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

Lead

2025

This factsheet is a revision of the 1999 Canadian soil quality guidelines for lead (Pb) factsheet and provides Canadian soil quality guidelines for lead for the protection of environmental and human health (Tables 1 and 2). It provides updated soil quality guidelines for human health, while the soil quality guidelines for environmental health have not been revised. Scientific criteria documents describe the derivation of the soil quality guidelines for human health (Canadian Council of Ministers of the Environment [CCME] 2025) and for environmental health (Environment Canada [EC] 1999). The soil quality guidelines in this document are considered provisional because the toxicological risk values on which they are based are considered provisional. Human health-based guidelines are provided to protect for two risk specific dose levels (RSD of 0.5- and 1-IQ point decrements), given that no threshold for risks has been identified for lead.

The guidelines in this factsheet are for general guidance only. Site-specific conditions should be considered before applying these values. The values may be applied differently in various jurisdictions. The use of some of the values listed in Tables 1 and 2 may not be permitted at the generic level in some jurisdictions. CCME recommends using the provisional soil quality guideline for human health ($PSoQG_{HH}$) for a 0.5-IQ point decrement RSD where soil and additional site-related media contain elevated concentrations of lead (e.g., groundwater, food grown on site, etc.) to allow for additional sources of elevated exposure and/or according to jurisdictional policy. CCME recommends using the $PSoQG_{HH}$ for a 1-IQ point decrement RSD when soil is the only site-related media with elevated concentrations of lead. Where additional site-related contaminated media are expected to contribute to exposures (e.g., groundwater, food grown on site, etc.), CCME recommends using the 0.5-IQ point decrement RSD to allow for additional sources of elevated exposure. When using the $PSoQG_{HH}$ based on the 1-IQ point decrement, the environmental site investigation report should include information on all media that may be affected above background levels, as well as fate and transportation information. The reader should consult the appropriate jurisdiction before applying the values.

Background Information

Lead (CAS# 7439-92-1) is an odourless, bluish-grey, lustrous metal that is malleable, ductile, and resistant to chemical corrosion. It is a post-transition metal (Group IVA) (14), with an atomic number of 82, an atomic weight of 207.2 (O'Neil 2001), a melting point of 327.4°C and a boiling point of 1740°C at atmospheric pressure (Agency for Toxic Substances and Disease Registry [ATSDR] 2007*a*).

Table 1. Soil quality guidelines for lead (mg/kg)

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
$PSoQG_F$[c]				
0.5-IQ pt decrement[a]	61	61	82	600
1-IQ pt decrement[b]	70	113	154	600
$PSoQG_{HH}$				
0.5-IQ pt decrement[a]	61	61	82	743
1-IQ pt decrement[b]	113	113	154	1,477
Limiting pathway for $PSoQG_{HH}$	Direct contact	Direct contact	Direct contact	Off-site migration
$SoQG_E$	70	300	600	600
Limiting pathway for $SoQG_E$	Soil and food ingestion	Soil contact	Soil contact	Soil contact

Notes: $PSoQG_F$ = provisional final soil quality guideline; $PSoQG_{HH}$ = provisional soil quality guideline for human health; $SoQG_E$ = soil quality guideline for environmental health. Soil guidelines and the data used to calculate them are, by convention, always expressed on a dry weight basis to allow the data to be standardized. In case of doubt and if the scientific criteria document does not specify whether wet or dry weight is used, readers are advised to check the references provided.

[a] CCME recommends using the $PSoQG_{HH}$ for a 0.5-IQ point decrement when soil and additional site-related media contain elevated concentrations of lead (e.g., groundwater, food grown on site, etc.) to account for additional sources of elevated exposure and/or according to jurisdictional policy.

[b] CCME recommends using the $PSoQG_{HH}$ for a 1-IQ point decrement when soil is the only site-related media with elevated concentrations of lead. Where additional site-related contaminated media are expected to contribute to exposures (e.g., groundwater, food grown on site, etc.), CCME recommends using the 0.5-IQ point decrement to account for additional sources of elevated exposure. When using the $PSoQG_{HH}$ based on 1-IQ point decrement, the environmental site investigation report should include information on all media that may be affected above background and fate and transport information.

[c] Data are sufficient and adequate to calculate a $PSoQG_{HH}$ and an $SoQG_E$, the lower of which becomes the provisional final soil quality guideline for each land use.

Lead exists in three oxidation states: elemental lead (Pb^0), Pb^{2+}, and Pb^{4+} (Canadian Council of Resource and Environment Ministers [CCREM] 1987; Reimann and de Caritat 1998). The water solubility of lead salts ranges broadly and depends on the associated anions. For example: $Pb(NO_3)_2$ and $C_4H_6O_4Pb$ are water soluble, whereas $PbCO_3$, $Pb_3(PO_4)_2$, $PbSO_4$, and PbS are relatively insoluble (Ontario Ministry of the Environment and Energy [OMEE] 1994).

Lead can form chelated compounds with calcium disodium ethylenediaminetetraacetate (calcium disodium EDTA) [used to treat lead poisoning], as well as with various nucleotide- and peptide-containing compounds (OMEE 1994). Lead readily alloys with other metals such as tin, antimony, copper, and zinc.

Of the heavy metals with atomic numbers > 60, lead is the most abundant in the earth's crust (Adriano 2001; World Health Organization [WHO] 2010*a*). Lead occurs naturally in bedrock, soils, tills, sediments, surface waters, groundwater, and seawater (Reimann and de Caritat 1998). As a result, lead also occurs naturally at low levels in foods due to uptake from soil into plants, particulate deposition onto plants, uptake from water and sediments into fish, and uptake into animals through their diets (Adriano 2001). While naturally occurring in food, lead may also be introduced during food processing, thus contributing to dietary exposure (U.S. Food and Drug Administration [US FDA] 2022).

Elemental lead is rare in nature, where it predominately exists in its divalent state combined with organic and inorganic compounds such as galena (PbS), anglesite ($PbSO_4$), cerussite ($PbCO_3$), pyromorphite ($Pb_5(PO_4)_3Cl$) and mimetesite ($Pb_5(AsO_4)_3Cl$) (ATSDR 2007*a*; Reimann and de Caritat 1998). Lead coexists in ore deposits with other metals, particularly zinc, copper, and cadmium (Adriano 2001; Reimann and de Caritat 1998).

Numerous anthropogenic sources produce lead. According to Environment and Climate Change Canada's (ECCC) National Pollutant Release Inventory (NPRI) database, approximately 223,000 kg of lead and lead compounds were released into the Canadian environment in 2019 (93,000 kg to air, 9,800 kg to water, and 120,000 kg to land) (ECCC 2020). The mining and metals production industries released approximately 60% of air emissions, and Canadian military bases accounted for approximately 96% of the releases to land (ECCC 2018). However, NPRI does not represent all industrial releases or sources (e.g., lead in products such as shot and sinkers).

Researchers have estimated that anthropogenic lead emissions have exceeded natural emissions by one to two orders of magnitude (Flegal *et al.* 1990; Jaworski *et al*. 1987). Given the nature of the main sources of emissions and discharges, most environmental impacts of lead tend to be relatively localized (Ewers and Schipköter 1991). Lead concentrations in source water (e.g., rivers, lakes and groundwater) are typically very low (HC 2019). However, lead can be introduced into drinking water after it leaves treatment plants from lead service lines, connection pipes, internal domestic plumbing, storage tanks and plumbing fixtures (ATSDR 2007*a*; *b*; HC 2019; Sannolo *et al.* 1995*a*).

Prior to the 1990s, organic lead compounds, including $Pb(C_2H_5)_4$ and $Pb(CH_3)_4$, were widely used as anti-knock additives in fuels in North America. Since the prohibition of leaded fuel, the principal sources of anthropogenic lead include releases from the non-ferrous smelting and refining industry, and the mining and smelting of lead and other ores in which lead is a byproduct or contaminant (ATSDR 2007*a*; EC 2020; International Programme for Chemical Safety [IPCS] 1995; United Nations Environment Programme [UNEP] 2010). In Canada, Avgas represents the third-largest source of lead emissions (EC 2020), while competition vehicles (such as Formula 1 cars) represent 0.3% of lead emissions from all sources. Electrical utilities also release lead into the environment in flue gas by burning lead-contaminated fuels, such as coal (ATSDR 2007*a*).

Both soluble and insoluble lead compounds have a variety of industrial uses and have been added to a broad range of products including plumbing pipes and fixtures, batteries, paint and plastics, cable sheathing, circuit boards, tank liners, chemical transmission pipes, decorative and optical glass, electrical components, and curtain weights (National Toxicology Program [NTP] 2004). Lead is used extensively in rolled and extruded lead products in the construction industry (International Agency for Research on Cancer [IARC] 2006). Soluble lead compounds are used in diverse industries. Lead acetate is used for mildew protection and as a mordant for dyes. Lead acetate trihydrate is used to produce varnishes and chrome pigments, and as an analytical reagent. Lead chloride is used to manufacture clutch or brake linings, and as a catalyst and flame retardant. Lead nitrate is used as a heat stabilizer in nylon, as an ingredient in the manufacture of matches and explosives, and as a paper coating for photothermography.

Insoluble lead is just as widely used. Lead azide and lead styphnate are used to manufacture munitions. Lead carbonate, lead fluoride, lead fluoroborate and lead naphthenate are all catalysts. They are also used in the electronic and optical industries (lead fluoride) and in thermographic coatings (lead carbonate), as well as to cure epoxy resins (lead fluoroborate), and dry varnish (lead naphthenate). Both lead phosphate and lead stearate are used as plastic stabilizers. Lead iodide is used in thermoelectric materials, lead sulphate is used in the production of galvanic batteries, and both were previously used in photography. Insoluble lead compounds are used in ceramic glazes, to vulcanize rubber and plastics, and to sense humidity in rockets. Until the 1960s, lead was added in significant quantities (10–50%) to paints, rubber, and plastics, either as a pigment or to speed up drying, resist corrosion, and increase durability, while lead tetraoxide was used in plasters, ointments, glazes, and varnishes (ATSDR 2007*b*; Canadian Mortgage and Housing Corporation [CMHC] 2009). Lead thiocyanate is used to manufacture safety matches and cartridges, while lead arsenate was historically used as an insecticide and herbicide but has no current application (NTP 2004).

Canada is a significant global producer and supplier of refined lead, ranking eighth in the world in 2018 in terms of mine production (13,897 tonnes) and eighth in terms of refined lead production (255,245 tonnes) (NRC 2018). In 2018, primary refined lead was produced using domestic and foreign concentrates at two smelters located in New Brunswick and British Columbia, while secondary lead metal was produced from recycled lead (primarily car batteries) at three sites in Québec, Ontario and British Columbia (NRC 2018). The Belledune smelter in New Brunswick closed in 2019.

The Canadian population may be exposed to background concentrations of lead through various sources including soil, air, dust, drinking water and food.

In Canada, background lead concentrations in soils sourced from various geographical areas are available through the Geological Survey of Canada website, the most populated Canadian soils database to date. These data generally reflect glacial tills that are considered to represent the background concentration of lead (i.e., the normal abundance of lead in unmineralized soil that is unaffected by anthropogenic activities) (Grunsky 2010; Rencz *et al*. 2006). Reported lead concentrations in glacial till range from < 2.0 to 152 mg/kg (arithmetic mean = 10 mg/kg; 90th percentile = 16 mg/kg; n = 7,398; < 63 µm size fraction) (Grunsky 2010).

Atmospheric lead is mainly associated with aerosol particles (Sannolo *et al*. 1995*b*) generated by high-temperature processes such as smelting and incineration (Bennett and Knapp 1989; Hill 1992; Jaworski *et al*. 1987). Data on ambient air lead concentrations across Canada (between 2000 and 2009), provide a range of 0.0004 to 0.014 $\mu g/m^3$ (5th to 95th percentile) in particulate matter with a diameter less than 2.5 µm ($PM_{2.5}$) (EC 2010). Higher concentrations in total suspended particulates, $PM_{2.5}$, and PM_{10}, have been reported in the vicinity of industrial sources of lead (Brecher *et al*. 1989; Dobrin and Potvin 1992; OMEE 1992). In 2007, the National Air Pollution Surveillance Network (NAPS) recorded a maximum of 0.5981 $\mu g/m^3$ ($PM_{2.5}$) from a sample collected near Flin Flon, Manitoba (EC 2010). According to NAPS data, lead concentrations in Canada declined significantly (> 99%) between 1984 (0.16 $\mu g/m^3$) and 2008 (< 0.0015 $\mu g/m^3$) after the 1975 introduction of unleaded gasoline and the prohibition of leaded gasoline in the 1990s (Government of Canada 2020). These measures, combined with greater controls on lead mining and smelting emissions, have resulted in average ambient lead concentrations consistently below 0.02 $\mu g/m^3$.

Few data regarding the concentrations of lead in indoor air in Canada are available. Rasmussen *et al*. (2006) reported concentrations in rural (0.0004 to 0.0026 μg/m^3) and urban (0.001 to 0.0051 μg/m^3) in the Ottawa area. Data from the American National Human Exposure Assessment Survey (Clayton *et al*. 1999) reported a median indoor air lead concentration (≤ 50 μm diameter particles) of 0.0066 μg/m^3.

While there is no national database of Canadian lead concentrations in household dust, between 2007 and 2010 the Canadian House Dust Study collected samples from 1025 urban homes (built between 1880 and 2000) (McDonald *et al*. 2010; 2011; Rasmussen *et al*. 2011). Concentrations of bioaccessible lead in vacuum samples ranged from 7.9 to 3,916 mg/kg dust (median = 63 mg/kg dust), and approximately 90% of homes had concentrations below 250 mg/kg (McDonald *et al*. 2010; 2011; Rasmussen *et al*. 2011).

Total lead concentrations in lake and river water range from 0.1 to 10 μg/L, with much higher lead concentrations reported in waters affected by lead emissions and discharges (Ewers and Schipköter 1991; Mayer and Manning 1990).

Most lead is removed from source water during municipal treatment (HC 2019). Data from the Province of Ontario Drinking Water Surveillance Program indicate that average lead concentrations in treated water are < 1 μg/L (OMOE 2011), and historical data indicate similar levels for the past five to 10 years (HC 2019). Lead can be reintroduced to drinking water from lead-contaminated supply lines and plumbing fixtures.

Environmental Fate and Behaviour in Soil

Natural levels of lead in soil reflect the mineralogy of the soil's parent (geological) material. Lead is present in soil as the soluble plumbous ion (Pb^{2+}), in precipitated forms as carbonates, sulphates, and oxides, and in the soil lattices as lead silicates (Davies 1995; Kabata-Pendias 2001). Reports suggest lead is mainly adsorbed onto clay minerals, adsorbed and co-precipitated with manganese oxides and iron and aluminum hydroxides, adsorbed onto colloidal organic matter, and complexed with organic moieties.

Lead is persistent in soil because of its low solubility (Carelli *et al.* 1995; Leita and De Nobili 1991), its strong complexing behaviour with organic matter (Kabata-Pendias 2001), and its relative freedom from microbial degradation (Davies 1995; Organisation for Economic Co-operation and Development [OECD] 1993). Due to lead's relatively low leaching potential, soils and sediments are generally considered to be mass sinks (Davies 1995; Hill 1992; OECD 1993; Stokes 1989). The soil's pH and concentrations of humic acid, fulvic acid, clay, and organic matter content can influence the potential for leaching (EC 1994; Ewers and Schipköter 1991). Acidic conditions favour lead solubilization and acidic soils tend to have lower lead contents (Kabata-Pendias 2001). Nelson and Campbell (1991) suggested humic and fulvic acid interactions, rather than acidification, may be the primary mechanism through which leaching occurs. Lead is not degraded in the environment, although some fate processes can transform certain lead species into others (ATSDR 2007*a*; Carelli *et al.* 1995). The biomethylation of inorganic lead can occur, but it is not considered a significant mobilization process (Andreae and Froelich 1984; ATSDR 2007*a*; Beijer and Jernelöv 1984; CCREM 1987; Walton *et al.* 1988). Organic lead forms are more likely to undergo microbial-mediated reactions (ATSDR 2007*a*).

The prevailing forms of lead associated with high-temperature combustion processes, such as smelter operations, include sulphide (PbS), the sulphates ($PbSO_4$ and $PbO \cdot PbSO_4$), and the oxides (PbO and PbO_2) (Hemphill *et al.* 1991).

Behaviour and Effects in Biota

Most studies on toxicity of lead to soil organisms are based on the solid forms of the metal in soil and not on the soluble forms of lead, which makes it difficult to link the mechanistic relationship between lead in soils and toxicity. In general, the Pb^{2+} free ion can react directly with biological membranes (EC 1996).

Bioaccumulation of Lead

Lead does not biomagnify in the food chain, although it may bioconcentrate to a limited extent in terrestrial plants and animals. The potential for lead (and other metals) to bioconcentrate is typically expressed as a ratio between its plant and soil concentrations (Sheppard and Evenden 1988). Finster *et al*. (2004) determined that accumulation is generally low from garden soils containing less than 4,580 µg/g of lead. Other studies summarized by ATSDR (2007*a*) similarly suggest a low potential for lead bioconcentration into terrestrial plants. However, plants may also accumulate external lead contamination from soil or dust that adheres to their surfaces (Finster *et al*. 2004), and the re-suspension of dust and aerial deposition onto plant leaves and fruit may in fact be a more important pathway for plant accumulation. In one study, leafy vegetables and herbs had greater concentrations of lead in their leaf tissue compared with non-leafy vegetables, even after both were washed with a detergent (Finster *et al*. 2004).

The derivation of an ecological value for the soil and food ingestion pathway (EC 1999) used a bioconcentration factor of 0.035 estimated from Jones and Johnston (1991) and OMOE (1992).

Soil Microbial Processes

Bhuiya and Cornfield (1974) reported that single doses of 1,000 mg Pb/kg had no effect on nitrification at pH 6.0, but did inhibit nitrification by 11% and 9% at pH 7.0 and 7.7, respectively. Single-dose applications of lead acetate at 1,036 mg Pb/kg reduced nitrification by 7–26%, depending on the soil type (Liang and Tabatabai 1978). Bollag and Barabasz (1979) reported that a concentration of 1,000 mg Pb/kg reduced denitrification by approximately 15%, while no reduction was observed at 500 mg Pb/kg. Wilke (1989) reported that nitrification was not inhibited at levels of 1,000 and 4,000 mg Pb/kg, but had actually increased by 12% and 16%, respectively. Nitrogen mineralization was reduced by 32% and 44% at concentrations of 1,000 and 4,000 mg Pb/kg, respectively. Oxygen consumption was decreased by 16–17% at 375 mg Pb/kg in sandy soil, but was not affected in a clay soil. Carbon dioxide release in the sandy soil was reduced by

12–59% at 400–8,000 mg Pb/kg soil and by 6–45% at 150–1,000 mg Pb/kg soil in a sandy loam (Doelman and Haanstra 1979; 1984).

Terrestrial Plants

Lead is considered a nonessential element for plants, although certain studies have reported a stimulating effect on growth at low concentrations (Balba *et al.* 1991; Muramoto *et al.* 1990; Nakos 1979). In general, most studies reported significant adverse effects on plants only at relatively high lead concentrations (Pahlsson 1989). Visible symptoms of lead toxicity include smaller leaves, chlorotic and reddish leaves with necrosis, short black roots, and stunted growth (Pahlsson 1989). In addition, exposed plants generally exhibit decreasing photosynthetic and transpiration rates with increasing lead concentrations. Researchers suggest these responses are related to changes in the stomata's resistance to both CO_2 and diffusion of water (Bazzaz *et al.* 1974). Lead ions have also been shown to inhibit chlorophyll biosynthesis, leading to lowered chlorophyll content. Thus, decreased photosynthesis could be partly related to the reduced chlorophyll content of leaves (Pahlsson 1989).

Uptake and accumulation rates of lead vary among and within species and appear to be influenced to a greater extent by pH than by any other soil properties. Seiler and Paganelli (1987) reported markedly elevated lead toxicity for red spruce *(Picea rubens)* due to the increased bioavailability of lead created by low-pH conditions. Allinson and Dzialo (1981) found that ryegrass *(Lolium hybridum)* and oats (*Avena sativa)* contained significantly higher lead concentrations after three months of growth in a soil with pH 4.5 than in a second soil with pH 6.4. Lead bioconcentration factors (BCFs) for most plants typically range from 0.001 to 0.03 (Jones and Johnston 1991). The OMOE (1992) adopted a general soil-to-plant BCF of 0.039 for common backyard fruits and vegetables.

Hassett *et al.* (1976) reported a 19% reduction in corn root elongation at 250 mg Pb/kg and no effect at 100 mg Pb/kg. Dry shoot weight in corn plants has been reduced by 13–29% in 125 mg Pb/kg soil (Miller *et al.* 1977). Researchers observed a significant reduction of 11% in the dry weight yield of onions at 50 mg Pb/kg, while fenugreek required a concentration of 400 mg Pb/kg to show a 20% dry weight yield reduction (Dang *et al.* 1990). The root biomass of oats and wheat was reduced at 500 mg Pb/kg (Khan and Frankland 1984).

EC (1995) reported no observed effect concentration (NOEC) endpoints of 421 mg Pb/kg, lowest observed effect concentration (LOEC) endpoints of 974 mg Pb/kg, and effective concentration (EC) endpoints of 833 and 1,236 mg Pb/kg, for EC_{25} and EC_{50} respectively, for radish *(Raphanus sativa)* seedling emergence. The NOEC, LOEC, EC_{25} and EC_{50} values for the seedling emergence of lettuce *(Lactuca sativa)* were 416, 740, 667 and 876 mg Pb/kg, respectively.

Seiler and Paganelli (1987) reported a reduction of 38–45% in red spruce root and shoot dry weight and in plant height at 150.1 mg Pb/kg, while they observed a 30% reduction in photosynthesis at 271.1 mg Pb/kg. Loblolly pine, on the other hand, showed reduced height and dry weight of roots and shoots at 1,179 mg Pb/kg, while photosynthesis was unaffected.

Terrestrial Invertebrates

Earthworms accumulate lead and are therefore useful bioindicators of lead pollution in soil. Total lead concentrations in soils almost always exceed the total lead concentrations in earthworms, except where unique conditions, such as high levels of lead in soils combined with low pH and low calcium, cause earthworms to accumulate greater amounts of lead from the soil (Ireland 1979). BCFs (the ratio of lead in worms to lead in the soil) range from 0.01 to 2.73, but are usually well below 1.0, indicating that there is no constant relationship between the concentration of lead in soil and that found in earthworms (Kabata-Pendias and Pendias 1992).

Carnivorous soil invertebrates such as harvestmen and carabid beetles are generally more susceptible to lead poisoning than herbivores such as weevils and ants (Bengtsson and Rundgren 1984). BCFs for lead in arthropods (i.e., the ratio of lead concentration in animals to lead concentration in the litter layer) range from 0.01 to 0.43 (Martien and Hogervorst 1993). As in earthworms, there is no constant relationship between the amount of lead in the litter layer and the amount of lead accumulated by arthropods.

All invertebrates cycle lead from the soil through their bodies, but they assimilate low net amounts of lead compared with other trace metals such as Cd because of their rapid excretion of lead (van Straalen and van Meerendonk 1987) and restricted absorption through the gut wall (Hopkin and Martin 1984). Half of the body burden of lead in the collembolan *Orchesella cincta* is in the gut, where it has a short half-life of < 1 day (van Straalen *et al.* 1985).

EC (1995) reported lethal concentration (LC) values of 2067, 2500, and 3,070 mg/kg, for LC_{25}, LC_{50}, and LC_{70} respectively, for the earthworm *Eisenia foetida* in artificial soil. The NOEC was reported to be 1,480 mg Pb/kg.

Spurgeon *et al.* (1994) reported lethal dose, LD_{50}, values for *E. foetida* of 3,760–4,480 mg Pb/kg depending on the exposure period. Cocoon production was not affected at 1,810 mg Pb/kg, but was reduced by 50% at 1,940 mg Pb/kg.

Livestock and Wildlife

Lead poses a threat to mammals and birds through a number of exposure routes. Mammals and birds inhale airborne lead directly or ingest particulate matter deposited on the ground and vegetation. Direct ingestion of contaminated soil and grit occurs when herbivores and birds feed and groom. Animals lick painted surfaces and drink lead-contaminated water. Waterfowl and raptors ingest substantial amounts of lead shot and fishing weights when they feed. Herbivores, insectivores, and carnivores at all trophic levels are exposed to lead by eating lead-contaminated vegetation or prey.

Lead toxicosis has been observed in many animals, but its effects are so diverse that it is difficult to identify any single organ failure as being responsible for death (Beyer *et al*. 1988; Humphreys 1991). Clinical signs of lead poisoning include behavioural aberrations such as vocalization, aggression, memory loss, muscle spasms, convulsions, imbalance, dehydration, emaciation, and impaction of the gastrointestinal tract (Morgan *et al*. 1975; MacDonald *et al*. 1983; O'Halloran and Myers 1988).

Lassen and Buck (1979) investigated the toxicity of lead to swine by giving 6-week-old pigs lead acetate in water at 0–35.2 mg Pb/kg bw. None of the pigs died, but clinical signs of lead toxicosis (coughing, rough coats, gaunt appearance) were seen in two of the three pigs treated at 35.2 mg Pb/kg bw. Feed consumption rates or weight gain were not affected in wether lambs fed lead acetate at 44.4 mg Pb/kg bw/d for 84 days (Fick *et al*. 1976).

Lynch *et al*. (1976) reported a 13% reduction in weight in calves receiving 7.7 mg Pb/kg bw/d, while only a 6% reduction was observed in calves receiving 3.9 mg Pb/kg bw/d.

Metallic lead powder was mixed with corn oil and given orally to American kestrel (*Falco sparverius*) hatchlings for the first 10 d of life (Hoffman et al. 1985). After 5 d, the growth rate and weight gain of the hatchlings on 125 mg Pb/kg bw/d was reduced by 16%. By day 6, 40% of the hatchlings on the 625 mg Pb/kg bw/d diet had died.

Custer et al. (1984) fed American kestrels with a diet of biologically incorporated lead for 60 days. At 28 mg Pb/kg bw/d, lead had no effect on the survival or body weight of kestrels and did not alter hematocrit, hemoglobin, or erythrocyte counts in blood, which are primary signs of lead toxicity.

Edens and Garlich (1983) added lead acetate to the feed of both domestic leghorn chicken hens and Japanese quail hens (*Coturnix coturnix japonica*). After 5 weeks, quail hens showed a 28% decrease in egg production at 1.8 mg Pb/kg bw/d, while a 77% decrease was observed after 4 weeks at 26.1 mg Pb/kg bw/d for chickens.

Limited data are available on lead's potential to bioconcentrate in animals. However, as in humans, we can expect to see greater lead body burdens in older animals due to lead accumulation over time (ATSDR 2007a).

Humans and Experimental Animal Health Effects

With respect to its toxicity, lead is one of the most extensively studied substances (Needleman and Gatsonis 1990). Lead is a well-known neurodevelopmental toxin in foetuses and children. In adults, exposure is associated with an increased risk of adverse cardiovascular effects. Preliminary experimental evidence suggests that lead is a carcinogenic chemical element.

IARC (International Agency for Research on Cancer) classifies lead as Group 2A, probably carcinogenic to humans, based on occupational inhalation data and *in vivo* oral studies (IARC 2006). The National Toxicology Program also concluded that inorganic lead "may reasonably be anticipated to be carcinogenic" (NTP 2004). The weight of evidence supports the conclusion that soluble inorganic lead is a carcinogen in animals, and that the kidney is the most sensitive tumour site in rodents. Evidence also suggests that lead promotes renal tumours in rats (HC 2019).

The principal finding of Health Canada's (HC) State of the Science (SOS) Report is that critical health effects can occur below 10 µg lead/dL (HC 2013*a*). Consistent with conclusions from the larger scientific community, the SOS Report recommends the adoption of additional measures to further reduce exposures of Canadians to lead. Currently available observational studies do not demonstrate a population-level threshold for the most sensitive endpoint identified (neurodevelopmental toxicity). The provisional soil quality guidelines for human health ($PSoQG_{HH}s$) are based on effects observed at the lowest levels of exposure. Carcinogenic effects are observed at higher exposures, and therefore the approach used to develop the $PSoQGs_{HH}$ protects against carcinogenicity.

Long-term exposure at blood lead levels (BLLs) below 10 µg/dL is associated with neurodevelopmental, neurodegenerative, cardiovascular, renal, and reproductive effects (Canfield *et al*. 2003*a*; *b*; Chandramouli *et al*. 2009; Chiodo *et al*. 2004; 2007; Després *et al*. 2005; Fraser *et al*. 2006; Lanphear *et al*. 2000; Miranda *et al*. 2007; Osman *et al*. 1999). Several studies report a dose-response relationship that extends down to 1–2 µg/dL, the lowest evaluated BLLs (Canfield *et al*. 2003*a*; Chiodo *et al*. 2004; Jedryschowski *et al*. 2009; Jusko *et al*. 2008; Lanphear *et al*. 2005; Miranda *et al*. 2007; Tellez-Rojo *et al*. 2006). The weight of evidence for effects in this range of exposure is strongest for adverse neurodevelopmental outcomes in children, most commonly a reduction of intelligence quotient (IQ) score as BLLs increase (ATSDR 2007*a*; CalOEHHA 2007; European Food Safety Authority [EFSA] 2013; HC 2013*b*; WHO 2010*b*). Current epidemiological evidence strongly suggests an adverse association between early-life chronic lead exposure and decrements in school-aged children's IQ. However, many of the studies used a limit of quantification between 1 and 3 µg/dL, which makes it difficult to interpret the lower end of the dose-response curve.

Critical Toxicological Endpoint for Children

In the most comprehensive analysis of neurodevelopmental toxicity, Lanphear *et al*. (2005) pooled and analysed data from seven longitudinal studies of 1,333 children from around the world. The authors concluded that intellectual deficits are associated with maximal BLLs of less than 7.5 µg/dL in children.

Based on the data set used by Lanphear *et al.* (2005), agencies such as EFSA, the California Environmental Protection Agency (CalEPA) and the WHO/Joint Food and Agriculture Association of the United Nations/WHO Expert Committee on Food Additives (WHO/JECFA) conducted dose-response analyses to characterize the neurodevelopmental risk. CalEPA estimated that a 1 µg/dL increment in BLL was associated with a 1-IQ point deficit (lower 97.5th percentile estimate) (CalEPA 2009; CalOEHHA 2007). EFSA (2013) estimated that a 1.2 µg/dL increment in BLL was associated with the 95th percentile lower confidence limit of the benchmark dose for a 1% additional risk ($BMDL_{01}$) of IQ deficit. WHO/JECFA (2011) concluded that a 2 µg/dL increase in BLL would be associated with a drop of 1 IQ point.

Using a 1.2 µg/dL change in BLL, EFSA (2013) derived a dietary intake value of 0.5 µg/kg body weight per day for neurodevelopmental toxicity at a population level. EFSA (2013) did not apply any uncertainty, safety, or modifying factors to this intake rate. Overall, CCME considers the EFSA (2013) analysis to be the most rigorous. While quite similar to the WHO/JECFA (2011) analysis, it had the additional benefit of a protection goal of a 95th percentile lower confidence limit rather than a central estimate. EFSA (2013) is also more consistent with the HC (2013*a*; *b*) conclusion that an incremental increase in BLL of 1 µg/dL is associated with a decrement of approximately 1 IQ point.

On the other hand, WHO/JECFA (2011) determined the relationship between BLLs and dietary exposure, estimating the range of mean dietary exposures between 0.03 to 9 µg/kg bw/d for children aged about 1–4 years. WHO/JECFA (2011) considered the health impact at the lower end of the range to be "negligible" because it is below the exposure level of 0.3 µg/kg bw/d calculated to be associated with a population decrease of 0.5-IQ point. Therefore, in order to reflect the lower range of WHO/JECFA (2011), CCME provides $PSoQGs_{HH}$ that are also protective of a 0.5-IQ decrement.

Consequently, for the purpose of derivation of the $PSoQGs_{HH}$, CCME is presenting two options, one for a 1-IQ point decrement and one using a 50% adjustment factor applied to the equation in order to target a 0.5-IQ point decrement for the protection of children.

Critical Toxicological Endpoint for Adults

Although an RSD based on increases in systolic blood pressure for adults is available (WHO/JECFA 2011), this endpoint may not be protective the developing foetus. Therefore, the EFSA (2013)-based RSD for the protection of developmental effects was adopted for women of childbearing age to protect developing foetuses. The same 50% adjustment factor that was applied for the protection of young children was applied to the derivation of $PSoQGs_{HH}$ for the protection of adults under the 0.5-IQ point decrement option.

Consequently, for the purpose of derivation of the $PSoQG_{HH}$ for industrial land use, CCME is presenting two options, one using the RSD of 0.5 µg/kg bw/d for the protection of adults, including women of childbearing age to target a 1 IQ point decrement and one using a 50% adjustment factor applied to the equation in order to target a 0.5-IQ point decrement.

Guideline Derivation

Canadian soil quality guidelines for different land uses are derived following the process outlined in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (the Protocol, CCME 2006). Different receptors and exposure scenarios are defined for each land use.

For lead, CCME used a non-threshold approach, with some modifications to the Protocol, to derive the $PSoQGs_{HH}$. Specifically, CCME developed guideline values for two end points (RSDs): targeting a 0.5-IQ point decrement and a 1-IQ point decrement in toddlers and adults (including pregnant and breastfeeding women). These risk-specific levels were developed to enable individual jurisdictions to determine their science policy positions. Jurisdictions may differ in selection of a PSoQG based on a 0.5- or 1-IQ point decrement. CCME recommends that jurisdictions select a 0.5-IQ point decrement to allow for background exposure to all sources of lead, including, but not limited to the diet, drinking water, and air. Jurisdictions that adopt a PSoQG based on a target 1-IQ point decrement may also want to apply the PSoQG based on a 0.5-IQ point decrement in situations where soils may also result in contamination of water used as drinking water and/or consumption of food grown on-site.

PSoQGs are presented in Table 2. Detailed derivations for the soil quality guidelines for lead are provided in CCME (2025) for the protection of human health and in EC (1999) for the protection of environmental health.

Soil Quality Guidelines for Environmental Health

Environmental soil quality guidelines ($SoQGs_E$) are based on soil contact using data from toxicity studies on plants and invertebrates. In the case of agricultural land use, soil and food ingestion toxicity data for mammalian and avian species are included. For the soil contact pathway, sufficient data are available to support the preferred weight of evidence procedure. Nutrient and energy cycling check values provide a broader scope of protection, as does the off-site migration check for industrial land use.

For the agricultural land use $SoQG_E$, CCME recommends the lower of the soil quality guideline for soil contact, the soil and food ingestion, and the nutrient and energy cycling check.

For the residential/parkland and commercial land use $SoQG_E$, CCME recommends the lower of the soil quality guideline for soil contact and the nutrient and energy cycling check.

For the industrial land use $SoQG_E$, CCME recommends the lower of the soil quality guideline for soil contact, the nutrient and energy cycling check, and the off-site migration check.

In the case of lead, the recommended $SoQG_E$ for agricultural land is based on the soil and food ingestion guideline, and for all other land use categories it is based on the soil contact guideline (Table 2).

Soil Quality Guidelines for Human Health

Researchers have widely concluded that a threshold for the effects of lead has not been determined (ATSDR 2007*a*; CalOEHHA 2007; EFSA 2013; HC 2013*a*; WHO 2010*b*; WHO/JECFA 2011). This lack of a threshold has crucial implications, as the Protocol does not provide an approach to derive a soil quality guideline for a non-threshold substance that is not a carcinogen (see Wilson and Richardson 2013). CCME used a novel non-threshold approach to develop the revised $PSoQG_{DH}$ (human health guideline for direct contact), which includes modifications to the non-threshold approach outlined by the Protocol. This method is described in greater detail in CCME (2025). The human health soil quality guidelines for direct contact with lead are derived using a risk-specific dose (RSD) for the most sensitive receptor designated for each land use. Due to the inherent sensitivities of children to the developmental effects of lead, toddlers were selected for the $PSoQG_{DH}$ calculations for the agricultural, residential/parkland, and commercial land uses. Toddlers are not expected to be present at industrial sites however, the guidelines for industrial land use consider the protection of developing foetuses in pregnant women by applying the RSD for the protection of IQ decrements when calculating the $PSoQG_{HH}$ for this land use.

The $PSoQGs_{DH}$ for lead are based on the derivation for three exposure pathways, combined (ingestion, inhalation, and dermal). Based on the EFSA (2013) analysis, CCME considers an intake rate of 0.5 μg/kg bw/d to be an RSD associated with a 1-IQ point decrement in infants, toddlers and children. Given that no threshold has been observed for developmental neurotoxicity over the lower ranges of environmental exposure, it is prudent to reduce children's exposure to lead (and associated risks) to the greatest extent practicable (HC 2013*b*). CCME applied a 50% adjustment factor to the RSD targeting a 1-IQ point decrement in order to target a 0.5-IQ point decrement, which was considered by WHO/JECFA (2011) to be the upper end of the negligible range for the neurotoxic effects of lead at a population level.

In the case of both the 0.5- and 1-IQ point decrement targets, the $PSoQGs_{HH}$ for lead in agricultural, residential/parkland, and commercial land uses are based on the direct contact soil quality guideline. The $PSoQGs_{HH}$ for lead in industrial land use are also both based on the off-site migration check.

SoQGs derived for industrial sites consider on-site exposure only. Transfers of contaminated soil from one property to another are possible by environmental occurrences such as wind and water erosion (CCME 2006). The off-site migration checks ($PSoQGs_{OM-HH}$) were lower than the $PSoQGs_{DH}$, and therefore the $PSoQGs_{HH}$ for the industrial land use were set according to the calculated $PSoQGs_{OM-HH}$.

To derive soil quality guidelines for the general Canadian population, CCME assumed the background soil lead concentration (10 mg/kg) to be conservative based on available data for till (e.g., that has no anthropogenic impacts). Surface soils and localized areas within Canada may have different background concentrations of lead and the bioavailability of lead in soil can vary widely across the country, based on several site- and contaminant-related factors. For specific locations with unusually high natural background concentrations that exceed these guidelines, jurisdictions have the option to set site-specific guidelines that consider the unique geological characteristics of the particular locations. Site-specific assessment of lead bioavailability can also reduce uncertainty related to screening values.

CCME did not derive a lead guideline for the protection of groundwater used as a source of raw water for drinking due to constraints on the mathematical model when applied to inorganic compounds (CCME 2006). CCME also did not carry out the check to assess the transfer of contaminants from soil into produce, meat, and milk, due to the inherent high variability related to site-specific soil properties and exposures.

Jurisdictions may differ in selection of a PSoQG based on a 0.5- or 1-IQ point decrement. CCME recommends that jurisdictions select a 0.5-IQ point decrement to allow for background exposure to all sources of lead, including, but not limited to the diet, drinking water, and air. Jurisdictions that adopt a PSoQG based on a target 1-IQ point decrement may also want to apply the PSoQG based on a 0.5-IQ point decrement in situations where soils may also result in contamination of water used as drinking water and/or consumption of food grown on-site.

Soil Quality Guidelines for Lead

The soil quality guidelines are intended to be protective of both environmental and human health and are taken as the lower of the $PSoQG_{HH}$ and the $SoQG_E$.

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

Table 2. Soil quality guidelines for lead (mg/kg)

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Provisional Soil quality guideline (PSoQG) -0.5-IQ pt decrement [a, c]	61	61	82	600
Provisional Soil quality guideline (PSoQG) -1-IQ pt decrement [a, d]	70	113	154	600
Human health guidelines/check values				
$PSoQG_{HH}$ -0.5-IQ pt decrement [b, c]	61	61	82	743
$PSoQG_{HH}$ -1-IQ pt decrement [b, d]	113	113	154	1,477
Direct contact ($PSoQG_{DH}$) – 0.5-IQ pt	61	61	82	1,194
Direct contact ($PSoQG_{DH}$) – 1-IQ pt	113	113	154	2378
Protection of indoor air quality ($SoQG_{IAQ}$)[e]	NC	NC	NC	NC
Protection of potable water ($SoQG_{PW}$)[f]	NC	NC	NC	NC
Off-site migration check ($PSoQG_{OM-HH}$) – 0.5-IQ pt	–	–	743	743
Off-site migration check ($PSoQG_{OM-HH}$) – 1-IQ pt	–	–	1,477	1,477
Produce, meat and milk check ($SoQG_{FI}$)[g]	NC	NC	–	–
Environmental health guidelines/check values (EC 1999)				
$SoQG_E$[h]	70	300	600	600
Soil contact ($SoQG_{SC}$)	300	300	600	600
Soil and food ingestion ($SoQG_I$)	70	–	–	–
Protection of freshwater life ($SoQG_{FL}$)[f]	NC	NC	NC	NC
Livestock watering ($SoQG_{LW}$)	–	–	–	–
Irrigation water ($SoQG_{IR}$)	–	–	–	–
Nutrient and energy cycling check ($SoQG_{NEC}$)	723	723	834	834
Off-site migration check ($SoQG_{OM-E}$)	–	–	870	870
Superseded soil quality guidelines (CCME 1999)	–	140	260	600
Superseded interim soil quality criteria (CCME 1991)	375	500	1,000	1,000

Notes: NC = not calculated; $PSoQG_{HH}$ = provisional soil quality guideline for human health; $SoQG_E$ = environmental soil quality guideline; a dash indicates a guideline/check value that is not part of the exposure scenario for that land use and therefore is not calculated. Soil guidelines and the data used to calculate them are, by convention, always expressed on a dry weight basis to allow the data to be standardized. In case of doubt and if the scientific criteria document does not specify whether wet or dry weight is used, readers are advised to check the references provided.

[a] Data are sufficient and adequate to calculate a $PSoQG_{HH}$ and a $SoQG_E$. The lower of the SoQGs becomes the soil quality guideline for this land use.

[b] The $PSoQG_{HH}$ is the lowest of the human health guidelines and check values.

[c] CCME recommends using the $PSoQG_{HH}$ for a 0.5-IQ point decrement when soil and additional site-related media contain elevated concentrations of lead (e.g., groundwater, food grown on site, etc.) to account for additional sources of elevated exposure and/or according to jurisdictional policy.

[d] CCME recommends using the $PSoQG_{HH}$ for a 1-IQ point decrement when soil is the only site-related media with elevated concentrations of lead. Where additional site-related contaminated media are expected to contribute to exposures (e.g., groundwater, food grown on site, etc.), CCME recommends using the 0.5-IQ point decrement to account for additional sources

of elevated exposure. When using the $PSoQG_{HH}$ based on 1-IQ point decrement, the environmental site investigation report should include information on all media that may be affected above background and fate and transport information.

[e] The inhalation of indoor air guideline applies to volatile organic compounds and is not calculated for metal contaminants.

[f] Applies to organic compounds and thus is not calculated for metal contaminants. Concerns about metal contaminants should be addressed on a site-specific basis.

[g] Not calculated due to high site-related variability in soil parameters and intake rates. Where these pathways are complete, assess on a site-specific basis.

[h] The $SoQG_E$ is the lowest of the ecological guidelines and check values.

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