set by the USEPA Superfund to determine if a risk assessment is necessary at a particular site.

Effect Concentration (EC_x): The concentration of a chemical in the medium that results in some *sublethal effect* to x% of the test organisms.[1]

Effects Range- High (ER-H): NOAA's definition of the sediment concentration above, which effects are always seen and below which they sometimes occur.

Effects Range- Low (ER-L): The 10th percentile of the distribution of toxic effects (LOAEC values) thresholds for organisms in soil. The USEPA defines it as the sediment concentration below which measured effects have never been seen and above which measured effects are sometimes seen.

Effects Range- Median (ER-M): The midpoint between the ER-H and the ER-L.

Environmental Impact Level (EIL): Australia's level for protecting ecological values. It is the concentration of a contaminant that does not cause an adverse effect on specified biota.

Epifauna: Australian term for animals that live in general contact with soil.

Equilibrium Partitioning Theory: The relationship between the concentration of a substance bound to the soil particles and the concentration in soil solution when the system is at equilibrium.

Final Acute Value: Acute water quality criteria developed by the USEPA for a group of organisms. Using the mean data from available genus and species tests, the 5th percentile of the lowest four values is calculated.

Infauna: Australian term for fauna that live within and in contact with soil.

Intervention Values: A soil concentration defined in The Netherlands as a level indicating serious contamination and requiring immediate remediation.

Lethal Concentration (LC_x): The concentration of chemical in the medium that results in *mortality* to x% of the test organisms.[1]

Lowest Effect Level: The State of New York's level of contamination that can be tolerated by the majority of organisms, but still causes a toxicity to a few species.

Lowest Observable Adverse Effect Concentration (LOAEC): The lowest concentration of a chemical used in a toxicity test that has a statistically adverse effect on test organisms relative to a control.[1]

Matrix Standard: A standard developed by British Columbia for substances with a larger database with separate numbers for human health and ecological receptors.

No Observable Adverse Effect Concentration (NOAEC): The highest concentration of a contaminant used in a toxicity test that has no statistically adverse effect on the exposed population of test organisms relative to a control.[1]

No Potential Effects Range (NPER): A Canadian point estimate in the distribution of LOAEC/NOAEC and EC_{50}/LC_{50} below which the proportion of definitive effects data does not exceed "acceptable levels."

Numerical Soil Standard: Standards developed by British Columbia for each land use category for substances with a limited toxicity database, intended to be protective of both human health and ecological receptors.

Precautionary Soil Value: The German term for the soil concentration above which the responsible party has to reduce or avoid future input of these substances onto the site or in the vicinity of the site.

Predicted No Effect Concentration (PNEC): The European value or the concentration below which unacceptable effects on organisms will most likely not occur. This is derived from the No Observable Effect Concentration.

Preliminary Soil Quality Guidelines: Canadian developed generic numerical concentrations of a contaminant considered safe for a broad range of conditions and regions.

Quantitative Structure Activity Relationship (QSAR): A prediction of how a molecule will react in and effect the environment based on its molecular structure.

Severe Effect Level: The State of New York's level of contamination at which pronounced disturbance of the sediment community can be expected.

Soil Protection Value: A general term used in this report to encompass all soil concentration values derived to protect all or part of the terrestrial system from unacceptable effects due to contamination. It includes screening level values, criteria, and clean-up target levels.

Soil Quality Remediation Objectives: Canadian developed numerical concentrations selected or derived to define acceptable residual contamination at a specific site.

Target Values: Clean-up goals.

Threshold Effects Concentration (TEC): The concentration of a chemical below which no adverse effect is expected to occur.

1. INTRODUCTION

Many jurisdictions around the world have begun developing Soil Protection Values (SPVs), variously known as "critical loads," "precautionary soil values," "soil criteria," ecological soil screening levels, or "soil quality objectives." These soil concentrations (based on total recoverable concentrations of chemical measured from bulk soils) are to be protective for terrestrial organisms. At the SPV or below, there is no reason to believe that adverse effects will occur to ecological receptors. At concentrations above the SPV, there may be adverse effects depending upon local conditions. Soil Protection Values are used to screen potentially contaminated sites for priority pollutants or, in some countries, as clean up goals or targets for allowable discharge rates. In screening sites, substances with concentrations below the particular SPV would be eliminated from further consideration, allowing the site-specific ecological risk assessment to focus only on those substances that may cause adverse effects.

Development of SPVs is a two-step process. The first is a data gathering and qualification exercise. Typically, this involves search of the peer reviewed and government literature on toxicological response and exposure relationships for terrestrial plants and animals. This is followed by a quality control screen to select only those studies that meet relatively stringent criteria for inclusion in the final database. This type of quality control screen is followed for all regulatory criteria development (e.g., water quality criteria, human health reference doses), as most of the studies reported in the literature were conducted with other objectives in mind. It therefore is necessary to screen such work carefully to find only those that are applicable to the regulatory effort, as well as those that embody sound, quality scientific approaches.

The next step in the SPV development process is determining how to use the retrieved data to set the final value. Differences in measurement endpoints and species sensitivity, as well as in test design and laboratory practices result in relatively large variability in reported toxicity threshold values. How all these values are integrated into final SPV is of great importance. The final value is intended to be protective of terrestrial species and critical ecological functions, but must also be reasonable and not so low that even at trivial concentrations (i.e., well below biological effects thresholds) no chemical is ever screened out from further risk analysis. Certainly, values for metals should not be significantly below natural background levels. Those metals that are essential micronutrients need to be present at minimal levels to sustain plants and invertebrate communities and microbial functions. Acceptable levels of either natural or synthetic organic substances must account for organismal mechanisms that protect against toxic insults as well as acknowledging the assimilative capacity of ecological systems.

Development of SPVs requires a review of the toxicology literature. Soil concentrations related to toxicity effects are used to set a soil concentration that will be protective of terrestrial species. In setting SPVs, regulatory agencies generally will err on the side of protection while not being unreasonably lower than known biological response levels. Achieving this balance between what is protective and reasonable has been the subject of much debate in many countries as SPVs are being developed. A blend of toxicology and ecology, as well as public interest and policies regarding species protection are required to attain protectiveness and reasonableness. In the United States, this means that the single screening value must be protective across such diverse regions as the New England forests, Rocky Mountain forests, Central Plains grasslands, and Great Basin desert scrublands.

Countries that currently are developing SPVs would benefit greatly from a critical review of the approaches used by other jurisdictions, with a particular emphasis on understanding where a scientific understanding of ecotoxicological principles can provide guidance and where regulatory policy should take precedence. This will enable regulatory agencies to build on what has been learned from the work by other jurisdictions. This report reviews all the approaches currently in use for establishing SPVs. It includes as well a review of water and sediment criteria development (as practiced in the U.S.) as these processes have addressed the same issues currently confronting soil evaluations. Final sections critically review some of the common issues associated with criteria development and highlight where particular approaches have had difficulty.

1.1. INFORMATION SOURCES

The U.S. Environmental Protection Agency has tabulated information on SPVs methods used by other jurisdictions as it began to develop Ecological Soil Screening Levels (EcoSSLs) for use in the Superfund program. The information was prepared by DynCorp and submitted to the USEPA on 16 March 1998 (DynCorp, 1998). The DynCorp report did not include information from European countries or Australia and, for many of the jurisdictions, it lacked information about methods used to calculate the soil values once the toxicity data have been retrieved. Information from Europe and Australia have been included in this report and have focused on the methods to convert toxicity data to soil criteria (Table 1-1). Where sufficient information was provided by DynCorp, it has been abstracted and incorporated into this report.

Table 1-1. Documents and other information sources reviewed

Technical guidance documents

- Australian Environmental Protection Authority
  (Environmental Australia, 1997)
- British Columbia Ministry of Environment, Lands and Parks
  (BCME 1995)
- Canadian Council of Ministers of the Environment
  - (CCME 1996a) -- Protocol for the derivation of environmental and human health soil quality guidelines
  - (CCME 1996b) - Guidance manual for developing site-specific soil quality remediation objectives for contaminated sites in Canada
- European Commission
  (EC 1996)
- Netherlands Ministry of Housing, Spatial Planning, and the Environment
  (De Vries and Bakker, 1998)
- Oak Ridge National Laboratory
  (Efroymson *et al*., 1997a,b; Sample *et al*., 1996).
- Washington River Site
  (WSRS 1998)
- DiToro *et al*. (1991)
- Long and Morgan (1991)
- Stephan *et al*., (1985)

Review articles

- Beyer, N. (1990)
- Cowan *et al*., (1995)
- Kimerle *et al*., (1995)

Internet

http://ci.mond.org/9513/951306.html

Other

- personal discussions between the authors and scientists involved in regulatory agencies in Germany, Denmark, Belgium, and Spain
- (personal communications 1999 at SETAC Pellston workshop on Hazard Assessment of Metals in Soil, San Lorenzo de El Escorial, Spain).
  ECO Update bulletin (USEPA, 1989).

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2. APPROACHES FOR ECO-SSL DEVELOPMENT

Derivation of criteria for protection of organisms against potential adverse effects of chemical exposure requires information about the concentration-response relationship (i.e., hazard) in media representative of that found in the natural environment. Additional information about the relative sensitivity of species is required, to select a concentration that is "protective" of all (or most) species. Thus, all criteria setting, whether in water, sediment, or soil, follows the same basic principles: develop a dataset of hazard information and then apply some extrapolation method to determine the "safe" value (Kimerle *et al.*, 1995).

Ideally, hazard information would be available for *all* species, thus allowing an accurate determination of the toxicity threshold, (i.e., that concentration below which effects never occur in any species and above which effects sometimes occur in one or more species). However, this can never be achieved, given the thousands of currently extant species. Therefore, tests are performed on a range of representative species and extrapolations are made to account for differences in species sensitivity. In aquatic and human toxicology, these extrapolations to non-tested species may be based on scientific knowledge of chemical-organism relationships through the use of comparative physiology and Quantitative Structure Activity Relationships (QSARs) (Enslein, 1988; Zeeman, 1995). However, QSARs for terrestrial organisms have not been developed. Therefore, determination of the range of species sensitivity becomes more difficult and derivation of a "safe" concentration may rely more on policy than science through the application of "assessment" or "safety factors" when there are very few data [but see Chapman *et al*. (1998) for a discussion of the drawbacks to this approach]. When more data are available, alternative approaches are used. These include using geometric mean toxicity values within or among trophic levels, or arranging the toxicity values in a frequency distribution and selecting a pre-specified lower percentile (Kimerle *et al*., 1995).

Wildlife soil criteria have been particularly problematic, as these animals generally have limited direct exposure to soil. Toxicological relationships are expressed in terms of dietary exposures, followed by a variety of methods to estimate a corresponding soil concentration. Many jurisdictions discussed below have chosen to leave out wildlife, focusing only on the soil infauna, to set soil criteria. Others have not set generic wildlife standards, but have chosen instead to derive values for individual species. These will be discussed in detail when describing methods for the respective jurisdictions.

While each of the jurisdictions described below differ to some degree in how the final soil values are derived, they all share a common struggle to use data that were not produced under standardized systems and in many cases, not intended for this purpose. They have grappled with issues arising from lack of information on some organism groups, and of desiring a value that is protective and reasonable. The following sections review each of the approaches currently in use. The intended use or purpose for developing the method (e.g., contaminated site clean up levels, discharge allocations, etc.) is provided. Terminology is explained and summarized in the Glossary (page viii), as each jurisdiction refers to the soil values differently. Issues associated with the various methods are critiqued in Section 4 of this report. Summary tables of the various approaches currently in use are provided in Appendix A.

2.1. EUROPEAN

The methods described here are contained in the European Community Technical Guidance Document for Environmental Risk Assessment (European Community, 1996). These methods have been used to derive Probable No Effect Concentrations (PNECs) values for local, regional, and continental scale risk assessments for substances in commerce (e.g., metals, plasticizers) as well as for derivation of critical loads of pollutants (particularly metals) in soils. The Netherlands provided extended discussions on the derivations of PNECs and soil values (De Vries and Bakker, 1998), and uses these numbers for ecological risk assessment (generic and site-specific), identification of seriously contaminated sites requiring intervention and target values for regulation for discharges (Ministry of Housing Spatial Planning and Environment, 1994; Soil Protection Act, 1998). Germany currently has no Federal legislation for contaminated soil issues, so each state is responsible for preparing their own values although there is no formal written documentation for how this is to be done. Bachmann *et al*. (1997) of the German Federal Environmental Agency, Section on Soil Protection compiled the available information for discussion at a European Community workshop. The German approach is conceptually similar to that used by The Netherlands and other European Community countries. Denmark also has been working to develop soil assessment and clean-up values for contaminated sites, but still has no formal documentation. Great Britain has documentation on allowable amounts of contaminants for sludge applications, but no similar documents for contaminated sites.

The information described here is the general approach followed by all the European Community countries, as embodied in the Technical Guidance document and further described by The Netherlands. The only major difference among countries is whether they have different intervention and target values and whether or not different values are used depending upon land use (Table 2-1). For the Netherlands, "intervention values" are indicative of seriously contaminated sites that require immediate clean-up action. "Target values" are protective levels intended to achieve desired soil quality. Land use is defined as industrial, residential, agricultural, or natural lands, requiring more protective (i.e., lower) values in the order listed.

Table 2-1. Contaminated sites soil criteria in Europe

Criteria levels	**Land use dependent**	**Land use independent**
Single value	Denmark	Germany (draft) Norway Sweden United Kingdom
Two values	Switzerland The Netherlands	Belgium Finland France

The Netherlands has developed methods for deriving *critical loads* of metals and persistent organic pollutants in soils, which is defined as the amount of material that can be present without causing harm to terrestrial organisms within the context of the specific soil chemistry (e.g., pH, organic matter, and cation exchange capacity). This includes derivation of *critical limits* of exposure for the organisms, which is the value where "unacceptable harmful effects" (De Vries and Bakker, 1998) occurs. This also is called the Maximum Permissible Concentration or the Maximum Allowable Concentration.

Germany uses the term *precautionary soil values* to denote the soil concentration above which the responsible party has to reduce or avoid future input of these substances onto the site or in the vicinity of the site (Bachmann *et al*., 1997). Site-specific permits may allow additional input of substances, but no guidance has been provided on how the annual allowable loading will be calculated.

Austria, Belgium, and Switzerland have developed laws and regulations for dealing with contaminated sites and soil protection. France, Norway, Finland, Denmark, and the United Kingdom have general pollution regulations that cover issues related to soil protection, but currently do not have contaminated lands legislation. These countries have, or are developing, *soil quality criteria* that can be used as guidelines for site-specific risk assessments.

The soil values developed by the Europeans are validated to some extent, particularly for metals. De Vries and Bakker (1998) includes an uncertainty analysis in the guidance for calculating critical soil loads, including a sensitivity analysis of which parameters contribute the most uncertainty to the final soil value. All jurisdictions recognize the concept of "natural background" levels for metals, but disagree on how these are defined. This concept is discussed further in Section 4 of this report.

The following sections describe three methods used by the European Community for deriving soil values, depending upon how much toxicity data are available. The distribution method is the preferred method, but can only be used with robust data sets. If fewer toxicity data are available, the factor method is used. If no toxicity data are available form terrestrial organisms, a proposal has been made to use the Equilibrium Partitioning method where information from aquatic studies, extrapolated to soil systems through pore water analysis. The numbers generated by these methods have, so far, relied only on toxicity data from soil organisms; wildlife information has not been included. However, the approach suggested by The Netherlands for deriving wildlife values also is reviewed. Regardless of the method used, a single number is derived that is meant to be protective of all organisms in the terrestrial ecosystem.

2.1.1. Distribution Based Method

This method has been used when there are an acceptable number of reported toxicity threshold values (i.e., four or more values), representing a wide spectrum of genera. It is assumed that the varying sensitivities of soil organisms follow a predictable statistical distribution with most genera having approximately the same sensitivity and fewer being more sensitive or less sensitive. The frequency distribution of species (or genera) sensitivities generally is assumed to follow a log-normal distribution (Figure 2-1). The 5th percentile (i.e., low end) of the toxicity threshold values is then estimated and is used as the final criterion value (Van Straalen and Denneman, 1989; Wagner and Løkke, 1991).

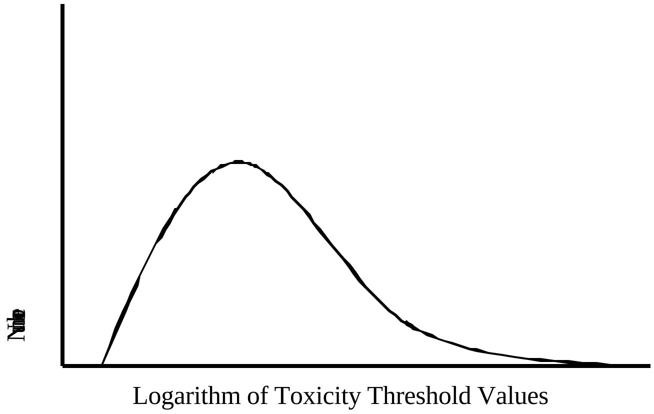

Figure 2-1. Frequency distribution of toxicity threshold (hypothetical).

2.1.2. Factor Application Method

The Factor Applications Method is used when there is little information available about the hazard of the chemical of concern to terrestrial organisms. It generally is applied if the data set is small (fewer than four studies) or when only acute data are available. Acute toxicity data, arise from short-term ecotoxicological experiments (defined by the European Union as less than one day in duration) and generally are expressed as an LC_{50} (lethal concentration for 50% of the test animals), but also may be a non-lethal response at the 50% or lower level. The lowest reported value is chosen, and then assessment factors (also known as "application factors," "uncertainty factors," or "safety factors") are applied. Generally, this entails dividing the toxicity value by 100 or 1,000 (Table 2-2). If chronic data (from studies one day to one month in duration) are available, but the number of tests or genera represented are still small, the lowest value is selected and divided by ten (Table 2-2). Chronic data are reported as the No Observable Adverse Effect Concentration (NOAEC). Note that the lowest reported toxicity number always is divided by at least ten. This is to account for uncertainties in the data, potential for additive or synergistic interactions among chemicals occurring in the environment, unknown differences in species sensitivity that may not be captured in the existing data set, and differences in laboratory methods as well as lab-to-field extrapolations. Data also are adjusted to standardize pH and organic matter according to algorithms developed from background conditions of uncontaminated sites (Table 2-2).

Table 2–2. Assessment factors for determination of soil quality criteria (Europe)

Information available	**Assessment Factor**
Only acute LC_{50} data are available and the data set is small or represents only a few genera (<3)	1,000
Only acute LC_{50} data are available, but there is an extensive phylogenetic range represented ($\geq$3)	100
Chronic test data are available but from a limited data set (<4)	10

2.1.3. Equilibrium Partitioning Method

For the equilibrium partitioning method, the assumption is made that toxicity to soil organisms is due to the amount of chemical in the soil pore water (for metals, this would be the free ion activity in the pore water). Thus, The Netherlands would prefer to set allowable amounts of chemicals in the soil as equivalent to the amount that would move into the pore water plus the amount that remains bound to soil particles. They propose that critical soil values can be set based on toxicity to standard aquatic organisms (daphnia and algae) and an estimation of soil pore water concentration using equilibrium partitioning theory (assuming reversible adsorption processes that can be described by linear sorption isotherms). The critical soil concentration is determined by multiplying the aquatic toxicity threshold value by the linear partition coefficient.

2.1.4. Wildlife

In general, vertebrate wildlife are not considered by European countries when setting soil criteria. However, The Netherlands provides directives for both a general and a food chain-specific method for calculating critical soil levels for the protection of wildlife from bioaccumulative contaminants. This is derived as:

$$MPC_{soil} = \frac{NOAEC_{wildlife}}{BCF_{food}} \qquad \text{(Equation 2-1)}$$

Where:

MPC_{soil} = maximum permissible concentration of a chemical in dry soil (mg/kg)

$NOAEC_{wildlife}$ = No observable adverse effect concentration for either all wildlife (derived by the extrapolation method described above) or species of concern

BCF_{food} = bioconcentration factor representing the ratio between the concentration in the food (wet weight) and the concentration in the soil (dry weight).

Up to three BCFs can be concatenated to determine the exposure to a particular trophic level of wildlife (soil to plants or invertebrates, then to birds or mammals, and then to predators). The Netherlands used field collected data to determine BCFs empirically for the wildlife food chain, applying a Monte Carlo analysis of all BCF data for each trophic level and selecting the 95th percentile (i.e., a high BCF to develop a conservative estimate). Species-specific food chains can be derived as well following this same model.

2.2. CANADIAN

2.2.1. Canadian Council of Ministers of the Environment

The Canadian Council of Ministers of the Environment (CCME) provides guidance for deriving *preliminary soil quality guidelines* (CCME, 1996a) and site specific *soil quality remediation objectives* (CCME, 1996b) for use in assessing risk at contaminated sites, clean-up goals, and monitoring remediation efforts. The recommended approaches were based (at least in part) from a review prepared by MacDonald and Sobolewski (1993) for CCME of approaches existing at that time. The guiding principle under which CCME operated in developing the soil numbers was to "provide a healthy functioning ecosystem capable of sustaining the current and likely future uses of the site by ecological receptors and humans." (CCME, 1996a). The CCME further describes the basis for their approach (CCME, 1996b) as needing to be practical, applicable to the objectives of the contaminated site program, and scientifically defensible. They listed 14 additional guiding principles for the derivation of site-specific soil remediation objectives (Appendix B) and conducted an uncertainty and sensitivity analysis of all the input parameters (CCME, 1996a).

Soil quality guidelines and remediation goals for receptors in direct contact with the soil (i.e., plants and invertebrates) are derived using one of several approaches, depending upon the quantity and type of toxicological data available and the specified land use. A single value is derived for each chemical under each land use that is assumed to be protective of all soil organisms, based on the lowest value derived for invertebrates, wildlife, and microorganisms (see Section 2.2.1.6 for details). Land use categories (listed here from most to least protective) are: agricultural lands, residential/parkland, commercial land, and industrial land. Differences in protection levels result from consideration of different receptors and different exposure pathways.

Ambient background levels of contaminants may be higher than the effects-based derived generic soil quality guidelines. In this instance, the CCME recognizes that background levels will take precedence over the derived values. Therefore, the final clean-up criterion will be the derived value or background, whichever is the highest. Background levels are based on regional or provincial limits and may be determined on a site-specific basis.

2.2.1.1. Weight of Evidence Approach

The Canadians prefer the "weight-of-evidence" approach where sufficient numbers of chronic studies are conducted from which Lowest Observable Adverse Effect Concentrations (LOAECs) and NOAECs have been derived. Studies that calculated EC_{50} or LC_{50} values also are included in this data set. The data set then is examined to determine if it is biased by excessive numbers of NOAEC or LOAEC values or if EC_{50} or LC_{50} values predominate. If one or the other type of study is over-represented, then this approach would not be used (determination of "over-represented" is based on "expert judgment"). If the data set is balanced, the 25th percentile of the frequency distribution is calculated and assumed to represent the "No Potential Effects Range" (NPER). The Threshold Effects Concentration (TEC) is then derived by dividing the NPER by an uncertainty factor between 1 and 5 (Table 2-3). An uncertainty factor need not always be applied and the magnitude of any factor used is left to expert judgment.

Table 2-3. Uncertainty factors for determination of soil quality criteria using the weight of evidence approach (Canada)

Information available	Suggested Uncertainty Factor
Only the minimum of 3 studies is available	5
> 3 studies are available, but <3 taxonomic groups are represented	3
> 25% of the data below the 25th percentile are definitive effects data (i.e., not LOAECs)	1

2.2.1.2. Lowest Observed Effect Concentration Method

When there are insufficient data to apply the weight of evidence method, the TEC is derived by dividing the lowest available LOAEC by an uncertainty factor. A minimum of three studies including at least one terrestrial plant and one soil invertebrate study must be available for application of this approach. The uncertainty factor is again between 1 and 5, dependent upon expert judgement (Table 2-4).

Table 2-4. Uncertainty factors for determination of soil quality criteria using the LOAEC method (Canada)

Information available	Suggested Uncertainty Factor
The LOAEC is "biologically significant" and not just statistically different from controls	1
The LOAEC is taken from an acute study	3
Only 3 studies were available and/or <3 taxonomic groups are represented	5

2.2.1.3. Median Effects Method

If only acute toxicity study data are available (EC_{50} or LC_{50} data), then neither of the above methods can be used. In this case, the TEC is estimated using the Median Effects Method. Here, the TEC is the lowest reported EC_{50} or LC_{50}, divided by an uncertainty factor. A minimum of three studies is required, including one terrestrial plant and one soil invertebrate study. If the lowest datum is an EC_{50} value, the uncertainty factor of five should be used. If the lowest datum is an LC_{50}, then an uncertainty factor of ten should be applied. An additional uncertainty factor between one and five may be applied if the factors listed in Table 2-4 are incurred as well. The use of uncertainty factors of five and ten applied to the EC_{50} and LC_{50} data, respectively, were selected after examination of acute versus chronic (NOAEC) data for 38 inorganic and organic contaminants for soil-dependent organisms.

2.2.1.4. Microbial Processes

Effect threshold concentrations for microbial processes (nutrient and energy cycling) are calculated in parallel with determination of the TEC for plants and soil invertebrates. Data on effects of chemicals on nitrification and denitrification are gathered and a TEC for microbial processes is derived by one of the above methods. If insufficient data are available, then decomposition, soil respiration, and nitrogen mineralization rate data are gathered as well, and the TEC derivation process is followed as above. If the minimum number of data sets are not available, no value is generated.

2.2.1.5. Wildlife

Critical values for wildlife are limited to those related to soil and food ingestion and further limited to herbivorous animals (using a livestock model). A minimum of three studies is required, one of which must be an oral mammalian study, and one must be an oral avian study. Only one laboratory rodent study may be used to fulfill the data requirements for mammalian species. The daily threshold effect dose is estimated using the lowest reported LOAEL divided by an uncertainty factor between one and five (Table 2-4). This value is converted to a soil concentration using the body weight, food ingestion rate, and soil ingestion rate of the species from which the LOAEL was determined. Bioconcentration factors (BCFs) are derived from the literature using "best professional judgement," with no guidance provided for how to select among the available BCFs or which one(s) to use in the final calculation. Additionally, it is assumed that 20% of the animal's estimated daily intake is from water, and apportionment of exposure estimates are made accordingly.

2.2.1.6. Final Soil Criteria

Once the TEC has been derived, it is compared with microbial process data (nutrient and energy cycling) and wildlife data. For agricultural lands, the lowest of the TEC, the microbial value, or the wildlife value is used as the criteria. For residential and park lands, the lowest of the TEC or the microbial values is used. For commercial and industrial land use, the TEC is used if it is below the microbial value. If the microbial value is lower, then the geometric mean of the microbial value and the TEC is calculated and used as the final criterion.

2.2.2. British Columbia

British Columbia also derives separate soil standards for soil organisms (plants and invertebrates), microbial functions, and livestock for five categories of land use (the same uses as defined by CCME, but residential and urban parklands are in separate categories). Single generic *numerical soil standard* are developed for each land use category for substances with a limited toxicity database. These standards are intended to be protective of both human health and environmental receptors. *Matrix standards* are provided for substances with a larger amount of data. For these, separate numbers are generated for human health (one based on contaminated soil intake and another based on protection of groundwater for drinking) and ecological receptors (soil invertebrates, plants, livestock, and microbial functions). The lowest matrix standard is used for purposes of defining a contaminated site or establishing remediation goals. The contaminated sites regulations state that clean-up below background will not be required for metals or other naturally occurring substances. Background levels may be determined on site-specific basis with approval of the protocol for doing so given by the Director of the Ministry of Environment, Lands, and Parks. Furthermore, for the few cases where the toxicologically-based standards are below current analytical detection limits, the value will be raised to the detection limit. Should better analytical chemistry techniques become available in the future, the standard may be lowered to the toxicologically-derived value.

2.2.2.1. Soil organisms

For soil organisms (plants and invertebrates) or microbial functions, all acceptable toxicity data are examined. Data are sorted into two data sets of either lethality endpoints (LCx values) or non-lethal endpoints (ECx values). Studies that report NOAEC or LOAEC values are used only if sufficient data are reported in the study for calculation of an ECx or LCx value. Within the lethal and non-lethal data sets, if multiple studies exist that report the same percent response (e.g., an LC_{50}), then the concentration causing that response is averaged to obtain a single value. For the non-lethal data, these responses represent a variety of measured endpoints, although reproduction studies are preferred. These revised data sets (one for lethality studies and one for the non-lethal endpoints) are then used to calculate the regression line representing the soil concentration as a function of the reported percent response (Figure 2-2). The predicted soil concentration where a 50% non-lethal response (EC_{50}) or a 20% lethal response (LC_{20}) occurs is then determined from the regression lines or equations. For Agricultural, Residential, or Park land uses, the lesser of the EC_{50} (non-lethal) or LC_{20} (lethal) soil concentration values is used as the criterion. For Commercial or Industrial land uses, the greater of the EC_{50} (non-lethal) or LC_{20} (lethal) soil concentration values is used. If insufficient data are available for the application of this method, an estimation of the EC_{50} or LC_{20} concentrations is made using best professional judgment (no guidance is provided on what constitutes a "sufficient" data set nor how this determination should be carried out).

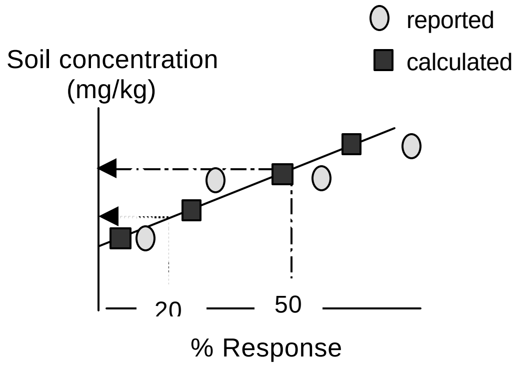

Figure 2-2. Example calculation of effects distribution for derivation of critical soil values by British Columbia

2.2.2.2. Microbial Function

British Columbia has adopted the CCME methods for derivation of criteria protective of soil microbial processes.

2.2.2.3. Wildlife

British Columbia soil matrix standards do not address wildlife. The Agriculture land use standards address livestock exposure through ingestion of soil and fodder. Development of these soil criteria are equivalent to those described above for CCME and European soil criteria.

2.2.3. Ontario

The Ontario Ministry of Environment and Energy (MOEE) has published guidelines containing both generic and site-specific approaches to clean up of contaminated sites (MOEE 1996). These criteria are meant to "protect against adverse effects to human health, ecological health and the natural environment" (MOEE, 1996). The guidance and associated criteria contain both human health and ecological effects information. The single soil criterion for each chemical is the lowest number from human health and ecological effects analyses. Human health criteria are derived from the lowest value from the following exposure routes: dermal exposure, incidental soil ingestion, groundwater contamination, or soil vapor to indoor air. Wildlife are considered for agricultural lands and residential/parklands, but only the herbivore food chain is evaluated. Unlike CCME and British Columbia, Ontario groups industrial and commercial uses together into a single category of land use. The guideline document (MOEE, 1996) does not describe how Ontario derives ecological effects criteria (other than to state that conservative exposure values are used), but does state that the Netherlands' numbers will be used whenever Ontario does not promulgate a specific number. As in British Columbia, the MOEE provides that soil criteria will be at or above background levels (for naturally occurring substances) or analytical detection limits. Province-wide background levels are published by the MOEE, but site-specific background numbers may be developed with MOEE approval.

2.2.4. Other provinces

None of the other Canadian provinces have developed soil criteria or guidance for contaminated sites, although Alberta is in the process of development of such documentation (personal communication, Ted Nason, Environment Canada,).

2.3. AUSTRALIA

Soil values are developed separately for two multi-exposure pathways: plants plus animals that live within soil (e.g., soil invertebrates, called “infauna” by the Australian EPA) and animals that live above ground having direct soil contact (called “epifauna” by the Australian EPA) plus potentially affected animals impacted indirectly or via off-site movement of contaminants (i.e., “cofauna” as used by the Australian EPA). The lowest of these values is then selected as the *Environmental Impact Level* for soil (EIL_{soil}) (Environment Australia, 1997). The aim of setting an EIL_{soil} is "to protect ecological values." These values include ecological processes, community systems, and populations or biota of particular value. The values and species differ for land uses, which include: residential, urban parkland, commercial, industrial, agricultural, rural parkland, and nature reserves. The EIL_{soil} should be the concentration of a contaminant that may persist in the soil without causing an adverse effect on specified biota. Where assumptions are made in deriving EILs, they should be conservative in nature. The technical guidance document for derivation of $EILs_{soil}$ (Environment Australia, 1997) includes an appendix with criteria for assessing the quality and applicability of ecotoxicological data in the literature for use in the derivation process. For substances with insufficient or low quality toxicity data, EILs should be based on background concentrations or chemical detection limits. Toxicologically-based EILs should not be below the background or detection concentrations. The EIL_{soil} are meant to be used a screening tools for assessing whether or not a site may be considered contaminated, and are also referred to as *Investigation Levels*. Soils that exceed these levels may require further assessment of actual risk through the derivation of site-specific $\mathrm{EILs}_{\mathrm{soil}}$.

The Australian method for derivation of $\mathrm{EIL}_{\mathrm{soil}}$ are part of the *National Framework for Ecological Risk Assessment of Contaminated Sites (Parts B and C).* This document is in draft form, and is available for public review and comment at: *http://www.environment.gov.au/epg/contam/ documents.html.* Because the Framework is only in draft form, soil ecological impact levels have not been published at this time.

2.3.1.1. Soil Organisms

The $\mathrm{EIL}_{\mathrm{in\ \&\ f}}$ (EIL for infauna and flora) is developed by selecting the lowest reported NOAEC from studies of plants or animals that live within the soil. The guidelines go into great detail describing how to evaluate toxicity studies for quality of the data, but very little detail on what to do with the information once it has been retrieved. There is a suggestion that NOAEC data should be used (i.e., from chronic studies), with the lowest reported value selected as the final value. However, this is not stated explicitly, nor are there rules for the application of assessment factors (if any).

2.3.1.2. Wildlife

The Australian approach focuses wildlife protection on a species-specific basis. The overall $\mathrm{EIL}_{\mathrm{epi\ \&\ co}}$ is obtained by selecting the lowest calculated wildlife value. The process used to determine critical soil values for Australian wildlife is fundamentally the same as that used in Europe (See Wildlife, Page 2-6) although specific guidance is provided for incorporation of exposures from inhalation and drinking water routes. Toxicity data are derived from studies where NOAECs are reported or can be calculated. For derivation of biomagnification factors (equivalent to the BCF), data from studies that pass the quality screen are pooled for each chemical. The "best estimate" for the BCF is the median value while a "conservative estimate" is the upper 95% confidence limit. This designation of "best" and "conservative" estimate applies to any of the input parameters for which a distribution of values is available (e.g., body weight, food ingestion rate, etc.). The lowest reported NOAEC for the species of interest is selected, if available. If not, surrogate species data may be used as well as EC_{50} data or data from acute studies (LC_{50}s), adjusted by assessment factors (Table 2-5).

Table 2-5. Assessment factors for determination of soil quality criteria (Australia)

Information available	Assessment Factor
Acute to chronic extrapolation	1,000
EC_{50} to LOAEL	10
LOAEL to NOAEL	10
Extrapolation across species within a Family	10
Extrapolation across Families within a Class	10
Extrapolation across Classes within a Phylum	10

2.4. OAK RIDGE NATIONAL LABORATORY (ORNL)

Oak Ridge National Laboratory (ORNL) developed a set of soil *benchmark* values for plants, invertebrates, microorganisms, and wildlife for use in their site-specific risk assessments. These values were used as screening values for soils at the Oak Ridge Department of Energy site to determine areas where more ecological risk assessments would be required. If the toxicologically-derived values were below background (as determined for ORNL soils), then background values were used instead. The benchmark values were posted on the Internet and were made available through published documents. These values have been adopted by various states and USEPA Regions in the absence of any alternative values. ORNL has since removed the tabulated information from the Internet, as they recognized the difficulty of maintaining quality control and updating information, although their technical guidance documents (with associated tables of benchmark values) are still available on the ORNL web site.

2.4.1. Microorganisms, Invertebrates and Plants

Soil benchmarks for microorganisms, invertebrates and plants proposed by ORNL were derived using a method similar to that developed by the National Oceanographic and Atmospheric Administration (NOAA) for calculating the Effects Range Low (ER-L) in sediments (Long and Morgan 1991). This approach has been recommended as a sediment screening benchmark by USEPA Region IV. The ER-L is the 10th percentile of the distribution of toxic effects thresholds for organisms in soil, using LOAEC values. If less than ten values were available for a chemical, the lowest LOAEC was used. For studies where a LC_{50} was reported instead of a LOAEC, the concentration was divided by five in the hope of approximating the more sensitive endpoints of growth and reproduction, prior to inclusion in the LOAEC data set. No other assessment factors are used. Invertebrates are represented only by earthworms; no other species were included in the assessment. The assessment endpoints for microorganisms are related to community function (e.g., carbon mineralization, nitrogen transformation, and enzyme activities). Plant toxicity benchmarks derived by this method for metals generally are lower than those for soil invertebrates or microbial processes, and the reverse is true for organic compounds.

2.4.2. Wildlife

ORNL did not develop single soil criteria protective of all wildlife for each chemical. Rather, they developed animal-specific benchmark concentrations in a manner similar to that used by the Australians. In the event that a single mammalian or single avian soil benchmark value is needed for site screening purposes, ORNL uses the short-tailed shrew (*Blarina brevicauda*) and the American woodcock (*Philohela minor)* as representative species, respectively.

ORNL differs from the Australian approach by looking for the single best study that represented chronic effects (preferably reproductive endpoints) in a species as closely related to the species of interest as possible, rather than using all acceptable toxicity study data from any species and selecting the lowest value. Only mammalian studies were used to represent mammalian wildlife and only avian studies were used for birds. However, the same study often was used to model all birds (or all mammals), so differences in soil benchmarks became a function only of the exposure factors (food consumption rates, body weights, dietary BCFs, etc.). Furthermore, ORNL extrapolated among species using dose on a mg/kg-body weight (BW) basis, with the body weight modified to reflect differences in metabolic rates. Because the initial assumption that dose differences are related to metabolic rates expressed as $(BW)^{0.75}$ has since been proven to not be a universal characteristic of all species and chemicals, ORNL has realized that their wildlife benchmarks may not have been calculated correctly (personal communication, B. Sample). ORNL has not published revised values, however, as the appropriate algorithm has not been determined. Most other jurisdictions that develop species-specific wildlife benchmarks (e.g., CCME, Australia) have followed the ORNL approach to cross-species extrapolations and so suffer from the same inaccuracies.

2.5. SAVANNAH RIVER SITE

The Savannah River Site is another Department of Energy facility faced with environmental contamination issues. To support the preparation of ecological risk assessments at the Savannah River Site, Friday (1998) compiled ecological screening values for soil, sediment, and surface water. The report explicitly states that the screening values are “inappropriate for setting remedial action cleanup levels.” The recommended soil screening levels, which were reviewed and adopted by the U.S. Environmental Protection Agency Region IV (http://www.epa.gov/region4/wastepgs/oftecser/epatab4.pdf), were selected from benchmarks published by the U.S. Fish and Wildlife Service (Beyer 1990), Oak Ridge National Laboratory (Efroymson et al. 1997a, b), Canadian Council of Ministers of the Environment (CCME 1997), and The Netherlands (MHSPE 1994, Crommentuijn et al. 1997). Generally, the most conservative and recently published value cited in these references was recommended as the ecological soil screening value. Dutch values comprised 60% of the recommended values; ORNL values comprised 38% whereas Canadian values comprised 2%. The report states that “no attempt is made to endorse a source or to evaluate the derivation process,” thus implying that no validation procedure took place. Unless the recommended values are to be used to support a preliminary ecological screening assessment, the investigator must ultimately determine which values are most appropriate

2.6. U.S. FISH AND WILDLIFE SERVICE

In 1990, the U.S. Fish and Wildlife Service published a compilation of the soil screening level values available at that time (Beyer, 1990). There was little to no information provided about how the various numbers were chosen; rather, the reader is referred to the original guidance documents for further details. Summaries are provided from ten jurisdictions, including two states (New Jersey and California) whose numbers were developed for groundwater protection. Canada, and both the Federal and provincial levels, had five different sets of numbers. The remaining three sets of values were from Japan (although these numbers were developed for human health purposes only), The Netherlands, and the former Soviet Union. All of the ecological values, with the exception of the former Soviet Union, have been superceded by the newer methods described in the above sections of this report.

2.7. STATES AND PROVINCES

DynCorp (1998) surveyed the various U.S. states to determine which ones have generic soil screening benchmarks for ecological receptors. Washington, Texas, and Delaware have adopted the ORNL values for use at the state level. Texas, however, is re-evaluating the ORNL benchmarks as they may not be as conservative as the state would like. Many other states have developed guidance for conducting site-specific ecological risk assessments, without including any specific soil benchmarks. For example, Michigan states that "the published literature … is not of sufficient quality to allow a clear-cut, quantitative approach in developing criteria" for aesthetics, terrestrial flora, fauna, food chain or other impacts (Michigan DEQ, 1998). The Michigan state guidance goes on to say that statewide, regional, or site-specific soil background levels will become default cleanup criteria where applicable risk-based criteria are lower than the background level.

2.8. USEPA

In January 1996, the USEPA Superfund program published an issue of the *Eco Update* bulletin devoted to *Ecotox Thresholds*. This discussed the use of thresholds to screen soil, sediment, or water chemical concentrations to determine if a risk assessment would be necessary at a particular site. Methods for calculating the Ecotox Thresholds are given for water (Ambient Water Quality Criteria) and sediment (USEPA's Sediment Quality Criteria). For soil, they state that "Methods to address toxicity in soils have not been sufficiently developed… The Superfund program is currently evaluating options in this area…"

USEPA Region IV provides guidance suggesting that soil screening values can be submitted by investigators based on information about potential direct toxicity to soil invertebrates and plants. For those contaminants that biomagnify, Region IV suggests that soil values can be determined by back-calculations from acceptable levels in prey items through two trophic levels to the soil. Furthermore, Region IV disallows the use of area or regional background levels, preferring instead to develop screening level concentrations based on data showing associations with "ecological" effects. Published soil screening level criteria available from Region IV are derived directly from the Westinghouse Savannah River Site documentation.

None of the other EPA regions have published soil values or guidance for their use in screening ecological risks at sites although internally Region VIII, for example, has applied soil screening levels at Superfund sites (personal communication, Gerry Henningsen). Region IX has

Preliminary Remediation Goals, but these were developed for human health assessments only. The other regions had no available guidance posted on their web sites.

2.9. USEPA WATER QUALITY CRITERIA

Although water quality criteria are not applicable to the derivation of soil criteria, it is instructive to examine how the USEPA develops water quality criteria. Once toxicity threshold information is generated for appropriate species in a particular media, the derivation process to set the final criterion value could be similar for water, soil, and sediment. The final goal of protection while being reasonable is the same in all media. How this is achieved is mostly a matter of policy rather than scientific rigor.

Development of a water quality criterion requires at least eight acute toxicity tests (LC_{50} values), including animal species from eight different families, as well as three animal chronic tests (one fish, one invertebrate, and one additional species), one algal test, and one test to determine the BCF (Stephen *et al*., 1985). Nearly all the water quality criteria are based on studies conducted specifically for the purposes of criteria setting, following standard protocols. Nevertheless, even these studies are subject to data quality review. If more than one result is available for any species, the geometric mean value is calculated. This value can then be used to calculate a Species Mean Acute Value in the same manner as the Genus Mean Acute Value is calculated as described when more than one species in a genus were tested.

The Genus (or Species) Mean Acute Values for each group of organisms tested are plotted to determine the four lowest values. These four values are used to calculate the 5th percentile. A triangular distribution is used to extrapolate this concentration known as the Final Acute Value. Using only the lowest four values, and assuming a triangular distribution, ensures that the extrapolation to the 5th percentile will not result in unrealistically low numbers. Nevertheless, if data are available that show a species-specific toxicity threshold below the calculated value, the measured value is used as the criterion.

Because acute tests are conducted for short intervals of exposure, chronic criteria (based on NOAECs) also are derived. The Chronic Maximum Concentration criteria (a value that may be exceeded for a few hours only once every three years) is set at one-half the Final Acute Value, to have a built-in safety factor.

The Chronic Continuous Criterion (the most environmentally relevant number) is derived by multiplying the Chronic Maximum Concentration by the ratio of the acute effect and the chronic effect levels. The USEPA recognizes that chronic studies are expensive and time-consuming, and thus requires a lower minimum number of studies. For those species with chronic studies, the ratio of the acute values to the chronic values is derived (acute-to-chronic ratio; ACR). Because organisms usually are more sensitive to long-term exposures than to very short ones, the chronic values are almost always lower than acute values, and so the acute-to-chronic ratio is greater than one. As with the acute values, any measured data that are below the calculated criterion take precedence and used as the final value.

2.10. SEDIMENT QUALITY CRITERIA

Sediment quality criteria have been proposed by the USEPA (Di Toro *et al*., 1991) for nonpolar organic substances, by the province of Ontario (Persaud *et al*., 1992) for metals, and by the NOAA (Long and Morgan, 1991) for a variety of substances. The USEPA approach differs from the other two, which use a similar method but rely on a different database.

2.10.1. Equilibrium Partitioning Method

Nonpolar organic substances partition between the sediment particles and the interstitial pore water in a relatively predictable fashion. The USEPA proposed setting sediment quality standards using toxicity data developed for aquatic organisms (e.g., daphnia, fish, and algae). Aquatic toxicity thresholds would be determined for these organisms and set equivalent to the maximum allowable concentration in pore water. Using equilibrium partitioning theory, the total amount of chemical in the sediment (pore water plus particulate) could then be calculated. This bulk sediment concentration would be the established sediment criteria.

2.10.2. Effects Range Method

Both NOAA and Ontario proposed basing sediment criteria on empirical relationships between organism effects and sediment concentrations as determined by field measurements. Ontario only used information from the Great Lakes (which are oligotrophic systems) to develop criteria for metals, while NOAA incorporated data from a wide variety of freshwater and saline sites throughout the U.S. and developed criteria for both organic compounds and metals. In this method, the measured field concentrations are arrayed in ascending order and identified as to whether or not measured effects on benthic biota were noted (Figure 2-3). The Effects Range-Low (ER-L) is the sediment concentration below which measured effects have never been observed and above which measured effects are sometimes seen. Similarly, the Effects

Range-High (ER-H) is the sediment concentration above, which effects are always seen and below which they sometimes (but not always) occur. The Effects Range-Median (ER-M) is the midpoint between the ER-L and ER-H. Comparison of the Ontario and NOAA values for metals shows a significantly lower ER-L for metals using the Ontario data set. This is attributable to the low organic matter (and thus increasing the bioavailability of the metals to aquatic organisms) in Great Lakes water as compared to the larger set of data used by NOAA.

The state of New York, like Ontario, set two sediment levels of protection: the Lowest Effect Level and the Severe Effect Level. The Lowest Effect Level indicates a level of contamination that can be tolerated by the majority of organisms, but may be toxic to a few species. This was derived as the lowest value between the NOAA and Ontario data sets. The Severe Effect Level [adopted from the Ontario values (equivalent to the ER-H of NOAA)] indicates the concentration at which pronounced disturbance of the sediment community can be expected and was. Contamination in between these two levels is considered moderate.

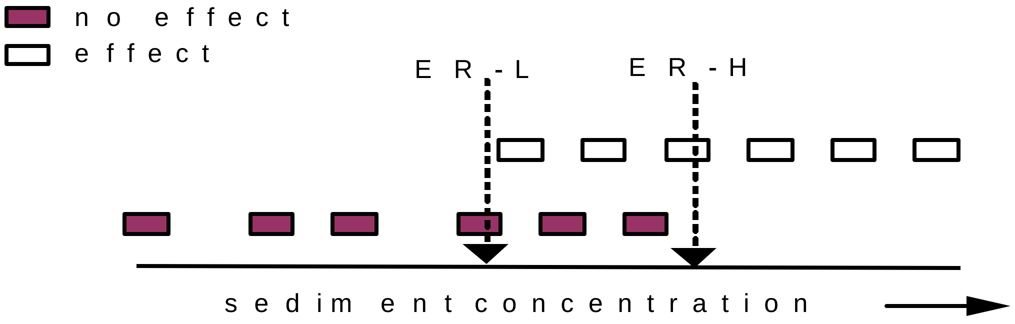

Figure 2-3. Sediment quality criteria derivation by Effects Range determination (Long and Morgan, 1991)

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3. SOIL CRITERIA VALUES

A comparison of ecological soil criteria for selected metals from various jurisdictions (Table 3-1)shows that criteria for most metals (except for mercury) are less than an order of magnitude among the different methods employed by various countries. This suggests that the differences in approaches may be relatively minor. However, the fact that mercury, which acts more like an organic substance than a metal, has criteria spanning a 20-fold range, suggests that it may be harder to develop consistent criteria for organic substances. A compilation of all published soil screening or criteria values is in Appendix A.

Table 3-1. Critical limits for heavy metals in soils in several countries[1]

Country	**Critical limits (mg/kg)**[2]						
	Pb	**Cd**	**Cu**	**Zn**	**Ni**	**Cr**	**Hg**
Denmark	40	0.3	30	100	10	50	0.1
Sweden[3]	30-60	--	--	--	--	--	0.2-0.3
Finland	38	0.3	32	90	40	80	0.2
Netherlands	85	0.8	36	140	35	100	0.3
Germany[3]	40-100	0.4-1.5	20-60	60-200	15-70	30-100	0.1-1.0
Switzerland	50	0.8	50	200	50	75	0.8
Czech Republic	70	0.4	70	150	60	130	0.4
Eastern Europe[4]	32	2	55	100	85	90	2.1
Ireland	50	1.0	50	150	30	100	1.0
Canada	25	0.5	30	50	20	20	0.1

[1] From De Vries and Bakker, 1998
[2] Values are for protection of all land uses
[3] The first value is for sandy soils; second value for clay soils
[4] Eastern Europe includes Russia, Ukraine, Moldavia and Belarus

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4. CRITICAL REVIEW

This section critically examines issues associated with the approaches that currently are in use to derive soil protection values. Significant issues include: intended application of the values, minimum data requirements, toxicity endpoints, data extrapolations, bioavailability, assessment factors, and validation. Some of these issues are common to all the methods; others are specific to only one. Where different methods use variations on the same theme, both are reviewed in relation to each other to highlight the relative strengths and weaknesses of the alternative approaches.

4.1. APPLICATION

Soil protection values have been derived for various intended applications by the different jurisdictions. Soil concentration levels may be established to either screen a particular site for contaminants that may cause potential ecological dysfunction, or they may be used as cleanup targets. The Netherlands is the only jurisdiction that explicitly acknowledges that these two goals may require different degrees of conservatism. They have two sets of values: a higher concentration that defines seriously contaminated sites requiring immediate cleanup (called the “intervention value”), and a lower value that will be used as a target for desired soil quality (called the “target value”), which is also used as the maximum amount allowable for release into the environment. If a value is between the intervention level and the target value, then further investigations are required to determine whether adverse effects are occurring, but remediation may or may not be necessary.

At both the federal and provincial level, Canada recognizes that their published soil values are most useful as screening tools. However, they require that sites be cleaned up to this level unless a site specific assessment is done to show that 1) local background values are higher than the published soil numbers or 2) a risk-based approach demonstrates no ecological concern. This puts the burden of proof on the principle responsible party to demonstrate lack of harm. For small sites, it generally is less expensive to clean up to the published levels, whereas at wide area, complex sites the risk assessment option may be more attractive. The Canadian numbers tend to be less conservative than those used by the Netherlands (certainly less so than The Netherlands target values). Additionally, the Canadians are more judicious about the use of assessment factors than are the other jurisdictions, preferring to use none, but never more than a factor of five (see Section 4.6 for a further critique of the use of assessment factors).

The other jurisdictions explicitly state that their values are developed for screening purposes only and should not be used as remediation goals. This requires that additional site-specific assessments *always* be conducted in instances where soil concentrations exceed the screening value. In order to refute the presumption of risk that has been established in these cases, it is most likely that bioassays or field studies would be required. Development of the screening values relied on a literature review and desktop models of trophic transfers, generic exposure pathways, and assumptions about bioavailability with very conservative exposure assumptions. For example, 100% bioavailability is assumed, wildlife are estimated to consume 100% of their diet from material containing the substance of concern, and invertebrates are assumed to be stationary in the contaminated portion of the soil. Most of the jurisdictions recognize the conservative nature of these values, and consider them to be *protective* rather than *predictive*. That is, the goal is to make sure that no contaminated sites are mistakenly screened out and declared “clean” when they really are not. Thus, they are willing to accept false positives (i.e., declaring a site “contaminated” when it is not), and to rely on the Tier 2 process to exonerate parties in such cases.

States and provinces are developing guidance for Tier 2 assessment of sites that do not pass the screening phase. British Columbia, Washington state, Oregon, Michigan, and Massachusetts, for example, all have simple, easy to follow guidance for Tier 1 and Tier 2 assessments (see websites for Departments of Environmental Quality for the various states or the British Columbia Ministry of Environment, Lands, and Parks to access specific guidance documents). Tier 2 relies on development of site-specific bioavailability and trophic transfer factors, either through relationships established from tissue analysis of field-collected biota or in laboratory bioassays. Further refutation of the presumption of risk requires site-specific field studies of ecological effects.

Experience has shown that the screening values generally are quite conservative and below site-specific risk levels, with the exception of values for bioaccumulative compounds that did not have wildlife values included in their derivation. However, for small sites (less than 5 hectares), or sites located within urban or industrial areas, it generally is not cost-effective to conduct a site-specific assessment. Thus, the conservative screening values often become *de facto* cleanup goals for these sites.

4.2. MINIMUM DATA SET REQUIREMENTS

All of the approaches for deriving soil protection values rely on published studies. The CCME has a minimum data set requirement for substances having only acute data. In those instances, at least three studies must be used, including at least one terrestrial plant and one soil invertebrate study. For all other jurisdictions and derivation methods, the implicit assumption is that even a single acceptable datum point is sufficient to set an SPV, albeit generally requiring the use of an assessment factor. In contrast to the relatively stringent data requirements for derivation of water quality criteria (a minimum of eight acute toxicity tests representing species from eight different families plus at least three chronic tests including one fish and one invertebrate and an algal assay), minimum data requirements are not included in soil protection value approaches. Recommendations from the recently convened SETAC-sponsored workshop on Methods for Hazard Assessment of Metals in Soils (Madrid, Spain, June 1999) include a minimum data set of three soil invertebrates (an earthworm, a collembola, and an enchytrid) and three plants (lettuce, radish, and a grass). This minimum dataset reduces uncertainty regarding the distribution of species sensitivity that would exist with smaller datasets.

4.3. TOXICITY ENDPOINT

All of the methods currently in use for soil protection value derivation rely on NOAEC or LOAEC values from chronic studies, except for British Columbia, which prefers EC20, or LC_{50} values. The CCME preferred method includes both NOAEC and LOAEC endpoints, chronic ECx, and acute LC_{50}s. Scientists have concluded that NOAECs do not accurately reflect a toxicity threshold, as they are more a function of test design than an actual dose-response relationship (e.g., Chapman *et al*., 1996). In fact, by only slightly changing the spacing of the test concentrations, Chapman *et al*. (1996) were able to change the calculated NOAEC in an aquatic toxicity test by nine-fold. Of even greater importance in NOAEC determination is the number of replicates at each treatment level relative to the amount of variability in a measured endpoint. An endpoint that is highly variable will return a NOAEC at a higher concentration than one with low variability, given the same number of replicates at each treatment level. Thus, the NOAEC (or corresponding LOAEC) becomes more an artifact of statistical design and acuity than an actual measure of toxicity.

Moreover, the use of a hypothesis test design to determine if one treatment is statistically similar to another is not an appropriate statistic to use in a regulatory context such as determination of toxicity thresholds. What is needed is a complete description of the dose-response relationship, so threshold concentrations can be determined, but only within relationship to the form of the remainder of the response function. If the concentration-response curve is very steep, this would suggest more protective levels might be required than for a chemical with a very shallow response function. In the first case, only a small addition of more chemical into the environment could potentially to cause a large response, while in the latter case a substantial amount of chemical could be added before an adverse effect would occur. Thus, in the ideal case, information would be available about the slope of the response function, as well as values close to the true toxicity threshold.

In human health risk assessments, this issue has been dealt with by using the Benchmark Dose (Rees and Hattis, 1994). The Benchmark Dose is calculated as the concentration at the upper 95th confidence interval of the EC_{10}. (Figure 4-1). The Reference Dose (RfD) is then calculated as the Benchmark Dose divided by appropriate assessment factors to provide a large "margin of safety." The Benchmark Dose has intuitive appeal, as it relies on calculation of the entire dose-response function, rather than a NOAEC derived from hypothesis testing.

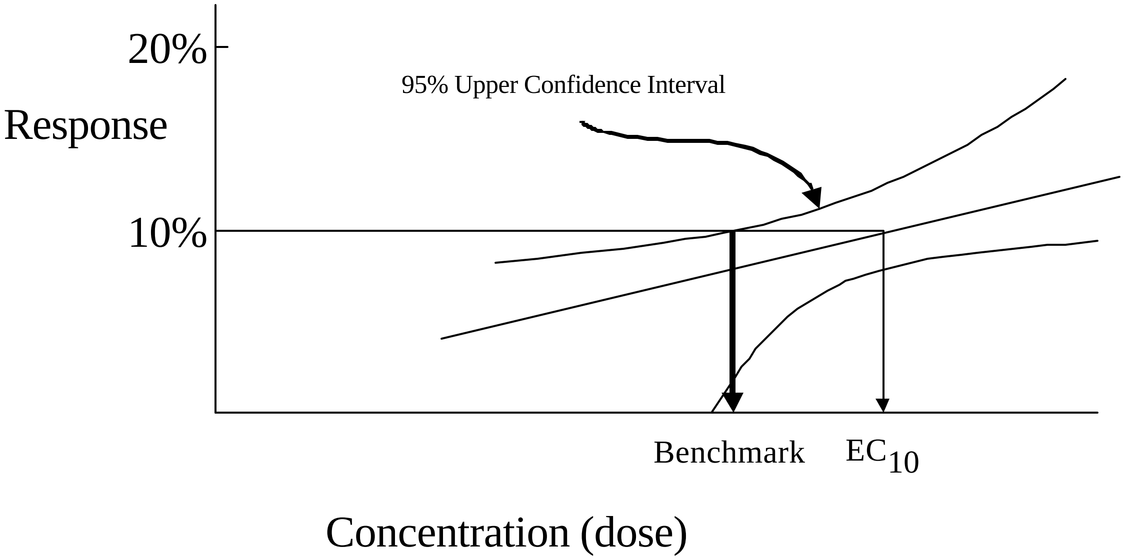

Figure 4-1. Derivation of the Benchmark Dose for human health risk assessment

The test design required for determination of point estimates differs slightly from that used in hypothesis testing in that it requires fewer replicates, but more test concentrations. Several researchers have concluded independently that most of the NOAEC values determined in terrestrial toxicity tests following standard protocols such as the ASTM early seedling growth (ASTM, 1994) are equivalent to an EC_{20} (personal communications, Brad Sample, CH2M Hill and Gladys Stephenson, ESG International). Therefore, using a Benchmark Dose approach at the EC_{10} or EC_{20} is equally protective, but more consistent among laboratories (Chapman *et al*. 1996), than the use of a NOAEC.

4.4. EXTRAPOLATIONS

Most jurisdictions use extrapolation methods to estimate a single soil protection value from the array of reported toxicity threshold endpoints. The Europeans assume that all species responses lie within a log normal distribution and calculate the 5th percentile. The CCME uses the 25th percentile. British Columbia deviates from this approach by arraying the ECx or LCx values along a straight line to estimate the "true" EC_{20} and LC_{50}. All of these approaches have drawbacks identified by Hopkin (1993).

Hopkin (1993) argues that there are four main objections for adopting the 5th percentile of species toxicity values as the soil criteria. First, this assumes that the most sensitive 5% of the species are not important ecologically and can be killed by the pollution. This may be in violation of other laws, such as the Endangered Species Act. Second, this method provides no means of making sure that ecosystem functions are protected, only that species diversity is considered. Third, the value may not be sufficiently protective to include reasonable worse case scenarios. And fourth, the toxicity values relate to individual effects and it is not known how these translate into population level consequences.

However, Hopkin's first argument that 5% of the species would not be protected probably is not true. Using a function such as the log normal distribution to represent the range of possible species sensitivities can result in unrealistically low values at the 5th percentile (i.e., generate value substantially lower than the most sensitive species response measured) as a result of a large number of very insensitive species. Insensitive species increase the spread of the distribution and stretch the lower, sensitive end of the assumed distribution. Other functions such as the Weibull function may not be as sensitive to this effect, but still are affected to some degree by highly insensitive species. Most importantly, there is no *scientific* basis on which to choose which function to use to represent the distribution of species sensitivities. Hopkin (1993) and Scott-Fordsmand *et al*. (1996) both independently concluded that the use of the log-normal distribution and 5th percentile calculations nearly always result in soil protection values for metals that are significantly below normal background concentrations. Therefore, they both conclude that the method is not feasible for use with metals. While similarly calculated values for synthetic organic substances cannot be compared to background concentrations, it is likely that they, too, are well below the assimilative capacity of the environment as the consequences of statistical artifact forcing the criteria value below any response likely to occur with these compounds as well.

The USEPA water quality criteria approach attempts to accommodate the shortcomings of the extrapolation method by using only the four most sensitive (measured) genera and applying a triangular distribution to derive the 5th percentile. Thus, addition of new, less sensitive species to the data set does not change the derived endpoint as it would in the log normal functions. This method does not "lose" information, as critics claim, but rather derives a protective value that is not unduly influenced by a large number of insensitive species.

4.5. BIOAVAILABILITY ADJUSTMENTS

The toxicity of a contaminant is influenced by its bioavailability. Both pH and organic matter content can influence the bioavailability of chemicals. In the derivation of soil protection values, bioavailability of the contaminant to biota is not considered by any jurisdiction, with the exception of The Netherlands. The Netherlands has developed algorithms for some metals to standardize toxicity values in terms of pH and organic matter. The algorithms were derived from analyses of soil parameters from uncontaminated sites. Their data are standardized to 10% organic matter. It is not clear whether these adjustments would work outside of the specialized conditions of the region, nor is it clear how much uncertainty is introduced with these adjustments.

4.6. ASSESSMENT FACTORS

Because of the apparent shortcomings of the extrapolation method, particularly the requirement for a relatively large data set, many jurisdictions provide the alternative approach of selection of a low value and division by appropriate assessment factors (also called uncertainty factors or safety factors). Cowan *et al*. (1995) suggest that this should be the preferred approach for setting values protective of terrestrial systems. Assessment factors range from three to 1,000, depending upon the jurisdiction and degree of desired conservatism. CCME is the least conservative of the jurisdictions using assessment factors, considering that the data themselves contain a large amount of conservative assumptions and therefore recommending that assessment factors should never exceed five. Most other jurisdictions apply orders of magnitude assessment factors in sequence, to account for interlaboratory variability, interspecific differences, and laboratory-to-field extrapolations.

For metals, dividing the lowest reported LOAEC by more than a factor of 10 often results in values that are below background concentrations (e.g., Scott-Fordsmand *et al*., 1996). Certainly, division of the lowest reported NOAEC (or any reported NOAEC, for that matter) by 100 or 1,000 will result in values so low as to be meaningless for screening out chemicals of little environmental concern. Therefore, for this reason alone, the assessment factor approach should be viewed with caution. Chapman *et al*. (1998) point out that applications of assessment factors are a matter of policy, not science, and grew out of human health risk assessments where a true margin of safety was desired to make sure that regulatory action levels were well below the predicted no effect level.

There is, however, sufficient knowledge about differences in measured endpoints among species, laboratories, and test conditions for ecological receptors to make some science-based generalizations. For plants, species differ in sensitivity by about 300-fold, and results obtained in glasshouse studies are not consistently higher or lower than those obtained in field studies (Fletcher, *et. al*, 1990; Kapustka and Reporter, 1993; Chapman *et al*., 1998). Examination of chemical data sets with information on animal species sensitivity differences has shown that all species are within an order of magnitude of each other (Chapman *et al*., 1998; Baril *et al*., 1994). Therefore, in situations where policy dictates that assessment factors should be used to accommodate uncertainty for protection of untested species under field conditions, the CCME approach of dividing by no more than five is supported by this information. Application of any additional safety factors will be a matter of policy and not a science-based approach. However, it is likely that this will result in criteria that are well below background concentrations for metals and ambient concentrations for organic substances (ambient concentrations are defined as an anthropogenically derived background resulting from diffuse nonpoint source applications such as atmospheric deposition).

4.7. EQUILIBRIUM PARTITIONING

The equilibrium partitioning approach is based on three assumptions. First, this method assumes that toxicity to terrestrial organisms results from exposure to chemicals in the interstitial pore water. Further, it assumes that chemicals in soil are in equilibrium between partitioning into the solid matrix and into the pore water. Further, this method assumes that sensitivity of terrestrial organisms to exposures through an aquatic medium is no different than that of terrestrial organisms. However, none of these assumptions are true.

Exposure to chemicals by soil-dwelling organisms is through uptake from the pore water and off of soil particles. Most plants accumulate virtually all nutrients and water through mycorrhizal fungi. The zone surrounding roots, known as the rhizosphere, is populated by microorganisms. Plant roots, along with symbiotic and associative microorganisms in the rhizosphere, alter their microenvironment in ways that facilitates extraction of substances not represented in pore water fractions. Furthermore, plants can restrict root growth into contaminated micro-zones or suspend uptake processes in roots exposed to harmful substances. Of the soil invertebrates, only enchytrids live wholly within the soil pore water. Many of the other families actually are exposed to soil contaminants through the intra-soil food chain, by consuming microorganisms, fungi, decaying plant material, or other invertebrates. Some organisms, such as the earthworm, actively ingest soil particles and may have some chemical exposure from removal of materials within the gastrointestinal tract.

The assumption of chemical equilibrium in the soil also is not met. As discussed above, the presence of soil organisms themselves disrupts any stable equilibrium through the active processes of nutrient uptake, decomposition, and energy cycling. Furthermore, physical-chemical processes leading to equilibrium are slow acting and may be disrupted by chaotic environmental processes such as leaching following rain events.

Finally, there is no scientific basis for the assumption that aquatic and terrestrial organisms respond similarly to chemical exposures. In point of fact, mechanistic toxicology suggests otherwise. For metals, for example, aquatic animals are exposed primarily through competitive binding of the cations to the gill membrane. This results in disruption of blood oxygenation. Terrestrial plants, on the other hand, are exposed by uptake through root surface or cortical membranes, which may be active or passive events and depend upon cell membrane channels or ion pumps. Terrestrial animal exposure is through similar mechanisms in gut wall epithelial cells. Mode of action and detoxification mechanisms for metals and organic substances also differ to a significant extent between aquatic and terrestrial organisms. Terrestrial animals rely more heavily on metallothioneins for metal sequestration and elimination than do aquatic animals, have significantly different metabolic partitioning of chemicals within the body, and have significant differences in kidney and liver physiology relating to detoxification and elimination rates. The significance of these differences is substantiated by comparison of results from daphnia testing with tests of the same chemicals in earthworms that show no predictable relationship (Clausen, 1999).

4.8. VALIDATION

An essential step in establishing soil protection values, whether for screening or as cleanup goals, is verification of protectiveness and reasonableness. Most jurisdictions state that the values should not be below background (for naturally occurring substances) or below analytical detection limits for xenobiotics. National or regional average background levels generally are provided in the guidance documents. Guidance documents further suggest that site-specific background levels can be derived, but only with oversight from the regulatory body. USEPA Region IV is the only jurisdiction that explicitly states that toxicologically-derived numbers are to be used for screening values in all cases, regardless of whether or not they were lower than background. However, regional guidance is silent on the subject of cleanup target values (i.e., whether cleanup would be required below background concentrations).

While most of the guidance documents tabulate regional or national background levels together with their toxicologically derived values, all the values still are presented, even if the derived values are below background. ORNL also published site-specific background numbers derived from uncontaminated areas on the Oak Ridge reservation, but likewise included all of the toxicologically-derived values. Thus, the user must be cognizant of the need to compare all screening values with the appropriate background concentrations prior to making a final determination of whether or not a substance is listed as a concern at a site.

The methods used to set soil protection values often yield values below background concentrations. This raises questions about the appropriateness of the extrapolation methods, but also begs for an ecotoxicological explanation. The ecological foundation of the problem lies in the fact that organisms evolved or adapted to great ranges of soil concentration of naturally occurring substances (Fairbrother and Kapustka, 1997). Organisms exhibit different levels of required nutrients and varying degrees of tolerance to soil concentrations of naturally occurring substances. Assemblages of plants, soil invertebrates, microorganisms, and to some extent birds and mammals reflect niche preferences aligned with local or regional patterns of background concentrations. Levels that are toxic to some organisms are optimal for others organisms and deficient for yet another suite of organisms. The procedures for developing SPVs generally search for the lowest concentrations that affect the most sensitive species. Such efforts generally are independent of regional differences in background concentrations, therefore, when applied over large geographic areas they may be unreasonable for screening purposes. As such values often are misused as cleanup targets, they may also fail in terms of being protective; if the clean up goals fall below the nutrient requirement levels for the regional biota deficiency conditions would occur.

Furthermore, the design of laboratory toxicity studies conducted to derive the toxicity threshold values have not addressed the need to use organisms acclimated to normal background levels of metals and minerals and frequently produce values much lower than would ever be found in natural systems. This problem has been recognized in the European approach to setting PNEC values for regional or large-scale risk assessments (Dutch National Health Council, 1998).

There has been no systematic examination of spatial distribution of background concentrations to determine how much of an area within a state, province, or country has naturally occurring levels above toxicologically-derived values. If large areas have background levels higher than the screening values, then the toxicologically-derived values are of little use. Either no sites would pass the screens or regional background concentrations would become the default screening level. There also has been no evaluation of how site-specific ecological risk assessments and cleanup goals compare to SPVs. Reports of literature reviews, field studies, and regulatory assessment documents (e.g., USEPA Superfund Records of Decision) could be reviewed to determine if significant ecological risks have been detected at soil concentrations comparable to the screening values. If such analysis documented adverse ecological effects within an order of magnitude or so of toxicologically-based SPVs, there would be justification for the process. However, if adverse effects are not demonstrated until much higher concentrations are present, then the process should be revisited. Until such validation steps are taken, the published soil protection values remain as “best guess” toxicological targets that may or may not relate to significant ecological consequences at the population, community, or systems level.

4.9. PEER REVIEW

Most of the soil protection values have not undergone peer review. The USEPA requires peer review and public comment on all policy and regulatory requirements prior to implementation. Not all jurisdictions have such a policy. The CCME and British Columbia guidelines for soil criteria derivation both underwent considerable scientific and public review prior to adoption. The ORNL approach has not received such a review, nor has the European approach. The European numbers are being reviewed and challenged during the current EU process of risk assessment of chemicals in commerce, providing an opportunity for comment and revision during the application process (similar to the notion of adaptive management by the U.S. resource management agencies). Australia requires some level of public review, but it is not known to what extent this occurred for the ecological risk assessment guidelines.

5. CONCLUSIONS

As development pressures from an expanding human population increase, requirements for cleanup of contaminated sites will continue to grow. Natural areas must be of sufficient quality to maintain desired species on diminishing acreage. Managed lands will provide a greater proportion of refugia for wild plants and animals and should not become a population sink because of excessive contamination. Therefore, regulatory bodies will be faced with an increasing need to provide soil screening values and, ultimately, cleanup goals and discharge targets. This review of the methods currently in use by various jurisdictions for derivation of such values highlights the inadequacy of our current knowledge for setting realistic numbers. We continue to be faced with the necessity of using highly conservative exposure assessments and deriving information from laboratory toxicity studies that frequently were designed for other purposes. Added to this is the desire of regulatory bodies to be precautionary during a screening level assessment to ensure that all contaminated sites are given further consideration. For these reasons, the final values derived by most of the methods reviewed here tend to include the use of assessment factors to provide a "margin of safety." Given the conservative nature of the final values, a systematic validation process needs to be done to determine 1) what proportion of the jurisdictions to which the various values apply would default to background levels (for naturally occurring substances) as the toxicologically-derived values are too low and 2) what proportion of tested sites have been screened out by this procedure. If the development of toxicologically-based soil screening values fails to screen out sites, or only screens those out that are at background, then the need for such conservative values becomes questionable.

All jurisdictions use the same base of toxicological and exposure information to derive their soil values. Final numbers differ primarily in how the literature is qualified for use, what measurement endpoints are acceptable (e.g., only reproduction endpoints; NOAEC/LOAEC vs. ECx), how interspecific differences are treated, and what type of assessment factors are applied. Ecological procedures differ most from human health criteria development due to the vast array of species under consideration and the ecotoxicological differences among the species. Ecological assessments are concerned with protection of a wide variety of species. There is often an expressed desire to develop screening values that are protective of "the most sensitive species," even when it is not known which species this is or how sensitive they might be. This has lead to the various approaches using statistical distributions, arrays, or single study effects data from toxicological tests. In aquatic systems, procedures for development of water quality criteria and sediment quality screening levels have been debated extensively. Difficulties with the distributional approach stem from a lack of knowledge about the shape of the distribution of species sensitivities and, even more, from insensitive species broadening the potential range of the distribution. The water quality criteria derivation solved this issue by using only the lower end of the species sensitivity curve to derive threshold values. This should be reviewed critically for terrestrial species as well. The approach for setting sediment screening values follows that suggested by CCME (when few data exist) and ORNL (for soil organisms) by setting a value between the concentrations at reported NOAEC and LOAEC values from all studies. The sediment screening values went one step further, however, by basing the exercise on field-collected data (relating benthic invertebrate community structure to sediment concentration), rather than relying on laboratory toxicity tests as is done for derivation of soil values.

Several regulatory bodies have been working towards development of soil protection values for nearly a decade. While a lot of thought has gone into the derivation of each of the methods, there obviously is no consensus about the best approach. All of the methods have a large degree of built in conservatism, although some jurisdictions recognize that different land uses may not need to support the same diversity of ecological services and functions and allow less conservative numbers to be used for commercial, industrial, or residential lands. Regardless of the methods chosen, all numbers are toxicologically based and do not incorporate many ecological considerations.

Although the process for derivation of soil screening values is based on ecotoxicological principles, regulatory policy has a significant influence on the outcome. How issues such as level of protection, use of assessment factors, background levels, and minimum data requirements are addressed varies with jurisdictions, which in turn affects the final values. It is important the users of these values recognize that both science and policy contribute to the derivation of soil protection values.

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Appendix A. Summary tables of methods for derivation of ecologically protective soil values

Table A- 1.

Jurisdiction	European Community
Technical Guidance Document	Technical guidance on environmental risk assessment of existing substances in the context of Regulation 94
Date	1996
Application	Screening, clean-up, and risk assessment
Approach	The Europeans use the Factor Application Method when there is little data. This applies an assessment factor to the lowest LC50 or NOAEL. When there have been numerous studies on different species, the Distribution Based Approach is used. This assumes that the frequency distribution follows a log-normal distribution, and calculates the final criterion values as the 5th percentile of the distribution.
Trophic Levels	Soil invertebrates, plants
Validation	Mostly just for metals
Soil Values Available	No
Other Comments	

Table A- 2

Jurisdiction	The Netherlands
Technical Guidance Document	Manual for calculating loads of heavy metals for terrestrial ecosystem: Guidelines for critical limits, calculation methods and input data
Date	1998
Application	Clean-up, screening
Approach	The Netherlands adds to the approach of the rest of the European Community. In the absence of soil toxicity data, the Dutch propose that soil pore water concentration be estimated through equilibrium partitioning. The critical soil concentration is derived using aquatic toxicity threshold values and the equilibrium partitioning theory. They also calculate critical soil levels for wildlife that takes into account BCFs derived from field-collected data.
Trophic Levels	soil invertebrates to wildlife predators
Validation	Yes for background concentrations of metals
Soil Values Available	Yes
Other Comments	

Table A- 3

Jurisdiction	Canadian Council of Ministers of the Environment
Technical Guidance Document	Recommended Canadian Soil Quality Guidelines
Date	1997
Application	Screening, clean-up goals
Approach	If there have been sufficient chronic studies, the Weight of Evidence approach is used. This takes a percentile of the NOAEC and LOAEC numbers, and divides by an uncertainty factor to get the Threshold Effect Concentration (TEC). If there are not enough data for this method, the LOAEC approach is used. This arrives at the TEC by dividing the lowest LOAEC by an uncertainty factor. If there are only acute toxicity data, The TEC is estimated by the Median Effects Method. By this method, the lowest reported EC50 or LC50 is divided by an uncertainty factor. Effects on microbial processes and wildlife are included. Land use determines which value is used for the final environmental guideline.
Trophic Levels	soil microbes, soil invertebrates, plants, terrestrial wildlife (mammalian and avian)
Validation	Gives regional or provincial background limits, may be site-specific. Detection limits for organics.
Soil Values Available	Yes
Other Comments	

Table A- 4

Jurisdiction	British Columbia Ministry of Environment, Lands, and Parks
Technical Guidance Document	A protocol for the derivation of environmental and human health soil quality guidelines
Date	1996
Application	Contaminated soils clean-up goals
Approach	For soil organisms, all toxicity data are examined. The lethal and non-lethal studies are compared and if multiple studies report the same percent age response, the concentrations that caused the response are averaged. This new data set is used to calculate a regression line to determine predicted soil concentrations. Land use determines whether the EC50 or LC20 soil concentration value is used.
Trophic Levels	soil invertebrates, plants, livestock
Validation	Background levels may be analyzed on a site-specific basis with protocol approval
Soil Values Available	Yes
Other Comments	

Table A- 5

Jurisdiction	Ontario Ministry of Environment and Energy
Technical Guidance Document	Guideline for use at Contaminated Sites in Ontario
Date	1996
Application	Soil clean-up
Approach	The soil criterion is the lowest number from human health and ecological effects analysis. No documentation was found on how the ecological effects analysis is conducted.
Trophic Levels	Soil microbes, herbivores, humans
Validation	Site-specific background may be developed
Soil Values Available	Yes
Other Comments	

Table A- 6

Jurisdiction	Australia
Technical Guidance Document	Draft national framework for ecological risk assessment of contaminated sites. Part B: Derivation of ecological impact levels for soils
Date	1997
Application	Screening
Approach	The available literature is studied, and the lowest reported NOAEC from soil organisms and wildlife is taken as the Environmental Impact Level. Extrapolation is allowed with use of appropriate assessment factors. The BCFs also are estimated from past studies.
Trophic Levels	Soil microorganisms, soil invertebrates, plants, wildlife
Validation	Yes, background or detection limits
Soil Values Available	No
Other Comments	

Table A- 7

Jurisdiction	Oak Ridge National Laboratory
Technical Guidance Document	Toxicological Benchmarks for Wildlife, Toxicological Benchmarks for Screening Contaminants of Concern for Effects on Terrestrial Plants, Benchmarks for Potential Contaminants of Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process
Date	1996, 1997, 1995
Application	Remediation goal
Approach	For invertebrates and plants, ORNL derived the soil benchmark from LOAEC values by calculating the 10th percentile of the distribution of toxic effects thresholds for soil organisms. For wildlife, they developed animal-specific benchmarks. Instead of averaging the values of many species studies, they looked for the single best chronic study that most closely related the species of interest.
Trophic Levels	Soil microorganisms, invertebrates, plants, wildlife
Validation	Regional and site-specific background concentrations
Soil Values Available	Yes
Other Comments	The wildlife benchmarks may have been incorrectly calculated since the extrapolation of data between species used an assumption that the ratio of body weight to metabolic rates was constant for all species and chemicals.

Table A- 8

Jurisdiction	United States Environmental Protection Agency
Technical Guidance Document	Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses
Date	1985
Application	Discharge
Approach	Water Quality Criteria: The USEPA mandates that at least eight acute toxicity tests, three chronic animal tests, one algal test, and one test to determine a BCF be used to develop a water quality criterion. A Species Mean Acute Value is calculated from the different tests. Mathematical extrapolation is performed on the four lowest values to estimate the 5th percentile. This is the Final Acute Value. The Chronic Continuous Criterion is half of the Final Acute Value multiplied by the ratio of the acute and chronic effect levels.
Trophic Levels	Algae, invertebrate, vertebrate
Validation	Site specific adjustments are encouraged
Soil Values Available	No
Other Comments	

Table A- 9

Jurisdiction	United States Environmental Protection Agency
Technical Guidance Document	Technical basis for establishing sediment quality criteria for nonionic organic chemicals by using equilibrium partitioning. Guidelines for the protection and management of aquatic sediment quality in Ontario. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program
Date	1991, 1992, 1991
Application	Site screening, clean-up goals
Approach	Sediment Quality Criteria: For non-polar organics, standards using aquatic toxicity data are suitable for concentrations in the pore water. The total amount of chemical in the sediment can be calculated using the equilibrium partitioning theory. The effects-range method is a compilation of results from NOAA, which studies many different marine environments, and Ontario, which only used the Great Lakes. A graph of the results gives an Effects Range-High, Low and Median.
Trophic Levels	Algae, invertebrate, vertebrate
Validation	Site specific adjustments are encouraged
Soil Values Available	No
Other Comments	

Appendix B. Guiding principles used by the Canadian Council of Ministers of the Environment for deriving soil protection values

The following guiding principles for the development of numerical soil quality remediation objectives for contaminated sites in Canada are based on the philosophy established by CCME (1991a; 1995a):

1. Site specific soil quality remediation objectives should be protective of human health and the environment.
2. Site specific soil quality remediation objectives should be protective of the appropriate land use at a contaminated site.
3. The land uses to be considered for protection include agricultural, residential/parkland, commercial, and industrial.
4. It is the philosophy of the CCME to encourage remediation to the lowest level practicable, considering the intended land use and other factors, such as technological limitations. Environmental quality guidelines are not intended to establish maximum levels of contamination acceptable at contaminated sites. Where the quality of site conditions is considered superior to the Canadian environmental quality guidelines, degradation of existing site conditions should be avoided.
5. Generic soil quality guidelines for a substance may be adopted directly (Method 1) as the recommended soil quality remediation objective for the intended or likely future use of a remediated contaminated site in Canada. Where it can be demonstrated that the guidelines are not applicable or appropriate to the specific site in question using the evaluation guidelines that follow, the guidelines may be modified within the limits prescribed in this guidance manual (Method 2). In some circumstances, the risk-based approach (Method 3) may be deemed more appropriate to determine site-specific remediation objectives.
6. If generic soil quality guidelines for the designated land use at a contaminated site are not available, the proponent should consult the jurisdictional authority. Options for guidelines development may include, but are not limited to, using risk assessment to develop remediation objectives, using the *Protocol* (CCME, 1995a) to develop remediation objectives, adopting appropriate background levels as remediation objectives, or adopting guidelines from other jurisdictions as remediation objectives.

7. The Explanations in this chapter specify the recommended conditions and procedures under which it is appropriate to modify generic guidelines or to develop risk-based remediation objectives.

8. The approach used to modify soil quality guidelines should adhere to the guidance documents relating to the guideline-based (this document) and risk-based approaches (CCME, 1995b and HC, 1995).

9. Generic soil quality guidelines were developed using information on defined exposure scenarios in Canada. Limited modification may be allowed to the parameters in three equations, and management check procedures may or may not be applicable. Apart from the equation and management check procedures specified in this guidance manual, the exposure scenario assumptions should not be altered without permission from the jurisdictional authority when using the guideline-based approach. However, these assumptions may be altered if the recommended soil quality remediation objective was modified using the risk-based approach.

10. Recommended soil quality remediation objectives may be modified within limits by omitting toxicological data on terrestrial organisms (e.g., annelids, arthropods) if it can be demonstrated by the proponent that specific toxicity data used to derive the national generic guidelines may be modified by recalculating them based on an adjusted data set derived by eliminating toxicological information not relevant to the site under investigation, provided that

    - The minimum data requirements for deriving generic soil quality guidelines in the *Protocol* (CCME, 1995a) are met; and
    - The administrative rules set out in Explanation 19 are followed.

11. Recommended soil quality remediation objectives (RSQRO) should normally be protective of the most sensitive water use associated with the groundwater at or near the contaminated site.

12. Each decision to accept or reject modification of the RSQROs should be carefully documented and justified.

13. In general, the Subcommittee recommends that socioeconomic and technical feasibility factors be considered in detail in developing a risk management strategy. The framework presented in this guidance manual provides for consideration of

socioeconomic and technological factors after an RSQRO has been developed, using either the guideline-based or risk-based approach. Guidance on socioeconomic and technical feasibility factors is, however, outside the scope of the Subcommittee.

14. Continued contamination of the site from readily identifiable sources (pits, ponds, lagoons, leaking storage tanks, etc.) should be prevented while detailed site investigations are conducted to support the development of site-specific soil quality remediation objectives using either the guide-based or risk-based approach. Under these circumstances, the generic soil quality guidelines, modified using the available information, may be used to guide the remedial action.

Appendix C. Comparison of methods for deriving ecologically protective soil values

	Europe	**CCME**	**British Columbia**	**Ontario**
Factor method	Yes	Yes	No	Yes
Assessment factors applied	10 to 1,000	1 to 5		10 to 1,000
When used		"small" data set		
Median effects method	No	Yes	No	No
Assessment factors applied		5 or 10		
When used		Only acute data		
Extrapolation approach	Yes	Yes	Yes	Yes
Type of distribution	Log normal	Not stated	Meta analysis	Log normal
Percentile used	5th	25th	LC_{50}/EC_{20}	5th
Assessment factors applied	No	1 to 5	No	No
Endpoints preferred	NOAEC	LOAEC	LC_{50}, EC_{50}	NOAEC
Equilibrium partitioning	Proposed for metals (Dutch)	No	No	No
Effects range method	No	No	No	No
Wildlife included	No	No	Livestock	No
BCF calculation			Measured	
Microbes included	Yes	Yes	Yes	Yes
Endpoints	Function and numbers	Functional endpoints	(uses CCME approach)	(uses CCME approach)

	Australia	**ORNL**	**Water quality**	**Sediment quality**

Factor method	Yes	Yes	No	No
Assessment factors applied	10 to 1,000	5		
When used	Acute data; only LOACs	Acute data only		
Median effects method	No	No	No	No
Assessment factors applied				
When used				
Extrapolation approach	No	No	Yes	No
Type of distribution			Triangular	
Percentile used			5th of lowest 4 values	
Assessment factors applied			2	
Endpoints preferred	NOAEC	LOAEC	NOAEC	NOAEC & LOAEC
Equilibrium partitioning	No	No	No	Yes
Effects range method	No	Yes	No	Yes
Wildlife included	Yes	Yes	No	
BCF calculation	Median	Measured		
Microbes included	No	No		No
Endpoints				

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Appendix D. Published soil values for use in screening, cleanup, or monitoring contaminated sites.

All values taken from the Technical Guidance Documents referenced in this report

JURISDICTIONAL ABBREVIATIONS

ORNL-E	Oak Ridge National Laboratory-Earthworms
ORNL-M	Oak Ridge National Laboratory-Microbes
ORNL-P	Oak Ridge National Laboratory-Plants
WSR	Westinghouse Savannah River Site
WSR-FN	Westinghouse Savannah River Site-Footnotes
BC Ag	British Columbia Agricultural
BC AG-FN	British Columbia Agricultural-Footnote
BC UP	British Columbia Urban Park
BC UP-FN	British Columbia Urban Park-Footnote
BC R	British Columbia Residential
BC R-FN	British Columbia Residential-Footnote
BC C	British Columbia Commercial
BC C-FN	British Columbia Commercial-Footnote
BC I	British Columbia Industrial
BC I-FN	British Columbia Industrial-Footnote
CCME Ag	Canadian Council of Ministers of the Environment Agricultural
CCME Ag-FN	Canadian Council of Ministers of the Environment Agricultural-Footnote
CCME RP	Canadian Council of Ministers of the Environment Residential/Parkland
CCME RP-FN	Canadian Council of Ministers of the Environment Residential/Parkland-Footnote
CCME C	Canadian Council of Ministers of the Environment Commercial
CCME C-FN	Canadian Council of Ministers of the Environment Commercial-Footnote
CCME I	Canadian Council of Ministers of the Environment Industrial
CCME I-FN	Canadian Council of Ministers of the Environment Industrial-Footnote
Ont Ag (M/F)	Ontario Agricultural (Medium and fine textured soils-ug/g)
Ont AG (M/F)	Ontario Agricultural land use (medium and fine textured soils-ug/g)
Ont Ag (C)	Ontario Agricultural land use (coarse-ug/g)
Ont Ag-FN	Ontario Agricultural -Footnote
Ont RP (M/F)	Ontario Residential/Parkland land use (medium and fine textured soils-ug/g)
Ont RP (C)	Ontario Residential/Parkland land use (coarse-ug/g)
Ont RP-FN	Ontario Residential/Parkland land use-Footnote
Ont IC (M/F)	Ontario Industrial/Commercial land use (medium and fine textured soils-ug/g)
Ont IC (C)	Ontario Industrial/Commercial land use (coarse-ug/g)
Ont IC-FN	Ontario Industrial/Commercial land use-Footnote
RIVM TV	The Netherlands soil/sediment (mg/kg dry material) target value
RIVM-FN	The Netherlands-Footnote
USSR MAC	USSR (Maximum allowable concentration)
USSR FN	USSR Footnote
USSR TAC	USSR (Tentative allowable concentration)

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
Halogenated Hydrocarbons																																													
	Bromodichloromethane																										0.12			0.12			0.12									0.12	0.12	0.12	3
	Chlorinated hydrocarbons (total)		30			0.1	a																																			0.1	30	1.73	2
	Dichlorophenols (total)																																				0.003					0.003	0.003	0.00	1
	Furan				600	600	b																																			600	600	600.00	2
	Monochlorophenols (total)																																				0.0025					0.0025	0.0025	0.00	1
	Organochlorinated (each)					0.1	a																																			0.1	0.1	0.10	1
	Organochlorinted (total)					0.1	a																																			0.1	0.1	0.10	1
	PCBs (total)				40	0.02	d											0.3	k	0.3	k	33	k,j	33	k,j												0.02	d				0.02	40	1.07	7
	PCBso	groundwater used for livestock watering							q		p																																		
	PCBso	livestock ingesting soil and fodder							b		b																																		
	PCBso	major microbial functional impairment							b		b																																		
	PCBso	toxicity to soil invertebrates and plants						0.5		5		5		50		50																										0.5	50	7.92	5
	Polychlorinated biphenyls																										0.5			5			25									0.5	25	3.97	3
	Polychlorinated Dioxons and Furans (PCDDs and PCDFs)	groundwater used for livestock watering							c,r																																				
	Polychlorinated Dioxons and Furans (PCDDs and PCDFs)	livestock ingesting soil and fodder							b,r																																				
	Polychlorinated Dioxons and Furans (PCDDs and PCDFs)	major microbial functional impairment							b,r																																				
	Polychlorinated Dioxons and Furans (PCDDs and PCDFs)	toxicity to soil invertebrates and plants						1E-05	r,s	0.001	r	0.001	r	0.003	r	0.003	r	0.00001	s	0.001	s		p		p																	0.00001	0.0025	0.00	7
	Polycyclic chlorinated hydrocarbons (total)					0.1	a																																			0.1	0.1	0.10	1
	Pentachlorophenol																																				0.002					0.002	0.002	0.00	1
	Tetrahydrofuran					0.1	a,d																														0.12					0.1	0.12	0.11	2
	Trichloroethene																																				0.001					0.001	0.001	0.00	1
	Trichloromethane																																				0.001					0.001	0.001	0.00	1
	Trichlorophenols (total)																																				0.001					0.001	0.001	0.00	1
	Tetrachlorophenols																																				0.001					0.001	0.001	0.00	1
Inorganic Compound																																													
	Aluminum			600	50	50	b																																			50	600	114.47	3
	Antimony				5	3.5	e	20		20		20		40		40		20		20		40		40			13			13		44	40		3.5	f,h			4.5			3.5	44	16.79	17
	Arsenic							60	a																																	60	60	60.00	1
	Arsenic							20																																		20	20	20.00	1
	Arsenic								b																																				
	Arsenic							35		35		35		150		150																										35	150	62.64	5
	Arsenic		60	100	10	10	b											12	a	12	a	12	a	12	a	25	20		25	20		50	40		34	c,g	29		2			2	100	19.92	17
	Barium			3000	500	165	e	750		500		500		2000		2000		750	b	500	b	2000	b	2000	b	1000	750		1000	750		2000	1500		165	f,h	200					165	3000	811.94	20
	Beryllium				10	1.1	e	4		4		4		8		8		4		4		8		8			1.2		1.2	1.2			1.2		1.1	f,g						1.1	10	3.17	16
	Bismuth																																												
	Boron			20	0.5	0.5	b	2										2	o		p		p		p																	0.5	20	1.82	5
	Boron (Available)																										1.5	a		1.5	a		1.5	a								1.5	1.5	1.50	3
	Bromine				10	10	b																																			10	10	10.00	2
	Cadmium		20	20	4	1.6	e											1.4	a	10	f	22	f	22	f	4	3			12			12		1.6	a,g	0.8					0.8	22	5.70	14
	Cadmium							1.5	e,f																																	1.5	1.5	1.50	1
	Cadmium							4500	e,f																																	4500	4500	4500.00	1
	Cadmium							2.5	e,f																																	2.5	2.5	2.50	1
	Cadmium							9	e,f																																	9	9	9.00	1
	Cadmium							50	e,f																																	50	50	50.00	1
	Cadmium							700	e,f																																	700	700	700.00	1
	Cadmium							8																																		8	8	8.00	1
	Cadmium								b																																				
	Cadmium							250		250		250		700		700																										250	700	377.40	5

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Chloride																											d			d			d											
	Chromium							150	g,h																																	150	150	150.00	1
	Chromium							9	i																																	9	9	9.00	1
	Chromium								b																																				
	Chromium							750	e,b	250		250		800		800																										250	800	495.93	5
	Chromium		0.4	10	1	0.4	b,c											64	a	64	a	87	a	87	a	1000	750		1000	750		1000	750		100	c,g	100		0.05			0.05	1000	44.49	17
	Chromium (VI)																	0.4	g	0.4	g	1.4	g	1.4	g		8		10	8		10	8									0.4	10	2.93	9
	Cobalt			1000	20	20	a,b,d	40		50		50		300		300		40		50		300		300		50	40		50	40		100	80		33	c,g	20					20	1000	71.91	20
	Copper							100	e,j																																	100	100	100.00	1
	Copper							90000	e,j																																	90000	90000	90000.00	1
	Copper							150	e,j																																	150	150	150.00	1
	Copper							500	e,j																																	500	500	500.00	1
	Copper							5000	e,j																																	5000	5000	5000.00	1
	Copper							40	k																																	40	40	40.00	1
	Copper							150	k																																	150	150	150.00	1
	Copper								b		b																																		
	Copper							150		150		150		250		250																										150	250	184.01	5
	Copper		50	100	100	40	e											63	a	63	a	91	a	91	a	200	150		300	225		300	225		40	a,g	36		3	b		3	300	82.60	17
	Cyanide (free)																	0.9	a	0.9	a	8	a	8	a		100			100			100				1					0.9	100	9.21	8
	Cyanide (SAD)							5	l	50	l	50	l	500	l	500	l																									5	500	79.24	5
	Cyanide (WAD)							0.5	m	10	m	10	m	100	m	100	m																									0.5	100	13.80	5
	Cynide Complex (pH<5)																																				5	a				5	5	5.00	1
	Cyanide complex (pH>5)																																				5					5	5	5.00	1
	Cyanide, comlex (total)					5	a																																			5	5	5.00	1
	Cyanide, free (total)					0.9	c																																			0.9	0.9	0.90	1
	Fluoride							200		400		400		2000		2000		200		400		2000		2000																		200	2000	701.16	9
	Fluorine			30	200																																					30	200	77.46	2
	Iodine				4																																					4	4	4.00	1
	Iron			200		200	b																																			200	200	200.00	2
	Lanathum					50	b																																			50	50	50.00	1
	Lead							150	e,n																																	150	150	150.00	1
	Lead							30000	e,n																																	30000	30000	30000.00	1
	Lead							250	e,n																																	250	250	250.00	1
	Lead							1500	e,n																																	1500	1500	1500.00	1
	Lead							350																																		350	350	350.00	1
	Lead								b																																				
	Lead							1000		1000		1000		2000		2000																										1000	2000	1319.51	5
	Lead		500	900	50	50	a,b											70	a	140	a	260	a	600	a		200			200			1000		140	a,g	85		20			20	1000	169.66	14
	Lithium			10	2	2	b																																			2	10	3.42	3
	Manganese			100	500	100	b																																1500			100	1500	294.28	4
	Mercury		0.1	30	0.3			0.8		2		2		10		10											10			10			10				0.3		2.1			0.1	30	2.54	13
	Mercury (Inorganic)					0.1	b											6.6	a	6.6	a	24	a	50	a										2.2	a						0.1	50	4.75	6
	Mercury (Methyl)					0.67	e																				6.8	b		6.8	b		10	b	0.67	c,g						0.67	10	2.91	5
	Molybdenum			200	2	2	b	5		10		10		40		40		5		10		40		40			5			40			40		254	f,h	10					2	254	17.23	17
	Nickel		200	90	30	30	b	150		100		100		500		500		50	k	50	k	50	k	50	k	200	150		200	150		200	150		38	c	35		4	c		4	500	87.61	22
	Nitrate																											d			d			d											
	Nitrates																																						130			130	130	130.00	1
	Nitrite																											d			d			d											
	Phosphorus pentoxide																																						200			200	200	200.00	1
	Selenium		70	100	1	0.81	e	2		3		3		10		10		2		3		10		10			2			10			10		0.81	f,h						0.81	100	5.08	17
	Silver			50	2	2	b	20		20		20		40		40		20		20		40		40		25	20		25	20		50	40									2	50	21.31	18
	Sodium																											d			d			d											
	Sulphur (elemental)							500										500			p		p		p																	500	500	500.00	2
	Technetium				0.2	0.2	b																																			0.2	0.2	0.20	2
	Thallium				1	1	b	2	d									1	l	1	m	1	m	1	m		4.1			4.1			32		1.3	f,h						1	32	1.93	11
	Thiocyanates					2	d																																			2	2	2.00	1
	Thiocyanates Total)																																												
	Tin			2000	50	53	e	5		50		50		300		300		5		50		300		30											53	f,h						5	2000	68.35	13
	Titanium			1000		1000	b																																			1000	1000	1000.00	2
	Tungsten			400		400	b																																			400	400	400.00	2
	Uranium				5	5	b																																			5	5	5.00	2
	Vanadium			20	2	2	b	200		200		200						130	k	130	k	130	n	130	n	250	200		250	200		250	200		43	f,h			150			2	250	89.91	18
	Zinc							450	e,t																																	450	450	450.00	1
	Zinc							550	e,t																																	550	550	550.00	1
	Zinc							1500	e,t																																	1500	1500	1500.00	1
	Zinc							9000	e,t																																	9000	9000	9000.00	1
	Zinc							70000	e,t																																	70000	70000	70000.00	1

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Zinc							150000	e,t																																	150000	150000	150000.00	1
	Zinc							200																																		200	200	200.00	1
	Zinc								b																																				
	Zinc							450		450		450		600		600																										450	600	504.88	5
	Zinc		200	100	50	50	b											200	k	200	k	360	k	360	k	800	600		800	600		800	600		160	a,g	140		23	d		23	800	230.62	17
	Zinc (erratum)																	200		200		360	q	360	q																	200	360	268.33	4
Other Organic Compound																																													
	Bromoform																										0.11			0.11			0.11									0.11	0.11	0.11	3
	Butylate																																								0.6	0.6	0.6	0.60	1
	Di(2-ethylthexyl)phthalate (DEHP)							30																																		30	30	30.00	1
	Dibutylphthalate (DBP)							30																																		30	30	30.00	1
	Dimethylphenol, 2,4-							0.1		1		1		10		10		0.1		1		10		10			0.94			0.94			0.94									0.1	10	1.45	12
	Ethylene glycol					97	c											960	j	960	j	960	j	960	j																	97	960	606.98	5
	Ethylene Glycol (erratum)																	103	q	103	q	428	q	428	q																	103	428	209.96	4
	Gasoline					20	a																																			20	20	20.00	1
	Lanthanum			50																																						50	50	50.00	1
	Mineral Oils					50	d																														50	i				50	50	50.00	2
	Nonaqueous phase liquids								x		x		x		x		x																												
	Odourous substances								x		x		x		x		x																												
	Petroleum Hydrocarbons (gas/diesel)																										100			100			100									100	100	100.00	3
	Petroleum Hydrocarbons (heavy oils)																										1000			1000			1000									1000	1000	1000.00	3
Pesticide																																													
	Abate																																								0.6	0.6	0.6	0.60	1
	Aldrin					0.0025	d																				0.05			0.05			0.05				0.0025					0.0025	0.05	0.02	5
	Amiben																																								0.5	0.5	0.5	0.50	1
	Atrazine					5E-05	d																														0.05	xxx	0.5			0.00005	0.5	0.01	3
	Basudin																																						0.2			0.2	0.2	0.20	1
	Bromophos																																								0.4	0.4	0.4	0.40	1
	Carbaryl					0.5	d																																0.05			0.05	0.5	0.16	2
	Carbofuran					0.2	d																																			0.2	0.2	0.20	1
	Carbophos																																						2			2	2	2.00	1
	Catechol					20	d																																			20	20	20.00	1
	Chloramp																																						0.05			0.05	0.05	0.05	1
	Chlordane																										0.29			0.29			0.29									0.29	0.29	0.29	3
	Chlorophos																																						0.5			0.5	0.5	0.50	1
	Cumene																																						0.5			0.5	0.5	0.50	1
	Cyanox																																								0.4	0.4	0.4	0.40	1
	Cycloate																																						0.8			0.8	0.8	0.80	1
	D, 2,4-																																						0.1			0.1	0.1	0.10	1
	D, ammonium salt, 2,4-																																						0.25			0.25	0.25	0.25	1
	Dacthal																																								0.1	0.1	0.1	0.10	1
	Dalapon Sodium, Salt																																						0.5			0.5	0.5	0.50	1
	DDD																										2.2			2.2			3.5									2.2	3.5	2.57	3
	DDE																										1.6			1.6			2.4									1.6	2.4	1.83	3
	DDT																	0.7	h	0.7	h	12	h,I	12	h,I		1.6			1.6			2						0.1			0.1	12	1.57	8
	DDT/DDE/DDD (total)					0.0025	d																														0.0025	e				0.0025	0.0025	0.00	2
	Desmetryn																																								0.6	0.6	0.6	0.60	1
	Dicamba																																						0.25			0.25	0.25	0.25	1
	Dichlorvos																																								0.1	0.1	0.1	0.10	1
	Dieldrin					0.0005	d																				0.05			0.05			0.05				0.0005					0.0005	0.05	0.01	5
	Dihydroheptachlor																																						0.5			0.5	0.5	0.50	1
	Dimethoate																																						0.3			0.3	0.3	0.30	1
	Dinobuton																																						1			1	1	1.00	1
	Dionin/Furan (ng TEQ/g soil)																										0.01		1	1			1									0.01	1	0.32	4
	Diuron																																								0.6	0.6	0.6	0.60	1
	Drins																																					f							
	Endosulfan																										0.18			0.18			0.18									0.18	0.18	0.18	3
	Endosulfon																																								0.1	0.1	0.1	0.10	1
	Endrin					0.001	d																				0.05			0.05			0.05				0.001					0.001	0.05	0.01	5
	Eptam																																						0.9			0.9	0.9	0.90	1
	Etaphos																																								0.1	0.1	0.1	0.10	1
	Ethylene Dibromide																									0.01	0.006		0.01	0.006		0.012	0.0056									0.0056	0.012	0.01	6

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Fenuron																																						1.8			1.8	1.8	1.80	1
	Folpet																																								0.3	0.3	0.3	0.30	1
	Gardona																																						1.4			1.4	1.4	1.40	1
	Glyphosate																																						0.5			0.5	0.5	0.50	1
	HCH Compounds																																					g							
	HCH, a-					0.0025	d																														0.0025					0.0025	0.0025	0.00	2
	HCH, b-					0.001	d																														0.001					0.001	0.001	0.00	2
	HCH, g- (Lindane)					5E-05	d																														0.05					0.00005	0.05	0.00	2
	Heptachlor																									0.12	0.084		0.12	0.084		0.15	0.084						0.05			0.05	0.15	0.09	7
	Heptachlor Epoxide																										0.06			0.06			0.09									0.06	0.09	0.07	3
	Herban																																								0.7	0.7	0.7	0.70	1
	Heterophos																																						0.05			0.05	0.05	0.05	1
	Hydrochinon					1	d																																			1	1	1.00	1
	Kelthane																																						1			1	1	1.00	1
	Lenacil																																								0.1	0.1	0.1	0.10	1
	Lindane																																						0.1			0.1	0.1	0.10	1
	Linuron																																						1			1	1	1.00	1
	Maneb					3.5	d																																			3.5	3.5	3.50	1
	Metathione																																						1			1	1	1.00	1
	Methaphos																																						0.1			0.1	0.1	0.10	1
	Methoxychlor																										4			4			4									4	4	4.00	3
	Monochlorobenzene							0.1		1		1		10		10																						m				0.1	10	1.58	5
	Monolinuron																																								0.7	0.7	0.7	0.70	1
	Monuron																																								0.6	0.6	0.6	0.60	1
	Pebulate																																								0.6	0.6	0.6	0.60	1
	Permethrin																																								0.05	0.05	0.05	0.05	1
	Phenazon																																								0.7	0.7	0.7	0.70	1
	Phenthoate																																								0.4	0.4	0.4	0.40	1
	Phosalone																																						0.5			0.5	0.5	0.50	1
	Phthalophos																																						0.1			0.1	0.1	0.10	1
	Picloram																																						0.05			0.05	0.05	0.05	1
	Pirimiphos-methyl																																						0.5			0.5	0.5	0.50	1
	Pirmicarb																																						0.3			0.3	0.3	0.30	1
	Pirmiphos-methyl (soil pH=5.5)																																						0.1			0.1	0.1	0.10	1
	Polychloropinewe																																						0.5			0.5	0.5	0.50	1
	Polytriazin (mixture of atrazine, simazine, and propazine)																																						0.01			0.01	0.01	0.01	1
	Prometrin																																						0.5			0.5	0.5	0.50	1
	Propanid																																						1.5			1.5	1.5	1.50	1
	Quinoline																	0.1			p		p		p																	0.1	0.1	0.10	1
	Resorcinol					1	d																																			1	1	1.00	1
	Simazin																																						0.2			0.2	0.2	0.20	1
	Solan																																								0.6	0.6	0.6	0.60	1
	Tenoran																																								0.4	0.4	0.4	0.40	1
	Terbacil																																								0.4	0.4	0.4	0.40	1
	Tetrahydrothiophene					0.1	a,d																														0.1					0.1	0.1	0.10	2
	Thiophene																	0.1			p		p		p																	0.1	0.1	0.10	1
	Total Pesticides					0.1	a																																			0.1	0.1	0.10	1
	Toxaphene																																						0.5			0.5	0.5	0.50	1
	Toxaphene																																						0.5			0.5	0.5	0.50	1
	Treflan																																								0.1	0.1	0.1	0.10	1
	Yalan																																								0.9	0.9	0.9	0.90	1
	Zineb																																						1.8			1.8	1.8	1.80	1
Semivolatile Organic Compound																																													
	Acenaphthene				20																						15			15			15									15	20	16.12	4
	Acenaphthylene																										100			100			130									100	130	109.14	3
	Aliphatic Chlorinated hydrocarbons (each)					0.1	a																																			0.1	0.1	0.10	1
	Aliphatic Chlorinated hydrocarbons (total)					0.1	a																																			0.1	0.1	0.10	1
	Anthracene																										28			28			28									28	28	28.00	3
	Benzo(a)anthracene							0.1		1		1		10		10		0.1		1		10		10			6.6			6.6			6.6									0.1	10	2.35	12
	Benzo(a)pyrene																	0.1	d	0.7	e	0.7	e	0.7	e		1.2			1.2			1.9						0.02			0.02	1.9	0.46	8
	Benzo(b)fluoranthene							0.1		1		1		10		10		0.1		1		10		10			12			12			18									0.1	18	2.83	12
	Benzo(g,h,I)perylene																										40			40			40									40	40	40.00	3

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Benzo(k)fluoranthene							0.1		1		1		10		10		0.1		1		10		10			12			12			18									0.1	18	2.83	12
	Benzo[a]pyrene								c		c		c																															
	Benzo[a]pyrene								b																																			
	Benzo[a]pyrene								d																																			
	Benzo[a]pyrene							0.1		1		1		10		10																										0.1	10	1.58	5
	Biphenyl				60																																					60	60	60.00	1
	Biphenyl, 1,1-																										0.89			0.89			0.89									0.89	0.89	0.89	3
	Bis(2-Chloroethyl)ether																										0.66			0.66			0.66									0.66	0.66	0.66	3
	Bis(2-ethylhexyl)phthalate																										100			100			100									100	100	100.00	3
	Aliphatics, Nonchlorinated (each)																	0.3			p		p		p																	0.3	0.3	0.30	1
	Chloroacetamide		2			2	b																																			2	2	2.00	2
	Chloroaniline, 3-				20	20	b																																			20	20	20.00	2
	Chloroaniline, p-																										1.3			1.3			1.3									1.3	1.3	1.30	3
	Chlorobenzene		40															0.1		1		10		10			2.4			2.4			2.4									0.1	40	2.94	8
	Chlorobenzene (each)					0.05	a											0.05	r	2	r	10	r	10	r																	0.05	10	0.87	5
	Chlorobenzene (total)					0.05	a																															c,j				0.05	0.05	0.05	1
	Chlorophenol, 2-																										0.1			0.1			0.1									0.1	0.1	0.10	3
	Chlorophenol, 3-		10		7																																					7	10	8.37	2
	Chlorophenol, 4-																																												
	Chlorophenol, meta							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Chlorophenol, ortho							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Chlorophenol, para							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Chrysene																										12			12			17									12	17	13.48	3
	Dibenz(a,h)anthracene							0.1		1		1		10		10		0.1		1		10		10			1.2			1.2			1.9									0.1	10	1.60	12
	Dichloro-2-butene, 1,4- (Trans)			1000		1000	b																																			1000	1000	1000.00	2
	Dichloro-2-butene, 1-4- (Cis)			1000		1000	b																																			1000	1000	1000.00	2
	Dichloroaniline, 2,4-		100			100	b																																			100	100	100.00	2
	Dichloroaniline, 3,4-		20			20	b																																			20	20	20.00	2
	Dichlorobenzene					0.01	d																																			0.01	0.01	0.01	1
	Dichlorobenzene (total)																																				0.01					0.01	0.01	0.01	1
	Dichlorobenzene, 1,2-							0.1		1		1		10		10		0.1		1		10		10																		0.1	10	1.67	9
	Dichlorobenzene, 1,2- (o-DCB)																										0.88			0.88			0.88									0.88	0.88	0.88	3
	Dichlorobenzene, 1,3-							0.1		1		2		10		10		0.1		1		10		10																		0.1	10	1.80	9
	Dichlorobenzene, 1,3- (m-DCB)																										30			30			30									30	30	30.00	3
	Dichlorobenzene, 1,4-		20					0.1		1		2		10		10		0.1		1		10		10																		0.1	20	2.29	10
	Dichlorobenzene, 1,4- (p-DCB)																										0.32			0.32			0.32									0.32	0.32	0.32	3
	Dichlorobenzidine, 3,3-																										1.3			1.3			1.3									1.3	1.3	1.30	3
	Dichlorophenol, 2,3-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Dichlorophenol, 2,4-							0.05		0.5		0.5		5		5		0.05		0.5		5		5			0.3			0.3			0.3						0.05			0.05	5	0.53	13
	Dichlorophenol, 2,5-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Dichlorophenol, 2,6-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Dichlorophenol, 3,4-		20		20			0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	20	1.49	11
	Dichlorophenol, 3,5-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Diethylphthalate				100	100	b																				0.71			0.71			0.71									0.71	100	5.14	5
	Dimethylphthalate		200			200	b																				0.7			0.7			0.7									0.7	200	6.72	5
	Di-n-butyl phthalate				200	200	b																																			200	200	200.00	2
	Dinitrophenol, 2,4-				20			0.1		1		1		10		10		0.1		1		10		10			0.2			0.2			0.2									0.1	20	1.24	13
	Dinitrophenol, 4,6- 2-methyl							0.1		1		1		10		10		0.1		1		10		10																		0.1	10	1.67	9
	Dinitrotoluene, 2,4-																										0.66			0.66			0.66									0.66	0.66	0.66	3
	Fluoranthene																										40			40			40									40	40	40.00	3
	Fluorene		30																								340			340			340									30	340	185.31	4
	HEPHs							1000	w	1000	w	1000	w	5000	w	5000	w																									1000	5000	1903.65	5
	Hexachlorobenzene			1000		0.0025	d											0.05		2		10		10													0.0025					0.0025	1000	0.67	7
	Hexachlorobenzene							0.05		2		2		10		10											0.46			0.46			0.76									0.05	10	1.16	8
	Hexachlorobutadiene																									2.2	0.38		2.2	0.38		2.2	0.38						0.5			0.38	2.2	0.84	7
	Hexachlorocyclohexane							0.01										0.01			p		p		p														0.1			0.01	0.1	0.02	3
	Hexachlorocyclohexane, Gamma																										0.41			0.41			0.49									0.41	0.49	0.44	3
	Hexachlorocyclopentadiene				10	10	b																																			10	10	10.00	2
	Indeno(1,2,3-c,d)pyrene							0.1		1		1		10		10		0.1		1		10		10			12			12			19									0.1	19	2.84	12
	LEPHs							1000	v	1000	v	1000	v	2000	v	2000	v																									1000	2000	1319.51	5
	Methylnaphthalene, 2-(*1-)																										1.2	c		1.2	c		1.2	c								1.2	1.2	1.20	3

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Naphthalene							0.1		5		5		50		50		0.1	c	0.6	g	22	g	22	g		4.6			4.6			4.6									0.1	50	4.02	12
	Nitrobenzene		40	1000		40	b																																			40	1000	116.96	3
	Nitrofor																																								0.2	0.2	0.2	0.20	1
	Nitrophenol, 2-							0.1		1		1		10		10		0.1		1		10		10																		0.1	10	1.67	9
	Nitrophenol, 4-		7					0.1		1		1		10		10		0.1		1		10		10																		0.1	10	1.93	10
	Nitrosodiphenylamine, N-		20			20	b																																			20	20	20.00	2
	pah (total of 10)																																				1	b,j				1	1	1.00	1
	Pentachloroaniline		100			100	b																																			100	100	100.00	2
	Pentachlorobenzene		20			0.0025	d	0.05		2		2		10		10		0.05		2		10		10													0.0025					0.0025	20	0.74	12
	Pentachlorophenol							750000	e																																	750000	750000	750000.00	1
	Pentachlorophenol							450000	e																																	450000	450000	450000.00	1
	Pentachlorophenol							4000	e																																	4000	4000	4000.00	1
	Pentachlorophenol							70	e																																	70	70	70.00	1
	Pentachlorophenol							6.5	e																																	6.5	6.5	6.50	1
	Pentachlorophenol							2	e																																	2	2	2.00	1
	Pentachlorophenol							1.5	e																																	1.5	1.5	1.50	1
	Pentachlorophenol							1	e																																	1	1	1.00	1
	Pentachlorophenol								b																																				
	Pentachlorophenol								b																																				
	Pentachlorophenol							20		20		20		50		50																										20	50	28.85	5
	Pentachlorophenol		6	400	3													7.6	a	7.6	a	7.6	a	7.6	a		5			5			5				0.002					0.002	400	4.13	11
	Phenanthrene							0.1		5		5		50		50		0.1		5		50		50			40			40			40									0.1	50	9.44	12
	Phenol		30	100	70			0.1		1		1		10		10		3.8	a	3.8	a	3.8	a	3.8	a		40			40			40				0.05	k				0.05	100	5.74	16
	Phthalates (total)					0.1	d																														0.01	h				0.01	0.1	0.03	2
	Phthalic acid esters (each)																	30			p		p		p																	30	30	30.00	1
	Pyrene							0.1		10		10		100		100		0.1		10		100		100			250			250			250									0.1	250	22.36	12
	Pyridine					0.1	a,d																														0.01					0.01	0.1	0.03	2
	Tetrachloroaniline, 2,3,5,6-		20		20	20	b																																			20	20	20.00	3
	Tetrachlorobenzene					0.01	d	0.05		2		2		10		10																										0.01	10	0.76	6
	Tetrachlorobenzene (total)																																				0.01					0.01	0.01	0.01	1
	Tetrachlorobenzene, 1,2,3,4-		10																																							10	10	10.00	1
	tetrachloroethane, 1,1,2,2-																	0.1		5		50		50																		0.1	50	5.95	4
	Tetrachlorophenol, 2,3,4,5-		20					0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	20	1.15	10
	Tetrachlorophenol, 2,3,4,6-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Tetrachlorophenol, 2,3,5,6-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Trichloroaniline 2,4,5-		20		20	20	b																																			20	20	20.00	3
	Trichloroaniline, 2,4,5-		20																																							20	20	20.00	1
	Trichlorobenzene					0.01	d	0.05		2		2		10		10																										0.01	10	0.76	6
	Trichlorobenzene (total)																																				0.01					0.01	0.01	0.01	1
	Trichlorobenzene, 1,2,3-		20																																							20	20	20.00	1
	Trichlorobenzene, 1,2,4-		20																								30			30			30									20	30	27.11	4
	Trichloroethane, 1,1,1-							0.1		5		5		50		50		0.1		5		50		50		34	26		34	26		34	26									0.1	50	11.19	15
	Trichlorophenol, 2,3,4-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Trichlorophenol, 2,3,5-							0.05		0.5		0.5		5		5																										0.05	5	0.79	5
	Trichlorophenol, 2,3,6-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
	Trichlorophenol, 2,4,5-		9		4			0.05		0.5		0.5		5		5		0.05		0.5		5		5			3.2			3.2			3.2									0.05	9	1.47	14
	Trichlorophenol, 2,4,6-		10					0.05		0.5		0.5		5		5		0.05		0.5		5		5			0.66			0.66			0.66									0.05	10	0.96	13
	Trichlorophenol, 3,4,5-							0.05		0.5		0.5		5		5		0.05		0.5		5		5																		0.05	5	0.83	9
Volatile Organic Compound																																													
	Acetaldehyde																																						10			10	10	10.00	1
	Acetone																										3.5			3.5			3.5									3.5	3.5	3.50	3
	Acrylonitrile			1000		1000	b																																			1000	1000	1000.00	2
	Benzene								c																																				
	Benzene								b																																				
	Benzene								b																																				
	Benzene							80		80		80		150		150																										80	150	102.87	5
	Benzene																	0.05	c	0.5	c	5	c	5	c		0.24			0.24			0.24				0.05	k	0.3			0.05	5	0.37	9
	Bis(2-chloroisopropyl)ether																										0.66			0.66			0.66									0.66	0.66	0.66	3
	Bromomethane																									0.38	0.061		0.38	0.061		0.38	0.061									0.061	0.38	0.15	6
	Carbon tetrachloride			1000		1000	b	0.1		5		5		50		50		0.1		5		50		50		0.64	0.1		0.64	0.1		0.64	0.1									0.1	1000	3.53	17
	Chloroform					0.001	d	0.1		5		5		50		50		0.1		5		50		50			0.13			0.13			0.13									0.001	50	1.24	13
	Cresol					0.5	d	0.1		1		1		10		10		0.01		1		10		10																		0.01	10	1.17	10
	Cresol, 2-																																												
	Cresole (total)																																												1
	Cyclohexane					0.1	a																																			0.1	0.1	0.10	1
	Cyclohexanone					0.1	d																														0.01					0.01	0.1	0.03	2

	Compound Name	Sub category	ORNL-E	ORNL-M	ORNL-P	WSR	WSR-FN	BC Ag	BC Ag-FN	BC UP	BC UP-FN	BC R	BC R-FN	BC C	BC C-FN	BC I	BC I-FN	CCME Ag	CCME Ag-FN	CCME RP	CCME RP-FN	CCME C	CCME C-FN	CCME I	CCME I-FN	Ont Ag (M/F)	Ont Ag (C)	Ont Ag-FN	Ont RP (M/F)	Ont RP (C)	Ont R/P-FN	Ont IC (M/F)	Ont IC (C)	Ont IC-FN	RIVM MPC	RIVM MPC-FN	RIVM TV	RhVM-FN	USSR MACa	USSR FN	USSR TACa.	Min	Max	Geo. Mean	N Values
	Dibromochloromethane																										0.09			0.09			0.09									0.09	0.09	0.09	3
	Dichloroethane							0.1		5		5		50		50																										0.1	50	5.74	5
	Dichloroethane, 1,1-							0.1		5		5		50		50		0.1		5		50		50			3			3			3									0.1	50	4.94	12
	Dichloroethane, 1,2-					0.04	d	0.1		5		5		50		50		0.1		5		50		50		0.05	0.022		0.05	0.022		0.05	0.022									0.022	50	0.61	16
	Dichloroethene, 1,1-																	0.1		5		50		50																		0.1	50	5.95	4
	Dichloroethene, 1,2-																	0.1		5		50		50																		0.1	50	5.95	4
	Dichloroethylene, 1,1-							0.1		5		5		50		50										0.015	0.002		0.015	0.002		0.015	0.0024									0.0024	50	0.14	11
	Dichloroethylene, 1,2-							0.1		5		5		50		50											2.3			2.3			2.3									0.1	50	4.08	8
	Dichloroethylene, Cis-1,2-																										2.3			2.3			2.3									2.3	2.3	2.30	3
	Dichloroethylene, Trans-1,2-																										4.1			4.1			4.1									4.1	4.1	4.10	3
	Dichloromethane					2	d	0.1		5		5		50		50		0.1		5		50		50														k				0.1	50	5.24	10
	Dichloropropane, 1,2-		700			700	b	0.1		5		5		50		50		0.1		5		50		50		0.12	0.019		0.12	0.019		0.12	0.019									0.019	700	1.88	17
	Dichloropropane, 1,3-																									0.04	0.007		0.04	0.007		0.04	0.0066									0.0066	0.04	0.02	6
	Dichloropropane, 1,3- cis							0.1		5		5		50		50																										0.1	50	5.74	5
	Dichloropropane, 1,3- trans							0.1		5		5		50		50																										0.1	50	5.74	5
	Dichloropropene, 1-2 (cis)																	0.1		5		50		50																		0.1	50	5.95	4
	Dichloropropene, 1-2 (trans)																	0.1		5		50		50																		0.1	50	5.95	4
	Ethylbenzene								c																																				
	Ethylbenzene								b																																				
	Ethylbenzene								b																																				
	Ethylbenzene							0.1	d	5		5		50		50																										0.1	50	5.74	5
	Ethylebenzene																	0.1	c	1.2	g	20	g	20	g		0.28			0.28			0.28				0.05	k				0.05	20	0.69	8
	Formaldehyde																																						7			7	7	7.00	1
	Hexachloroethane																									6.3	3.8		6.3	3.8		8.5	3.8									3.8	8.5	5.14	6
	Methyl ethyl ketone																										0.27			0.27			0.27									0.27	0.27	0.27	3
	Methyl isobutyl ketone																										0.48			0.48			0.48									0.48	0.48	0.48	3
	Methyl tert butyl ether																										5.7			5.7			5.7									5.7	5.7	5.70	3
	Methylene chloride																										1.1			1.1			1.1									1.1	1.1	1.10	3
	Styrene				300	0.1	a,d	0.1		5		5		50		50		0.1		5		50		50		1.7	1.2		1.7	1.2		1.7	1.2				0.1					0.1	300	2.89	18
	Tetrachloroethene					0.01	d																														0.01					0.01	0.01	0.01	2
	Tetrachloroethene, 1,1,1,2-																									0.12	0.019		0.12	0.019		0.12	0.019									0.019	0.12	0.05	6
	Tetrachloroethene, 1,1,2,2-							0.1		5		5		50		50											0.01			0.01			0.01									0.01	50	0.53	8
	Tetrachloroethylene																	0.1	d	0.2	e	0.5	e	0.6	e		0.45			0.45			0.45									0.1	0.6	0.34	7
	Tetrachloroethylene (PERC)								c																																				
	Tetrachloroethylene (PERC)								b																																				
	Tetrachloroethylene (PERC)								b																																				
	Tetrachloroethylene (PERC)							0.1	d	5		5		50		50																										0.1	50	5.74	5
	Tetrachloromethane					0.001	d											0.1		5		50		50													0.001					0.001	50	0.33	6
	Tetrachloromethane, 1,1,1-							0.1		5		5		50		50																										0.1	50	5.74	5
	Tetrachloromethane, 1,1,2-							0.1		5		5		50		50																										0.1	50	5.74	5
	Toluene								c																																				
	Toluene								b																																				
	Toluene								b																																				
	Toluene							0.1	d	3		3		30		30																										0.1	30	3.82	5
	Toluene				200													0.1	d	0.8	e	0.8	e	0.8	e		2.1			2.1			2.1				0.05	k	0.3			0.05	200	1.04	10
	Trichloroethane, 1,1,2-							0.1		5		5		50		50		0.1		5		50		50			0.28			0.28			0.28									0.1	50	2.73	12
	Trichloroethylene																	1	c	3	g	31	g	31	g	3.9	1.1		3.9	1.1		3.9	1.1									1	31	3.43	10
	Trichloroethylene (TCE)							0.15																																		0.15	0.15	0.15	1
	Trichloroethylene (TCE)								b																																				
	Trichloroethylene (TCE)								b																																				
	Trichloroethylene (TCE)							0.1	d	5		5		50		50																										0.1	50	5.74	5
	Vinyl chloride					0.01	d																			0.0075	0.003		0.0075	0.003		0.0075	0.003									0.003	0.01	0.01	7
	VPHs							200	u	200	u	200	u	200	u	200	u																									200	200	200.00	5
	Xylene								c																																				
	Xylene								b																																				
	Xylene								b																																				
	Xylene							0.1	d	5		5		50		50																										0.1	50	5.74	5
	Xylene																	0.1	d	1	e	17	e	20	e		25			25			25				0.05	k				0.05	25	3.57	8

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FOOTNOTES

Footnotes for BC Screening Level Figures

All values in µg/g unless otherwise stated. Substances shall be analyzed using methods in protocols approved under section 50 or methods acceptable to the Director.

1	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 14.9 µg/g.
2	No standard. Insufficient acceptable scientific data exists, so no standard is calculated.
3	No standard. No appropriate standard, guideline, or criterion exists to use to develop a soil quality standard.
4	No standard. Insufficient acceptable environmental data exists, so standards are set equal to the Canadian Council of Ministers of the Environment Interim soil quality criteria.
5	The pH is the pH of the soil at a site.
6	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 1.3 µg/g.
7	Standard is for chromium (total).
8	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 58.9 µg/g.
9	Standard is for chromium+6.
10	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 74.0 µg/g.
11	Standard varies. If sheep are the livestock of concern, standard is 40 µg/g. For all other livestock the standard is 150 µg/g.
12	WAD means weak acid dissociable.
13	SAD means strong acid dissociable.
14	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 108.6 µg/g.

15	Polychlorinated biphenyls (PCBs) include Arochlor mixtures 1242, 1248, 1254, and 1260.
16	No standard. No appropriate model to calculate data exists, so no standard is calculated.
17	Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) expressed in 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) toxicity equivalents. NATO International Toxicity Equivalency Factor (I-TEFs) for congeners and Isomers of PCDDs and PCDFs are as follows:

PCDD Congener	I-TEF	PCDF Congener	I-TEF
2,3,7,8,-T$_4$CDD	1.0	2,3,7,8-T$_4$CDF	0.1
1,2,3,7,8-P$_5$CDD	0.5	2,3,4,7,8-P$_5$CDF	0.5
1,2,3,4,7,8-H$_6$CCD	0.1	1,2,3,7,8-P$_5$CDF	0.05
1,2,3,7,8,9-H$_6$CDD	0.1	1,2,3,4,7,8-H$_6$CDF	0.1
1,2,3,4,6,7,8-H$_7$CDD	0.1	1,2,3,7,8,9-H$_6$CDF	0.1
1,2,3,4,6,7,8-H$_7$CDD	0.01	1,2,3,6,7,8-H$_6$CDF	0.1
O$_8$CDD	0.001	2,3,4,6,7,8-H$_6$CDF	0.1
		1,2,3,4,6,7,8-H$_7$CDF	0.01
		1,2,3,4,7,8,9-H$_7$CDF	0.01
		O$_8$CDF	0.001

18	Insufficient acceptable environmental data exists, so AL, PL, and RL standards are set equal to the Canadian Council of Ministers of the Environment interim soil quality criteria.
19	Standard has been adjusted based on a reference provincial background soil concentration. Standard represents the rounded sum of the toxicologically-based value plus the reference provincial background soil concentration. For all land uses, the reference provincial background soil concentration is 138.1 µg/g.
20	Volatile petroleum hydrocarbons with the exception of benzene, toluene, ethylbenzene and xylenes.
21	Light extractable petroleum hydrocarbons with the exception of benzo(a)anthrancene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene and pyrene.
22	Heavy extractable petroleum hydrocarbons with the exception of benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthrancene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene and pyrene.
23	Soil must be remediated so that substances are not present in quantities in excess of that acceptable to a manager.

API Footnotes RE: Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health.

a	Data are sufficient and adequate to calculate an SQG$_{HH}$ and an SQG$_{E}$. Therefore the soil quality guideline is the lower of the two and represents a fully integrated de novo guideline for this land use, derived in accordance with the soil protocol (CCME 1996). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

b	Data are insufficient/inadequate to calculate an SQG_{HH}, an SQG_E, or a provisional SQG_E. Therefore the interim soil quality criterion (CCME 1991) is retained as the soil quality guideline for this land use.
e	Data are sufficient and adequate to calculate only a provisional SQG_E. It is greater than the corresponding interim soil quality criterion (CCME 1991). Therefore, in consideration of receptors and/or pathways not examined, the interim soil quality criterion is retained as the soil quality guideline for this land use.
c	Data are sufficient and adequate to calculate an SQG_{HH} and a provisional SQG_E. Both are greater than the corresponding interim soil quality criterion (CCME 1991). Therefore, in consideration of receptors and/or pathways not examined, the interim soil quality criterion is retained as the soil quality guideline for this land use.
e	Data are sufficient and adequate to calculate an SQG_{HH} and a provisional SQG_E. Both are less than corresponding interim soil quality criterion (CCME 1991). Therefore, the soil quality guideline supersedes the interim soil quality criterion for this land use.
f	The soil-plant-human pathway was not considered in the guideline derivation. If produce gardens are present or planned, a site-specific objective must be derived to take into account the bioaccumulation potential (e.g., adopt the agricultural guideline as objective). The off-site migration check should be recalculated accordingly.
g	Data are sufficient and adequate to calculate only a provisional SQG_E, which is less than the existing interim soil quality criterion (CCME 1991). Therefore, the soil quality guideline supersedes the interim soil quality criterion for this land use.
h	Data are sufficient and adequate to calculate only an SQG_E. An interim soil quality criterion (CCME 1991) was not established for this land use, therefore the SQG_E becomes the soil quality guideline.
i	In site-specific situations where the size and/or the location of commercial and industrial land uses may impact primary, secondary, or tertiary consumers, the soil and food ingestion guideline is recommended as the SQG_E.
j	Data are sufficient and adequate to calculate only a provisional SQG_E.
k	Data are sufficient and adequate to calculate only an SQG_E, which is less than the interim soil quality criterion (CCME 1991) for this land use. Therefore the SQG_E becomes the soil quality guideline, which supersedes the interim soil quality criterion for this land use.
l	Data are sufficient and adequate to calculate only an SQG_{HH} and an SQG_E. The provisional SQG_{HH} is equal to the SQG_E and to the existing interim soil quality criterion (CCME 1991) and thus becomes the soil quality guideline, which supersedes the interim soil quality criterion for this land use.
m	Data are sufficient and adequate to calculate a provisional SQG_{HH} and an SQG_E. The provisional SQG_{HH} is less than the SQG_E and thus becomes the soil quality guideline for this land use.
n	Data are sufficient and adequate to calculate only an SQG_E. An interim soil quality criterion (CCME 1991) was not established for this land use, therefore the SQG_E becomes the soil quality guideline.
o	Hot water soluble.

p	Values not estimated.			
q	An erratum with this change was issued in the technical supporting document for this substance (dated December 1996).			
r	Chlorobenzenes include all trichlorobenzene isomers, all tetrachlorobenzene isomers, pentachlorobenzene			
s	Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) expressed in 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) toxicity equivalents. NATO International Toxicity Equivalency Factor (I-TEFs) for congeners and Isomers of PCDDs and PCDFs are as follows:			
	PCDD Congener	I-TEF	PCDF Congener	I-TEF
	2,3,7,8,-T_4CDD	1.0	2,3,7,8-T_4CDF	0.1
	1,2,3,7,8-P_5CDD	0.5	2,3,4,7,8-P_5CDF	0.5
	1,2,3,4,7,8-H_6CCD	0.1	1,2,3,7,8-P_5CDF	0.05
	1,2,3,7,8,9-H_6CDD	0.1	1,2,3,4,7,8-H_6CDF	0.1
	1,2,3,4,6,7,8-H_7CDD	0.1	1,2,3,7,8,9-H_6CDF	0.1
	1,2,3,4,6,7,8-H_7CDD	0.01	1,2,3,6,7,8-H_6CDF	0.1
	O_8CDD	0.001	2,3,4,6,7,8-H_6CDF	0.1
			1,2,3,4,6,7,8-H_7CDF	0.01
			1,2,3,4,7,8,9-H_7CDF	0.01
			O_8CDF	0.001

The Netherlands Footnotes:

a. Acidity: pH (0.01 M $CaCI_2$). In order to determine whether pH is greater than or equal to 5, or less than 5, the 90 percentile of the measured values is taken.

b. "PAH (total of 10)" here means the total of anthracene, benzo(a)anthracene, benzo(k)fluoroanthene, benzo(a)pyrene, chrysene, phenantrene, fluoroanthene, indeno(1,2,3-cd)pyrene, naphthalene and benzo(ghi)perylene.

c. "Chlorobenzenes (total)" here means the total of all chlorobenzenes (mono-, di-, tri-, penta- and hexachlorobenzene).

d. In the case of the intervention value, "polychlorobiphenyls" (total) means the total of PCB, 28, 52, 101, 118, 138, 153, and 180. For the target value it refers to the total excluding PCB 118.

e. "DDT/DDD/DDE" means the total of DDT, DDD and DDE.

f. "Drins" means the total of aldrin, dieldrin, and endrin.

g. "HCH compounds" means the total of α-HCH, β-HCH, γ-HCH and δ-HCH.

h. "Phathalates (total)" means the total of all phthalates.

i. "Mineral oil means" the sum of all the alkanes, both straight-chain and branched-chain. Where the contamination is due to mixtures (e.g., gasoline or domestic heating oil), then not only the alkane content but also the content of aromatic and/or polycyclic aromatic hydrocarbons must be determined. This aggregate parameter has been adopted for practical reasons. Further toxicological and chemical disaggregation is under study.

j. The values for total polycyclic aromatic hydrocarbons, total chlorophenols and total chlorobenzenes in soil/sediment apply to the total concentration of the compounds belonging to the relevant category. If the contamination is due to only one compound of a category, the value used is the intervention value for the compound, where there are two or more compounds the value for the total of these compounds applies, etc. For soil/sediment, effects are directly additive (i.e., 1 mg of substance A has the same effect as 1 meg of substance B) and can be checked/compared against an aggregate standard by summing the concentrations of the substances involved. For further information about this additivity see, for example, the Technical Committee for Soil Protection (1989)[1].

m. Detection threshold

MPC (Maximum Permissible Concentrations Footnotes

a. MPA based on statistical extrapolation, toxicity data follow a long-logistic distribution.

c. MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC

f. MPA based on equilibrium partioning

g. Van de Meent *et al.*, (1990)

h. Van de Plassche and De Bruijn (1992)

Westinghouse Savannah River Site Footnotes

1. Beyer (1990)
2. Oak Ridge National Laboratory (Efroymson et al. 1997a,b)
3. CCME (1997)
4. Ministry of Housing, Spatial Planning and Environment (1994)
5. Crommentuijn et al. (1997)

USSR Footnote:

1. Maximum allowable concentration (MAC) and tentative allowable concentrations (TAC) of pesticides and other substances in soil in the Soviet Union (from USSR State Committee for Science and Technology, 1984).

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[1] Technical Committee for Soil Protection (1989). *Advies beoordeling van bodemverontreiniging met polycyclische aromate* (Advice regarding the assessment of soil contaminated with polycyclic aromatics) TCB A89-03