



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

**Zinc
2018**

Zinc (Zn, CAS 7440-66-6) is a transition metal with an atomic number of 30 and an atomic weight of 65.38. It is divalent and tends to strongly react with organic and inorganic compounds. It forms stable combinations with many organic substances, including humic and fulvic acids and a wide range of biochemical compounds. Metallic zinc is itself insoluble, while zinc compounds range from insoluble to extremely soluble.

Human releases of zinc into the environment come from sources such as 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, intensive animal production, erosion of agricultural soils, and tire debris. A total of 1,085 tonnes of zinc and zinc compounds were released to Canada's environment by major industrial sources in 2013, of which 476 tonnes were released to the air, 255 tonnes to water and 354 tonnes to land (Environment and Climate Change Canada 2015). The major emitters were metallurgical facilities. These numbers include data only for large facilities and therefore may not represent all emissions. Improvements in manufacturing processes are reducing human releases of zinc.

Worldwide, human and non-human sources release roughly equal amounts of zinc into the environment. Natural processes release an estimated 4,600 tonnes of zinc to Canada's atmosphere each year. The largest natural source to the atmosphere is wind-blown dust, although emissions from sea-salt spray may also be significant, particularly in coastal regions. Forest fires can also be a source of natural zinc emissions. Erosion is the largest natural source of zinc to surface water.

Canada is geologically diverse, and average soil background concentrations and ranges vary regionally. For the derivation of the human health soil quality guideline, the average background concentration used for Canada was 48.1 mg/kg (Grunsky 2010a; Rencz *et al.* 2006). Table 2 summarizes other Canadian sampling data (more data can be found in CCME 2018).

Due to the complexity of zinc interactions in soil, zinc transport behaviour in soil cannot be predicted accurately and soil adsorption effects cannot be separated from solution effects such as precipitation (World Health Organization 2001). Zinc is highly reactive in soils. Its mobility in soil is affected by factors such as soil pH, clay mineralogy, soil organic matter content, rainfall and infiltration, and soil drainage, with pH being the main factor. Zinc may precipitate as a hydroxide at pH values above 8.0. It may also form stable organic complexes, and these can affect its mobility or solubility. Under anaerobic conditions, it can form immobile precipitates such as zinc sulphide. Zinc becomes more soluble as pH decreases, and so zinc leaches more readily from acidic soils.

Table 1. Soil Quality Guidelines for Zinc (mg/kg)

Guideline	Land use			
	Agricultural	Residential/ parkland	Commercial	Industrial
	250^a	250^a	410^a	410^a
Human health soil quality guideline	10,000	10,000	16,000	140,000
Limiting pathway	Direct contact	Direct contact	Direct contact	Off-site migration
Environmental soil quality guideline	250	250	410	410
Limiting pathway	Soil contact	Soil contact	Nutrient and energy-cycling check	Nutrient and energy-cycling check

^a Data are sufficient and adequate to calculate guidelines for human health and environmental health. Therefore, the soil quality guideline is the lower of the two and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

Table 2. Background Soil Concentrations of Zinc in the Canadian Environment (mg/kg)

Value or range	Sampling location	Depth	Reference
48.1 (mean)	Newfoundland and Labrador, New Brunswick, Québec, Nunavut, Northwest Territories, Manitoba, Saskatchewan, Alberta and British Columbia	till	Grunsky 2010a; Rencz <i>et al.</i> 2006
51.5 (mean)	New Brunswick, Nova Scotia and Prince Edward Island	0–5 cm	Grunsky 2010b
41.25 (median)		A horizon	
56.3 (mean)			
47.2 (median)			
160 (rural) 180 (urban)	Ontario, old urban and rural parklands not impacted by local point sources of pollution (Ontario Typical Range)	0–5 cm	Ontario Ministry of the Environment 2011
34-57 120	Mining and smelting regions (uncontaminated soil); Sudbury, Ontario Rouyn-Noranda, Québec	0–10 cm	Feisthauer <i>et al.</i> 2006
100 184	Uncontaminated organic soil; Sudbury, Ontario Rouyn-Noranda, Québec	FH horizon	Johnson and Hale 2004
55	Northwest Alberta, agricultural soils (Beaverlodge Research Station)	surface horizons	Soon 1994
94 81	Northwest Alberta, agricultural soils	0–20 cm	Soon and Abboud 1990
		20–35 cm	
74–107	Saskatchewan, agricultural areas	0–18 cm	Lipoth and Schoenau 2007
15.5–137	British Columbia (Mount Robson Provincial Park)	0–25 cm	Arocena <i>et al.</i> 2006
94.1	British Columbia (Trail)	0–15 cm	Sanei <i>et al.</i> 2007

Bioavailability of zinc varies depending on the physical-chemical properties of the zinc species and the surrounding environment and is determined by the amount of soluble zinc present. Bioavailability may also decrease with time as zinc gets adsorbed to soil and forms complexes with the surrounding material.

Within a given soil, equilibrium exists between the different forms of zinc (adsorbed, exchangeable, secondary minerals, insoluble complexes) in the liquid and solid soil phases. Plant uptake, losses by leaching, input of zinc in various forms, changes in the moisture content of the soil, pH changes, mineralization of organic matter and changing redox potential of the soil will all influence the equilibrium.

Behaviour and Effects in Biota

Zinc is an essential element for plant and animal life. However, too much zinc can be harmful. Wildlife and livestock are sensitive to high concentrations of zinc in their diet. 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 and diarrhea. Table 3 summarizes zinc toxicity effects in other biota (more data can be found in CCME 2018).

Table 3. Effects of Zinc in Non-Human Biota

Taxon	Effect value (mg/kg in soil)	Effects	Reference
Bacteria	10	21% reduction in carbon dioxide respiration	Cornfield 1977
Bacteria	327	24% inhibition of nitrification	Liang and Tabatabai 1978
Bacteria	2,377 (median of 8 soils)	50% reduction in respiration	Broos <i>et al.</i> 2007
Turnip	25 (at pH 6.3)	50% reduction in seed yield	Sheppard <i>et al.</i> 1993
Barley	240-7300 (9 soils)	50% reduction in growth	Hamels <i>et al.</i> 2014
<i>Lumbricus terrestris</i> (earthworm)	80	Death; value given is the LC ₅₀	Sheppard <i>et al.</i> 1993
<i>Eisenia fetida</i> (earthworm)	500	12-20% reduction in reproduction	Owojori <i>et al.</i> 2009
Cheviot sheep	750 (mg/kg in food)	64% reduction in the number of viable offspring	Campbell and Mills 1979

Health Effects in Humans and Experimental Animals

High exposure to zinc can have a wide variety of effects, such as gastrointestinal distress and deficiencies of other nutrients, notably copper. These have been noted in both laboratory animals and people. However, zinc is an essential element, and zinc deficiency also causes harm.

Tolerable upper intake levels consider risks both from nutrient deficiencies and from toxicity, as well as variability among individuals. For essential trace elements like zinc, a safe range of intakes

between deficiency and toxicity is generally represented by a U-shaped “dose-response” or risk-probability curve. Tolerable upper intake levels are not specific data points from any particular dose-response study, but are derived using well-established principles.

No major health agency currently provides carcinogenic toxicological reference values for zinc, and instead all agencies reviewed consider zinc to be a non-carcinogen for the purposes of evaluation of health effects. Therefore, the human health soil quality guidelines were based on non-cancer end points. Zinc’s potential effect on human copper status is the key concern of health agencies.

For adults, the Institute of Medicine estimated a tolerable upper intake level based on a lowest observed adverse effect level of 60 mg/day of zinc from several studies (Institute of Medicine 2001). The institute applied an uncertainty factor of 1.5 to account for variability between individuals and for the extrapolation from low effect to no effect. This calculation resulted in a tolerable upper intake level from food, water and supplements of 40 mg/day for adults. For younger age groups, the institute’s limits have been adopted based on known zinc intake levels that are associated with no adverse effects, without the use of additional uncertainty factors. For toddlers, the tolerable upper intake level is 4 to 12 mg/day depending on the age group.

For this assessment, the Canadian Council of Ministers of the Environment (CCME) adopted the Institute of Medicine’s tolerable upper intake levels as the tolerable daily intakes for zinc after adjustment to be consistent with CCME default body weights. Therefore tolerable daily intakes of 0.48 mg/kg of body weight per day for toddlers and 0.57 mg/kg for adults were used in developing the soil quality guideline for human health.

Guideline Derivation

CCME derives Canadian soil quality guidelines for four different land uses using different receptors and exposure scenarios for each land use (see Table 1). Table 4 provides the soil quality guidelines and check values for all uses. Detailed derivations for zinc soil quality guidelines are provided in the scientific criteria document for zinc (CCME 2018).

Soil Quality Guidelines for Environmental Health

CCME bases environmental soil quality guidelines on soil contact data from toxicity studies on plants and invertebrates. To provide a broader scope of protection, a nutrient and energy-cycling check is calculated. Impacts to surface water bodies from zinc-contaminated soil should be addressed on a site-specific basis. In the case of agricultural land use, soil and food ingestion toxicity data for mammalian and avian species are included. For commercial and industrial land uses, an off-site migration check is calculated. For all land uses, the lowest of the applicable guideline and check values becomes the overall guideline.

Soil Quality Guidelines for Human Health

Health Canada (CCME 2018; Health Canada 2011) estimated daily intakes for the Canadian population on the basis of the estimated average exposure to concentrations of zinc in uncontaminated environmental media. These estimates do not include exposures that may occur from contaminated sites or activities that may result in increased exposure. The estimated daily intakes are 0.545 mg/kg of body weight per day for toddlers and 0.178 mg/kg body weight per day for adults. These are considered background exposure.

For protection against non-cancer effects, CCME typically bases Canadian soil quality guidelines on the residual tolerable daily intake, where the residual intake refers to the tolerable daily intake less the estimated daily (background) intake. However, in the case of zinc exposure in toddlers, the estimated daily intake is greater than the tolerable daily intake and results in a negative residual tolerable daily intake. In these cases (that is, for all land uses other than industrial in the case of zinc), the soil quality guideline for human health may be set at the background soil concentration. However, Health Canada has established a procedure (Health Canada 2011) for these situations whereby the guideline can be based on a residual tolerable daily intake that is the lower of either 10 percent of the estimated daily intake or 20 percent of the tolerable daily intake.

In the case of zinc at agricultural, residential/parkland and commercial sites (land uses where toddlers are assumed to be present on a regular basis), the guideline was developed based on 10 percent of the estimated daily intake, since it provides a more conservative value than 20 percent of the tolerable daily intake. For industrial sites, where only adults are present, the estimated daily intake does not exceed the tolerable daily intake. Thus, no adjustment is necessary, and the residual tolerable daily intake was used.

CCME derived no guideline for zinc for protection of groundwater that is used as a source of drinking water, due to constraints on the mathematical model when applied to inorganic compounds. Nor was a produce, meat and milk check carried out, since zinc exhibits very limited potential for food web mediated transfer, and organisms are able to regulate zinc levels in their tissues.

The human health-based soil quality guidelines for agricultural, residential/parkland and commercial land uses are based on direct contact with zinc in soils. The off-site migration check value is lower than the industrial soil quality guideline but higher than the commercial guideline. Therefore, only the industrial soil quality guideline is based on the off-site migration check.

Soil Quality Guidelines for Zinc

The final soil quality guideline for each land use is the lowest of the human health soil quality guideline and the environmental soil quality guideline.

Sufficient data were available to calculate both environmental and human health guidelines. Therefore, the soil quality guidelines in Table 1 supersede the previous zinc soil quality guidelines developed in 1999 and the 1991 interim remediation criteria for soil. CCME (1996) has provided

guidance on potential modifications to the recommended soil quality guidelines when setting site-specific objectives.

Table 4. Soil Quality Guidelines and Check Values for Zinc (mg/kg).

Guideline	Land use			
	Agricultural 250 ^a	Residential/ parkland 250 ^a	Commercial 410 ^a	Industrial 410 ^a
Human health guidelines/check values				
Soil quality guideline	10,000	10,000	16,000	140,000
Direct contact guideline ^b	10,000	10,000	16,000	270,000
Inhalation of indoor air check ^c	NC	NC	NC	NC
Off-site migration check	—	—	140,000	140,000
Groundwater check (drinking water) ^d	NC	NC	NC	NC
Produce, meat and milk check ^e	NC	NC	—	—
Environmental health guidelines/check values				
Soil quality guideline	250	250	410	410
Soil contact guideline	250	250	450	450
Soil and food ingestion guideline	960	—	—	—
Nutrient and energy-cycling check	280	280	410	410
Off-site migration check	—	—	2,900	2,900
Groundwater check (aquatic life) ^d	NC	NC	NC	NC
1999 zinc soil quality guideline (Environment Canada 1996)	200	200	360	360
Interim remediation criteria for soil (CCME 1991)	600	500	1,500	1,500

Notes: NC = not calculated

The dash indicates guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

^a Data are sufficient and adequate to calculate an environmental and health guideline. Therefore, the soil quality guideline is the lower of the two, and supersedes the 1999 soil quality guideline and the 1991 interim remediation criteria for soil.

^b The direct human health-based soil quality guideline is based on direct exposure to soil by ingestion, dermal contact and particulate inhalation.

^c The inhalation of indoor air check applies to volatile organic compounds and is not calculated for metal contaminants.

^d Applies to organic compounds and is not calculated for metal substances. Concerns about metal contaminants should be addressed on a site-specific basis.

^e This check is intended to protect against chemicals that may bioconcentrate in human food. Zinc is not expected to exhibit this behaviour, and therefore this pathway was not evaluated.

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