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Canadian Soil Quality Guidelines for

Zinc: Environmental

Supporting Document — Final Draft
December 1996

NOTICE

This final draft document provides the information supporting the derivation of environmental soil quality guidelines for zinc. Development of these soil quality guidelines was initiated through the National Contaminated Sites Remediation Program (NCSRP) which officially ended in March 1995. Given the need for national soil quality guidelines for contaminated sites management and many other applications, development was pursued under the direction of the CCME Soil Quality Guidelines Task Group after the end of the NCRSP.

This document is a working document that was released shortly after the publication of "A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines" (CCME 1996). The CCME recognizes that some refinements or changes to the Protocol may become necessary upon application and testing. If required, amendments to the Protocol will be made and the guidelines will be modified accordingly. For this reason guidelines are referred to in this document as CCME Recommended Guidelines. Readers who wish to comment or provide suggestions on the Protocol or on the guidelines presented in this document should send them to the following address:

Guidelines Division
Science Policy and Environmental Quality Branch
Ecosystem Science Directorate
Environment Canada
Ottawa, Ontario
K1A 0H3

Or by E-Mail: Connie.Gaudet@EC.GC.CA
Sylvain.Ouellet@EC.GC.CA

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This document should be cited as:
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This document is a supporting technical document. It is available in English only. A French Abstract is given on page vii.

Ce document technique de soutien n'est disponible qu'en anglais avec un résumé en français présenté à la page vii.

ERRATUM: An error has occured in the document intitled: "Recommended Canadian Soil Quality Guidelines, March 1997" regarding the Canadian Soil Quality Guidelines for Zinc. In the mentionned document, Tables 1 and 2 on pages 141 and 145 respectively, should be corrected as follow:

Table 1: Corrections are indicated in underlined bold italics.

Table 1. CCME recommended Canadian soil quality guidelines for total zinc (mg/kg).

Soil quality guidelines	Land use: Agricultural	Residential/ parkland	Commercial	Industrial
CCME 1997 Recommended Guidelines	**200** [a]	**200** [a]	***360*** [a]	***360*** [a]
SQG_{HH}	NC [b]	NC [b]	NC [b]	NC [b]
Limiting pathway for SQG_{HH}	ND	ND	ND	ND
SQG_{HH}—provisional guidelines	NC [b]	NC [b]	NC [b]	NC [b]
Limiting pathway for SQG_{HH}—provisional	ND	ND	ND	ND
SQG_E	200	200	***360*** [c]	***360*** [c]
Limiting pathway for SQG_E	soil contact	soil contact	nutrient and energy cycling check	nutrient and energy cycling check
SQG_E—provisional guidelines	NC [d]	NC [d]	NC [d]	NC [d]
Limiting pathway for SQG_E—provisional	ND	ND	ND	ND
CCME 1991 Interim Soil Quality Criteria	600	500	1500	1500

Notes:
SQG_{HH} = soil quality guideline for human health; SQG_E = soil quality guideline for environmental health; NC = not calculated; ND = not determined

[a] Data are sufficient and adequate to calculate SQG_E guidelines only. The SQG_E guideline is less than the existing CCME 1991 Interim Soil Quality Criterion for this land use. Therefore the CCME 1997 Recommended Soil Quality Guideline represents a revised CCME 1991 Interim Soil Quality Criterion for this land use.

[b] There are no SQG_{HH} guidelines or SQG_{HH}—provisional guidelines at this time.

[c] The SQG_E, for this land use, is the geometric mean of the ***effects concentration low (ECL)*** and the nutrient and energy cycling check.

[d] Data are sufficient and adequate to calculate a SQG_E guideline for this land use. Therefore the SQG_E—provisional guideline is not calculated.

Table 2: Corrections are indicated in underlined bold italics.

Table 2. Canadian soil quality guidelines and check values for zinc (mg/kg).

	Land use			
Soil quality guidelines/check values	Agricultural	Residential/ parkland	Commercial	Industrial
CCME 1997 Recommended Guidelines	**200** [a]	**200** [a]	***360*** [a]	***360*** [a]
Human health guidelines/check values				
SQG_{HH}	NC [b]	NC [b]	NC [b]	NC [b]
Soil ingestion guidelines	NC [b]	NC [b]	NC [b]	NC [b]
Inhalation of indoor air check	NC [b]	NC [b]	NC [b]	NC [b]
Off-site migration check	—	—	—	NC [b]
Groundwater check (drinking water)	NC [b]	NC [b]	NC [b]	NC [b]
Produce, meat and milk check	NC [b]	NC [b]	—	—
SQG_{HH}—provisional guidelines	NC [b]	NC [b]	NC [b]	NC [b]
Limiting pathway for SQG_{HH}—provisional	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG_E	200 [c]	200 [c]	***360*** [d]	***360*** [d]
Soil contact guidelines	200	200	***360***	***360***
Soil and food ingestion guideline	640	—	—	—
Nutrient and energy cycling check	320	320	***320***	***320***
Off-site migration check	—	—	—	1000
Groundwater check (aquatic life)	NC [e]	NC [e]	NC [e]	NC [e]
SQG_E—provisional guidelines	NC [f]	NC [f]	NC [f]	NC [f]
Limiting pathway for SQG_E—provisional	ND	ND	ND	ND
CCME 1991 Interim Soil Quality Criteria	600	500	1500	1500

Notes:

SQG_{HH} = soil quality guideline for human health; SQG_E = soil quality guideline for environmental health; NC = not calculated; ND = not determined; — The dashes indicate guidelines/check values that are not part of the exposure scenario for that land use and therefore are not calculated.

[a] Data are sufficient and adequate to calculate SQG_E guidelines only. The SQG_E guideline is less than the existing CCME 1991 Interim Soil Quality Criterion for this land use. Therefore the CCME 1997 Recommended Soil Quality Guideline represents a revised CCME 1991 Interim Soil Quality Criterion for this land use.

[b] There are no values for the human health guidelines/check values and/or SQG_{HH}—provisional guidelines at this time.

[c] The SQG_E for this land use is based on the soil contact guideline.

[d] The SQG_E for this land use is the geometric mean of the nutrient and energy cycling check and the ***effects concentration low***.

[e] The environmental groundwater check for aquatic life applies to organic compounds and is not calculated for metal contaminants. Concerns about metal contaminants should be addressed on a site-specific basis.

[f] Data are sufficient and adequate to calculate a SQG_E guideline for this land use. Therefore the SQG_E—provisional guideline is not calculated.

End of corrections

ERRATUM: Une erreur s'est glissée dans le document intitulé: "Recommandations canadiennes pour la qualité des sols, Mars 1997" au niveau des recommandations canadiennes pour la qualité des sols relatives au zinc. Les Tableaux 1 et 2 présentés aux pages 155 et 159 dudit document doivent être corrigés de la façon suivante:

Tableau 1: Les corrections sont en caractères gras, italiques, soulignés.

Tableau 1. Recommandations du CCME pour la qualité des sols relatives au zinc total (mg/kg de sol sec).

	Vocation du terrain			
Recommandations pour la qualité des sols	Agricole	Résidentielle/ parc	Commerciale	Industrielle
Recommandations proposées par le CCME en 1997	**200** [a]	**200** [a]	***<u>360</u>*** [a]	***<u>360</u>*** [a]
RQS_{SH}	NC [b]	NC [b]	NC [b]	NC [b]
Voie limitant la RQS_{SH}	ND	ND	ND	ND
RQS_{SH}—provisoire	NC [b]	NC [b]	NC [b]	NC [b]
Voie limitant la RQS_{SH}—provisoire	ND	ND	ND	ND
RQS_E	200 [c]	200 [c]	***<u>360</u>*** [c]	***<u>360</u>*** [c]
Voie limitant la RQS_E	contact avec le sol	contact avec le sol	cycle des nutriments et de l'énergie	cycle des nutriments et de l'énergie
RQS_E—provisoire	NC [d]	NC [d]	NC [d]	NC [d]
Voie limitant la RQS_E—provisoire	ND	ND	ND	ND
Critères provisoires pour la qualité des sols (CCME 1991)	600	500	1500	1500

Notes:

RQS_{SH} = recommandation pour la qualité des sols: santé humaine; RQS_E = recommandation pour la qualité des sols: environnement; NC = non calculée; ND = non déterminée

[a] Les données ne sont suffisantes et adéquates que pour calculer des RQS_E seulement. La RQS_E est inférieure au critère provisoire pour la qualité des sols existant (CCME 1991) pour cette utilisation du terrain. Par conséquent la Recommandation pour la qualité des sols proposée par le CCME en 1997 représente une révision du critère provisoire pour la qualité des sols (CCME 1991) pour cette utilisation du terrain.

[b] Présentement, il n'y a aucune RQS_{SH} ni RQS_{SH}—provisoire.

[c] Pour cette utilisation du terrain, la RQS_E est la moyenne géométrique ***<u>entre la plus faible concentration produisant un effet (PFCE) et la</u>*** vérification du cycle des nutriments et de l'énergie pour la protection de l'environnement.

[d] Les données sont suffisantes et adéquates pour calculer une RQS_E pour cette utilisation du terrain. Par conséquent aucune RQS_E provisoire n'est calculée.

Tableau 2: Les corrections sont en caractères gras, italiques, soulignés.

Tableau 2. Recommandations canadiennes pour la qualité des sols et valeurs de vérification relatives au zinc (mg/kg de sol sec).

Recommandations pour la qualité des sols/valeurs de vérification	Vocation du terrain			
	Agricole	Résidentielle/ parc	Commerciale	Industrielle
Recommandations proposées par le CCME en 1997	**200** [a]	**200** [a]	***360*** [a]	***360*** [a]
Santé humaine				
RQS_{SH}	NC [b]	NC [b]	NC [b]	NC [b]
Recommandations pour l'ingestion de sol	NC [b]	NC [b]	NC [b]	NC [b]
Vérification de l'inhalation de l'air intérieur	NC [b]	NC [b]	NC [b]	NC [b]
Vérification de migration hors-site	—	—	—	NC [b]
Vérification de la nappe phréatique (eau potable)	NC [b]	NC [b]	NC [b]	NC [b]
Vérification des produits, du lait et de la viande	NC [b]	NC [b]	—	—
RQS_{SH}—provisoire	NC [b]	NC [b]	NC [b]	NC [b]
Voie limitant la RQS_{SH} —provisoire	ND	ND	ND	ND
Environnement				
RQS_E	200 [c]	200 [c]	***360*** [d]	***360*** [d]
Recommandation relative au contact avec le sol	200	200	***360***	***360***
Recommandation relative à l'ingestion de sol et de nourriture	640	—	—	—
Vérification du cycle des nutriments et de l'énergie	320	320	***320***	***320***
Vérification de migration hors-site	—	—	—	NC [e]
Vérification de la nappe phréatique (vie aquatique)	NC [e]	NC [e]	NC [e]	NC [e]
RQS_E—provisoires	NC [f]	NC [f]	NC [f]	NC [f]
Voie limitant la RQS_E—provisoire	ND	ND	ND	ND
Critère provisoire pour la qualité des sols (CCME 1991)	600	500	1500	1500

Notes:

RQS_{SH} = recommandation pour la qualité des sols: santé humaine; RQS_E = recommandation pour la qualité des sols: environnement; NC = non calculée; ND = non déterminée; — Les tirets indiquent des recommandations/valeurs de vérification qui ne font pas partie du scénario d'exposition pour cette utilisation du terrain et qui, par conséquent, ne sont pas calculées.

[a] Les données ne sont suffisantes et adéquates que pour calculer des RQS_E seulement. La RQS_E est inférieure au critère provisoire pour la qualité des sols existant (CCME 1991) pour cette utilisation du terrain. Par conséquent la Recommandation pour la qualité des sols proposée par le CCME en 1997 représente une révision du critère provisoire pour la qualité des sols (CCME 1991) pour cette utilisation du terrain.

[b] Présentement, il n'y a pas de recommandations ni de vérifications pour la protection de la santé humaine, ni de RQS_{SH} provisoire.

[c] La RQS_E pour cette utilisation du terrain est fondée sur la recommandation relative au contact avec le sol.

[d] Pour cette utilisation du terrain, la RQS_E est la moyenne géométrique ***entre la plus faible concentration produisant un effet (PFCE) et la*** vérification du cycle des nutriments et de l'énergie pour la protection de l'environnement.

[e] La vérification de la nappe phréatique pour la protection de la vie aquatique ne s'applique qu'aux composés organiques et ne sont pas calculées pour les métaux. Les préoccupations soulevées par les métaux devraient être traitées site par site.

[f] Les données sont suffisantes et adéquates pour calculer une RQS_E pour cette utilisation du terrain. Donc aucune RQS_E—provisoire n'est calculée.

Fin des corrections

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ABSTRACT

Canadian environmental quality guidelines, developed under the auspices of the Canadian Council of Ministers of the Environment (CCME), are numerical concentrations or narrative statements recommended to support and maintain designated resource uses. CCME Canadian soil quality guidelines can be used as the basis for consistent assessment and remediation of contaminants at sites in Canada.

This report was prepared by the Guidelines Division of the Science Policy and Environmental Quality Branch (Environment Canada), which acts as Technical Secretariat for the CCME Soil Quality Guidelines Task Group. The Guidelines were derived according to the procedures described in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996).

Following the introduction, chapter 2 presents chemical and physical properties of zinc and a review of the sources and emissions in Canada. Chapter 3 discusses zinc's distribution and behavior in the environment while chapter 4 reports the toxicological effects of zinc on microbial processes, plants, and animals. These informations are used in chapter 5 to derive soil quality guidelines for zinc to protect environmental receptors in four types of land uses: agricultural, residential/parkland, commercial, and industrial.

The following soil quality guidelines are recommended by the CCME based on the available scientific data. For zinc, the environmental soil quality guideline (SQG_E) relative to agricultural and residential/parkland land uses is 200 $mg \cdot kg^{-1}$ soil, and it is 360 $mg \cdot kg^{-1}$ soil for commercial and industrial land uses. These environmental soil quality guidelines are optimized for soils within the pH range of 4 to 8.3 as the toxicological studies on which they are based were conducted within this pH range.

RÉSUMÉ

Les recommandations canadiennes pour la qualité de l'environnement, élaborées sous les auspices du Conseil Canadien des Ministres de l'Environnement (CCME), sont des concentrations ou des énoncés décrivant les limites recommandées dans le but d'assurer le maintien et le développement durable d'utilisations désignées des ressources. Les recommandations canadiennes pour la qualité des sols proposées par le CCME peuvent être utilisées comme base pour l'uniformisation des processus d'évaluation et d'assainissement des terrains contaminés au Canada.

Le présent document a été préparé par la Division des Recommandations de la Direction de la Qualité de l'Environnement et de la Politique Scientifique (Environnement Canada), qui agit comme secrétaire technique pour le Groupe de Travail du CCME sur les Recommandation pour la Qualité des Sols. Les Recommandations ont été élaborées selon les procédures décrites dans le *Protocole d'élaboration de recommandations pour la qualité des sols en fonction de l'environnement et de la santé humaine* (CCME 1996).

Faisant suite à une brève introduction, le chapitre 2 présente les propriétés physiques et chimiques du zinc de même qu'un survol des sources et des émissions au Canada. Le chapitre 3 discute du devenir et du comportement de cette substance dans l'environnement alors que le chapitre 4 rapporte ses effets toxicologique sur les processus microbiens, les plantes et les animaux. Ces informations sont utilisées au chapitre 5 afin d'élaborer des recommandations pour la qualité des sols relatives au zinc en vue de la protection de l'environnement dans le cadre de quatre types d'utilisations de terrains: agricole, résidentiel/parc, commercial et industriel.

Les recommandation pour la qualité des sols suivantes, proposées par le CCME, sont fondées sur les données scientifiques disponibles. Pour le zinc, la recommandation pour la qualité des sols en vue de la protection de l'environnement (RQS_E) relative aux terrains à vocation agricole et résidentielle/parc est de 200 $mg \cdot kg^{-1}$ de sol et elle est de 360 $mg \cdot kg^{-1}$ de sol pour les terrains à vocation commerciale et industrielle. Ces recommandations pour la qualité des sols en vue de la protection de l'environnement sont à leur optimum dans des sols avec pH entre 4 et 8.3 puisque les études toxicologiques utilisées pour leur élaboration ont été effectuées dans ces mêmes conditions de pH.

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CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites

1. INTRODUCTION

The Canadian Council of Ministers of the Environment's (CCME) Canadian Environmental Quality Guidelines are numerical limits for contaminants intended to maintain, improve, or protect environmental quality and human health. CCME Canadian Environmental Quality Guidelines can be used as the basis for consistent assessment and remediation of contaminants at sites in Canada along with the CCME guidelines issued for the protection of water quality, sediment quality and tissue quality. In response to the urgent need to begin remediation of high priority "orphan" contaminated sites, an interim set of criteria was adopted from values currently in use in various jurisdictions across Canada (CCME 1991). Many of the CCME interim soil remediation criteria do not have a complete supporting scientific rationale and are being updated based on current scientific information.

This report reviews the sources and emissions of zinc, its distribution and behaviour in the environment and its toxicological effects on plants, microbial processes and animals. This information is used to derive guidelines for zinc to protect ecological receptors according to the processes outlined in CCME 1996 for agricultural, residential/parkland, commercial and industrial land uses.

The values derived herein are environmental soil quality guidelines and are intended as general guidance. Site specific conditions should be considered in the application of these values. The values may be applied differently in various jurisdictions, therefore the reader should consult the appropriate jurisdiction for application of the values.

2. BACKGROUND INFORMATION

2.1 Physical and Chemical Properties

Zinc, Zn, is a transition metal (group IIb); it has an atomic number of 30 in the Periodic Table of Elements and atomic weight of 65.38. Zinc is a lustrous, bluish-white, relatively soft metal. In its pure state, zinc has a relatively low melting point of 419°C and a boiling point of 907°C (Weast 1986). Zinc has five stable isotopes (Zn^{64}, Zn^{66}, Zn^{67}, Zn^{68} and Zn^{70}) and six radioactive isotopes (Zn^{62}, Zn^{63}, Zn^{65}, Zn^{69}, Zn^{72} and Zn^{73}) (CMBEEP 1979). The physical and chemical properties of zinc and its principal compounds are listed in Table 1. Zinc is divalent in all its compounds and tends strongly to react with organic and inorganic compounds (Elinder 1986). Zinc forms stable combination with many organic substances including humic and fulvic acids and a wide range of biochemical compounds. Metallic zinc is insoluble while the solubilities of different zinc compounds range from insoluble (oxides, carbonates, phosphates, silicates) to extremely insoluble (sulphates and chlorides) (CMBEEP 1979).

Zinc constitutes 0.004% of the earth's crust and is the 25th most abundant element. It is also an essential trace element for living organisms since it is a constituent of over 200 metalloenzymes and other metabolic compounds (Vallee 1959). The earth's crust contains about 70 $mg{\cdot}kg^{-1}$ of this metal, while soils have an average content of about 50 $mg{\cdot}kg^{-1}$ (CMBEEP 1979).

2.2 Analytical Methods

Inductively Coupled Plasma-Atomic Emission Spectroscopy (U.S. EPA Method 6010) is the recommended analytical method for the measurement of zinc in soils by the CCME (1993). The detection limit and precision of this method are 2 $\mu g{\cdot}L^{-1}$ and 45%, respectively. There are two analytical methods for the measurement of zinc in water, wastewater, and soil extracts. These methods include: *Direct Air-Acetylene Flame Method* (U.S. EPA Method 3111B) and *Inductively Coupled Plasma Method* (U.S. EPA Method 3120B). The detection limits in the liquid digest are respectively, 5 $\mu g{\cdot}L^{-1}$ and 2 $\mu g{\cdot}L^{-1}$. Following corrections for a 1 g sample digested in 100 ml of acid, detection limits of 0.5 and 0.2 $mg{\cdot}kg^{-1}$ respectively can be calculated in the solid phase. For further details please refer to the CCME (1993) publication.

2.3 Production Uses and Global Sources

Global Production, Canadian Exports and Imports

Western world mine production of zinc was 5.58 million tonnes in 1992, marginally higher than the 1991 level (EMRC 1992). Canada is the western world's largest producer of zinc concentrate, producing 1.32 million tonnes in 1992 representing 24% of the supply and an increase of 176,000 tonnes relative to 1991. Canadian refined zinc metal production increased by 1% in 1992 over the previous year for a total of 670,000 tonnes. The western world refined zinc metal production totalled 5.35 million tonnes in 1992, a slight decrease from the 1991 level. Canada's zinc production is expected to continue to increase due to increasing demand for zinc galvanized steel. Canadian zinc mining is expected to decrease in the mid-1990's due to mine closures in the Northwest Territories and Ontario. This loss in zinc mining will be partially offset by new mines opening in Quebec and British Columbia (EMRC 1992).

Canada exported a total of 1.17 million tonnes of zinc in 1991. Approximately 80% of these exports consisted of zinc ores and concentrates. The majority of these materials are exported to the U.S. and then Germany, Belgium, Spain and Taiwan. The remaining zinc exported is in the form of zinc metal, zinc scrap, zinc oxide, zinc alloys and miscellaneous zinc products. During that year Canada also imported 195,844 tonnes of zinc, most of which consisted of zinc ores and concentrates (90%). Other zinc imports were zinc in lead ores, zinc peroxide, zinc sulphate, zinc alloys, zinc bars and wire, pipes and fittings (EMRC 1992).

Zinc obtained from secondary sources is increasing in importance. In 1991, western countries recovered 1.83 million tonnes of zinc from secondary sources. Canada has the capacity to recover 13,000 tonnes of secondary zinc annually (EMRC 1992).

Uses

The western world consumption of zinc decreased slightly in 1992 to 5.36 million tonnes, a reduction of 1% from a record consumption level in 1991 (EMRC 1992). Canadian zinc consumption in 1991 was estimated at 98,505 tonnes of primary zinc and 3,715 tonnes of secondary zinc for a total of 102,220 tonnes. Approximately 73% of this use consisted of galvanized products with the balance consisting of zinc die cast alloys (22%), copper alloys (2%) and other products including rolled and ribbon zinc, and zinc oxide (EMRC 1992).

Worldwide, 48% of total zinc use in 1991 produced galvanized materials (EMRC 1992). The use of zinc in galvanizing is the fastest growing usage of zinc and is expected to continue due to increasing demand for galvanized products for automobiles and for structural components in the construction industry. The second most important use of zinc is in the manufacture of brass and bronze (1.08 million tonnes or 19% in 1991) for plumbing components and heating and cooling system components (EMRC 1992). The demand for these materials is highly dependent upon an active construction industry. Approximately 14% of the 1991 zinc use was in the die casting industry for builder's hardwares and automobile fittings (EMRC 1992). The balance of zinc use was for the manufacture of zinc semi-manufactures, oxides, chemicals, and zinc dust. Zinc oxide is important in the manufacture of tires and other rubber products (EMRC 1992).

Zinc consumption is predicted to increase 2.5% per year through the end of the 1990's, mainly due to increased demand for corrosion resistant galvanized steel. Rolled zinc is a popular roofing material in Europe which Canadian zinc producers are beginning to promote. In addition, there has been increased research for zinc in batteries with a Zn-air battery recently developed for personal computers which lasts 3 times longer than Ni-Cd batteries and is easily recyclable. Zinc powder is used in the production of mercury-free batteries (EMRC 1992).

2.4 Levels in the Canadian Environment

Distribution of Zinc in the Canadian Environment

Evaluation of the levels of both background and anthropogenic zinc in air, soil, water, sediment, and biota provides a means of determining the routes and magnitudes of exposures to environmental receptors. These data, in conjunction with detailed toxicological information, can be used to assess the hazards associated with exposure to zinc for terrestrial and aquatic organisms in the Canadian environment.

Sources of anthropogenic zinc in the environment include electroplaters, smelting and ore processors, mine drainage, domestic and industrial sewage, combustion of solid wastes and fossil fuels, road surface runoff, corrosion of zinc alloy and galvanized surfaces, and erosion of agricultural soils (CCREM 1992; Eisler 1993; Nriagu and Pacyna 1988; Taylor and Demayo 1980). For Canada, Taylor and Demayo (1980) identified natural weathering of materials as the single largest source of zinc released to the environment at 725,000 tonnes annually. In addition, significant anthropogenic zinc emission sources for the Canadian environment include: primary zinc production at 99,000 $t \cdot year^{-1}$; wood combustion, 75,000 $t \cdot yr^{-1}$; waste incineration, 37,000 $t \cdot yr^{-1}$; iron and steel production, 35,000 $t \cdot yr^{-1}$; other atmospheric emissions, 68,000 $t \cdot yr^{-1}$; and municipal wastewater, 100,000 $t \cdot yr^{-1}$. Soil erosion is a natural source of zinc, contributing 25,000 tonnes annually while other natural sources comprise 18,500 tonnes of the annual contribution of natural zinc. A total of 1.18 million tonnes of zinc are released to the Canadian environment each year, with 65% (768,500 tonnes) originating from natural sources and the balance of 414,000 tonnes contributed by anthropogenic sources (Taylor and Demayo 1980).

Soil

Background levels for zinc in Canadian soils have been reported by various researchers. Table 2 presents a summary of zinc concentrations in soils from various locations in Canada. McKeague and Wolynetz (1980) reported a mean of 74 mg $Zn \cdot kg^{-1}$ for the A, B and C horizons of Canadian soils. These levels are similar to those reported for the U.S., 50 mg $Zn \cdot kg^{-1}$ and for world soils, 60 mg $Zn \cdot kg^{-1}$ (Davies and Jones 1988; Holmgren et al. 1993). McKeague and Wolynetz (1980) reported variable soil concentrations across Canada measuring soil zinc content on the Canadian shield at 54 mg $Zn \cdot kg^{-1}$ and in the Interior Plains at 64 mg $Zn \cdot kg^{-1}$. In the Cordilleran region, soil zinc was measured at 73 mg $Zn \cdot kg^{-1}$ while the highest zinc concentrations occur at 80 mg $Zn \cdot kg^{-1}$ in the St. Lawrence Lowlands and in the Appalachians at 81 mg $Zn \cdot kg^{-1}$. These researchers concluded from their evaluation that the amount of total zinc in Canadian agricultural soils is dependent upon the content of zinc within soil parent material and anthropogenic input to the soil.

Zinc in the surface horizons of northwest Alberta agricultural soils at the Beaverlodge Research Station was measured at 55 mg $Zn \cdot kg^{-1}$ (Soon, 1994). In another study, Soon and Abboud (1990) reported zinc levels in agricultural soils of northwest Alberta with a surface soil (0-20 cm) concentration of 94 mg $Zn \cdot kg^{-1}$ and a subsurface soil (20-35 cm) concentration of 81 mg $Zn \cdot kg^{-1}$. Dudas and Pawluk (1980) sampled the A, B and C horizons of Chernozemic and Luvisolic soils supporting native vegetation in southeast and central Alberta. The soils chosen were located 30 km from urban settlement, remote from ore bodies and ranged in concentration from 29 to 235 mg $Zn \cdot kg^{-1}$ soil. All Ah horizons were enriched with zinc in comparison to the levels determined in respective C horizons (Dudas and Pawluk 1980). The researchers also noted elevated zinc levels in the LFH layer of Luvisolic soils. Evaluation of zinc distribution with grain size indicated that the clay fraction contained the majority of zinc followed by the silt and the sand fractions. Zinc concentration in the C horizon of soils studied by Dudas and Pawluk (1980) were similar to the zinc content of shale, granite and limestone rocks which comprise Alberta's glacial till.

Whitby et al.(1978) sampled 26 agricultural soils from six watersheds in Southwestern Ontario for total zinc content. Average zinc concentrations were 88, 87 and 71 $mg \cdot kg^{-1}$ for the A_p, B and C horizons respectively. Zinc content ranged from 40 - 163 $mg \cdot kg^{-1}$ for the A_p horizon. Webber and Shamess (1987) studied zinc content in the plough layer (15 cm) of cultivated soils from Halton Region. Mean zinc concentration for the samples analyzed was 126 $mg \cdot kg^{-1}$. Two soil series sampled in this study corresponding to the Dumfries and Guelph, contained 227 and 200 mg $Zn \cdot kg^{-1}$, respectively, which was related to high zinc mineral content within the soil parent material according to the authors (Webber and Shamess 1987). Frank et al. (1976) sampled soils collected from all agricultural areas of Ontario and reported zinc content in the plough layer soil under field crops averaging 56.7 $mg \cdot kg^{-1}$. Organic soils contained the highest average concentration of 66.3 mg $Zn \cdot kg^{-1}$ while sandy soils contained the lowest average concentration of 39.9 mg $Zn \cdot kg^{-1}$.

Surface soil samples (0-5 cm) from old urban and rural parklands not impacted by local point sources of pollution throught Ontario were analyzed by the Ontario Ministry of the Environment and Energy for a wide variety of chemicals to determine average background concentrations known as "Ontario Typical Range" (OTR_{98}) (OMEE 1994a). The OTR_{98} concentrations in rural parkland (n=101 sites) and old urban parkland soils (n=60 sites) were 120 and 140 $\mu g \cdot g^{-1}$, respectively. The OTR_{98} corresponds to the 97.5 percentile of the distribution. Samples were digested by HNO_3/HCl and analyzed by inductively coupled plasma emission spectroscopy and flame atomic absorption spectrometry.

Water

Background zinc levels in water are generally less than 40 $\mu g \cdot L^{-1}$ (Eisler 1993). CCREM (1992) also reported that ambient aquatic levels of dissolved zinc in Canada are usually lower than 40 $\mu g \cdot L^{-1}$ with a range of 1 to 100 $\mu g \cdot L^{-1}$ in surface waters. In Canadian surface waters, levels of dissolved zinc monitored by region from 1980 to 1985 ranged as follows: Pacific (1 to 30 $\mu g \cdot L^{-1}$); Western (1 to 290 $\mu g \cdot L^{-1}$); Central (1 to 1170 $\mu g \cdot L^{-1}$); and Atlantic (0.1 to 190 $\mu g \cdot L^{-1}$).

Sediments

In sediments, zinc background levels are usually lower than 200 $mg \cdot kg^{-1}$ (Eisler 1993). In Canada, NRCC (1979) documented baseline sediment concentrations of approximately 90 μg $Zn \cdot kg^{-1}$ with high concentrations associated with sediments close to point sources and occasionally in natural deposition zones. Sediment levels greater than 300 μg $Zn \cdot kg^{-1}$, attributed to sewage/industrial effluents, occurred in the Rideau, Ottawa and St. Lawrence Rivers in eastern Ontario and western Quebec. Industrial outfalls in Quebec at Valleyfield, Candiac and Quebec City resulted in nearby sediment levels of 3000 μg $Zn \cdot kg^{-1}$ (NRCC 1979). Mining activities have also been identified as the source of higher sediment zinc levels in the Nepisiquit River estuary of New Brunswick (447 $\mu g \cdot kg^{-1}$) and in Howe Sound, British Columbia (200 to 357 $\mu g \cdot kg^{-1}$). The highest zinc concentrations in the sediments of Howe Sound occur within 3 kilometres of a mining site. However, high zinc levels were found up to 15 kilometres from the mine with the potential source suggested as being the mine or natural ore deposits (NRCC 1979).

Air

Little information was found on the levels of zinc in the Canadian atmosphere. However, available data exhibited low zinc concentrations in air. Eisler (1993) reports that the background level of zinc in air seldom exceeds 0.5 $\mu g \cdot m^{-3}$. Chan et al. (1986) reported mean air zinc concentrations for Ontario in 1982 as 0.019 (southern), 0.013 (central) and 0.007 (northern) $\mu g \cdot m^{-3}$. In Canada, the main sources of atmospheric zinc are anthropogenic, including primary zinc production, wood combustion, waste incineration, iron and steel production, other atmospheric emissions and soil erosion (Taylor and Demayo 1980).

2.5 Existing Criteria and Guidelines

Existing guidelines, criteria, or standards for zinc in soil from provincial, national, and international agencies are summarized in Table 3.

3. ENVIRONMENTAL FATE AND BEHAVIOUR

3.1 Soil

The fate of zinc in soil is somewhat simplified since it occurs in the soil solution under the single valence state Zn^{+2}. Zinc is highly reactive in soils, so that in addition to inorganic Zn^{+2}, zinc is present as part of both soluble and insoluble organic compounds. Zinc can also be adsorbed to clay minerals or metallic oxides and may be present within primary minerals of the soil parent material (Sachdev et al. 1992). Several researchers have presented estimates of zinc in soil solution relative to total zinc concentration in soil. In a review on zinc behaviour, Lindsay (1972) estimated that 2 to 10% of total soil zinc is present in the soil solution. In a review by Kiekens (1990), zinc concentrations in the soil solution were estimated in the range of 3×10^{-8} to 3×10^{-6} M. In addition to Zn^{+2}, zinc is present in soil solution as part of soluble organic compounds. In general, total zinc was found to be evenly distributed throughout soil profiles. However, EDTA-extractable zinc was reported to decrease with depth in the profile (Lindsay 1972).

The concentration of zinc in soil solution is dependant upon the amount of zinc present in the soil, solubility of the particular zinc compound and the extent of adsorption. Zinc compounds vary significantly in solubility; zinc sulphate is readily soluble in soil solution while zinc oxide is relatively insoluble. Soil properties including texture and organic matter content influence the behaviour of zinc in soil. Zinc may be adsorbed to clay minerals and may also form stable compounds with soil organic matter, hydroxides, oxides and carbonates. Soil chemical properties such as pH and cation exchange capacity (CEC) are further aids in predicting the fate of zinc in soils. Soil pH has been identified in many studies as one of the main factors affecting zinc mobility and sorption in soils (Davis-Carter and Shuman 1993; Duquette and Hendershot 1990; Evans 1989; Shuman 1975). Zinc becomes more soluble as pH decreases therefore zinc is more mobile and increasingly available to organisms with low pH, as pH decreases below 5 (Duquette and Hendershot, 1990). At pH <7.7, zinc occurs as Zn^{2+} in soil solution whereas at pH >7.7, the dominant form is $Zn(OH)_2$ (Giordano and Mortvedt 1980). Therefore, leaching of zinc occurs more readily from acid soils.

The amount of bioavailable zinc will be determined by the amount of zinc present which is soluble or may be solubilized. Within a given soil, an equilibrium exists between the different forms of zinc (adsorbed, exchangeable, secondary minerals, insoluble complexes) in the liquid and solid phases of the soil. Plant uptake, losses by leaching, input of zinc in various forms, changes in moisture content of the soil, pH changes, mineralisation of organic matter and changing redox potential of the soil will influence the equilibrium. Due to the complexity of zinc interactions in soil, zinc transport behaviour in soil cannot be predicted accurately (Hinz and Selim 1994) and soil adsorption effects cannot be separated from solution effects such as precipitation.

Sources of large amounts of zinc to soils include sewage sludge applications to agricultural cropland. Mullins and Sommers (1986) determined the changes of zinc levels in soil solution resulting from sludge application. Zinc content in soil solution increased in all four soils studied after the addition of sludge. They reported that 91% of the total soluble zinc was in the Zn^{+2} form.

Studies have been conducted which document the effect of contaminant caused increases in soil zinc on the levels of zinc in plants grown on the contaminated soils. Chang et al. (1983) grew barley on land which had repeatedly received sludge applications resulting in heavy metal accumulation. It was calculated that over 90% of the deposited metals were present in the surface (0-15 cm) soil layer. Zinc contents in barley grown on these soils increased as the rate of sludge application was increased.

Pierzynski and Schwab (1993) conducted a study to evaluate the influence of various soil amendments on the availability of zinc for soybeans grown in a soil contaminated by mining sediments. Additions of limestone resulted in the reduction of bioavailable zinc, increased soybean yields, and decreased tissue zinc concentrations. The addition of cattle manure produced similar effects with lower response. The addition of limestone combined with cattle manure produced significantly higher soybean yields, but did not produce similar reductions in zinc bioavailability as limestone alone. Shuman (1988) studied the effect of organic matter additions on zinc availability in surface soil. Zinc increased in the manganese-oxide fraction and amorphous iron-oxide fractions in relation to the soluble fraction thereby reducing bioavailable zinc.

Some plants can alter soil characteristics in the rhizosphere to facilitate zinc uptake by decreasing soil pH in the rhizosphere and increasing metal solubility (Davis-Carter and Shuman 1993). Soon (1994) reported that some forage and legume crops having roots with a high CEC increase the weathering of soil minerals in the root zone releasing more soil zinc into the soil solution.

3.2 Water

The solubility of zinc in aqueous systems varies with pH and concentrations of zinc complexing ligands (Evans 1989). Bas et al. (1990) studied the zinc levels in groundwater of the Netherlands and found them to be largely independent of surrounding soil conditions. Zinc in groundwater was believed by these authors to originate from atmospheric inputs of nearby smelters and transferred through the water cycle.

In freshwater systems, zinc has an oxidation state of +2 and can be found in several chemical forms including hydrated ions, dissolved chemical species, inorganic and organic complexes (CCREM 1992; Eisler 1993). Insufficient information exists to predict transport and transformation of zinc in natural waters (Spear 1981). However, Zn^{2+} predominates in water and that high organic matter content dominates wich chemical form of zinc is present. Most of the zinc introduced into aquatic environments is eventually deposited in the sediments (Eisler 1993).

Reimer and Duthie (1993) found a negative correlation between sulphate and zinc levels in the sediments of water bodies in the Sudbury and Muskoka regions. They noted that in these areas of high sulphur input, unbuffered lakes become more acidic increasing the solubility of zinc in the aquatic environment.

3.3 Air

Zinc has a fairly high boiling point of 907°C, and therefore is not likely to volatize except under extreme conditions for example during volcanic activity or forest fires (Nriagu 1980). Zinc primarily enters the atmosphere as a particulate via several natural and anthropogenic processes including: wind erosion of soils and industrial materials, the burning of coal, oil, or sewage sludge, refining of zinc and other metals (lead, nickel) (Nriagu and Pacyna 1988; Taylor and Demayo 1980). Studies conducted in the vicinity of smelters have documented the deposition of atmospheric zinc to occur generally within 25 kilometres of the smelters (Hopkin 1986; Ma et al. 1983; Storm et al. 1994). Nriagu, in 1980, studied the levels of atmospheric zinc in relation to various human activities. In rural areas, atmospheric zinc concentrations were 10-100 $ng{\cdot}m^{-3}$ while urban areas exhibited levels of 100-500 $ng{\cdot}m^{-3}$ (Nriagu 1980). The author also reported hotspots in close proximity to smelters or metal mining facilities where zinc levels were greater than 1000 $ng{\cdot}m^{-3}$. Ontario levels of wet (2.2 to 4.2 x 10^{-2} kg $Zn{\cdot}ha^{-1}{\cdot}yr^{-1}$) and dry (0.51 to 1.51 $mg{\cdot}m^{-2}$) deposition of zinc were measured by Chan et al. (1986) in 1982.

4. BEHAVIOUR AND EFFECTS IN BIOTA

The LOEC endpoints reported in the toxicity tables (Tables 4 - 11) represent the lowest observed effects concentration at which there was a statistically and biologically significant difference from the controls, as reported by the author(s). If no such statistical tests were reported by the author(s), the percentage of adverse effect, as compared to the controls, from zinc concentrations within the soil will be calculated by the CCME from the data presented by the author(s). This percentage of adverse effect is represented by an "EC" (effects concentration) endpoint within the toxicity tables. Actual EC_{xx} endpoints reported by the author(s), such as EC_{25} or EC_{50}, will be presented as such without any calculation of a percentage of adverse effect. Measured concentrations and metal extraction methods are reported in the toxicity tables ony if they involve digestion of soil with a strong acid, such as HCl or HNO_3. Otherwise, the nominal concentrations are reported.

4.1 Soil Microbial Processes

Toxicity studies consulted for soil microbial processes are presented in Table 4 while studies selected for use in soil quality guidelines derivation are listed in Table 9. Soil enzyme activities reported here were not included in the selected data since they may not represent measured effects of chemicals on soil microbial populations. This is due to the fact that many enzymes produced by plants and microbes can exist and function extracellularly in soil for varying periods of time, depending on soil micro-environmental factors (Tabatabai 1982).

Carbon mineralization decreased by 21% after 8 weeks of treatments at a concentration of 10 mg $Zn{\cdot}kg^{-1}$ in a sandy soil of pH 4.9 (Cornfield 1977). This author also reported that a concentration of 100 mg $Zn{\cdot}kg^{-1}$ reduced the amount of CO_2 release by 45% relative to the controls. In a similar soil texture but at a higher pH of 6.0, Bhuiya and Cornfield (1972) documented a 16% inhibition of carbon mineralization at 1074 mg $Zn{\cdot}kg^{-1}$.

The effect of a single concentration of soil zinc, added as zinc oxide, on nitrogen mineralization was studied by Bhuiya and Cornfield (1974) at various pH values in a sandy soil. At a concentration of 1074 mg $Zn{\cdot}kg^{-1}$ soil, no effect on nitrogen mineralization was observed at pH 6.0 while 8% and 32% reductions in nitrogen mineralization were recorded at pH 7.0 and 7.7, respectively.

Doelman and Haanstra (1984) measured the effects of relatively high zinc concentrations upon soil respiration in various soil textures and pHs. In a sandy soil with a pH 7.0, a 44% inhibition of respiration was observed at 1000 mg $Zn{\cdot}kg^{-1}$. In a silt loam soil of pH 7.7 and higher clay (19% vs 2%) content, soil respiration was inhibited by 38% at a concentration of 8000 mg $Zn{\cdot}kg^{-1}$. Lower inhibition rates of soil respiration (26%) were also documented by these authors in clay (pH 7.5) and sandy peat at 3000 mg $Zn{\cdot}kg^{-1}$.

Many studies on nitrification monitored an inhibition over time in various soil types with added zinc. In a single concentration study, Bhuiya and Cornfield (1974) measured a 13% inhibition of nitrification in sand at a concentration of 1074 mg $Zn{\cdot}kg^{-1}$ at pH 7.0, a 33% decrease at pH 7.7 and no effect at pH 6.0. The level of nitrification decreased with time, suggesting an adaptation of the microbial population to zinc concentrations in soil. Liang and Tabatabai (1977) monitored zinc effects on nitrification in soils ranging in texture from loam to silty clay and in pH from 5.8 to 7.8, and reported similar inhibition levels (12-15%) after 20 days at 327 mg $Zn{\cdot}kg^{-1}$. The inhibitive effects of zinc on nitrification after 10 days in various soils ranged from 39 to 72% at 327 mg $Zn{\cdot}kg^{-1}$ (Liang and Tabatabai 1978). Wilson (1977) obtained a greater inhibitive response on nitrification process with various soil types. A 70% inhibition occurred in a sandy loam soil, pH 6.2, after 3 weeks of treatment with 100 mg $Zn{\cdot}kg^{-1}$. The same zinc concentration in a loamy sand of pH 7.4 resulted in 27% inhibition of nitrification. Wilson (1977) also observed complete inhibition of nitrification in sandy loam, loamy sand and clay loam soils after 7 weeks of treatment with 1000 mg $Zn{\cdot}kg^{-1}$ soil.

Bollag and Barabasz (1979) studied the effects of various zinc nitrate concentrations on the process of denitrification. In a 21 day exposure period, a 40% reduction in denitrification was observed at 250 mg $Zn{\cdot}kg^{-1}$ soil in a silt loam soil of pH 6.75. Under similar test conditions, a 65% reduction in denitrification was documented at 500 mg $Zn{\cdot}kg^{-1}$ soil.

Chaudri et al. (1992) monitored the long term effects of zinc on nitrogen fixation by *Rhizobium leguminosurum* over time. In a sandy loam soil, pH 6.5, nitrogen fixation was not affected after 2 months at 455 mg $Zn{\cdot}kg^{-1}$ soil. However, 18 months of treatment at 385 mg $Zn{\cdot}kg^{-1}$ soil resulted in complete inhibition of nitrogen fixation.

Elevated zinc concentrations in soil were also found to inhibit enzyme activity. Doelman and Haanstra (1986) monitored urease activity in soils at varying zinc levels during 6 week and 18 month periods. For the sand, sandy loam and clay soils tested, the EC_{50} decreased with time, ranging from 420 to 1780 mg $Zn{\cdot}kg^{-1}$ after 6 weeks and ranging from 90 to 290 mg $Zn{\cdot}kg^{-1}$ after 18 months. These authors also determined LOEC values for urease activity (10% reduction) ranging from 30 to 460 mg $Zn{\cdot}kg^{-1}$ at 6 weeks and from 1 to 160 mg $Zn{\cdot}kg^{-1}$ at 18 months. In another study, phosphatase activity was inhibited by 28 to 59% in loam to clay loam soils treated with 1643 mg $Zn{\cdot}kg^{-1}$ (Juma and Tabatabai 1977). Ohya et al. (1985) investigated glucose mineralization in a sandy clay loam soil at 1000 mg $Zn{\cdot}kg^{-1}$ and reported a 44% inhibition of activity after 24 hours and an 11% decrease after 96 hours. These authors also observed an increase in bacterial population in the zinc amended soil after 48 hours and suggest that the population increased by selection for zinc tolerance.

4.2 Terrestrial Plants

Metabolic Fate and Behaviour

Zinc is an essential element for normal plant growth (Brennan 1992; Giordano and Mortvedt 1980; Nable and Webb 1993; Soper et al. 1989; Wallace and Berry 1989) and is commonly deficient during growth of agricultural crops (Elinder 1986). Terrestrial plants predominantly absorb zinc as Zn^{+2} from the soil solution but hydrated zinc and several other complexes and organic chelates may be absorbed (Kiekens 1990). Most soils contain sufficient total zinc levels for plant growth but plant uptake is dependent upon the availability, solubility and movement of zinc to plant roots (Eisler 1993; Giordano and Mortvedt 1980; Soon and Abboud 1990). The amount of zinc in soil must satisfy plant growth requirements while not exceeding concentrations which cause phytotoxicity to plants and subsequent potential to contaminate other organisms along the food chain.

Zinc availability to terrestrial plants is a function of soil physico-chemical properties and plant biological characteristics (OMEE 1994; Tyler et al. 1989). The uptake rate of zinc by plants generally increases with increasing zinc concentration in soil (Chang et al. 1983; Nwankwo and Elinder 1979; Petruzelli et al. 1989; Schuhmacher et al. 1993; Smith 1994). Uptake and distribution of zinc in higher plants is influenced by the form of zinc (Davis-Carter and Schuman 1993; Mortvedt and Giordano 1975; Speaker 1991; Wallace 1963), other metal ions present in the system (Fontes and Cox 1993; Sarkunan et al. 1989; Wallace 1989; Wallace and Berry, 1989), soil phosphorus level (Grant and Bailey 1989; Hamilton et al. 1993, Singh 1992; Smilde et al, 1974), cation exchange capacity, soil texture (Chang et al. 1983; Singh 1992), soil properties such as pH (Davies 1992; Schuhmacher et al. 1994; Smith 1994; van der Watt et al. 1994; Xian and Skohohifard 1989), and organic matter content (Hamilton et al. 1993; Pierzynski and Schwab 1993; Singh 1992). Plant species (Chino and Chino 1991; Chukwuma 1993; Sieghardt 1990; Soon 1994; Tyler et al. 1989; Vedagiri and Ehrenfeld 1991; Viets et al. 1954), intraspecies variations (Nriagu 1980; Yang 1994), the developmental stage of the plant (McKenna et al. 1993; Sanka and Dolezal 1992), presence of mycorrhizae (Faber et al. 1990) and growth conditions (Markert and Weckert 1989) such as temperature, light and nutrient availability are all contributing factors to the interaction between zinc and plants.

Toxicity

A summary of available zinc toxicity studies for plants are presented in Table 5. Table 10 summarizes the selected toxicity data used for the derivation of the soil quality guideline.

Data for the acute toxicity (exposure period less than 14 days) of zinc to terrestrial plants are available for the effect on seedling emergence of lettuce (*Lactuca sativa*) and radish (*Raphanus sativa*)(Environment Canada 1996). For radish planted in an artificial soil, ranging in pH from 4.0 to 4.2 and in organic matter content from 4.7 to 6.3%, a 50% reduction in seedling emergence was observed at concentrations ranging from 280 to 670 mg $Zn \cdot kg^{-1}$ soil. The NOEC ranged from 100 to 230 mg $Zn \cdot kg^{-1}$ soil under similar test conditions. A 50% reduction in seedling emergence of lettuce was documented at concentrations ranging from 400 to 720 mg $Zn \cdot kg^{-1}$ soil while the NOEC ranged from 200 to 250 mg $Zn \cdot kg^{-1}$ soil in artificial soils of pH 4.0 to 4.2 and organic matter contents of 4.7 to 10.4%.

Chronic toxicity data (exposure period greater than 14 days) of zinc effects are available for 14 species of terrestrial plants, including 9 crop species and 4 tree species grown in Canada. An 18% yield reduction, measured as total dry matter weight, in onion grown for 8 weeks occurred at 400 mg $Zn \cdot kg^{-1}$ in a clay loam soil, pH 8.3 (Dang et al. 1990). Smilde et al. (1992) measured a 53% reduction in the yield of endive grown to maturity in a sandy soil (pH 4.2) at 60 mg $Zn \cdot kg^{-1}$ soil and a 91% yield reduction at 80 mg $Zn \cdot kg^{-1}$. In the same study spinach exhibited lower sensitivity to zinc than endive with a 27% yield reduction at 80 mg $Zn \cdot kg^{-1}$. No effect on spinach yield was observed on spinach grown to maturity in a loam soil (pH 7.2) at 160 mg $Zn \cdot kg^{-1}$.

Sheppard et al. (1993) measured various responses of lettuce (*Lactuca sativa*) and turnip (*Brassica rapa*) in several soil types with differing zinc concentrations. In a sandy soil with pH 6.3, 50% reductions in first bloom and seed yield were observed for turnip at 25 mg $Zn \cdot kg^{-1}$ and a 50% reduction in seedling emergence occurred at 65 mg $Zn \cdot kg^{-1}$. Lettuce grown in an identical sandy soil was less sensitive to zinc with a 50% reduction in seedling emergence at 207 mg $Zn \cdot kg^{-1}$. When grown in a clay garden soil of pH 7.3, no effect on seedling emergence of lettuce or turnip was observed at 1000 mg $Zn \cdot kg^{-1}$, the highest concentration used, while 50% reductions in first bloom and seed yield were noted in turnip at 600 and 715 mg $Zn \cdot kg^{-1}$ soil, respectively. In a silty clay soil (pH 7.9), no response was observed on seedling emergence of lettuce at 1000 mg $Zn \cdot kg^{-1}$, the maximum applied concentration, while turnip exhibited 50% reductions in emergence, first bloom and seed yield at 600 mg $Zn \cdot kg^{-1}$.

MacLean (1974) studied the effects of zinc sulphate on plant yield in sandy soils. Corn (*Zea mays*) grown over six weeks in a fine sandy loam (pH 4.9) demonstrated a 13% yield reduction at 303 mg $Zn \cdot kg^{-1}$ soil while no effect on yield was reported for sandy loam soils, pH 7.2 to 7.5, with 329 mg $Zn \cdot kg^{-1}$ soil. MacLean (1974) documented 100% mortality of lettuce (*Lactuca sativa*) tested at 303 mg $Zn \cdot kg^{-1}$ soil over 5 weeks in a fine sandy loam soil (pH 4.9). Alfalfa grown in this soil over 16 weeks exhibited a 71% reduction in yield at 303 mg $Zn \cdot kg^{-1}$ soil. As with corn, no effect on the dry matter yield of lettuce or alfalfa was observed at 329 mg $Zn \cdot kg^{-1}$ soil for the sandy loam soils, pH 7.2 and 7.5, .

Jones (1982) and Jones et al. (1987) studied the yields of agricultural crops grown in well drained drumlin soils of pH 7.1, sampled within one meter of hydroelectrical transmission towers in Ontario. Levels up to 1425 mg $Zn \cdot kg^{-1}$ soil were measured and would originate from corrosion of the galvanized towers. However, no effects were noted on the yields of lettuce or radish grown in this soil for 45 days (Jones 1982) or on corn yield grown to maturity (Jones et al. 1987). Mortvedt and Giordano (1975) also documented the effect of zinc sulphate on corn yield. In a sandy loam soil of pH 5.5, a 50% reduction in corn (*Zea mays*) yield was observed at 240 mg $Zn \cdot kg^{-1}$ soil. This study also reported 100% mortality at a concentration of 1400 mg $Zn \cdot kg^{-1}$ soil.

Blackgram (*Vigna mungo*) grown for 65 days in soils of pH 6.2 exhibited a 22% yield reduction at 200 mg $Zn \cdot kg^{-1}$ soil and a 45% yield reduction at 250 mg $Zn \cdot kg^{-1}$ (Kalyanaraman and Sivagurunathan 1994). Another study documented yield reductions of wheat and rice occurring at much higher zinc concentrations (Muramoto et al. 1990). Wheat grown for 23 weeks in an alluvial soil exhibited a 64% yield reduction at 1,000 mg $Zn \cdot kg^{-1}$, an 82% yield reduction at 10,000 mg $Zn \cdot kg^{-1}$ and no grain yield at 30,000 mg $Zn \cdot kg^{-1}$. For rice grown in this alluvial soil, a 25% yield reduction occurred at 50,000 mg $Zn \cdot kg^{-1}$ (Muramoto et al. 1990).

The effects of zinc on trees grown in sandy soils were documented in several studies. Jack pine (*Pinus banksiana*) grown in a sandy loam soil of pH 6.0 demonstrated 25% reduced root yields at 25 mg $Zn \cdot kg^{-1}$ and 6% decreased shoot yields at 50 mg $Zn \cdot kg^{-1}$ over a 12 week treatment (Dixon and Buschena 1988). These authors reported white spruce root and shoot yield decreases of 13% and 28%, respectively, at 50 mg $Zn \cdot kg^{-1}$ soil. Hagemeyer et al. (1993) grew beech (*Fagus grandifolia*) saplings for 2 years in a soil mixture of sand, peat and forest soil of pH 4.8 with various zinc levels. At 65 mg $Zn \cdot kg^{-1}$ soil, the thickness of tree growth rings demonstrated a 50% growth reduction and shoot growth was reduced by 39%. Mortality of all beech trees occurred at 490 mg $Zn \cdot kg^{-1}$ soil after the first year. Hogan and Wotton (1984) grew black spruce (*Picea mariana*) and jack pine in sandy loam to loamy sand soils of pH 4.9. No effects on the concentration of other foliar nutrients were noted at 1200 mg $Zn \cdot kg^{-1}$.

4.3 Terrestrial Invertebrates

Metabolic Fate and Behaviour

Earthworms are important organisms in the soil macrofauna since their activities mix the soil improving aeration, water permeability and mineral turnover in the soil. Earthworms may be an important component of terrestrial food chains providing a food source for many small mammals and birds (Honda et al. 1984). Earthworms accumulate zinc and are therefore useful bioindicators of soil zinc contamination (Ma 1982; Ma et al. 1983). There is some evidence in the literature about earthworm abilities to regulate the concentration of zinc in their tissues. Studies by Ireland (1979) and by Morgan and Morgan (1988) report a physiological regulation of zinc concentration in the tissues of earthworms.

Soil characteristics play a significant role in the uptake of zinc by worms. Ma (1982) found that the level of zinc in the earthworm *Lumbricus rubellus* was generally related to zinc concentration in the soil and highly correlated with zinc concentrations in low pH soils. At lower pH, the soil adsorbs less zinc thereby increased concentrations in the soil solution occur, rendering zinc more bioavailable to earthworms. Ma et al. (1983) reported a negative correlation between CEC and zinc concentration in earthworms, the concentration in the worms increasing as CEC decreased. This effect was also attributed to an increase in bioavailable zinc as CEC decreased. Organic matter content in the soil did not affect zinc uptake by earthworms (Ma 1982).

In a study on woodlice (*Porcellio scaber)*, zinc was found to accumulate within the body tissues without any positive correlation with zinc levels in the leaf litter and soil (Hopkin 1986). Mortality of woodlice occurred at a zinc concentration of 1430 mg $Zn \cdot kg^{-1}$ in leaf litter (Hopkin 1986). A long term study conducted by Hopkin and Hames (1994) over 360 days for woodlice found mortality of all individuals at a concentration of 1090 mg $Zn \cdot kg^{-1}$ maple leaf litter. A predator of woodlice, the spider, *Dysdera crocata*, was found by Hopkin and Martin (1985) to accumulate large amounts of zinc in its body with no ill effects.

Toxicity

The available data for the effects of zinc on invertebrates are summarized in Table 6. Table 10 summarizes selected toxicity data on plants and invertebrates used for the derivation of the soil quality guideline.

Malecki et al. (1982) looked at the toxic effects of different chemical forms of zinc (acetate, carbonate, chloride, nitrate, oxide and sulphate) on the growth and reproduction of young earthworms (*Eisenia foetida*) during 8 weeks. The metals were mixed with a known quantity of horse manure which was placed on top of screened soil. LOEC's (lowest observable effects concentration) for cocoon production and body weight ranged from 500 to 4000 while for body weight, the LOEC values ranged from 2000 to over 40,000. Generally, reproduction was a more sensitive endpoint for various zinc compounds than growth.

Several studies documented zinc mortality for earthworm on various soil types. Sheppard et al. (1993) determined LC_{50} of 80 mg $Zn \cdot kg^{-1}$ for *Eisenia fetida* in clay soil, pH 7.3. However, in sandy soil of pH 6.3, the LC_{50} was determined at 460 mg $Zn \cdot kg^{-1}$ and in silty clay (pH 7.9), the LC_{50} was 600 mg $Zn \cdot kg^{-1}$. Environment Canada (1995) reported slightly higher soil zinc concentrations which resulted in 50% mortality for earthworms. The LC_{50} ranged in concentration from 700 to 800 mg $Zn \cdot kg^{-1}$ soil when *E. fetida* were exposed over 14 days to zinc chloride in artificial soil of pH 4.0 to 4.2. Under similar test conditions, this study documented 25% earthworm mortality for soil concentrations of 500 to 700 mg $Zn \cdot kg^{-1}$ soil and no effect on mortality for concentrations ranging from 300 to 500 mg $Zn \cdot kg^{-1}$ soil.

Neuhauser et al. (1985) documented an LC_{50} of 662 mg $Zn \cdot kg^{-1}$ for earthworms exposed for 14 days to zinc nitrate in an artificial sandy loam soil (pH 6.0). Spurgeon et al. (1994) also conducted 14 day LC_{50} tests for earthworms on an artificial sandy loam soil with zinc nitrate and reported an LC_{50} of 1010 mg $Zn \cdot kg^{-1}$ soil. Under the same experimental conditions, an exposure period of 56 days resulted in an LC_{50} of 745 mg $Zn \cdot kg^{-1}$, and a NOEC for mortality of 289 mg $Zn \cdot kg^{-1}$. A 50% reduction in cocoon production occurred after 56 days at 276 mg $Zn \cdot kg^{-1}$ while the estimated NOEC for cocoon production was 199 mg $Zn \cdot kg^{-1}$ soil.

Van Gestel et al. (1993) studied the effects of various concentrations of zinc on growth and reproduction of *Eisenia andrei* in an artificial soil. Significant effects included reduced reproduction (31%) and increased production (89%) of malformed cocoons at 560 and 1000 mg $Zn \cdot kg^{-1}$ soil, respectively. These authors also found that earthworms had some ability to regulate their body content of zinc. However, concentrations of soil zinc exceeding 1000 mg $Zn \cdot kg^{-1}$ soil did cause an increase of zinc body content of earthworms. Hartenstein et al. (1981) also reported the effects of various soil zinc concentrations on the growth on earthworms. This study reported an LOEC ranging from 1300 to 13,000 mg $Zn \cdot kg^{-1}$ soil for earthworms (*Eisenia fetida*) in silt loam soils of pH 6.5 to 7.0 when exposed for 8 weeks to soil zinc added as zinc sulphate.

4.4 Mammals and Birds

Metabolic Fate and Behaviour

Zinc is present in all tissues and is an essential trace element for proper growth, development, and function in mammals and birds (NRC 1980). Zinc is absorbed from the intestine according to the needs of the animal and is primarily excreted in the faeces. The absorption is species dependent and is influenced by factors such as age, dose and length of exposure (Davies et al. 1977; Eisler 1993; Ott et al. 1966). It has been reported that more than 200 metalloenzymes require zinc in which the metal is located at the active site of the enzyme and is involved in the catalytic process (Eisler 1993). Zinc assures stability of biological molecules such as DNA and RNA and of biological structures such as membranes and ribosomes (Underwood, 1971). Zinc is an inducer of metallothioneins, proteins which temporarily store zinc and aid in counteracting zinc toxicity (NRC 1980). Many studies document the accumulation of absorbed zinc in the liver and kidneys of sheep, cattle, poultry and rats (Dewar et al. 1983; Llobet et al. 1988; Ott et al. 1966). In a study of zinc amended diets, Llobet et al. (1988) also found significant increases of zinc content in the heart, bone, and blood tissues of rats.

Mammals and birds obtain zinc primarily from dietary sources. Zinc requirements for young domestic animals and fowl range from about 40 to 100 ppm in the diet. In a review by NRC (1980), the following values for zinc content in various animal feeds were reported; pasture, 17-60 ppm; cereal grains, 20-30 ppm; soybean meal, 50-70 ppm dry weight. For humans, foods rich in zinc include red meats, milk, egg yolks, shellfish, liver, whole grain cereals, and legumes. Livestock may ingest elevated levels of zinc by licking galvanized or painted surfaces or by ingestion of contaminated soil, vegetation or water. Birds may ingest elevated zinc by ingestion of zinc shot or by ingestion of contaminated food sources such as vegetation, insects or other prey.

Inorganic salts of zinc, including zinc oxide, carbonate, acetate, chloride, and metallic zinc are readily available sources for mammals. Those salts that are insoluble are solubilized by gastric juice. Contamination of food, water and soil with large amounts of zinc can occur from storage in galvanized containers, deposition of zinc from mining activities or by sewage sludge land applications, and by corrosion of galvanized structures such as electrical transmission towers (Jones 1983; NRC 1980; Nriagu 1980)

Wildlife and livestock tested on Zn-contaminated lands near smelters were found to have much higher zinc concentrations in their liver and kidney than mammals grazing on uncontaminated lands. Strong correlations occurred between soil zinc concentration and the level of zinc accumulated in organs (Reif et al. 1989). Trowbridge's shrews (*Sorex trowbridgii*), deer mice (*Peromyscus maniculatus*) and shrew-moles (*Neurotrichus gibbsii*) collected in a sludge-treated forest in Washington State, USA, accumulated zinc in their kidneys and liver with no other observed effects (Hegstrom and West 1989). Some birds have the ability to eliminate zinc when returned to normal level diet after extended dosage of high Zn. Dewar et al. (1983) found that liver zinc concentrations of laying hens fed a normal diet after a short term exposure to a high zinc diet returned to almost normal levels after 6 weeks.

Puls (1988) indicates there is a strong relationship between zinc and calcium (Ca) in the dietary requirements of cattle. The recommended daily requirement for cattle is 45 mg $Zn \cdot kg^{-1}$ dry matter intake with 0.3% Ca. For each additional 0.1% Ca, 16 mg $Zn \cdot kg^{-1}$ should be added to the diet.

Toxicity

Tables 7 and 8 summarize available toxicological data of the effects of zinc on mammals and birds. Table 11 summarizes the selected toxicity data used for the derivation of the soil quality guideline.

Zinc toxicity has been reported in livestock with the common exposure routes as galvanized feed troughs, galvanized wire, feeds supplements with high zinc contents, heavy use of zinc-containing fertilizers and fungicides and the direct ingestion of zinc contaminated soils and forage. Zinc toxicity has been observed in many animals but its effects are so diverse that it is difficult to identify any single mechanism as being responsible for death (Campbell and Mills 1979; Ott et al. 1966). Clinical signs of zinc toxicity include loss of appetite, decreased water consumption and dehydration, increased mineral consumption, loss of condition (decrease in weight gain or loss of weight), weakness, jaundice, diarrhoea and paralysis of the legs in birds (Allen et al. 1983; Dean et al. 1991; Gasaway and Buss 1972; Ott et al. 1966). Morphological changes noted as a result of zinc ingestion included: anaemia; lesions in the kidney, gizzard and pancreas; reduction in gonad growth of young ducks; enlarged and pale kidneys; significant increase of zinc in liver, kidneys, heart, bone and blood tissues; decreased copper and increased iron concentrations in the liver; effect on kidney function; and pathological changes in the pancreas, kidney, liver, rumen, abomasum, small intestine and adrenal gland.

At zinc doses of 33.6 mg $Zn \cdot kg^{-1}$ BW·day, reduced rates of weight gain were observed in lambs (Davies et al. 1977). Mallard ducks fed zinc metal shot showed reduced weight gain at a calculated dose of 17.9 mg $Zn \cdot kg^{-1}$ BW (French et al. 1987). Young mallard ducks exhibited an average 19% weight loss at 109 mg $Zn \cdot kg^{-1}$ BW and moderate to severe weight loss (23-45%) at 158 mg $Zn \cdot kg^{-1}$ BW (Gasaway and Buss 1972). Food consumption and the rate of weight gain both decreased with increasing zinc dosage (Dewar et al. 1983; Ott et al. 1966). Davies et al (1977) reported reduced weight gain for sheep fed zinc while maintaining feed consumption at the same level as control animals. At 178 mg $Zn \cdot kg^{-1}$ BW, Ott et al. (1966) observed that lambs stopped feeding completely and reduced their water intake by 75% compared to controls. Weight loss and reduced food intake were also observed in a 28 day study of one day old chicks at a dosage of 1074 mg $Zn \cdot kg^{-1}$ BW (Dean et al. 1991). No effects on weight gain or food intake were observed in rats up to a dosage of 640 mg $Zn \cdot kg^{-1}$ BW (Llobet et al. 1988).

The effects of zinc exposure on kidneys, liver and pancreas were documented for mammals and birds in several studies. Mallard ducks developed liver and kidney lesions at 17.9 mg $Zn \cdot kg^{-1}$ BW (French et al. 1987). In young poultry, gizzard and pancreatic lesions were observed at dosages greater than or equal to 65.7 mg $Zn \cdot kg^{-1}$ BW (Wight et al. 1986). Rats developed kidney lesions and exhibited renal dysfunction at 320 mg $Zn \cdot kg^{-1}$ BW (Llobet et al. 1988). Decreased Cu content in the livers of sheep were noted at 33.6 mg $Zn \cdot kg^{-1}$ BW (Davies et al. 1977).

Zinc fed to 7 week old mallard ducks at 109 mg $Zn \cdot kg^{-1}$ BW for a period up to 60 days resulted in leg paralysis, yellowish to reddish yellow kidneys, moderate to high reduction in gonadal growth and mortality (Gasaway and Buss 1972). In the same study a dosage of 158 mg $Zn \cdot kg^{-1}$ BW resulted in leg paralysis along with reduction in gonadal growth and mortality of all ducks within 40 days.

Reproductive effects of zinc on pregnant sheep were reported by Campbell and Mills (1979). When pregnant sheep were fed 20 mg $Zn \cdot kg^{-1}$ BW during the first 10 days of the gestation period and 10 mg $Zn \cdot kg^{-1}$ BW during the final 10 weeks, 64% of the offspring were non-viable. These authors also observed reduced rates of weight gain and feed consumption by the sheep and lower offspring weights when pregnant sheep were fed zinc. Dewar et al. (1983) studied the effects of high zinc diets to laying hens and reported that a diet of 25,000 mg $Zn \cdot kg^{-1}$ prevented hens from laying eggs. Zinc is often used in commercial egg production to control and improve egg laying (Dewar et al. 1983; Eisler 1993; Wight et al. 1986).

5. DERIVATION OF ENVIRONMENTAL SOIL QUALITY GUIDELINES

5.1 Introduction

Canadian soil quality guidelines are designed to protect four different land uses: agricultural, residential/parkland, commercial and industrial. The Canadian Soil Quality Guidelines for zinc are based on the procedures described in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996).

All data selected for use in the following derivations have been screened for ecological relevance. Note that *E. foetida* is known to inhabit Canadian soils. The selected data for plants and invertebrates used in the derivation of the guidelines for soil contact are presented in Table 10 while Table 9 presents selected microbial studies used in the nutrient and energy cycling check. The SQG_I for soil and food ingestion was derived using the selected data shown in Table 11. Studies were excluded from use because of one or more of the following reasons:

1. soil pH was not recorded;
2. soil pH was below 4 (since this is considered outside the normal pH range of most soils in Canada)
3. no indication of soil texture was provided;
4. inappropriate statistical analysis was used;
5. test soil was amended with sewage sludge or a mixture of toxicants.
6. test was not conducted using soil or artificial soil.
7. test did not use controls

LOEC and EC data used in the following derivations were considered to be statistically significant according to the study from which the data were taken.

According to Section 7.5.2.2 of the Protocol, the geometric mean should be used when multiple data are available for the same endpoint with the same species. For the zinc data, the geometric mean has been applied to the several values including: the NOEC, EC_{25} and EC_{50} values for radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*) from Environment Canada (1995); the EC_{50} values for turnip (*Brassica rapa*) and the NOEC values for lettuce (*Lactuca sativa)* from Sheppard *et al.* (1993); the NOEC values for earthworm (*Eisenia fetida*) from Environment Canada (1995) and Spurgeon *et al.* (1994); the LC_{25} values for the earthworm *Eisenia fetida* from Environment Canada (1995); the LC_{50} values for earthworm (*Eisenia fetida*) from Environment Canada (1995), Spurgeon *et al.* (1994), Neuhauser *et al.* (1985), Sheppard *et al.* (1993); the EC_{50} values for the earthworm *Eisenia fetida* from van Gestel *et al.* (1993) and Spurgeon *et al.* (1994); and the NOEC values for corn (*Zea mays*), lettuce (*Lactuca sativa*) and alfalfa from MacLean (1974).

5.2 Soil Quality Guidelines for Agricultural and Residential/Parkland Land Uses

5.2.1 Soil Quality Guideline for Soil Contact (SQG_{SC})

The derivation of the soil quality guideline for soil contact (SQG_{SC}) is based on toxicological data for vascular plants and soil invertebrates. The toxicological data for plants and invertebrates selected according to CCME (1996) are presented in Table 10. The LOEC method was used to derive the soil quality guideline for soil contact as greater than 75% of the effects data are $EC_{<40}$.

The threshold effects concentration (TEC) was calculated as follows:

$$TEC = \text{lowest LOEC} / UF$$

where,

TEC = threshold effects concentration ($mg \cdot kg^{-1}$ soil)
LOEC = lowest observed "adverse" effect concentration ($mg \cdot kg^{-1}$ soil)
UF = uncertainty factor (if needed); no uncertainty factor was applied.

The lowest LOEC corresponds to the value of 200 mg $Zn \cdot kg^{-1}$ soil from the Environment Canada (1995) test on seedling emergence of radish (*Raphanus sativa*).

Thus TEC = 200 mg $Zn \cdot kg^{-1}$ soil

Nutrient and Energy Cycling Check

The nutrient and energy cycling check was calculated using the selected microbial processes data presented in Table 9. Nitrification and nitrogen fixation data are considered to be primary data, whereas nitrogen mineralisation, denitrification and carbon cycling data are considered secondary data. LOEC data, as reported by the author are used directly while effective concentration (EC) data producing >15% and <40% effects in primary data (i.e. EC_{15} to EC_{40}) and >15% and <25% effects in secondary data (i.e., EC_{15} to EC_{25}) are interpreted as LOEC values. Insufficient primary data were available for the calculation, so the primary and secondary data were combined and the check was carried out using a modified LOEC method whereby the geometric mean of available LOECs is calculated as the nutrient and energy cycling check.

The nutrient and energy cycling check (NECC) is calculated as follows:

$$NECC = (LOEC_1 \cdot LOEC_2 \cdot LOEC_3 \cdot \ldots \cdot LOEC_n)^{1/n}$$

where,

NECC = effects concentration low ($mg \cdot kg^{-1}$ soil)
LOEC = lowest observed effects concentration ($mg \cdot kg^{-1}$ soil)
n = number of available LOECs

Thus, $NECC = (327 \cdot 327 \cdot 327 \cdot 1074 \cdot 1074 \cdot 10 \cdot 10 \cdot 100 \cdot 327 \cdot 327 \cdot 327 \cdot 327 \cdot 1074 \cdot 3000 \cdot 3000)^{1/15}$
$= 323 \cong 320$ mg $Zn \cdot kg^{-1}$ soil

Since the TEC (200 mg·kg^{-1} soil) is lower than the NECC (320 mg·kg^{-1} soil), the TEC is considered to be protective of microbial nutrient and energy cycling processes and is adopted directly as the SQG_{SC} for agricultural and residential/parkland land uses.

5.2.2 Soil Quality Guidelines for Soil and Food Ingestion (SQG_I)

The soil quality guideline for soil and food ingestion applies only to agricultural land use.

Calculation of the SQG_I is based on the lowest observed adverse effects level (LOAEL) taken from the selected mammalian and avian toxicological data listed in Table 11. The lowest observed adverse effects level, indicating the species most threatened, was 10 mg Zn·kg^{-1} bw·day^{-1} for the final ten weeks of an experiment with sheep resulting in a significant reduction in the number of viable offspring produced (Campbell and Mills 1979).

The LOAEL is used to calculate the daily threshold effects dose (DTED) according to the equation:

$$DTED = \text{lowest } LOAEL / UF$$

where,

DTED = daily threshold effects dose (mg·kg^{-1} bw·day^{-1})
LOAEL = lowest observed adverse effects dose (mg·kg^{-1} bw·day^{-1})
UF = uncertainty factor; no uncertainty factor was applied.

Thus, DTED = 10 mg·kg^{-1} bw·day^{-1}

An animal may be exposed to a contaminant by more than one route. Total exposure comes from a combination of contaminated food, direct soil ingestion, dermal contact, contaminated drinking water and inhalation of air and dust. Exposure from all of these routes should not exceed the DTED. Assuming that drinking water, dermal contact and inhalation account for 25% of the total exposure (CCME 1996), the remaining 75% of exposure is attributed to the ingestion of food and soil. It follows then, that exposure from soil and food ingestion should not exceed 75% of the DTED:

$$\text{exposure from direct soil ingestion} + \text{exposure from food ingestion} = 0.75 \cdot DTED$$

Exposure from Direct Soil Ingestion

To estimate the exposure of an animal from direct soil ingestion, the rate of soil ingestion must be calculated. The ingestion rate of soil and forage together is referred to as the dry matter intake rate (DMIR). To estimate the rate of soil ingested directly, the percentage of the DMIR attributed to soil ingestion must be isolated. In most soil-based exposure studies, the proportion of soil ingested (PSI) is reported with the DMIR. The animal's soil ingestion rate is calculated as a proportion of the DMIR according to the equation:

$$SIR = DMIR \cdot PSI$$

where,

SIR = the soil ingestion rate (kg dw soil·day^{-1})

DMIR = geometric mean of available dry matter intake rates (kg·day^{-1}) which was determined to be 1.89 kg·day^{-1} (Campbell and Mills 1979).
PSI = geometric mean of available soil ingestion proportions reported with DMIR. As no information is available on the PSI for the species used, a default value of 0.083 (McMurther 1993) was used for the above equation.

Thus, SIR = 1.89 · 0.083 = 0.16 kg dw soil·day^{-1}

The SIR can then be combined with the bioavailability factor (BF), body weight (BW) and a concentration of the contaminant in the soil (SQG_I) to represent the exposure from soil ingestion. The soil concentration at this point is unknown but it should not provide for greater than 75% of the DTED when combined with the exposure calculated for food ingestion:

$$\text{exposure from soil ingestion} = SIR \cdot BF \cdot SQG_I / BW$$

where,
SIR = soil ingestion rate (kg dw soil·day^{-1})
BF = bioavailability factor; Due to lack of specific information on the bioavailability of zinc from ingested soil for livestock and terrestrial wildlife, a BF of 1 is assumed (CCME 1996).
SQG_I = concentration of the contaminant in soil that will not result in greater than 75% DTED (mg·kg^{-1} soil)
BW = mean body weight (kg); the mean body weight of sheep was determined to be 80.0 kg (Campbell and Mills 1979).

Exposure from Food Ingestion

Similar to SIR, the food ingestion rate (FIR) for livestock and wildlife, is expressed as a portion of DMIR. The FIR is the remaining proportion of the DMIR minus soil ingestion rate. The FIR is calculated as:

$$FIR = DMIR - SIR$$

where,
FIR = food ingestion rate (kg dw food·day^{-1})
DMIR = geometric mean of dry matter intake rates (kg dw food·day^{-1})
SIR = soil ingestion rate (kg dw soil·day^{-1})

Thus, FIR = 1.89 - 0.16 = 1.73 kg dw food·day^{-1}

The FIR can then be combined with the bioconcentration factor (BCF), BW and the SQG_I to express the exposure from food ingestion:

$$\text{exposure from food ingestion} = FIR \cdot BCF \cdot SQG_I / BW$$

where,
FIR = food ingestion rate (mg·kg^{-1} dw food·day^{-1})
BCF = bioconcentration factor; (calculated as 0.45 from the geometric mean of data obtained from consulted studies, calculated according to CCME 1996, see Appendix 1 and 2)

SQG_I = concentration of the contaminant in soil that will not result in greater than 75% DTED (mg Zn·kg^{-1} soil)
BW = mean body weight (kg); the mean body weight of sheep was determined to be 80.0 kg (Campbell and Mills 1979).

Exposure from Direct Soil Ingestion and Food Ingestion

The equations for exposure from soil ingestion and exposure from food ingestion can be combined and rearranged to solve for the SQG_I:

$$(SIR \cdot BF \cdot SQG_I / BW) + (FIR \cdot BCF \cdot SQG_I / BW) = 0.75\ DTED$$

$SQG_I = (0.75\ DTED \cdot BW) / (SIR \cdot BF) + (FIR \cdot BCF)$

$SQG_I = (0.75 \cdot 10 \cdot 80.0) / (0.16 \cdot 1) + (1.73 \cdot 0.45)$

$SQG_I = 639 \cong 640$ mg Zn·kg^{-1} soil

5.3 Soil Quality Guidelines for Commercial and Industrial Land Uses

5.3.1 Soil Quality Guidelines for Soil Contact (SQG_{SC})

The derivation of the SQG_{SC} is also based on toxicological data for vascular plants and soil invertebrates presented in Table 10. The effects concentration low was calculated using the lowest observed effects concentration method as follows:

The effects concentration low (ECL) is calculated as:

$$ECL = (LOEC_1 \times LOEC_2 \times ... \times LOEC_n)^{1/n}$$

where,
ECL = effects concentration low (mg·kg^{-1} soil)
LOEC = lowest observed effect concentration (mg·kg^{-1} soil)
n = the number of available LOECs

Thus,
$ECL = (200 \times 490 \times 490 \times 600)^{1/4} = 412 \cong 410$ mg Zn·kg^{-1} soil

Nutrient and Energy Cycling Check

The nutrient and energy cycling check was calculated using the selected microbial processes data presented in Table 9. Nitrification and nitrogen fixation data are considered to be primary data, whereas nitrogen mineralisation, denitrification and carbon cycling data are considered secondary data. LOEC data, as reported by the author are used directly while effective concentration (EC) data producing >15 and < 50% effects in primary data (i.e. EC_{15} to EC_{50}) and >15 and < 35% effects in secondary data (i.e. EC_{15} to EC_{35}) are interpreted as LOEC values. Insufficient primary data were available for the calculation, so the primary and secondary data were combined and the check was carried out using a modified LOEC method whereby the geometric mean of available LOECs is calculated as the nutrient and energy cycling check.

The nutrient and energy cycling check (NECC) is calculated as follows:

$$NECC = (LOEC_1 \cdot LOEC_2 \cdot LOEC_3 \cdot \ldots \cdot LOEC_n)^{1/n}$$

where,

NECC	=	effects concentration low (mg Zn·kg^{-1} soil)
LOEC	=	lowest observed effects concentration (mg Zn·kg^{-1} soil)
n	=	number of available LOECs

Thus,

$$NECC = (327 \cdot 327 \cdot 327 \cdot 1074 \cdot 1074 \cdot 10 \cdot 10 \cdot 100 \cdot 327 \cdot 327 \cdot 327 \cdot 327 \cdot 1074 \cdot 3000 \cdot 3000 \cdot 33 \cdot 3270)^{1/17}$$
$$= 324 \cong 320 \text{ mg Zn·kg}^{-1} \text{ soil}$$

Since the ECL (410 mg·kg^{-1} soil) is lower than the NECC (320 mg·kg^{-1} soil), the ECL is not considered to be protective of microbial nutrient and energy cycling processes and is modified by taking the geometric mean of the ECL and NECC.

$(ECL \times NECC)^{1/2} = (410 \times 320)^{1/2} = 360$ mg Zn·kg^{-1} soil

Therefore, the SQG_{SC} for commercial and industrial land uses is 360 mg Zn·kg^{-1} soil

5.4 Derivation of the Final Environmental Soil Quality Guidelines (SQG_E)

The following environmental soil quality guidelines are optimized for soils within the pH range of 4.0 to 8.3. The toxicological studies upon which these guidelines are based were conducted within this pH range. Table 12 presents the environmental soil quality guidelines derived for the different land uses.

Agricultural Land Use:

The lower value from the two procedures (SQG_{SC} and SQG_I) is selected as the final environmental soil quality guideline for agricultural land. The lower of the two procedures is the SQG_{SC}. Therefore, the final SQG_E is 200 mg Zn·kg^{-1} dry soil.

Residential/Parkland Land Use:

The final SQG_E for residential/parkland land use is 200 mg Zn·kg^{-1} dry soil.

Commercial and Industrial Land Use:

The ECL for commercial and industrial land use is 410 mg $Zn \cdot kg^{-1}$ dry soil. This value is higher than the NECC value of 320 $mg \cdot kg^{-1}$ soil and is thus not protective of microbial processes. Therefore, the SQG_{SC} for commercial and industrial land use is 360 mg $Zn \cdot kg^{-1}$ dry soil, the geometric mean of the ECL and the NECC. For commercial and industrial land use, the SQG_{SC} is taken as the final SQG_E. Thus, the final SQG_E is 360 mg $Zn \cdot kg^{-1}$ dry soil.

6. DATA GAPS

Sufficient data exist on the toxicity of zinc to soil ecosystem receptors to derive soil quality guidelines for the three major land uses (Agricultural, Residential/Parkland, and Commercial/Industrial). An extensive database exists on the fate of zinc in soils and other environmental media. The database contains varying results of zinc toxicity effects in the soil and upon soil processes and organisms. Much of the variety can be explained by the factors affecting zinc fate in soils: soil pH, soil texture, organic matter content, CEC and soil moisture. Zinc compounds vary in solubility and bioavailability in soils. Also, soil organisms are capable of using or need zinc to different extents. Therefore, additional information is required to fully understand the influence of these factors in the determination of the fate of zinc in soils.

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TABLES

Table 1: Physical and chemical properties of zinc and its common salts.

Properties (units)	Zinc	Zinc Oxide	Zinc sulphide	Zinc sulphate	Zinc chloride	Zinc fluoride	Zinc bromide	Zinc iodide	Zinc acetate	Zinc borate	Zinc carbonate	Zinc chromate	Zinc dichromate
Chemical Formula	Zn	ZnO	ZnS	$ZnSO_4$	$ZnCl_2$	ZnF_2	$ZnBr_2$	ZnI_2	$Zn(C_2H_3O_2)_2$	$3ZnO \cdot 2B_2O_3$	$ZnCO_3$	$ZnCrO_4$	$ZnCr_2O_7 \cdot 3H_2O$
Molecular Weight ($g \cdot mol^{-1}$)	65.4	81.37	97.43	161.43	136.29	103.37	225.19	319.18	183.46	383.35	125.39	181.36	335.4
Physical state	bluish white, lustrous metal hexagonal	white hexa-gonal	colourless cubic	colourless solid ortho-rombic	white granules	colourless mono-cyclic or tricyclic	colourless rhombic	colour less hexa-gonal	monocyclic	white tricyclic or amorph powder	trigonal	yellow prism	brown-red crystals or orange-yellow powder
Boiling point (°C)	907	ND	ND	ND	732	1500	650	624	ND	ND	ND	ND	ND
Melting point (°C)	420	1975	1020	600	290	872	394	446	200	980	300	ND	ND
Density (water=1)	7.14	5.606	4.102	3.54	2.907	4.95	4.201	4.7364	1.84	4.22	4.398	3.4	ND
Solubility ($g \cdot 100\ mL^{-1}$, cold water)	insoluble	.00079	.000065	soluble	432	1.62	447	432	30	soluble	.001	insoluble	very soluble

Source: NRC 1978;
ND = no data

Table 2: Available data on zinc concentrations in Canadian soils.

Location	Sample depth	Soil Type	Concentration (SD) ($mg \cdot kg^{-1}$)	Range ($mg \cdot kg^{-1}$)	Comments	Reference
Alberta - along transect from southeast to central	Ah horizon Bm hoizon	uncultivated - Brown Chernozem	92 (NR) 85 (NR)	45 - 98	uncomtaminated soils	Dudas and Pawluk 1980
	Ah horizon Bm hoizon	uncultivated - Dark Brown Chernozem	85 (NR) 59 (NR)			
	Ah horizon Bm hoizon	uncultivated - Black Chernozem	98* (NR) 66 (NR)			
	Ah horizon Bm hoizon	uncultivated - Gray Luvisol	45* (NR) 56* (NR)			
Alberta - northwestern	surface soils subsoils	agricultural	94 (47) 81 (35)	NR NR	uncontaminated soils	Soon and Abboud 1990
Alberta - northwestern	surface soils	agricultural soils	55	11	Beaverlodge Research Station	Soon 1994
Canada Appalachian Region Canadian Shield St. Lawrence Lowlands Interior Plains Cordilleran Region	A, B & C horizons	uncultivated soils	74 (NR) 81 (NR) 54 (NR) 80 (NR) 64 (NR) 73 (NR)	10 - 200	uncontaminated, remote from ore bodies	McKeague and Wolynetz 1980
Southwestern Ontario	Ap B C	agricultural soils	88 (28) 87 (29) 71 (26)	40-163 35-140 40-128	uncontaminated	Whitby et al. 1978
Halton, Ontario	surface	agricultural soils	126 (89) 113 (34)	50-821 57-243	sludge treated background	Webber and Shamess 1987
Winnipeg, Manitoba	surface	urban soils	96 (NR) 116 (NR)	62-116	urban soils	Mills and Zwarich 1975
Flin Flon, Manitoba	LFH 0 to 5 cm 5 to 10 cm 10 to 15 cm	forested soils	98 (6) 90(6) 100 (6) 80 (6)	NR	control soil, 68.2 km from a copper-zinc smelter and mine	Hogan and Wotton 1984

SD = standard deviation
NR = not reported
* = average of values reported

Table 3. Existing soil quality criteria, guidelines and standards for zinc from various jurisdictions.

Jurisdiction	Category	Guideline ($mg \cdot kg^{-1}$)	Reference
Canada	Interim assessment criteria	60 (A)	CCME 1991
	Interim remediation criteria (to protect human and environmental health)	120 (Agr) 500 (R/P) 1500 (C/I)	
Ontario	Clean-up criteria: Surface soil in a potable groundwater situation (only applies to soil pH 5.0-9.0)	600 (Agr) 600 (R/P) 600 (C/I)	OMEE 1993
	Surface soil in a non-potable groundwater situation (only applies when soil pH is 5.0-9.0)	600 (R/P) 600 (C/I)	
	Subsurface soil in a potable and non-potable groundwater situation (only applies when soil pH is 5.0-11.0)	2500 (R/P) 5000 (C/I)	
Alberta	Tier I assessment and remediation criteria	120	CCME, 1991
British Columbia	Soil remediation criteria	80 (A) 500 (Agr, R/P) 1500 (C/I)	
Quebec	Remediation guidelines	100 (A) 500 (B) 1500 (C)	
The Netherlands	Target value Intervention value	140 3000	
New Jersey	Remediation guideline	350 (R/P)	
United Kingdom	Remediation criteria	1000 (Agr)	
France	Remediation criteria	300	

A - background concentrations in soil
B - moderate soil contamination which requires additional study
C - threshold value that requires immediate clean-up

Agr - Agricultural land use
R/P - Residential/Parkland land use
C/I - Commercial/Industrial land use

Table 4: Available data on the toxicity of zinc to soil microbial processes.

Microbial process	Effect	Endpoint *	Concentration ($mg\ Zn \cdot kg^{-1}$)	Zn compound	Exposure period	Soil Type	pH	OM %	Clay %	Extraction method	Reference
Nitrification	58% reduction	EC	327‡	$ZnSO_4$	10 d	Webster loam	5.8	2.58	23	Nominal	Liang and Tabatabai 1978
	24% reduction					Harps clay loam	7.8	3.74	30		
	39% reduction					Okoboji silty clay loam	7.4	5.45	34		
Nitrification	14% reduction	EC	327‡	$ZnSO_4$	20 d	Webster loam	5.8	2.58	23	Nominal	Liang and Tabatabai 1977
	12% reduction					Judson silty clay	6.6	2.95	45		
	15% reduction					Harps clay loam	7.8	3.74	30		
	14% reduction					Okoboji silty clay loam	7.4	5.45	34		
Nitrification	no reduction	EC	1074‡	ZnO	6 weeks	Bagshot sand	6.0	2.2	5.5	Nominal	Bhuiya and Cornfield 1974
	13% reduction						7.0				
	33% reduction						7.7				
Nitrification	67% reduction	EC	100	$ZnSO_4$	2 weeks	Cecil sandy loam	6.2	1.6	7.6	Nominal	Wilson 1977
	70% reduction				3 weeks						
	67% reduction	EC	100		3 weeks	Leefield loamy sand	7.4	1.14	2.4		
	31% reduction				4 weeks						
	36% reduction				5 weeks						
	20% reduction				7 weeks						
	100% reduction	EC	1000		7 weeks	Cecil sandy loam	6.2	1.6	7.6		
	100% reduction	EC				Decatur clay loam	6.8	2.37	28.1		
	100% reduction	EC				Leefield loamy sand	7.4	1.14	2.4		
Respiration	44% reduction	EC	1000	$ZnCl_2$	70 weeks	sand	7.0	1.6	2	Nominal	Doelman and Haanstra 1984
	40% reduction		400		43 weeks	sandy loam	6.0	5.7	9		
	38% reduction		8000		90 weeks	silt loam	7.7	2.4	19		
	26% reduction		3000		80 weeks	clay	7.5	3.2	60		
	26% reduction		3000		82 weeks	sandy peat	4.4	12.8	5		
Respiration	20% reduction	EC	327	$ZnSO_4$	45 d	Sharpsburg	8.2	4.7	11	Nominal	Lighthart, Baham, and Volk 1983
	45% reduction		3270								
	18% reduction		33								
	20% reduction		327			Walla Walla silt loam	7.2	1.7	21		
	50% reduction		3270								
	20% reduction		327			Crider silt loam	6.7	3.1	27		
	30% reduction		3270								
	20% reduction		327			Toledo clay	7.0	5.5	51		
	40% reduction		3270								

Microbial process	Effect	Endpoint *	Concentration (mg Zn*kg^{-1})	Zn compound	Exposure period	Soil Type	pH	OM %	Clay %	Extraction method	Reference
Denitrification	40% reduction 65% reduction	EC	250 500	$Zn(NO_3)_2$	21 d	silt loam	6.75	1.8	28.1	Nominal	Bollag and Barabasz 1979
Respiration	21% reduction 45% reduction 24% reduction	EC	10 100 100	$ZnSO_4$	8 weeks 2 weeks	loamy sand	4.9	2.1	5.2	Nominal	Cornfield 1977
Respiration	16% reduction	EC	1074‡	ZnO	12 weeks	Bagshot sand	6.0	2.2	5.5	HCl 6N	Bhuiya and Cornfield 1972
Nitrogen mineralization	08% reduction 32% reduction –	EC NOEC	1074‡	ZnO	6 weeks	Bagshot sand	7.0 7.7 6.0	2.2	5.5	HCl 6N	Bhuiya and Cornfield 1974
Nitrogen fixation	100 % reduction 90 % reduction –	EC NOEC	385 282 455	$ZnSO_4$	18 months 2 months	sandy loam	6.5	NR	9	aqua regia digestion	Chaudri et al. 1992
Glucose mineralization	13% reduction 33% reduction 44% reduction 11% reduction	EC	100 300 1000 1000	$ZnCl_2$	24 hours 96 hours	sandy clay loam	6.7	1.17	NR	Nominal	Ohya, Komai and Yamaguchi 1985
Acid phosphatase activity	32% reduction 33% reduction 30% reduction	EC	1643‡	$ZnSO_4$	1.5 hours	clay loam silty clay loam	7.8 7.4 5.8	3.74 5.45 2.58	30 34 23	Nominal	Juma and Tabatabai 1980
Alkaline phosphatase activity	59% reduction	EC	1643‡	$ZnSO_4$	1.5 hours	clay loam	7.8	3.74	30	Nominal	Juma and Tabatabai 1980

Microbial process	Effect	Endpoint ⁎	Concentration (mg Zn·kg^{-1})	Zn compound	Exposure period	Soil Type	pH	OM %	Clay %	Extraction method	Reference
Urea hydrolysis	–	LOEC	70	$ZnCl_2$	6 weeks	sand	7.0	1.6	2	Nominal	Doelman and Haanstra 1986
	50% reduction	EC	420								
	90% reduction		2490								
	–	LOEC	160		18 months						
	50% reduction	EC	290								
	90% reduction		2490								
	–	LOEC	30		6 weeks	sandy loam	6.0	5.7	19		
	50% reduction	EC	480								
	90% reduction		8320								
	–	LOEC	1		18 months						
	50% reduction	EC	110								
	90% reduction		17400								
	–	LOEC	30		6 weeks	silt loam	7.7	2.4	19		
	50% reduction	EC	1030								
	90% reduction		38200								
	–	LOEC	NR		18 months						
	50% reduction	EC	NR								
	90% reduction		NR								
	–	LOEC	460		6 weeks	clay	7.5	3.2	60		
	50% reduction	EC	1780								
	90% reduction		6820								
	–	LOEC	8		18 months						
	50% reduction	EC	90								
	90% reduction		980								

⁎ The EC endpoints represent the percentage of adverse effects, compared to controls, as caculated by the CCME from the data presented by the author(s).
* NR = not reported.
‡ Single concentration study.

Table 5: Available data on the toxicity of zinc to terrestrial plants

Organism	Effect (% reduction)	Endpoint *	Conc. (mg·kg⁻¹)	Exposure Period	Chemical form	Soil pH	Test Substrate	Extraction Method	Reference
Onion *Allium cepa*	yield (18% reduction)	EC	400	8 weeks	$ZnSO_4$	8.3	clay loam, 0.28% O.M., 24% clay	nominal	Dang et al. 1990
Black Spruce *Picea mariana*	on other foliar nutrient conc.	NOEC	1200	field study	Zn (from smelter)	4.9	sandy loam	HF/HNO_3 $/HClO_4$	Hogan and Wotton, 1984
Jack Pine *Pinus banksiana*	on other foliar nutrient conc.	NOEC	1200						
Lettuce *Lactuca sativa*	yield	NOEC	1425	45 days	Zn from galvanized metal	7.1	drumlin soil, 6.2% O.M.	0.1N HCl	Jones 1982
Radish *Raphanus sativa*	yield	NOEC	1425						
Corn *Zea mays*	yield	NOEC	1425						Jones et al. 1987
Blackgram *Vigna mungo L.*	yield (22% reduction) (45% reduction)	EC EC	200 250	65 days	$ZnSO_4$	6.2	NR	nominal	Kalyanaraman and Sivagurunathan 1994
Endive *Cichorium endiva*	yield (53% reduction) (91% reduction)	EC EC	60 80	growing season	$ZnSO_4$	4.2	sand, 4.4% O.M., 3% clay	H_2SO_4 / HNO_3	Smilde et al. 1992
Spinach *Spinacia oleracea*	 yield (27% reduction)	NOEC EC	20 80						
		NOEC	160			7.2	loam, 3.7% O.M., 40% clay		
Jack Pine *P. banksiana*	shoot yield (6% reduction) root yield (25% reduction) (36% reduction)	EC EC EC	50 25 50	12 weeks	$ZnCl_2$	6.0	sandy loam, 1.5% O.M.	nominal	Dixon and Buschena 1988
White Spruce *Picea glauca*	shoot yield (13% reduction) root yield (28% reduction)	EC EC	50 50						
Beech *Fagus grandifolia*	growth ring size (48% reduction) (50% reduction)	EC EC	65.4 65.4	1 year 2 years	$ZnSO_4$	4.8	mixture of sand, peat, forest soil	nominal	Hagemeyer et al. 1993
	mortality	LC_{100}	490	1 year					
	shoot yield (21% reduction) (39% reduction)	EC EC	65.4 65.4	2 years					
Rice *Oryza sativa*	yield (23% reduction)	EC EC_{25} EC_{25}	10 000 30 000 50 000	15 weeks	ZnO	5.95	alluvial soil	nominal	Muramoto et al. 1990
Wheat *Triticum estiva*	yield (64% reduction) (82% reduction) (99% reduction)	EC EC EC	1000 10 000 30 000	23 weeks					

Organism	Effect (% reduction)	Endpoint *	Conc. (mg·kg⁻¹)	Exposure Period	Chemical form	Soil pH	Test Substrate	Extraction Method	Reference
Lettuce *L. sativa*	seedling emergence	NOEC	1000	NR	$ZnSO_4$	7.3	clay, 8.9%O.M., 46% clay	$HCl + HNO_3$ (ICP)	Sheppard et al. 1993
		NOEC	1000			7.9	silty clay, 2.7%O.M., 43% clay		
		EC_{50}	207			6.3	sand, 3% clay		
Turnip *Brassica rapa*	seedling emergence	NOEC	1000	NR	$ZnSO_4$	7.3	clay, 8.9%O.M., 46% clay	$HCl + HNO_3$ (ICP)	Sheppard et al. 1993
		EC_{50}	65			6.3	sand, 3% clay		
		EC_{50}	600			7.9	silty clay, 2.7%O.M., 43% clay		
	first bloom	EC_{50}	600			7.3	clay, 8.9%O.M., 46% clay		
		EC_{50}	25			6.3	sand, 3% clay		
		EC_{50}	600			7.9	silty clay, 2.7%O.M., 43% clay		
	seed yield	EC_{50}	715			7.3	clay, 8.9%O.M., 46% clay		
		EC_{50}	25			6.3	sand, 3% clay		
		EC_{50}	600			7.9	silty clay, 2.7%O.M., 43% clay		
Radish *R. sativa*	seedling emergence	NOEC	100	3 days	$ZnCl_2$	4.1	artificial soil, 4.8% O.M.	$HNO_3 + H_2O_2 + HCl$	Environment Canada 1995
		LC_{25}	160						
		LOEC	200						
		LC_{50}	280						
		NOEC	230			4.2	artificial soil, 4.7% O.M.		
		LC_{25}	420						
		LOEC	490						
		LC_{50}	670						
		NOEC	130			4.0	artificial soil, 6.3% O.M.		
		LOEC	240						
		LC_{25}	320						
		LC_{50}	520						
Lettuce *L. sativa*	seedling emergence	NOEC	220	5 days	$ZnCl_2$	4.2	artificial soil, 4.7% O.M.	$HNO_3 + H_2O_2 + HCl$	Environment Canada 1995
		LC_{25}	350						
		LOEC	490						
		LC_{50}	500						
		NOEC	250			4.0	artificial soil, 6.3% O.M.		
		LC_{25}	470						
		LC_{50}	720						
		NOEC	200			4.1	artificial soil, 4.8% O.M.		
		LC_{25}	280						
		LC_{50}	400						
		LOEC	410						
Corn *Z. mays*	yield	NOEC	329	6 weeks	$ZnSO_4$	7.5	sandy loam, 2.4% O.M., 16% clay	$HNO_3 + HClO_4 + HF$	MacLean 1974
		NOEC	328			7.2	sandy loam, 5.6% O.M., 13.3% clay		
	yield (13% reduction)	EC	303			4.9	fine sandy loam, 1.9% O.M., 16% clay		
Lettuce *L. sativa*	yield	NOEC	329	5 weeks	$ZnSO_4$	7.5	sandy loam, 2.4% O.M., 16% clay	$HNO_3 + HClO_4 + HF$	MacLean 1974
		NOEC	328			7.2	sandy loam, 5.6% O.M., 13.3% clay		
		LC_{100}	303			4.9	fine sandy loam, 1.9% O.M., 16% clay		

Organism	Effect (% reduction)	Endpoint *	Conc. (mg·kg⁻¹)	Exposure Period	Chemical form	Soil pH	Test Substrate	Extraction Method	Reference
Alfalfa *Medicago sativa*	yield	NOEC	329	16 weeks	$ZnSO_4$	7.5	sandy loam, 2.4% O.M., 16% clay	$HNO_3 + HClO_4 +$ HF	MacLean 1974
		NOEC	328			7.2	sandy loam, 5.6% O.M., 13.3% clay		
	yield (71% reduction)	EC	303			4.9	fine sandy loam, 1.9% O.M., 16% clay		
Corn *Z. mays*	yield	EC_{50}	240	7 weeks	$ZnSO_4$	5.5	fine sandy loam	0.5N HCl + DTPA + $CaCl_2$	Mortvedt and Giordano 1975
	mortality	LC_{100}	1400						

* The EC endpoints represent the percentage of adverse effects, compared to controls, as caculated by the CCME from the data presented by the author(s).

Table 6: Available data on the toxicity of zinc to terrestrial invertebrates

Organism	Effect (% reduction)	Endpoint *	Concentration (mg Zn·kg soil)	Chemical form	Exposure Period	pH	Test Substrate	Extraction Method	Reference
Earthworm *Eisenia fetida*	mortality	LC_{50}	662	$Zn(NO_3)_2$	14 days	6.0	sandy loam, 10% O.M., 20% clay	nominal	Neuhauser et al. 1985
Earthworm *E. fetida*	mortality	LC_{50}	1010	$Zn(NO_3)_2$	14 days	6.3	sandy loam, 10% O.M., 20% clay	HNO_3	Spurgeon et al. 1994
		NOEC	289 (est.)		56 days				
		LC_{50}	745						
	cocoon production	NOEC	199 (est.)						
		LC_{50}	276						
Earthworm *E. fetida*	mortality	LC_{50}	80	$ZnSO_4$	30 days	7.3	clay, 8.9% O.M., 46% clay	HCl + HNO_3 (ICP)	Sheppard et al. 1993
		LC_{50}	460			6.3	sand, 3% clay		
		LC_{50}	600			7.9	silty clay, 2.7% O.M., 43% clay		
Earthworm *E. fetida*	cocoon production	LOEC	2000	$Zn(C_2H_3O_2)_2$	8 weeks	NR	metal mixed with horse manure over screened soil	nominal	Malecki et al. 1982
		LOEC	2000	$ZnCl_2$					
		LOEC	2000	$Zn(NO_3)_2$					
		LOEC	4000	ZnO					
		LOEC	500	ZnS					
		LOEC	500	$ZnCO_3$					
	body weight	LOEC	4000	$Zn(C_2H_3O_2)_2$					
		LOEC	2000	$ZnCl_2$					
		LOEC	2000	$Zn(NO_3)_2$					
		LOEC	4000	ZnO					
		LOEC	2000	ZnS					
		LOEC	>40 000	$ZnCO_3$					
Earthworm *E. fetida*	mortality	LC_{50}	13 $\mu g \cdot cm^{-2}$	$Zn(C_2H_3O_2)_2$	48 hours	NR	filter paper contact test	nominal	Neuhauser et al. 1985
		LC_{50}	12 $\mu g \cdot cm^{-2}$	$ZnCl_2$					
		LC_{50}	10 $\mu g \cdot cm^{-2}$	$Zn(NO_3)_2$					
		LC_{50}	13 $\mu g \cdot cm^{-2}$	ZnS					
Earthworm *E. fetida*	growth	LOEC	1300 to 13 000	$ZnSO_4$	8 weeks	6.5 to 7.0	silt loam	nominal	Hartenstein et al. 1981
Earthworm *Eisenia andrei*	cocoon production (31% reduction)	EC	560	$ZnCl_2$	3 weeks	6.0	sandy loam, 10% O.M., 20% clay	HNO_3/HCl	van Gestel et al. 1993
		EC_{50}	659						
	cocoon production (89% reduction)	EC	1000						
	no. of juveniles produced/worm	EC_{50}	512						
	growth	NOEC	320						
	reproduction	NOEC	320						

Organism	Effect (% reduction)	Endpoint *	Concentration (mg Zn·kg soil)	Chemical form	Exposure Period	pH	Test Substrate	Extraction Method	Reference
Earthworm *E. fetida*	mortality	NOEC	500	$ZnCl_2$	14 days	4.2	artificial soil, 4.7% O.M.	HNO_3 + H_2O_2 + HCl	Environment Canada 1995
		LC_{25}	700						
		LC_{50}	800						
	90% mortality	LC	900						
		NOEC	400			4.0			
		LC_{25}	500						
		LC_{50}	700						
		LC	1000						
	93% mortality								
		NOEC	300			4.1			
		LC_{25}	500						
	40% mortality	LC	600						
		LC_{50}	700						
Wood Lice *Porcellio scaber*	mortality	LC_{50}	1090	$Zn(NO_3)_2$	100 days	NR	leaf litter	nominal	Hopkin and Hames, 1994

* The EC endpoints represent the percentage of adverse effects, compared to controls, as caculated by the CCME from the data presented by the author(s).
NR = not reported
est. = estimated

Table 7: Available data on the acute and chronic toxicity of zinc to mammals

Organism	Effect (% decrease)	Endpoint	Diet Concentration ($mg \cdot kg^{-1}$)	Average Dose $mg \cdot kg^{-1}$ $BW \cdot d^{-1}$	Form of Zinc (exposure period)	Reference
Cheviot sheep	number of viable offspring (64%) feed consumption (24%) body weight gain during pregnancy (67%)	EC EC EC	750	20 for 10 days 10 for final 10 weeks	$ZnSO_4$ (80 days)	Campbell and Mills 1979
	viability of offspring feed intake body weight gain	NOEC	150	NR		
Rats	urine excretion (72%)	EC	NR	320	Zn acetate (3 months)	Llobet et al. 1988
	urine excretion (75%)	EC		640		
	renal function body weight gain feed consumption organ weights	NOEC		160		
Sheep	body weight gain (33%) feed consumption (15%)	EC	2000	76.7 (calc.)	ZnO (10 weeks)	Ott et al. 1966
	feed consumption (53%) weight loss (NQ)	EC	4000	123 (calc.)		
	body weight gain (16%)	LOEC	1000	42.4 (calc.)		
	feed consumption (13%)	LOEC	1500	57.2 (calc.)		
	feed consumption (100%) water consumption (75%)	EC	6000	178 (calc.)	(11 days)	
Sheep	body weight gain (43%) enlarged & pale kidneys (NQ) decreased liver copper content (NQ)	EC	134.3	33.6	ZnO (33 days)	Davies et al. 1977

NR = not reported
NQ = not quantified

Table 8: Available data on the acute and chronic toxicity of zinc to birds

Organism	Effect (% decrease)	Endpoint	Diet Concentration (mg·kg^{-1})	Average Dose mg·kg^{-1} BW·d^{-1}	Form of Zinc (exposure period)	Reference
Mallard duck	body weight gain body weight gain	NOEC NOEC	100 150	9.32 14.4	Zn metal shot (28 days)	French et al. 1987
Mallard duck	mortality (60%) mortality (100%)	LC	3000 6000	109 (calc.) 158 (calc.)	$ZnCO_3$ (60 days) (40 days)	Gasaway and Buss 1972
Poultry	body weight (35%)	EC	5280	1074 (calc.)	ZnO (28 days)	Dean et al. 1991
Poultry	development of pancreatic lesions (38%) increased zinc liver concentration (NQ)	LOAEL	1000	65.7 (calc.)	ZnO (28 days)	Dewar et al. 1983
	food consumption (11%) development of pancreatic lesions (62%)	EC	2000	129.4 (calc.)		
	body weight (54%) food consumption (17%) development of pancreatic lesions (100%)	EC	4000	494.3 (calc.)		

NQ = not quantified

Table 9: Selected microbial toxicological studies for zinc.

Species\Process	Effect (% decrease)	Endpoint *	Concentration ($mg \cdot kg^{-1}$)	Form of Zn (exposure period)	Soil pH	Test Substrate	Extraction Method	Reference
Nitrification	inhibition (24%)	EC	327	$ZnSO_4$ (10 days)	7.8	3.74% O.C .30% clay	nominal	Liang and Tabatabai 1978
	inhibition (39%)	EC	327		7.4	5.45 % O.C. 34% clay		
Nitrification	inhibition (15%)	EC	327	$ZnSO_4$ (20 days)	7.8	3.74% O.C. 30% clay	nominal	Liang and Tabatabai 1977
N-Mineralization	inhibition (32%)	EC	1074	ZnO (6 weeks)	7.7	2.2% O.M. 5.5% clay	6N HCl	Bhuiya and Cornfield 1974
Nitrification	inhibition (33%)	EC	1074					
Respiration CO_2 release	reduction (21%)	EC	10	$ZnSO_4$ (8 weeks)	4.9	2.1% O.M. 5.2% clay	nominal	Cornfield 1977
	reduction (20%)	EC	10	$ZnSO_4$ (2 weeks)				
	reduction (24%)	EC	100	$ZnSO_4$ (2 weeks)				
Respiration CO_2 release	reduction (32%)	EC	33	$ZnSO_4$ (45 days)	8.2	4.7% O.M. 11% clay	nominal	Lighthart et al. 1983
	reduction (20%)	EC	327					
	reduction (20%)	EC	327		7.2	1.7% O.M. 21% clay		
	reduction (25%)	EC	327		6.7	3.1% O.M. 27% clay		
	reduction (20%)	EC	327		7.0	5.5% O.M. 51% clay		
	reduction (30%)	EC	3270		6.7	3.1% O.M. 27% clay		
Respiration CO_2 release	reduction (16%)	EC	1074	ZnO (12 weeks)	6.0	2.2% O.M. 5.5% clay	6N HCl	Bhuiya and Cornfield 1972
Respiration CO_2 release	reduction (26%)	EC	3000	$ZnCl_2$ (82 weeks)	4.4	12.8% O.M. 5% clay	nominal	Doelman and Haanstra 1984
	reduction (26%)	EC	3000	nCl_2 (80 weeks)	7.5	3.2% O.M. 60% clay		

* The EC endpoints represent the effects concentration as calculated by the CCME from the data presented by the author(s).

Table 10: Selected plant and invertebrate toxicological studies for zinc.

Organism	Effect (% decrease)	Endpoint*	Concentration ($mg \cdot kg^{-1}$)	Form of Zn (exposure period	Soil pH	Test Substrate	Extraction Method	Reference
Onion *Allium cepa*	dry matter yield (18% reduction)	LOEC	400	$ZnSO_4$ (8 weeks)	8.3	clay loam 0.28% O.M. 24% clay	nominal	Dang et al. 1990
Jack Pine *Pinus banksiana*	root yield (36% reduction)	EC	50	$ZnCl_2$ (12 weeks)	6.0	sandy loam 1.5% O.M.	nominal	Dixon and Buschena 1988
White Spruce *Picea glauca*	shoot yield (13% reduction)	EC	50	$ZnCl_2$ (12 weeks)	6.0	sandy loam 1.5% O.M.	nominal	Dixon and Buschena 1988
	root yield (28%) reduction	EC	50					
Radish *Raphanus sativa*	seedling emergence	NOEC	100	$ZnCL_2$ (3 d)	4.1	artificial soil 4.8% O.M.	$HNO_3 + H_2O_2 +$ HCl	Environment Canada 1995
		LC_{25}	160					
	(37% reduction)	LOEC	200					
		LC_{50}	280					
		NOEC	230		4.2	artificial soil 4.7% O.M.		
		LC_{25}	420					
	(34% reduction)	LOEC	490					
		LC_{50}	670					
		NOEC	130		4.0	artificial soil 6.3% O.M.		
	(11% reduction)	LOEC	240					
		LC_{25}	320					
		LC_{50}	520					
Lettuce *Lactuca sativa*	seedling emergence	NOEC	220	$ZnCl_2$ (5 d)	4.2	artificial soil 4.7% O.M.	$HNO_3 + H_2O_2 +$ HCl	Environment Canada 1995
		LC_{25}	350					
	(49% reduction)	LOEC	490					
		LC_{50}	500					
		NOEC	250		4.0	artificial soil 6.3% O.M.		
		LC_{25}	470					
		LC_{50}	720					
		NOEC	200		4.1	artificial soil 10.4% O.M.		
		LC_{25}	280					
		LC_{50}	400					

Organism	Effect (% decrease)	Endpoint*	Concentration (mg·kg⁻¹)	Form of Zn (exposure period	Soil pH	Test Substrate	Extraction Method	Reference
Earthworm *Eisenia fetida*	mortality	NOEC	500	$ZnCl_2$ (14 d)	4.2	artificial soil 4.7% O.M.	$HNO_3 + H_2O_2 +$ HCl	Environment Canada
		LC_{25}	700					
		LC_{50}	800					
		NOEC	400		4.0	artificial soil 6.3% O.M.		
		LC_{25}	500					
		LC_{50}	700					
		NOEC	300		4.1	artificial soil 10.4% O.M.		
		LC_{25}	500					
	(40% mortality)	LOEC	600					
		LC_{50}	700					
Beech *Fagus grandifolia*	shoot growth (21% reduction)	EC	65.4	$ZnSO_4$ (1 year)	4.8	mix: sand/peat/forest soil	nominal	Hagemeyer et al. 1993
	shoot growth (39% reduction)	EC	65.4	(2 years)				
Blackgram *Vigna mungo*	yield (22% reduction)	EC	200	$ZnSO_4$ (65 d)	6.2	NR	nominal	Kalyanaraman and Sivagurunathan 1994
	yield (45% reduction)	EC	250					
Corn *Zea mays*	yield (13% reduction)	EC	303	$ZnSO_4$ (6 weeks)	4.9	fine sandy loam 16% clay 1.9% O.M.	$HNO_3 + HClO_4$ + HF	MacLean 1974
		NOEC	329		7.5	sandy loam 16% clay 2.4% O.M.		
		NOEC	328		7.2	sandy loam 13.3% clay 5.6% O.M.		
Lettuce *L. sativa*	dry matter yield	NOEC	329	$ZnSO_4$ (5 weeks)	7.5	sandy loam 16% clay 2.4% O.M.	$HNO_3 + HClO_4$ + HF	MacLean 1974
		NOEC	328		7.2	sandy loam 13.3% clay 5.6% O.M.		
Alfalfa *Medicago sativa*	dry matter yield	NOEC	329	$ZnSO_4$ (16 weeks)	7.5	sandy loam 16% clay 2.4% O.M.	$HNO_3 + HClO_4$ + HF	MacLean 1974
		NOEC	328		7.2	sandy loam 13.3% clay 5.6% O.M.		
Corn *Zea mays*	yield	EC_{50}	240	$ZnSO_4$ (7 weeks)	5.5	sandy loam	nominal	Mortvedt and Giordano 1975
Rice *Oryza sativa*	yield (23% reduction)	EC	10 000	ZnO (15 weeks)	5.95	alluvial soil	nominal	Muramoto et al 1990

Organism	Effect (% decrease)	Endpoint*	Concentration (mg·kg^{-1})	Form of Zn (exposure period	Soil pH	Test Substrate	Extraction Method	Reference
Earthworm *E. fetida*	mortality	LC_{50}	662	$Zn(NO_3)_2$ (14 d)	6.0	artificial sandy loam 10% O.M. 20% clay	nominal	Neuhauser et al 1985
Turnip *Brassica rapa*	first bloom seed yield seedling emergence	EC_{50} EC_{50} NOEC	600 715 1000	$ZnSO_4$	7.3	clay 8.9% O.M. 46% clay	HCl + HNO_3 (ICP)	Sheppard et al. 1993
	first bloom seed yield seedling emergence	EC_{50} EC_{50} EC_{50}	25 25 65		6.3	sand, negligible O.M.,3% clay		
	first bloom seed yield seedling emergence	EC_{50} EC_{50} EC_{50}	600 600 600		7.9	silty clay 2.7% O.M. 43% clay		
Lettuce *L. sativa*	seedling emergence	NOEC	1000	$ZnSO_4$	7.3	clay 8.9% O.M. 46% clay	HCl + HNO_3 (ICP)	Sheppard et al. 1993
		EC_{50}	207		6.3	sand negl. O.M. 3% clay		
		NOEC	1000		7.9	silty clay 2.7% O.M. 43% clay		
Earthworm *E. fetida*	mortality	LC_{50}	80	$ZnSO_4$ (30 d)	7.3	clay, 8.9% O.M., 46% clay	HCl + HNO_3 (ICP)	Sheppard et al. 1993
		LC_{50}	460		6.3	sand, negl. O.M., 3% clay		
		LC_{50}	600		7.9	silty clay, 2.7% O.M., 43% clay		
Spinach *Spinacea oleracea*	yield (27% reduction)	EC NOEC	80 20	$ZnSO_4$ (growing season)	4.2	sand, 4.4% O.M., 3% clay	H_2SO_4 / HNO_3	Smilde et al. 1992
		NOEC	160		7.2	loam, 4.4% O.M., 40% clay		
Earthworm *E. fetida*	mortality	LC_{50} LC_{50} NOEC	1010 745 289 (est.)	$Zn(NO_3)_2$ (56 d)	6.3	artificial sandy loam 10% O.M. 20% clay	HNO_3	Spurgeon et al. 1994
	cocoon production	EC_{50} NOEC	276 199 (est.)					

Organism	Effect (% decrease)	Endpoint*	Concentration (mg·kg⁻¹)	Form of Zn (exposure period	Soil pH	Test Substrate	Extraction Method	Reference
Earthworm *E. fetida*	cocoon production (31% reduction)	EC EC_{50}	560 659	$ZnCl_2$ (3 weeks)	6.0	artificial sandy loam 10% O.M. 20% clay	HNO_3 / HCl	van Gestel et al. 1993
	number of juveniles produced/worm	EC_{50}	512					
	body weight gain	NOEC	320					
	reproduction	NOEC	320					

* The EC endpoints represent the effects concentration as calculated by the CCME from the data presented by the author(s).
NR = not reported
negl. = negligible
est. = estimated

Table 11: Selected livestock and wildlife toxicological studies for zinc

Organism	Effect (% decrease)	Endpoint *	Diet Concentration ($mg \cdot kg^{-1}$)	Average Dose $mg \cdot kg^{-1}$ $BW \cdot d^{-1}$	Form of Zinc (exposure period)	Reference
Cheviot sheep	number of viable offspring (64%) feed consumption (24%) body weight gain during pregnancy (67%)	EC	750	20 for 10 days 10 for final 10 weeks	$ZnSO_4$ (80 days)	Campbell and Mills 1979
Sheep	body weight gain (33%) feed consumption (15%)	EC	2000	76.7 (calc.)	ZnO (10 weeks)	Ott et al. 1966
	body weight gain (16%)	LOAEL	1000	42.4 (calc.)		
	feed consumption (13%)	LOAEL	1500	57.2 (calc.)		
Sheep	body weight gain (43%) enlarged & pale kidneys (NQ) decreased liver copper content (NQ)	EC	134.3	33.6 (calc.)	ZnO (33 days)	Davies et al. 1977
Poultry	body weight (35%)	EC	5280	1074 (calc.)	ZnO (28 days)	Dean et al. 1991
Poultry	development of pancreatic lesions (38%) increased zinc liver concentration (NQ)	LOAEL	1000	65.7 (calc.)	ZnO (28 days)	Dewar et al. 1983
Rats	urine excretion (72%)	EC	NR	320 †	Zn acetate (3 months)	Llobet et al. 1988

* : the EC endpoints represent the effects concentration as calculated by the CCME from the data presented by the author(s).
calc.: calculated from data reported by the author(s).
† : as reported by the author(s)

Table 12: Summary of Soil Quality Guideline Derivation for Zinc

Guideline	LAND USE		
	Agriculture (mg/kg)	Residential/Parkland (mg/kg)	Commercial/Industrial (mg/kg)
TEC or ECL	200	200	410
Nutrient and energy cycling check	320	320	320
SQG_{SC}	200	200	360
SQG_{I}	640	Not applicable	Not applicable
SQG_{E}	200	200	360
Interim Remediation Criteria (CCME 1991)	600	500	1500

NA: not applicable

APPENDIX 1

Appendix 1: Data on the accumulation of zinc in terrestrial plant tissues.

SPECIES	TISSUE TYPE	pH	SOIL TYPE	n	Zinc in TISSUE (mg/kg dw)	Zinc in SOIL (mg/kg dw)	BCF†	LOG (BCF+1)‡	REFERENCE
GRAMINAEAE FAMILY									
Corn *(Zea mays)*	shoot	7.1	sand-loam	5	484	1425	0.34	0.13	Jones et al. 1987
	root	7.1		5	1330	1425	0.93	0.29	
	shoot	7.2		5	25.3	67.3	0.38	0.14	
	root	7.2		5	21	67.3	0.31	0.12	
	root	5.8	sandy loam	4	34.6	49.7	0.70	0.23	Petruzzelli et al. 1989
	leaves	6.2	silt loam	4	59	78	0.76	0.25	Hinesly et al. 1976
		6.2		4	122	173	0.71	0.23	
		6.2		4	193	264	0.73	0.24	
		6.2		4	293	460	0.64	0.21	
		5.3		4	328	360	0.91	0.28	
Ryegrass *(Lolium perenne, cv Melle)*	shoot	5.1	loam	4	450	970	0.46	0.17	Smith 1994
		4.4		5	630	1473	0.43	0.15	
		5.3		5	370	1473	0.25	0.10	
		5.9		5	270	1473	0.18	0.073	
		6.0		5	260	1473	0.18	0.071	
		6.2		5	250	1473	0.17	0.068	
		6.8		5	195	1473	0.13	0.054	
		5.9		4	320	970	0.33	0.12	
		6.2		4	330	970	0.34	0.13	
		6.5		4	280	970	0.29	0.11	
		6.6		4	285	970	0.29	0.11	
		6.9		4	230	970	0.24	0.09	
Barley *(Hordeum vulgare)*	leaves	7.9	very fine	4	23.2	63.6	0.36	0.13	Viets et al. 1954
		8.2	sandy loam	4	20.3	67.6	0.30	0.11	
Wheat *(Triticum aestivum)*	leaves	7.9	very fine	4	14.1	63.6	0.22	0.086	Viets et al. 1954
		8.2	sandy loam	4	15.0	67.6	0.22	0.086	
Oats *(Avena sativa)*	leaves	7.9	very fine	4	10.5	63.6	0.17	0.068	Viets et al. 1954
		8.2	sandy loam	4	12.1	67.6	0.18	0.072	
CRUCIFERAE FAMILY									
Radish *(Raphanus sativus)*	shoot	6.0	N.R.	46	209	547	0.38	0.14	Davies 1992
	root	6.0		46	139	547	0.071	0.030	
	leaves	7.1	garden soil	5	549	1425	0.38	0.14	Jones 1982
		7.1		5	49	143	0.34	0.13	
		7.1		5	42	68	0.62	0.21	
	roots	7.1		5	167	1425	0.12	0.049	
		7.1		5	37	143	0.26	0.10	
		7.1		5	27	68	0.40	0.15	
LEGUMINEAE FAMILY									

SPECIES	TISSUE TYPE	pH	SOIL TYPE	n	Zinc in TISSUE (mg/kg dw)	Zinc in SOIL (mg/kg dw)	BCF†	LOG (BCF+1)‡	REFERENCE
Soybean (*Glycine max*)	shoot	6.4	silt loam	4	1090	1165	0.94	0.29	Pierzynski and Schwab 1993
		6.3		4	923	933	0.99	0.30	
		6.4		4	725	1076	0.67	0.22	
		6.3		4	768	933	0.82	0.26	
		6.4		4	965	1076	0.90	0.28	
	roots	6.4		4	1248	1076	1.16	0.33	
	leaves	7.9	very fine	4	19.1	63.6	0.30	0.11	Viets et al. 1954
		8.2	sandy loam	4	16.4	67.6	0.24	0.093	
Lima beans (*Phaseolus vulgaris*)	leaves	7.9	very fine	4	18.3	63.6	0.29	0.11	Viets et al. 1954
		8.2	sandy loam	4	15.2	67.6	0.22	0.086	
Safflower (*Carthamus tinctorius*)	leaves	7.9	very fine	4	14.1	63.6	0.22	0.086	Viets et al. 1954
		8.2	sandy loam	4	9.3	67.6	0.14	0.057	
Alfalfa (*Medicago sativa*)	whole shoot	7.9	very fine	4	16.8	63.6	0.26	0.10	Viets et al. 1954
		8.2	sandy loam	4	15.6	67.6	0.23	0.090	
Red Clover (*Trifolium pratense*)	whole shoot	7.9	very fine	4	13.4	63.6	0.21	0.083	Viets et al, 1954
		8.2	sandy loam	4	12.0	67.6	0.18	0.072	
COMPOSITAE FAMILY									
Lettuce (*Lactuca sativa*)	leaves	7.1	garden soil	5	272	1425	0.19	0.076	Jones 1982
		7.1		5	64	143	0.45	0.16	
		7.1		5	56	68	0.82	0.26	
	roots	7.1		5	673	1425	0.47	0.17	
		7.1		5	42	143	0.29	0.11	
		7.1		5	41	68	0.60	0.20	
CHENOPODIACEA FAMILY									
Sugarbeet (*Beta vulgaris*)	leaves	7.9	very fine	4	19.2	63.6	0.30	0.11	Viets et al, 1954
		8.2	sandy loam	4	22.5	67.6	0.33	0.12	
SOLANACEA FAMILY									
Potato (*Solanum tuberosum*)	leaves	7.9	very fine	4	17.7	63.6	0.28	0.11	Viets et al, 1954
		8.2	sandy loam	4	16.9	67.6	0.25	0.097	

SPECIES	TISSUE TYPE	pH	SOIL TYPE	n	Zinc in TISSUE (mg/kg dw)	Zinc in SOIL (mg/kg dw)	BCF†	LOG (BCF+1)‡	REFERENCE
WOODY PLANTS									
Red Maple seedlings *(Acer rubrum)*	whole plant	3.7 5.2 4.7 3.7 5.2 4.7	sandy peat	5 5 5 7 7 7	137 280 225 37.2 55.8 228.8	37.1 328.9 212.8 37.1 328.9 212.8	3.69 0.85 1.06 1.00 0.17 1.08	0.67 0.27 0.31 0.30 0.068 0.32	Vedagiri and Ehrenfeld 1991
Cranberry *(Vaccinium macrocarpon)*	whole plant	3.7 5 4.7	sandy peat	5 5 5	180 52 60	37.1 328.9 212.8	4.85 0.16 0.28	0.77 0.064 0.11	Vedagiri and Ehrenfeld 1991
Alder *(Alnus sp.)*	leaves	4.3 4.6 4.2 4.4 4.6 5.5 4.9	sandy loam	6 6 6 6 6 6 6	53 69 289 226 145 55 145	80 90 627 207 87 80 153	0.66 0.77 0.46 1.09 1.67 0.69 0.95	0.22 0.25 0.16 0.32 0.43 0.23 0.29	Hogan and Wotton 1984
Labrador Tea *(Ledum groenlandicum)*	leaves	4.2 4.4 4.6 5.5 6.9 4.9 4.3 4.6	sandy organic	6 6 6 6 6 6 6 6	324 166 223 60 376 150 74 61	627 207 87 80 2133 153 80 90	0.52 0.80 2.56 0.75 0.18 0.98 0.93 0.68	0.18 0.26 0.55 0.24 0.072 0.30 0.29 0.23	Hogan and Wotton 1984
Jack Pine *(Pinus banksiana)*	leaves	4.2 4.4 4.6 5.5 4.9 4.3 4.6	sandy loam	6 6 6 6 6 6 6	363 294 201 95 184 137 75	627 207 87 80 153 80 90	0.58 1.42 2.31 1.19 1.20 1.71 0.83	0..20 0.38 0.52 0.34 0.34 0.43 0.26	Hogan and Wotton 1984
Black Spruce (Picea mariana)	leaves	4.2 4.4 4.6 5.5 4.9 4.3 4.6	sandy loam	6 6 6 6 6 6 6	227 165 163 76 132 120 62	627 207 87 80 153 80 90	0.36 0.80 1.87 0.95 0.86 1.5 0.69	0.13 0.26 0.46 0.29 0.27 0.40 0.23	Hogan and Wotton 1984

† BCF: bioconcentration factor
‡ log BCF: log bioconcentration factor
NR: not reported

APPENDIX 2

Appendix 2: Summary of statistical measures for the BCFs surveyed for zinc.

	n	Mean	Stan. Dev	0%	25th %	Median	75th %	100th %	Range	Shapiro-Wilk test
leaves	56	0.72		0.14	0.30	0.66	0.91	2.56	2.42	not normal
transformed	*56*	*0.22*	0.12	*0.057*	*0.11*	*0.22*	*0.28*	*0.55*	*0.49*	*normal*
shoots	24	0.40		0.13	0.21	0.29	0.43	0.99	0.86	not normal
transformed	*24*	*0.14*	0.08	*0.054*	*0.083*	*0.12*	*0.17*	*0.30*	*0.25*	*normal*
roots	11	0.48		0.071	0.26	0.40	0.60	1.16	1.09	not normal
transformed	*11*	*0.16*	0.09	*0.030*	*0.10*	*0.15*	*0.20*	*0.33*	*0.30*	*normal*
whole plant	9	1.46		0.16	0.28	1.0	1.08	4.85	4.69	not normal
transformed	*9*	*0.32*	0.25	*0.064*	*0.11*	*0.30*	*0.32*	*0.77*	*0.71*	*normal*
Total	100									

The geometric mean of all BCFs is 0.45, calculated by using the log BCF.

† BCF = bioconcentration factor
‡ log BCF = log (bioconcentration factor + 1)
* from method outlined in Procedure for the calculation of a soil-to-plant bioconcentration factor for use within the derivation of the soil quality criterion for food ingestion (SQC_{FI}), January, 1994

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