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

LEAD
1999

This fact sheet provides Canadian soil quality guidelines for lead (Pb) for the protection of environmental and human health (Table 1). Supporting scientific documents are also available (Environment Canada 1996; Health Canada 1996).

Background Information

Lead (CAS 7439-92-1) is a lustrous, soft, and dense silvery metal that tarnishes in the presence of air to become a dull, bluish grey. The metal has a relatively low melting point of 327.5°C and a boiling point of 1740°C. The solubility of metallic lead is very low, while the solubilities of other lead compounds range from very soluble to extremely insoluble (Environment Canada 1996). In natural environments, lead is rarely found in its elemental form (OMEE 1994), but exists predominantly as the stable plumbous ion, Pb(II) (CCREM 1987). Lead readily alloys with other metals such as tin, antimony, copper, and zinc.

Primary ores account for over 95% of mined lead production. Lead production from ore is often associated with zinc production as lead and zinc are frequently found together in nature. There is a downward trend in consumption of lead in the Western world, although Canadian lead production is expected to continue its increase. In 1991, Canada was responsible for 5% of world refined lead production (Environment Canada 1996). During the 1990s, Canadian mines, located mainly in Yukon, New Brunswick, British Columbia, and the Northwest Territories, have produced an average of 243 kt per year (Keating 1995).

Table 1. Soil quality guidelines for lead (mg·kg^{-1}).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**70**[a]	**140**[a]	**260**[a]	**600**[a]
SQG_{HH}	140	140	260	740
Limiting pathway for SQG_{HH}	Soil ingestion	Soil ingestion	Soil ingestion	Off-site migration
Provisional SQG_{HH}	NC[b]	NC[b]	NC[b]	NC[b]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
SQG_E	70	300	600	600
Limiting pathway for SQG_E	Soil and food ingestion	Soil contact	Soil contact	Soil contact
Provisional SQG_E	NC[c]	NC[c]	NC[c]	NC[c]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	375	500	1000	1000

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

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

[b] Because data are sufficient and adequate to calculate an SQG_{HH} for this land use, a provisional SQG_{HH} is not calculated.

[c] Because data are sufficient and adequate to calculate an SQG_E for this land use, a provisional SQG_E is not calculated.

The guidelines in this fact sheet are for general guidance only. Site-specific conditions should be considered in the application of these values. The values may be applied differently in various jurisdictions. The reader should consult the appropriate jurisdiction before application of the values.

The primary and secondary lead consumption in Canadian industry in 1991 was due to the production of antimonial lead, batteries and battery oxides, lead for chemical uses, copper alloys, lead alloys, and semifinished products, such as pipe, sheet, traps, bend, and blocks for caulking and ammunition (OECD 1993; Keating and Wright 1994; Keating 1995; Environment Canada 1996). Lead and its various compounds are used in the production of pigments, in glass and ceramic production, and in lithographic processes. Lead is also associated with phosphate fertilizers. Land application of sewage sludge, animal wastes from animal production, coal residues, municipal refuse incineration, wastewaters, and auto emissions all contribute to the earth's lead burden (Nriagu and Pacyna 1989).

Natural sources, such as volcanoes, forest fires, and sea salt, are responsible for the natural part of atmospheric emissions of trace metals. Biogenic sources such as non-methane natural hydrocarbons, continental particulates, and continental volatiles also contribute to the total background levels of lead (Laube 1995; Environment Canada 1996).

Background levels for total lead in Canadian soils have been estimated by different researchers and reflect those measured in uncontaminated soils remote from ore bodies. Nriagu (1978) suggested a mean of 12 mg·kg^{-1} for Canadian soils, while McKeague and Wolynetz (1980) reported a mean of 20 mg·kg^{-1}. Higher background levels were reported for the St. Lawrence lowlands (25 mg·kg^{-1}) and the Appalachian and Canadian Shield regions (21 mg·kg^{-1}), while lower levels were found in the Interior Plains (15 mg·kg^{-1}) and Cordilleran (16 mg·kg^{-1}) areas (McKeague and Wolynetz 1980).

The amount of total lead in agricultural soils depends on the parent material and anthropogenic input to the soil. Warren et al. (1970) suggested that normal Canadian agricultural soils range between <1 and 12 mg·kg^{-1}. A study of 296 agricultural soils in Ontario produced a mean of 46 mg·kg^{-1}, with values ranging from 1.5 to 888 mg·kg^{-1} (Frank et al. 1976). Soils in fruit orchards had the highest lead concentrations (mean of 123 mg·kg^{-1}) resulting from the use of lead arsenate pesticides, while other cropped soils averaged 14 mg·kg^{-1}. Lead levels in agricultural soils close to settlements in Alberta range from 2 to 28 mg·kg^{-1}, with a mean of 9 mg·kg^{-1} (J. Lutwick 1993, Alberta Environmental Protection, pers. com.).

Ecosystems often become contaminated in areas where ore smelters are located. Hogan and Wooton (1984) found high levels of lead in the soil of a boreal forest <10 km from a copper–zinc smelter in Manitoba. Soil lead levels were elevated up to 35 km from the emission stack. Bisessar (1982) reported lead concentrations of up to 28 000 mg·kg^{-1} in soils around a secondary lead smelter, with values of 703 mg·kg^{-1} in soils located 1 km south of the smelter.

Environmental Fate and Behaviour in Soil

Lead can pose a threat to the environment if it moves through the soil and contaminates groundwater and surface waters, or if it is transferred to biota. Many factors influence the mobility and bioavailability of lead: pH, soil texture (especially clay content), and organic matter content. Since dissolved lead in soils is commonly in the form of Pb^{2+}, the adsorption on cation exchange sites of clays or organic matter can decrease the mobility and availability of lead in the short term. Erosion of soils by wind or water is an important pathway by which lead-contaminated soils can migrate and contaminate the surrounding environment.

Lead is added to soils as a result of fallout from the atmosphere, by either accidental or deliberate dumping of lead-containing wastes, or from the addition of pesticides and fertilizers that contain lead. The form of the metal that is being added to the soil will affect its solubility and initial mobility. For example, lead chlorides, lead acetates, and lead nitrates are readily soluble in the soil environment and will be leached from soil. Lead oxides, although less soluble than the salts, are still more soluble than some of the lead compounds that form in soils. Metallic lead is relatively insoluble and can be oxidized in soils to form PbO, which may then be dissolved or transformed into a more stable compound. In aerobic soils, weathering of the very soluble lead compounds results in the formation of more stable compounds such as $Pb_3CO_3(OH)_2$ (Lindsay 1979). In anaerobic soils, the reduction of SO_4^{2-} to S^{2-} leads to the formation of lead sulphide (PbS), a very insoluble, nonreactive lead species. Even in composted municipal solid waste, the solubility of lead decreases as the material ages and becomes more stabilized (Leita and De Nobili 1991).

In soils, lead solubility seems to be controlled by relatively insoluble compounds such as $PbCO_3$, $Pb(OH)_2$, $Pb_3(PO_4)_2$, or $Pb_5(PO_4)_3OH$, which have a pH-dependent solubility in contrast to the lead salts normally used in toxicity testing, whose solubilities are not dependent on pH (Santillan-Medrano and Jurinak 1975). For example, $Pb(OH)_2$ would maintain a concentration of Pb^{2+} of about 300 g·L^{-1} in solution at pH 4.0, but at pH 7.0, the concentration would be only 0.0003 g·L^{-1}.

There seems to be no conclusive evidence as to which forms of lead are available to soil biota. The evidence relating the effects of soil properties, such as pH, cation exchange capacity, and the presence of ligands capable of binding lead (e.g., PO_4 or organic matter), all suggests that the amount of free metal (i.e., Pb^{2+}) in solution is the critical fraction (Adriano 1986; Kabata-Pendias and Pendias 1992).

In contrast to uncontaminated soils, lead content in contaminated soils is usually higher in surface horizons than deeper in the soil profile. This trend is due in part to aerial deposition of lead as well as its tendency to form strong complexes with organic matter (Adriano 1986). In the presence of soluble organic acids, such as fulvic acid, lead can be mobilized and leach downward in the soil profile. Although the addition of organic matter to soil has been shown to decrease lead availability to plants, the eventual decomposition of the organic complexes may release the lead to the soil solution (Kabata-Pendias and Pendias 1992).

In addition to the effect of organic matter, manipulation of soil pH by liming or adding phosphate fertilizers have been shown to decrease the amount of uptake (Adriano 1986; Kabata-Pendias and Pendias 1992).

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 and have a direct toxic effect (Environment Canada 1996).

Microbial Processes

Bhuiya and Cornfield (1974) reported that single doses of 1000 mg $Pb \cdot kg^{-1}$ 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 1036 mg $Pb \cdot kg^{-1}$, reduced nitrification by 7–26% depending on soil type (Liang and Tabatabai 1978).

Bollag and Barabasz (1979) reported that concentration of 1000 mg $Pb \cdot kg^{-1}$ reduced denitrification by approximately 15%, while no reduction was observed at 500 mg $Pb \cdot kg^{-1}$.

Wilke (1989) reported that nitrification was not inhibited at levels of 1000 and 4000 mg $Pb \cdot kg^{-1}$, but was actually increased by 12% and 16%, respectively. Nitrogen mineralization was reduced by 32% and 44% at concentrations of 1000 and 4000 mg $Pb \cdot kg^{-1}$, respectively. Oxygen consumption was decreased by 16–17% at 375 mg $Pb \cdot kg^{-1}$ in sandy soil, but was not affected in a clay soil. Carbon dioxide release in sandy soil was reduced by 12–59% at 400–8000 mg $Pb \cdot kg^{-1}$ soil and by 6–45% at 150–1000 mg $Pb \cdot kg^{-1}$ soil in a sandy loam (Doelman and Haanstra 1979, 1984).

Terrestrial Plants

Lead is considered a nonessential element to plants, although certain studies have reported a stimulation effect on growth at low concentrations (Nakos 1979; Muramoto et al. 1990; Balba et al. 1991). In general, for most studies, significant adverse effects on plants were seen 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. The responses are suggested to be related to changes in resistance of the stomata to CO_2 and diffusion of water (Bazzaz et al. 1974). Lead ions are also shown to inhibit chlorophyll biosynthesis leading to lowered chlorophyll contents. Thus, decreased photosynthesis could be partly related to reduced chlorophyll contents 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 3 months of growth in a soil with pH 4.5 than in a second soil with pH 6.4. Lead 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 $Pb \cdot kg^{-1}$ and no effect at 100 mg $Pb \cdot kg^{-1}$. Dry shoot weight in corn plants have been reduced by 13–29% at 125 mg $Pb \cdot kg^{-1}$ soil (Miller et al. 1977). A significant reduction of 11% in dry weight yield of onions was observed at 50 mg $Pb \cdot kg^{-1}$, while fenugreek required a concentration of 400 mg $Pb \cdot kg^{-1}$ to show 20% dry weight yield reduction (Dang et al. 1990). The root biomass of oats and wheat was reduced at 500 mg $Pb \cdot kg^{-1}$ (Khan and Frankland 1984).

Environment Canada (1995) reported NOEC, LOEC, EC_{25}, and EC_{50} endpoints of 421, 974, 833, and 1236 mg $Pb \cdot kg^{-1}$, respectively, for radish *(Raphanus sativa)* seedling emergence. The NOEC, LOEC, EC_{25}, and EC_{50} values for seedling emergence of lettuce *(Lactuca sativa)* were 416, 740, 667, and 876 mg $Pb \cdot kg^{-1}$, 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 $Pb \cdot kg^{-1}$, while a 30% reduction in photosynthesis was observed at 271.1 mg $Pb \cdot kg^{-1}$. Loblolly pine, on the other hand, showed reduced height, and dry weight of roots and shoots at 1179 mg $Pb \cdot kg^{-1}$ while photosynthesis was unaffected.

Terrestrial Invertebrates

Earthworms accumulate lead and are thus 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 (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., ratio of lead concentration in animal to lead concentration in the litter layer) range from 0.01 to 0.43 (Martien and Hogervorst 1993). Like 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 cadmium because of 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 collembola *Orchesella cincta* is in the gut, where it has a short half-life of <1 d (van Straalen et al. 1985).

Environment Canada (1995) reported LC_{25}, LC_{50}, and LC_{70} values of 2067, 2500, and 3070 $mg \cdot kg^{-1}$, respectively, for the earthworm *Eisenia foetida* in artificial soil. The NOEC was reported at 1480 mg $Pb \cdot kg^{-1}$.

Spurgeon et al. (1994) reported LD_{50} values for *E. foetida* of 3760–4480 mg $Pb \cdot kg^{-1}$ depending on exposure period. Cocoon production was not affected at 1810 mg $Pb \cdot kg^{-1}$, but was reduced by 50% at 1940 mg $Pb \cdot kg^{-1}$.

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 abberations 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 $Pb \cdot kg^{-1}$ bw. None of the pigs died, but clinical signs of lead toxicosis (coughing, rough coats, and gaunt appearance) were seen in two of the three pigs treated at 35.2 mg $Pb \cdot kg^{-1}$ bw. Feed consumption rates or weight gain were not affected in wether lambs fed lead acetate at 44.4 mg $Pb \cdot kg^{-1}$ bw per day for 84 d (Fick et al. 1976).

Lynch et al. (1976) reported a 13% reduction in weight in calves receiving 7.7 mg $Pb \cdot kg^{-1}$ bw per day, while only a 6% reduction was observed in calves receiving 3.9 mg $Pb \cdot kg^{-1}$ bw per day.

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 $Pb \cdot kg^{-1}$ bw per day was reduced by 16%. By day 6, 40% of the hatchlings on the 625 mg $Pb \cdot kg^{-1}$ bw per day diet had died.

Custer et al. (1984) fed American kestrels with a diet of biologically incorporated lead for 60 d. At 28 mg $Pb \cdot kg^{-1}$ bw per day, 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 hens and Japanese quail hens *(Coturnix coturnix japonica)*. After 5 weeks, quail hens showed a 28% decrease in egg production at 1.8 mg $Pb \cdot kg^{-1}$ bw per day, while a 77% decrease was observed after 4 weeks at 26.1 mg $Pb \cdot kg^{-1}$ bw per day for chickens.

Human and Experimental Animal Health Effects

For the general population, exposure to lead is mainly through food, cigarette smoking, and dust/soil from food (including water-based food items) (Health Canada 1994). Higher exposure can occur in people living near point sources of lead such as lead smelters, drinking water or food containing higher than average lead concentrations, or being exposed to nonfood items such as ink, paint chips, and plaster.

Absorption of lead by the body can occur through inhalation, ingestion, dermal contact, or transfer via the placenta (Health and Welfare Canada 1992). Once lead is absorbed, it enters either a "rapid turnover" biological pool with distribution to the soft tissues (blood, liver, lungs, spleen, kidneys, and bone marrow) or a "slow turnover" pool with distribution mainly to the skeleton (Rabinowitz et al. 1976). In adults and children, respectively, about 80–95% and 73% of the total body lead accumulates in the skeleton (Barry 1978; Alessio and Foa 1983).

Lead is a cumulative general poison, with fetuses, infants, children up to 6 years of age, and pregnant women (because of the fetus) being most susceptible to adverse health effects. Lead can severely affect the central nervous system. Overt signs of acute intoxication include dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, hallucinations, and loss of memory (ATSDR 1993), with encephalopathy occurring at blood lead levels of 100–120 $\mu g \cdot dL^{-1}$ in adults and 80–100 $\mu g \cdot dL^{-1}$ in children (USEPA 1986).

The metabolic effects of lead are through interferences with the activity of several of the major enzymes involved in the biosynthesis of heme (USEPA 1986). As heme is a constituent of several hemoproteins, disturbances to its biosynthesis would be expected to result in multi-organ toxicity, but the only clinically well-defined symptom is anemia (Moore 1988), which occurs only at blood lead levels in excess of 40 $\mu g \cdot dL^{-1}$ in children (WHO 1977). Anemia results both from lead-induced inhibition of heme synthesis and shortening of erythrocyte survival (Moore et al. 1980). The NOEL for changes in hemoglobin concentration in blood has been suggested to be 50 $\mu g \cdot dL^{-1}$ in adults and 40 $\mu g \cdot dL^{-1}$ in children (Rosen et al. 1974; WHO 1977). Changes in growth patterns in infants <42 months old have been associated with the increased levels of erythrocyte protoporphyrin, with persistent increases in the high blood levels leading initially to a rapid gain in weight but subsequently to a retardation of growth. Lead has also been shown to interfere with calcium metabolism, both directly and by perturbation of the heme-mediated generation of the vitamin D precursor 1,25-dihydroxycholecalciferol. The vitamin D-endocrine system plays a major role in the maintenance of extra- and intra-cellular calcium homeostasis, in bone remodelling, in intestinal absorption of minerals, in cell differentiation, and in immunoregulatory capacity.

Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pain, and gastrointestinal symptoms, may appear in adults with blood lead levels of 50–80 $\mu g \cdot dL^{-1}$ (Hänninen et al. 1979). After 1 or 2 years of exposure, muscle weakness, gastrointestinal symptoms, lower scores on psychometric tests, disturbances in mood, and symptoms of peripheral neuropathy were observed in occupationally exposed populations at blood lead levels of 40–60 $\mu g \cdot dL^{-1}$ (Health and Welfare Canada 1992). Several lines of evidence demonstrate that both the central and peripheral nervous systems are principal targets for lead toxicity. Significant reduction in maximal motor-nerve conduction velocity have been observed (Schwartz et al. 1988). The auditory nerve may be a target for lead toxicity, reducing hearing acuity in children (Robinson et al. 1985).

Several epidemiological studies with contentious interpretations of the results have been conducted. Significant correlations have been observed between levels of lead (dentine, blood, and umbilical cord blood) and intellectual or behavioral performance of children (intelligence scores, reading and number skills, and juvenile delinquency). Inconsistent association were common in various studies, particularly the ones on fetal exposure. It appears that prenatal exposure may have early effects on mental development, but that these effects do not persist to age 4, at least not using the tests so far employed. Several studies indicated that the generally higher exposures of children in the 18- to 36-month age range may be negatively associated with mental development, but this too is not confirmed in other studies (Health Canada 1996).

The carcinogenicity of lead in humans has been investigated in several epidemiological studies of occupationally exposed workers (Health and Welfare Canada 1992). The evidence for the carcinogenicity of lead in humans in inconclusive, due to the limited number of studies, small cohorts leading to lack of statistical power, and a lack of consideration of confounding variables. Lead has been classified in Group IIIB, possibly carcinogenic to humans, according to the classification scheme of the Environmental Health Directorate of Health Canada.

The evidence for an effect of lead on genetic material is conflicting, but the weight of evidence suggests that some salts of lead are genotoxic (Health Canada 1996).

Some studies on reproductive and teratogenic effects of lead have been conducted. Gonadal dysfunction in men has been associated with blood lead levels of 40–50 $\mu g \cdot dL^{-1}$, and there may also be reproductive dysfunction in females occupationally exposed to lead. Increased spontaneous abortion and rates of stillbirths have been associated with lead intoxication of workers in the lead industry. Exposure of pregnant women to lead also increases the risk of pre-term delivery (Health Canada 1996).

The provisional tolerable intake of 3.57 $\mu g \cdot kg^{-1}$ bw per day is recommended by WHO (1993) for all age groups for the derivation of human health soil quality guidelines for lead.

Guideline Derivation

Canadian soil quality guidelines are derived for different land uses following the process outlined in CCME (1996a) using the different receptors and exposure scenarios for each land use (Table 1). Detailed derivations of the soil quality guidelines for lead are provided in Environment Canada (1996) and Health Canada (1996).

Soil Quality Guidelines for Environmental Health

Environmental soil quality guidelines (SQG_Es) 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 allow use of the preferred weight of evidence procedure. To provide a broader scope of protection, a nutrient and energy cycling check is calculated. For industrial land use, an off-site migration check is also calculated.

For all land uses, the preliminary soil contact value (also called threshold effects concentration [TEC] or effects concentration low [ECL], depending on the land use) is compared to the nutrient and energy cycling check. If the nutrient and energy cycling check is lower, the geometric mean of the preliminary soil contact value and the nutrient and energy cycling check is calculated as the soil quality guideline for soil contact. If the nutrient and energy cycling check is greater than the preliminary soil contact value, the preliminary soil contact value becomes the soil quality guideline for soil contact.

For agricultural land use, the lower of the soil quality guideline for soil contact and the soil and food ingestion guideline is recommended as the SQG_E.

For residential/parkland and commercial land uses, the soil quality guideline for soil contact is recommended as the SQG_E.

For industrial land use, the lower of the soil quality guideline for soil contact and the off-site migration check is recommended as the SQG_E.

In the case of lead, the recommended SQG_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

Human health soil ingestion guidelines (SQG_{HH}s) for threshold contaminants are derived using a TDI for the most sensitive receptor designated for a land use. For lead, a provisional TDI is used in place of a conventional TDI.

The CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection. The lower of the soil ingestion guideline and any of the calculated checks is recommended as the SQG_{HH}.

Therefore for lead, the soil ingestion guidelines are recommended as the SQG_{HH} guidelines for agricultural, residential/parkland, and commercial land uses. For industrial land, the off-site migration check value is recommended (Table 2).

Soil Quality Guidelines for Lead

For each land use category, the soil quality guideline for lead is the lower of the SQG_{HH} and SQG_E (Table 1).

Because there are sufficient data to calculate both an SQG_{HH} and an SQG_E for each land use, the soil quality

Table 2. Soil quality guidelines and check values for lead (mg·kg^{-1}).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**70**[a]	**140**[a]	**260**[a]	**600**[a]
Human health guidelines/check values				
SQG_{HH}	140[b]	140[b]	260[b]	740[b]
Soil ingestion guideline	140	140	260	8200
Inhalation of indoor air check	NC[c]	NC[c]	NC[c]	NC[c]
Off-site migration check	—	—	—	740
Goundwater check (drinking water)	NC[d]	NC[d]	NC[d]	NC[d]
Produce, meat, and milk check	NC[e]	NC[e]	—	—
Provisional SQG_{HH}	NC[f]	NC[f]	NC[f]	NC[f]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG_E	70[g]	300[h]	600[h]	600[h]
Soil contact guideline	300	300	600	600
Soil and food ingestion guideline	70	—	—	—
Nutrient and energy cycling check	723	723	834	834
Off-site migration check	—	—	—	2272
Groundwater check (aquatic life)	NC[d]	NC[d]	NC[d]	NC[d]
Provisional SQG_E	NC[i]	NC[i]	NC[i]	NC[i]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	375	500	1000	1000

Notes: NC = not calculated; ND = not determined; SQG_E = soil quality guideline for environmental health; SQG_{HH} = soil quality guideline for human health. 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 SQG_{HH} and an SQG_E. Therefore the soil quality guideline is the lower of the two and represents a fully integrated de novo guideline for this land use, derived in accordance with the soil protocol (CCME 1996a). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

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

[c] Applies only to volatile organic compounds and is not calculated for metal contaminants.

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

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

[f] Because data are sufficient and adequate to calculate an SQG_{HH} for this land use, a provisional SQG_{HH} is not calculated.

[g] The SQG_E for this land use is based on the soil and food ingestion guideline.

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

[i] Because data are sufficient and adequate to calculate an SQG_E for this land use, a provisional SQG_E is not calculated.

guideline represents a fully integrated de novo guideline for each land use, derived according to the soil protocol (CCME 1996a). The interim soil quality criteria (CCME 1991) for lead are superseded by the soil quality guidelines.

CCME (1996b) provides guidance on potential modifications to the final recommended soil quality guidelines when setting site-specific objectives.

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