



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

CHROMIUM
total chromium 1997
hexavalent chromium (VI)
1999

This fact sheet provides soil quality guidelines for total chromium (Cr) in Canada for the protection of environmental and human health (Table 1), and soil quality guidelines for hexavalent chromium (Cr(VI)) for the protection of environmental health (Table 2). Supporting scientific documents are also available (Environment Canada 1996; Health Canada 1996).

Background Information

Chromium (CAS 7440-47-3) is a lustrous metal that melts at $1903 \pm 10^\circ\text{C}$. Although chromium is a naturally occurring element, elemental chromium does not occur in

nature (Shupak 1991). Rather, it is found complexed with oxygen, iron, or lead, forming oxides such as chromite (FeOCr_2O_3), chromitite ($\text{Fe}_2\text{O}_3 \cdot 2\text{Cr}_2\text{O}_3$), and crocitic (PbCrO_4) (Williams 1988). Although chromium can exist in nine different oxidation (valence) states, trivalent (III) and hexavalent (VI) chromium are the two most common species (Langård 1982; WHO 1988; Shupak 1991). The trivalent form of chromium is generally considered to be the most thermodynamically stable species under ambient redox conditions. Cr(VI) is not thermodynamically stable, behaving as a strong oxidizing agent. While complexed Cr(III) occurs naturally and is ubiquitous in the environment, the principal source of Cr(VI) in the environment is anthropogenic pollution; it rarely occurs naturally due to

Table 1. Soil quality guidelines for total chromium ($\text{mg} \cdot \text{kg}^{-1}$).

	Land use			
	Agricultural	Residential/ parkland	Commercial	Industrial
Guideline	64^a	64^a	87^a	87^a
SQ _{GHH} Limiting pathway for SQ _{GHH}	220 Soil ingestion	220 Soil ingestion	630 Soil ingestion	2300 Off-site migration
Provisional SQ _{GHH} Limiting pathway for provisional SQ _{GHH}	NC ^b ND	NC ^b ND	NC ^b ND	NC ^b ND
SQ _{GE} Limiting pathway for SQ _{GE}	64 ^c Nutrient and energy cycling check	64 ^c Nutrient and energy cycling check	87 Nutrient and energy cycling check	87 Nutrient and energy cycling check
Provisional SQ _{GE} Limiting pathway for provisional SQ _{GE}	NC ^d ND	NC ^d ND	NC ^d ND	NC ^d ND
Interim soil quality criterion (CCME 1991)	750	250	800	800

Notes: NC = not calculated; ND = not determined; SQ_{GE} = soil quality guideline for environmental health; SQ_{GHH} = soil quality guideline for human health.

^aData are sufficient and adequate to calculate an SQ_{GHH} and an SQ_{GE}. Therefore the soil quality guideline 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.

^bBecause data are sufficient and adequate to calculate an SQ_{GHH} for this land use, a provisional SQ_{GHH} is not calculated.

^cThe SQ_{GE} for this land use is the geometric mean of the preliminary soil contact value (TEC or ECL).

^dBecause data are sufficient and adequate to calculate an SQ_{GE} for this land use, a provisional SQ_{GE} 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.

Table 2. Soil quality guidelines for hexavalent chromium (mg·kg⁻¹).

Guideline	Land use			
	Agricultural	Residential/ parkland	Commercial	Industrial
Guideline	0.4 ^a	0.4 ^a	1.4 ^a	1.4 ^a
SQ _{GHH} Limiting pathway for SQ _{GHH}	NC ^b ND	NC ^b ND	NC ^b ND	NC ^b ND
Provisional SQ _{GHH} Limiting pathway for provisional SQ _{GHH}	NC ^c ND	NC ^c ND	NC ^c ND	NC ^c ND
SQ _{GE} Limiting pathway for SQ _{GE}	NC ^d ND	NC ^d ND	NC ^d ND	NC ^d ND
Provisional SQ _{GE} Limiting pathway for provisional SQ _{GE}	0.4 ^e Soil contact	0.4 ^e Soil contact	1.4 ^e Soil contact	1.4 ^e Soil contact
Interim soil quality criterion (CCME 1991)	8	8	No value	No value

Notes: NC = not calculated; ND = not determined; SQ_{GE} = soil quality guideline for environmental health; SQ_{GHH} = soil quality guideline for human health.

^aData are sufficient and adequate to calculate only a provisional SQ_{GE}, which is less than the existing interim soil quality criterion (CCME 1991). Therefore the soil quality guideline supersedes the interim soil quality criterion for this land use.

^bThere is no SQ_{GHH} for this land use at this time.

^cThere is no provisional SQ_{GHH} for this land use at this time.

^dData are insufficient/inadequate to calculate an SQ_{GE} for this land use.

^eData are sufficient and adequate to calculate only a provisional SQ_{GE} for this land use.

its affinity to react with organic matter and other reducing substances (USEPA 1984a; Jaworski 1985; Bartlett and James 1988).

Chromium is widely used in the metallurgical industry or the production of ferrochromium alloys such as stainless steel, high-speed steel, alloy cast irons, and nonferrous alloys. Chromium is also used in the manufacture of refractory bricks, furnace linings, mortars, and castables and in coating materials to close pores and to join bricks in furnaces. Another primary use of chromium is in chemical applications such as metal finishing (Cr(VI)), corrosion control (Cr(III)), leather tanning (Cr(III)) and finishing, wood treatment (Cr(VI)), and the production of pigments (both Cr(VI) and Cr(III)) (Langård 1982; USEPA 1984b; Nriagu 1988; ATSDR 1989). Chromium has been measured in a wide range of environmental media from across Canada. Elevated chromium levels have been found in association with industries producing or using chromium products.

Environmental Fate and Behaviour in Soil

The degree to which Cr(III) can interact with other soil constituents is limited by the fact that most Cr(III) is

present in the form of insoluble chromium oxide precipitates. Thus Cr(III) is relatively stable in most soils (Kabata-Pendias and Pendias 1984), although oxidation of Cr(III) to Cr(VI) can occur under specific environmental conditions. Factors influencing the rate of chromium oxidation include soil pH, Cr(III) concentration, presence of competing metal ions, availability of manganese oxides, presence of chelating agents (i.e., low molecular weight organic compounds), and soil water activity.

Cr(III) oxidation is favoured under acidic conditions (Bartlett and James 1979; Bartlett 1986; Fendorf et al. 1992). This behaviour is attributable to increased solubility of Cr(III) at lower pH, which enables increased contact with the oxidizing agent (Bartlett 1991). Cr(III) must be in a mobile form to undergo oxidation on the surfaces of manganese oxides (Bartlett 1991). Aside from decreasing soil pH, Cr(III) solubility is enhanced by chelation to low molecular weight compounds such as citric or fulvic acids (Bartlett and James 1988).

There are relatively few oxidants known to mediate oxidation of Cr(III) in the soil environment because the redox potential of the Cr(VI)/Cr(III) couple is quite high (Rai et al. 1989). Typical oxidizing agents include dissolved oxygen and manganese oxides.

Factors influencing the reduction of Cr(VI) to Cr(III) in soil include soil pH, the presence of electron donors such as organic matter or ferrous ions, and soil oxygen levels. Many studies have shown that Cr(VI) reduction increases with decreasing soil pH (Bartlett and Kimble 1976; Bloomfield and Pruden 1980; Bartlett 1991; Eary and Rai 1991). Soil pH affects the degree of positive and negative charge on the surfaces of soil colloids, thus directly influencing the availability of electron donors (Bartlett and James 1988). Rai et al. (1989) conclude that acidic soil solutions enhance the release of divalent iron (Fe(II)) ions from soil minerals, which increases the reduction of Cr(VI). The authors likewise note that the chromium-reducing action of organic matter increases with decreasing pH.

Cr(VI) reduction to Cr(III) is significantly retarded in soils that lack appropriate electron donors such as ferrous iron minerals, silicate minerals, reduced sulphur species, and soil organic matter (Palmer and Wittbrodt 1991). Bartlett and Kimble (1976) found no evidence for Cr(VI) reduction in soils with very low organic matter (<0.05%) content. Similarly, Ottabong (1989) found that chromium reduction increased linearly with increasing soil humus content. The reduction of Cr(VI) by Fe(II) could be an important fate process in subsoils, where levels of organic matter are typically low (Bartlett and James 1988; Eary and Rai 1991).

Chromium reduction is enhanced under anaerobic conditions, such as within waterlogged soils (Bloomfield and Pruden 1980; Bartlett 1991; Losi et al. 1994a). Since oxygen is an electron acceptor, it is believed to inhibit Cr(VI) reduction through direct competition for electron donors (Losi et al. 1994b). Waterlogged soils may also enhance chromium reduction because of increased CO₂ trapping, which tends to lower soil pH (Losi et al. 1994a). Soil microbial activity may indirectly influence Cr(VI) reduction by decreasing soil oxygen concentrations and increasing CO₂ levels.

Cr(III) is strongly adsorbed by clay particles, soil organic matter, metal oxyhydroxides, and other negatively charged particles. Below pH 4, Cr(III) is strongly adsorbed by both kaolinite and montmorillonite clays. Between pH 4 and 5, the combination of adsorption and precipitation renders this species immobile in most soils (NRCC 1976; Jaworski 1985). Since clay surfaces become more negatively charged with increasing pH, Cr(III) adsorption by clay minerals increases with increasing soil pH.

Although Cr(VI) is not readily adsorbed to most surfaces, it is adsorbed by clay minerals that possess exposed inorganic hydroxyl groups, including iron and aluminum oxides (Rai et al. 1989; Zachara et al. 1989). Cr(VI) adsorption increases with decreasing pH as a result of

protonation of the surface hydroxyl sites. The adsorption process can be described as a surface complexation reaction between Cr(VI) species and a surface hydroxyl site either on iron or aluminum oxides or on the edges of layer silicates (Zachara et al. 1989). Thus Cr(VI) adsorption increases in proportion to concentrations of iron and aluminum oxides. Alternatively, the presence of SO₄²⁻ and dissolved inorganic carbon depresses the adsorption of Cr(VI) (Zachara et al. 1989). In general, highly weathered (southern) soils dominated by oxide-rich colloids adsorb more Cr(VI) than the less weathered (northern) acid soils (Bartlett and James 1988; Bartlett 1991).

It is important to note that the processes of chromium adsorption and reduction may occur simultaneously in a soil matrix. Distinguishing which process is responsible for an experimentally observed decline in Cr(VI) soil levels is difficult. This may pose significant implications for site remediation efforts, since adsorbed Cr(VI) can be remobilized by changes in subsurface geochemistry (e.g., pH changes following the application of lime- or phosphate-rich fertilizer).

Cr(III) solids, such as Cr(III) oxide (Cr₂O₃) and Cr(III) phosphate complexes, are practically insoluble at pH >4 and thus do not tend to leach from the soil matrix into the groundwater system (Calder 1988). Rarely exceeding 50 µg·L⁻¹, Cr(III) constitutes a very small percentage of the total chromium found in natural and polluted groundwaters.

Cr(VI) solids, except BaCrO₄, are soluble within the soil environment. Cr(VI) adsorption by clays, soils, and natural aquifer materials is low to moderate within the pH range typical of groundwater (e.g., pH 6.8). At a pH >8.5, Cr(VI) is completely mobile and can readily leach out of the soil and into the groundwater system. Cr(VI) can be stabilized within the soil profile by reduction to relatively immobile Cr(III) or adsorption to mineral solids. However, Cr(VI) that is not adsorbed or reduced to Cr(III) remains highly mobile within the soil profile.

Behaviour and Effects in Biota

Soil Microbial Processes

The toxicity of Cr(III) and Cr(VI) to microbial-mediated soil processes has been compared by Fenke (1977), who determined Cr(VI) to be a more effective inhibitor of nitrification than Cr(III). Cr(VI) temporarily inhibited nitrification at concentrations of 60 and 120 mg·kg⁻¹ dw, but the rate of nitrification returned to normal after 100 d of incubation. However, the 240 mg·kg⁻¹ dw treatment of Cr(VI) inhibited nitrification beyond 100 d. In contrast,

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180 mg·kg⁻¹ dw of Cr(III) slightly enhanced nitrification from day 14 to 100. Liang and Tabatabai (1978) reported that nitrification was inhibited by 59–96% 10 d post-treatment in three different soils treated with 50 μmol of CrCl₃.

The EC₅₀ for reduced soil respiration in five types of soil was >5000 mg·kg⁻¹ dw (Doelman and Haanstra 1984). Skujinš et al. (1986) reported an EC₅₀ for soil respiration inhibition following a 20-d incubation at >200 μg Cr(III)·kg⁻¹ dw. Chang and Broadbent (1981) reported a 45% decrease in cumulative CO₂ evolution at 50 mg·kg⁻¹ dw. Drucker et al. (1979) reported that 1 mg·kg⁻¹ dw of Cr(VI) significantly reduced respiration after 13 d of exposure. After 24 d, the NOEC was 10 mg Cr(VI)·kg⁻¹ dw, with respiration being significantly reduced at 100 mg Cr(VI)·kg⁻¹ dw.

Terrestrial Plants

Chromium is a natural component of plant tissues, although concentrations vary considerably between different plant species, plant tissues, and soil types. Levels in shoots of plants grown on uncontaminated soil usually do not exceed 0.5 mg·kg⁻¹ dw. Whole plant concentrations ≥3 mg·kg⁻¹ dw indicate possible contamination and/or increased accumulation (Williams 1988; Janus and Krajnc 1989). There are reported cases of plants growing on serpentine soils that accumulated tissue chromium concentrations as high as 100 mg·kg⁻¹ dw, but plants rarely exceed this value (Brookes 1987).

Although it has been well established that Cr(III) is essential to animal nutrition, the essentiality of chromium to plants has yet to be determined. Detectable concentrations of chromium are found in plants, and there is some evidence that Cr(III) has stimulatory effects on plant growth and yield (Mertz 1969; WHO 1988).

Many studies have demonstrated that chromium uptake from soils or nutrient solution and translocation to plant cells is very low. Thus, concentrations of chromium in the edible portions of the plant remain low, even when growing on chromium-contaminated soil (Patterson 1971; Cunningham et al. 1975a, 1975b, 1975c; Cary et al. 1977a, 1977b; Dowdy and Ham 1977; Lahouti and Peterson 1979; Sykes et al. 1981; de Haan et al. 1985). In general, roots contain higher chromium concentrations than stems, leaves, or fruit (Williams 1988).

The visual symptoms of chromium toxic injury to plants include chlorosis, stunted growth, curled and discoloured leaves, and poorly developed root systems (NRCC 1976).

The lowest soil concentrations of total chromium at which phytotoxic effects have been observed are 21 and 31 mg·kg⁻¹, resulting in a 50% decrease in the yield of tomatoes and oats, respectively. Radish and lettuce seed germination are reduced by 50% at concentrations ranging from 81 to 397 mg·kg⁻¹.

The lowest soil concentrations of Cr(VI) at which phytotoxic effects have been observed are 1.8 and 6.8 mg·kg⁻¹, which resulted in 50% yield reductions of lettuce and tomatoes, respectively (Adema and Henzen 1989). Fifty percent reductions in a variety of growth endpoints have been reported at concentrations ranging from 1.8 to 67 mg Cr(VI)·kg⁻¹.

Terrestrial Invertebrates

Heavy metals are generally absorbed across the intestinal wall. Some metals (e.g., lead) are also absorbed through the skin. Hall (1988) proposed that the mucoid coat surrounding the earthworm *Acini fatuity* can bind and retain heavy metals. This mucus may in fact prevent cuticular exposure to heavy metals (Hall 1988).

Ma (1982) studied the uptake of heavy metals by three species of earthworms (*Allolobophora caliginosa*, *Lumbricus rubellus*, and *Dendrobaena rubida*) in six different soils. Chromium behaved similarly in all soils and did not significantly accumulate in any of the three species of worms. Ma (1982) concluded that the lack of chromium accumulation reflected its decreased bioavailability to earthworms.

Van Gestel et al. (1993) examined the bioaccumulation and elimination of Cr(III) nitrate (Cr(NO₃)₃) in *Acini andrei* in an artificial soil substrate. Tissue concentrations (ranging from 0.8 to 18 mg·kg⁻¹ dw) at the three highest chromium levels were significantly different from those in the control earthworms. BCF values ranged between 0.031 and 0.019 (from lowest to highest dose level) for the exposed worms and was 0.048 in the control soil. At the end of the 3-week recovery period, chromium concentrations returned to normal in all dose groups (0.3–1.1 mg Cr·kg⁻¹ dw).

The growth and cocoon production of the earthworm *Eisenia andrei* is significantly reduced at 1000 mg Cr·kg⁻¹. Soil concentrations resulting in 50% mortality of the earthworm *Eisenia fetida* range from 671 to 1400 mg·kg⁻¹.

Studies reporting the toxicological effects of Cr(VI) on soil invertebrates were not found.

Livestock and Wildlife

The major source of exposure to chromium for wild birds and mammals is through food ingestion. Gastrointestinal chromium absorption is generally low (Taylor and Parr 1978; Halford et al. 1983). Cr(VI) compounds are generally absorbed from the gastrointestinal tract more efficiently (2–10% of dose) than inorganic Cr(III) compounds (0.5–3%).

Inhalation may be generally less important as a route of uptake than dietary sources. In contrast, however, absorption of inhaled chromium appears to be greater than that of ingested chromium. Approximately 12% of inhaled Cr(III) and 30% of Cr(VI) are absorbed by the epithelial lining of the lungs (Outridge and Scheuhammer 1993).

Following oral exposure to Cr(III), the liver is the principal site of chromium accumulation. In contrast, Cr(VI) is more widely distributed within the kidneys, spleen, liver, lungs, and bones (Outridge and Scheuhammer 1993). Long-term chromium exposure results in significant chromium accumulation in bone tissue (Fitzgerald et al. 1985).

Few studies have examined the toxicological effects of chromium on wildlife, bird species, or livestock in controlled experiments, and none of these studies has involved animal exposure from the soil environment.

NOAELs for chromium range from 5.5 mg·kg⁻¹ bw per day for histopathological changes in the dog, cat, and rabbit to 200 mg·kg⁻¹ fresh weight for fright stimulus in the black duck (Environment Canada 1996).

Behaviour and Effects in Humans and Experimental Animals

The pharmacokinetics and toxic effects of chromium and chromium compounds have been extensively reviewed in the Canadian Environmental Protection Act assessment report on chromium and its compounds (Government of Canada 1994).

Because of the lack of specific information on the form of chromium encountered in environmental media, it was not possible to make separate exposure estimates for Cr(III) and Cr(VI), and the estimated daily intakes refer to total chromium.

Adults, teenagers, school-aged children, preschoolers, and infants (assumed exclusively breast-fed) are estimated to be exposed to 0.31, 0.43, 0.69, 1.43, and 0.22 µg Cr·kg⁻¹ bw per day, respectively, with the highest estimated intakes for preschoolers.

Food is the most important route of exposure, constituting from 60 to 81% of the total daily estimated intake for all age groups except breast-fed infants. Generally, the consumption of cereal/grain and dairy products was estimated to contribute the most chromium to daily dietary intakes. Dietary intake estimates determined in this assessment fall somewhat below current U.S. dietary intake values ranging from 28 to 48 µg per day (Anderson and Kozlowsky 1985; Parr et al. 1991; Anderson et al. 1992). Furthermore, all of these values fall well below the estimated safe and adequate daily dietary intakes established by the U.S. National Academy of Sciences (NAS 1989).

Infants excepted, estimates of exposure from combined soil and dust ranged from 6 to 29% of total intake; intakes from water ranged from 10 to 17%; and exposure via air was insignificant at <1%. Due to the lower intake of chromium through breast milk, the percentage of contribution from food to total intake of breast-fed infants was only 13%, with exposure from soil and dust contributing 87%.

Reliable data are not available to estimate exposure in populations living in mineralized areas and those living in the vicinity of industrial chromium-related activities. Higher-than-average chromium exposures can, however, be estimated for smokers. Assuming mainstream exposure of 0.147 µg per cigarette (Labstat Incorporated 1992), adults and teenagers smoking a pack of cigarettes a day (20) would be exposed to an additional 0.042 and 0.052 µg Cr·kg⁻¹ bw per day, respectively.

Trivalent Chromium

Cr(III) is considered to be an essential trace element in animal and human nutrition (Langård and Norseth 1986). Suboptimal intake of chromium may lead to impaired glucose tolerance, elevated levels of circulating insulin, cholesterol, and triglycerides, and an increased occurrence of aortic plaques (Anderson 1981).

Minimum dietary requirements of chromium for adults and infants have not been established by HWC (1990) on the basis of insufficient data and information. The Food and Nutrition Board of the U.S. National Research Council (NAS 1989), however, has tentatively recommended an estimated safe and adequate daily dietary intake (ESADDI) ranging from 50 to 200 µg per day for adults (0.7 to 2.9 µg·kg⁻¹ bw per day, assuming an average body weight of 70 kg). For younger age groups, tentative recommendations were derived by extrapolation on the basis of the expected food intake as follows: birth to 6 months, 10–40 µg per day; 6 months to 1 year,

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20–60 µg per day; 1 to 3 years, 20–80 µg per day; 4 to 6 years, 30–120 µg per day; and 7 to 11 years and older children, 50–200 µg per day (NAS 1989).

Cr(III) compounds have been classified by the Government of Canada (1994) in Group VI, “unclassifiable with respect to carcinogenicity in humans”, according to the Canadian Environmental Protection Act classification scheme, based on the inadequate database from carcinogenicity studies in experimental animals and the limited database from exposed human populations. IARC (1990) classified metallic chromium and Cr(III) compounds as “not classifiable as to their carcinogenicity” (Group 3).

In its assessment of chromium and its compounds, Government of Canada (1994) indicated that available data on the non-neoplastic effects of Cr(III) in epidemiological and experimental animal studies conducted to date are limited and inadequate for derivation of effects levels; hence, no TDI was derived for this form of chromium following oral administration.

In the absence of a reliable TDI for Cr(III) compounds, it is proposed to adopt the upper range values of the ESADDIs recommended by the U.S. National Research Council (NAS 1989) for adults and young children (age 1 to 3 years) as TDIs for the derivation of human health soil quality guidelines. Since the upper range values of the ESADDIs for chromium exceed the estimated daily intakes (EDIs) in young children and adults by a comfortable margin, the use of ESADDIs does not appear to be unreasonably conservative in this case.

Hexavalent Chromium

The group of Cr(VI) compounds as a whole has been classified as “carcinogenic to humans” (Group 1) on the basis of documented carcinogenicity in human populations exposed by inhalation in occupational environments (Government of Canada 1994). The International Agency for Research on Cancer (IARC 1990) has also categorized Cr(VI) as carcinogenic to humans (Group 1).

A reference dose (RfD) of 5 µg·kg⁻¹ bw per day was derived for Cr(VI) soluble salts by the USEPA, based on the results of a limited chronic study (K₂CrO₄ in drinking water) in rats by Mackenzie et al. (1958). The USEPA, however, indicated that the level of confidence in the RfD was low (HC 1996).

Neither Health Canada nor the World Health Organization has derived an oral TDI for Cr(VI) to establish their drinking water guideline for chromium. Furthermore, Government of Canada (1994) did not identify any

experimental animal study of chronic duration considered adequate as a basis to assess the carcinogenicity of Cr(VI) or to determine an effect level for non-neoplastic endpoints following administration of Cr(VI) compounds via ingestion or inhalation. It would, therefore, be inappropriate to adopt the USEPA’s RfD for Cr(VI) soluble salts. Thus, there is no TDI to serve as a basis for the derivation of soil quality guidelines for Cr(VI) (HC 1996).

Guideline Derivation

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

Total Chromium

In the case of total chromium, the SQG_E for agricultural and residential/parkland land uses is based on the geometric mean of the preliminary soil contact value and the nutrient and energy cycling check. For commercial and industrial land uses, the SQG_E is based on the soil contact guideline (Table 3).

Hexavalent Chromium

There are insufficient data to derive any of the environmental health guidelines or check values for Cr(VI). There are, however, sufficient data to derive a provisional SQG_E based on soil contact for plants (Table 4).

Soil Quality Guidelines for Human Health

Total Chromium

Human health soil quality guidelines (SQG_{HHS}) for total chromium are derived using a TDI for the most sensitive receptor designated for a land use. For total chromium, the upper range values of the ESADDIs recommended by the U.S. National Research Council (NAS 1989) for adults and young children (age 1 to 3 years) are adopted as TDIs for the derivation of SQG_{HHS} .

The soil ingestion guidelines for total chromium have been approved by the Standards and Guidelines Rulings Committee of the Bureau of Chemical Hazards of Health Canada as a preliminary SQG_{HH} . However, the CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection. The lowest of the soil ingestion guideline, the inhalation of indoor air check, the off-site migration check, and the groundwater for drinking water check is recommended as the SQG_{HH} .

Therefore, the SQG_{HHS} for agricultural, residential/parkland, and commercial land uses are based on the soil ingestion guidelines. For industrial land use, the SQG_{HH} is based on the off-site migration check (Table 3).

Hexavalent Chromium

There are no human health guidelines or check values for Cr(VI) at the present time (Table 4).

Soil Quality Guidelines for Total Chromium

The soil quality guidelines are the lower of the SQG_{HH} and the SQG_E . For all land uses, the soil quality guideline for total chromium is the soil concentration calculated for the SQG_E , which is based on the soil contact guideline (Table 3).

Because there are sufficient data to derive an SQG_{HH} and an SQG_E for each land use, the soil quality guidelines represent fully integrated de novo guidelines, derived according to the soil protocol (CCME 1996b). The interim soil quality criteria (CCME 1991) for total chromium are superseded by the soil quality guidelines.

Soil Quality Guidelines for Hexavalent Chromium

The soil quality guidelines are the lower of the provisional SQG_E and the interim soil quality criteria (CCME 1991) (Table 2).

Agricultural and Residential/Parkland

The provisional SQG_{ES} are less than the interim soil quality criteria (CCME 1991) for agricultural and residential/parkland land uses. Therefore the soil quality guidelines for Cr(VI) supersede the interim soil quality criteria for these land uses.

Commercial and Industrial Land

There are no interim soil quality criteria (CCME 1991) for Cr(VI) for commercial and industrial land uses, and only provisional SQG_{ES} can be derived at present. Therefore, the soil quality guidelines for these land uses are the provisional SQG_{ES} .

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

References

- Adema, D.M.M., and L. Henzen. 1989. A comparison of plant toxicities of some industrial chemicals in soil culture and soilless culture. *Ecotoxicol. Environ. Saf.* 18:219–229.
- Anderson, R. 1981. Nutritional role of chromium. *Sci. Total Environ.* 17:13–28. (Cited in Government of Canada 1994.)

Table 3. Soil quality guidelines and check values for total chromium (mg·kg⁻¹).

Guideline	Land use			
	Agricultural	Residential/ Parkland	Commercial	Industrial
	64^a	64^a	87^a	87^a
Human health guidelines/check values				
SQ _{HH}	220 ^b	220 ^b	630 ^b	2 300 ^b
Soil ingestion guideline	220	220	630	6 700
Inhalation of indoor air check	NC ^c	NC ^c	NC ^c	NC ^c
Off-site migration check	—	—	—	2300
Groundwater check (drinking water)	NC ^d	NC ^d	NC ^d	NC ^d
Produce, meat, and milk check	NC ^e	NC ^e	—	—
Provisional SQ _{HH}	NC ^f	NC ^f	NC ^f	NC ^f
Limiting pathway for provisional SQ _{HH}	ND	ND	ND	ND
Environmental health guidelines/check values				
SQ _E	64	64	87	87
Soil contact guideline	64 ^g	64 ^g	87	87
Soil and food ingestion guideline	NC ^h	—	—	—
Nutrient and energy cycling check	52	52	NC ⁱ	NC ⁱ
Off-site migration	—	—	—	91
Groundwater check (aquatic life)	NC ^d	NC ^d	NC ^d	NC ^d
Provisional SQ _E	NC ^j	NC ^j	NC ^j	NC ^j
Limiting pathway for provisional SQ _E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	750	250	800	800

Notes: NC = not calculated; ND = not determined; SQ_E = soil quality guideline for environmental health; SQ_{HH} = soil quality guideline for human health. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

^aData are sufficient and adequate to calculate an SQ_{HH} and an SQ_E. Therefore the soil quality guideline 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.

^bThe SQ_{HH} is the lowest of the human health guidelines/check values.

^cApplies only to volatile organic compounds and is not calculated for metal contaminants.

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

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

^fBecause data are sufficient and adequate to calculate an SQ_{HH} for this land use, a provisional SQ_{HH} is not calculated.

^gThe soil contact guideline is the geometric mean of the preliminary soil contact value (TEC or ECL) and the nutrient and energy cycling check for this land use.

^hData are insufficient/inadequate to calculate the food and soil ingestion guideline for this land use.

ⁱData are insufficient/inadequate to calculate the nutrient and energy cycling check for this land use.

^jBecause data are sufficient and adequate to calculate an SQ_E for this land use, a provisional SQ_E is not calculated.

Table 4. Soil quality guidelines and check values for hexavalent chromium (mg·kg⁻¹).

Guideline	Land use			
	Agricultural	Residential/ Parkland	Commercial	Industrial
	0.4^a	0.4^a	1.4^a	1.4^a
Human health guidelines/check values ^b				
SQG _{HH}	NC	NC	NC	NC
Soil ingestion guideline	NC	NC	NC	NC
Inhalation of indoor air check	NC	NC	NC	NC
Off-site migration check	—	—	—	NC
Groundwater check (drinking water)	NC	NC	NC	NC
Produce, meat, and milk check	NC	NC	—	—
Provisional SQG _{HH}	NC ^c	NC ^c	NC ^c	NC ^c
Limiting pathway for provisional SQG _{HH}	ND	ND	ND	ND
Environmental health guidelines/check values ^d				
SQG _E	NC	NC	NC	NC
Soil contact guideline	NC	NC	NC	NC
Soil and food ingestion guideline	NC	—	—	—
Nutrient and energy cycling check	NC	NC	NC	NC
Off-site migration	—	—	—	NC
Groundwater check (aquatic life)	NC	NC	NC	NC
Provisional SQG _E	0.4	0.4	1.4	1.4
Limiting pathway for provisional SQG _E	Soil contact	Soil contact	Soil contact	Soil contact
Interim soil quality criterion (CCME 1991)	8	8	No value	No value

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

^aData are sufficient and adequate to calculate only a provisional SQG_E, which is less than the existing interim soil quality criteria (CCME 1991). Therefore the soil quality guideline supersedes the interim soil quality criterion for this land use.

^bThere are no values for the human health guidelines/checks at this time.

^cThere is no provisional SQG_{HH} for this land use at this time.

^dData are insufficient/inadequate to calculate any of the environmental health guidelines or check values. However, there are sufficient and adequate data to calculate provisional SQG_Es.

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