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

TRIVALENT, HEXAVALENT AND TOTAL CHROMIUM

Canadian Soil Quality Guidelines (CSoQGs) are numerical concentrations or narrative statements that specify levels of toxic substances or other parameters in soil that are recommended to maintain, improve or protect environmental quality or human health.[1] They are developed using the procedures described in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 2006) to ensure scientifically defensible values that are consistent throughout Canada.

The CSoQGs presented in this factsheet are intended as generic guidance. Site-specific conditions should be considered when applying these values; see CCME (1996) for specific guidance on developing site-specific soil quality objectives or consult local jurisdictions for applicable implementation procedures. CCME (2006) provides further implementation guidance pertaining to the generic guidelines. Soil Quality Guidelines are calculated to an approximate "no- to low effect" level (or threshold level) based only on the toxicological information and other scientific data (fate, behaviour, etc.) available for the substance of interest. The guidelines do not consider socio-economic or technological factors. Site managers should consider these non-scientific factors at the site-specific level as part of the risk management process.

This fact sheet provides Canadian soil quality guidelines for the protection of human health ($CSoQG_{HH}$) for both trivalent (Cr(III)) and hexavalent (Cr(VI)) chromium and CSoQGs for the protection of the environment ($CSoQG_{E}$) for total chromium (Cr(T) and Cr(VI)) (Table 1 and Table 2). The $CSoQG_{HH}$s were developed based on CCME's 2006 protocol. The $CSoQG_{E}$s were developed based on CCME's 1996 protocol. Scientific supporting documents describe the derivation of the $CSoQG_{HH}$ (CCME 20XX) and $CSoQG_{E}$ (CCME 1999).

In many circumstances, only data on Cr(T) in soil are available. These data can be compared to the $CSoQG_{E}$ for Cr(T) or the $CSoQG_{HH}$ for Cr(III), because the majority of environmental chromium (Cr) is expected to be present as Cr(III) compounds. $CSoQG_{E}$s for Cr(T) are expected to be protective of sites where Cr(VI) accounts for only a small component of Cr species. Analytical measurement of Cr(VI) in soil is strongly recommended for any site potentially contaminated by activities involving Cr(VI).

[1] 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, or if the scientific criteria document does not specify whether wet or dry weight is used, readers are advised to check the references provided.

Table 1. Soil quality guidelines for hexavalent chromium (Cr(VI)) in surface soil (mg·kg dry weight [dw]$^{-1}$)[a]

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline[b]	**0.4**	**0.4**	**1.4**	**1.4**
$CSoQG_{HH}$				
ILCR 10^{-6}	18	18	18	18
ILCR 10^{-5}	70	70	106	174
$CSoQG_E$[c]	0.4	0.4	1.4	1.4

Notes: $CSoQG_E$ = soil quality guideline for environmental health; $CSoQG_{HH}$ = soil quality guideline for human health; ILCR = incremental lifetime cancer risk.

[a] See table 6 for more details on the selection of $CSoQG_{HH}$ and $CSoQG_E$, including component values and check values.

[b] Data are sufficient and adequate to calculate a $CSoQG_{HH}$ and a provisional $CSoQG_E$. The soil quality guideline is the lower of the two and the $CSoQG_{HH}$ represents a fully integrated guideline.

[c] $CSoQG_E$ taken from CCME (1999 update).

Table 2. Soil quality guidelines for trivalent chromium (Cr(III)) and total chromium (Cr(T)) in surface soil (mg·kg dw^{-1})[a]

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline[b]	**64**	**64**	**87**	**87**
$CSoQG_{HH}$ (Cr(III))	26 000	26 000	86 000	96 000
$CSoQG_E$[c] (Cr(T))	64	64	87	87

Notes: $CSoQG_E$ = soil quality guideline for environmental health; $CSoQG_{HH}$ = soil quality guideline for human health.

[a] See table 5 for more details on the selection of $CSoQG_{HH}$ and $CSoQG_E$, including component values and check values.

[b] Data are sufficient and adequate to calculate a $CSoQG_{HH}$ and a $CSoQG_E$. The soil quality guideline is the lower of the two and it represents fully integrated guidelines.

[c] $CSoQG_E$ taken from CCME (1999 update).

Background Information

Chromium (CAS 7440-47-3) is a naturally occurring element, although elemental chromium—meaning chromium in its pure form (Cr(0)—does not appear in nature (Shupack 1991); rather, it occurs in compound forms. Chromium can exist in nine different oxidation states (from -2 to +6) (Kumral 2007). Under ambient conditions, only the Cr(III) and (Cr(VI)) oxidation states are stable enough to be of environmental or toxicological importance. Chromium is most commonly found in the Cr(III) state in environmental media, and can occur in ores such as chromite ($FeCr_2O_4$) (ATSDR 2012; EC/HC 1994). Hexavalent chromium only occurs naturally in crocoite ($PbCrO_4$) (ATSDR 2012).

The principal source of Cr(VI) in the environment is anthropogenic pollution; it rarely occurs naturally due to its affinity for organic matter and other reducing substances (US EPA 1984; Jaworski 1985; Bartlett and James 1988; Hammond 2002). Cr(VI) is a strong oxidizing agent, and therefore is not stable in the environment unless redox potential is high (Rai *et al*. 1989). It forms

different tetrahedral oxo species (CrO_4^{2-}, $HCrO_4^-$, or $Cr_2O_7^{2-}$) depending on the pH and the Cr(VI) concentration (Kumral 2007). In solution, Cr(VI) exists as an anion and is thus quite mobile in the environment (Saleh *et al.* 1989).

Chromium is typically present only in trace amounts (i.e., <3400 mg/kg) with an average concentration of 125 mg/kg in the continental crust (Adriano 2001). Chromium is found in ultrabasic and basic rock, particularly feldspar minerals (Nriagu and Nieboer 1988). Among the minerals containing chromium as a major constituent, chromite ($FeCr_2O_4$) is the most common. Natural chromium levels in igneous rock vary from 13 mg/kg (granitic rock) to 1800 mg/kg (ultramafic or basic and serpentine protolith rock) (Brookes 1987; Oze *et al*. 2004).

The only commercial source of chromium is chromite ore. About 95% of the world's chromium resources are geographically concentrated in Kazakhstan and South Africa (USGS 2012). Ore-grade chromite has been identified at more than 250 locations in Canada, with the ore resources estimated to be about 20 million tonnes (EC/HC 1994).

The three principal industrial applications for chromium are metallurgical, refractory and chemical processes. The main use of chromium in the metallurgical industry is for the production of ferrochromium alloys such as stainless steel, high-speed steel, alloy cast irons and nonferrous alloys. Chromium is used in the manufacture of refractory bricks, furnace linings, mortars, ramming mixtures for domestic iron and steel, portland cement, glass, castables, and coating materials to close pores and to join bricks in furnaces (Langård 1982; US EPA 1984; Nriagu and Kabir 1995; ATSDR 2012).

Chromium is generally present as Cr(III) in soil, and is only present as Cr(VI) when there is an anthropogenic source. Data collected from geological surveys conducted across Canada provided the information used to identify a background soil concentration for Cr(T) for Canada of 42 mg/kg. Chromium in soil is expected to be present mainly as Cr(III) considering that is the most stable oxidation state. Based on this information and the data on Ontario's typical range for chemical parameters in soil (OMOE 1993), a Cr(VI)/Cr(T) fraction of 2% is assumed for Canadian soils. Therefore, the background soil concentration for Cr(VI) is estimated at 0.84 mg/kg.

Databases from three Canadian provinces (Ontario, Saskatchewan and Newfoundland and Labrador) were consulted to obtain data on background drinking water concentrations. Based on the available data, a background Canadian drinking water chromium concentration of 1.49 µg/L (arithmetic mean, SD = 3.4 µg/L, n = 14 633) was estimated.

CCME (2016) recommends analytical methods for (Cr(T)) and Cr(VI). Cr(III) is calculated from the difference of Cr(T) and Cr(VI). When reporting method detection levels (MDL) or lower reporting limits (LRL) for samples determined this way, normally the MDL and LRL for Cr(T) are used. However, if Cr(VI) is ≥1/3 Cr(T), the confidence of detection is reduced and the limit of detection should be increased to reflect this uncertainty. Refer to CCME (2016) for guidance.

Environmental Fate and Behaviour in Soil

Chromium occurs naturally in trace amounts in rocks and soils as relatively inert Cr(III) solid phases. It is released into the aquatic environment in limited quantities by the weathering and erosion of these materials. Anthropogenic pollution is the other major source of chromium in the environment and the principal source of Cr(VI). As an element, chromium is not biodegradable and consequently is persistent in the environment (Bartlett 1991; ATSDR 2012).

Nearly all of the chromium in soils (excluding those contaminated with Cr(VI)) (Bartlett and James 1988; Katz and Salem 1994), sediments (excluding those immediately below the interface with overlying aerobic waters) (Nriagu *et al.* 1993), and in biological tissues (Bartlett and James 1988; Nriagu *et al*. 1993) is likely to be present as Cr(III). However, Cr(VI) is the dominant form of dissolved chromium in surface waters (HC 2016). It is generally assumed that Cr(III) is not likely to be present in waters of ≥pH 5 because of the low solubility of the hydrated oxide (HC 1986). Cr(III) could nevertheless be elevated in some deep anoxic waters and in waters receiving direct discharges of Cr(III)-containing wastes.

Chromium oxidation and reduction processes must be considered in risk assessment. In addition to standard modifying parameters (such as pH, organic matter, and cation exchange capacity), the oxidation (valence) state of the chromium species determines its mobility, bioavailability, uptake kinetics and toxicity and hence determines the overall exposure risk. The difference between the observed toxicity of Cr(VI) and Cr(III) species can largely be attributed to differences in bioavailability. In the environment, Cr(III) tends to be associated with relatively inert solid phases whereas Cr(VI) tends to form quite soluble compounds and does not readily adsorb onto particulate matter (EC/HC 1994). Cr(III) can therefore accumulate and persist in sediments and soils, but its availability for uptake by biota may be limited. However, labile forms of Cr(III) may be oxidized photochemically to Cr(VI) in aerobic surface waters. Cr(VI), in contrast, can persist in bioavailable forms in aerobic surface waters and soil pore waters (EC/HC 1994), although it tends to be reduced to the less mobile form of Cr(III) under anaerobic conditions.

The fate of chromium in soil is greatly dependent upon its speciation, which is a function of redox potential and soil pH (ATSDR 2012). Cr(III) dominates in most unpolluted soils, primarily as insoluble hydroxides and oxides and adsorbed to particles (Bartlett and James 1988; Katz and Salem 1994; Puls *et al.* 1994; McGrath 1995) and is considered relatively immobile and stable in most soils (CCME 1999). Cr(III) solids show increased sorption and immobilization with increasing soil pH (practically insoluble at pH >4) (Puls *et al*. 1994; CCME 1999).

Relatively few oxidants are known to mediate the conversion of Cr(III) to Cr(VI) in the soil environment and only a small percentage of the Cr(III) in soils is normally present in oxidizable forms (Bartlett and James 1988). The rate of oxidation increases with decreasing pH and with increasing surface-to-volume ratios (Eary and Rai 1989). Abiotic oxidation of Cr(III) to Cr(VI) is also facilitated by the presence of moisture and small amounts of organic matter (Bartlett 1991; Panichev *et al*. 2008).

Cr(VI) solids (except $BaCrO_4$) are soluble and highly mobile within the soil environment (Bartlett and James 1988). Cr(VI) added to or formed in soils can be removed from soil solution by uptake into living organisms, adsorption, reduction to Cr(III), or leaching resulting in transfer to

groundwater, where it is quite stable and can have a long residence time (Prokisch *et al*. 1997; Bartlett and James 1988).

Cr(VI) adsorbs to clay minerals (Rai *et al*. 1989; Zachara *et al*. 1989). Cr(VI) adsorption increases with decreasing pH, as a result of protonation of surface hydroxyl sites on clay (Zachara *et al*. 1988; 1989). Adsorption can inhibit or completely prevent the reduction of Cr(VI) to Cr(III) in some soils (Bartlett and James 1988). Factors influencing the reduction of Cr(VI) to Cr(III) in soil include soil pH, the presence of electron donors, and soil oxygen. Cr(VI) reduction increases with decreasing soil pH (Bartlett and Kimble 1976; Bloomfield and Pruden 1980; McGrath 1995; Bartlett 1991; Eary and Rai 1991). A lack of appropriate electron donors significantly slows Cr(VI) to Cr(III) reduction in soils (Palmer and Wittbrodt 1991). Reduction of Cr(VI) is enhanced under anaerobic conditions (Bloomfield and Pruden 1980; Bartlett 1991; Losi *et al*. 1994*a*). Oxygen is believed to inhibit Cr(VI) reduction through direct competition for electron donors (Losi *et al*. 1994*b*). Therefore, waterlogged soils may enhance reduction due to reduced O_2 competition and because of lower soil pH (Losi *et al*. 1994*a*; *b*).

A review of the literature has identified concentration data for speciated chromium in environmental media. Based on a review of this data, Cr(VI)/Cr(T) ratios have been estimated for environmental media; these were used to calculate estimated daily intakes for the human population to derive CSoQGs for Cr(VI) and Cr(III). The assumed fractions of Cr(VI) and Cr(III) are presented in Table 3.

Table 3. Assumed fractions of Cr(III) and Cr(VI) in different environmental media used to develop $CSoQG_{HH}$

Medium	Cr(III) %	Cr(VI) %
Soil	98	2
Drinking water	0	100
Outdoor air	80	20
Indoor air	80	20
Dust	90	10
Breast milk	100	0
Food	90	10

Soil Microbial Processes

Fenke (1977) compared the toxicity of Cr(III) and Cr(VI) to microbial-mediated soil processes and 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 dw, but the rate of nitrification returned to normal after 100 days of incubation. However, the 240 mg/kg dw treatment of Cr(VI) inhibited nitrification beyond 100 days. In contrast, 180 mg/kg dw of Cr(III) slightly enhanced nitrification from day 14 to 100. Liang and Tabatabai (1978) reported that nitrification was inhibited by 59 to 96% 10 days post-treatment in three different soils treated with 50 µmol of $CrCl_3$.

The EC_{50} for reduced soil respiration in five types of soil was >5000 mg/kg dw (Doelman and Haanstra 1984). Skujinš *et al*. (1986) reported an EC_{50} of >200 µg Cr(III)/kg dw for soil respiration inhibition following a 20-day incubation. Chang and Broadbent (1981) reported a 45% decrease in cumulative CO_2 evolution at 50 mg/kg dw. Drucker *et al*. (1979) reported that 1 mg Cr(VI)/kg

dw significantly reduced respiration after 13 days of exposure. After 24 days, the NOEC was 10 mg Cr(VI)/kg dw, with respiration being significantly reduced at 100 mg Cr(VI)/kg dw.

Terrestrial Plants

Chromium is a natural component of plant tissues, although concentrations vary considerably between different plant species, plant tissues and soil types. Concentrations in shoots of plants grown on uncontaminated soil usually do not exceed 0.5 mg/kg dw. Whole plant concentrations ≥3 mg/kg dw indicate possible contamination 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 dw, but plants rarely exceed this value (Brookes 1987).

Although it is 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 grown in chromium-contaminated soil (Patterson 1971; Cunningham *et al*. 1975*a*; *b*; *c*; Cary *et al*. 1977*a*; *b*; 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 Cr(T) at which phytotoxic effects have been observed are 21 and 31 mg/kg, resulting in a 50% decrease in the yield of tomatoes and oats, respectively (Adema and Henzen 1989). Radish and lettuce seed germination was reduced by 50% at concentrations ranging from 81 to 397 mg/kg (Environment Canada (EC) 1995a; b).

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

Terrestrial Invertebrates

Heavy metals are generally absorbed across the intestinal walls. 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 mucous 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*, *Lubricus 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. Ma 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 ($Cr(NO_3)_3$) in *Esenia andrei* (earthworm) in an artificial soil substrate. Tissue concentrations (ranging from 0.8 to 18 mg/kg dw) at the three highest chromium levels were significantly different from those in the control earthworms. Bioconcentration factors (BCF) values ranged between 0.031 and 0.19 (from lowest to highest dose level) for the exposed worms and was 0.048 in the control soil. At the end of the three-week recovery period, chromium concentrations returned to normal in all dose groups (0.3 to 1.1 mg Cr/kg dw).

The growth and cocoon production of the earthworm *Eisenia andrei* is significantly reduced at 1000 mg Cr(III) nitrate/kg dw (Van Gestel *et al*. 1992). Soil concentrations resulting in 50% mortality of the earthworm *Eisenia fetida* range from 671 to 1400 mg/kg (EC 1995*a*; *b*).

No studies reporting the toxicological effects of Cr(VI) on soil invertebrates were found.

Livestock and Wildlife

The major source of exposure to chromium for wild birds and mammals is 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 to 10% of dose) than inorganic Cr(III) compounds (0.5 to 3%).

Inhalation may be generally less important as a route of uptake than dietary sources. In contrast, however, the 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 have involved animal exposure from the soil environment.

No observable effects levels (NOAELs) for chromium range from 5.5 mg/kg bw/d for histopathological changes in dogs, cats and rabbits to 200 mg/kg fresh weight for fright stimulus in black ducks (EC 1999).

Human and Experimental Animal Health Effects

Trivalent and hexavalent chromium are absorbed via oral, inhalation and dermal routes. The amount of chromium absorbed into the bloodstream and eventually distributed to tissues depends on the oxidation state (Cr(III) vs Cr(VI)), exposure route, chemical and physical properties (e.g., solubility, particle size), physiological characteristics of the individual exposed (e.g., age, gastric pH) and, in the case of oral absorption, interactions with other dietary components. Measured absorption of dietary chromium (occurring mainly as Cr(III)) has ranged from 0.4 to 2% in humans, although absorption in the range of 0.7 to 5.2% chromium in the form of picolinate (Cr (III) dietary supplement) has been observed (Anderson and Kozlovsky 1985; WHO 1988; Stearns *et al*. 1995).

In general, soluble chromium compounds are better absorbed than insoluble forms and Cr(VI) is more easily absorbed than Cr(III) (ATSDR 2012; Cohen 2009). Note, however, that a major determinant of Cr(VI) absorption is the extent of its initial reduction to Cr(III) in the gastrointestinal (GI) tract (Sasso and Schlosser 2015; De Flora 2000), in the respiratory tract (De Flora 2000) or on the skin (Cohen 2009). This initial reduction greatly reduces the amount of Cr(VI) available for absorption into the bloodstream. Reduction capacity appears to be greater in the GI tract compared to the respiratory tract (Proctor *et al*. 2014). With respect to dermal absorption, Cr(VI) is largely reduced to Cr(III), but absorption of Cr(VI) may increase considerably if the skin is damaged, as documented in cases of chromic acid burns in workers (Cohen 2009).

Once absorbed, chromium distributes to nearly all tissues, with the highest concentrations found in the kidney and liver. Absorbed Cr(VI) is unstable and will be reduced to Cr(V), Cr(IV) and ultimately Cr(III). This process can produce reactive intermediates and result in chromium adducts with proteins and DNA. In blood, Cr(VI) is taken up by the red blood cells, where reduction products form complexes with hemoglobin and other proteins. Absorbed chromium is primarily eliminated in the urine, but secondary excretion of small amounts may occur via the bile and feces (ATSDR 2012).

The acute toxicity of chromium compounds in orally exposed experimental animals increases with solubility, with Cr(VI) being more toxic than Cr(III). Lethal dose causing 50% mortality (LD_{50}) values for Cr(III) have been reported at approximately 200 mg Cr(III)/kg for soluble compounds administered to rats and 2400 mg Cr(III)/kg for less soluble chromium acetate (ATSDR 2012). In contrast, for Cr(VI) compounds, reported LD_{50} values are generally an order of magnitude lower (ATSDR 2012; European Chemicals Bureau 2005). No LD_{50} values have been reported for dermal or inhalation exposure in experimental animals. Limited information is available on the acute effects of chromium in humans. In all cases of fatality, highly water-soluble forms were implicated and doses, when estimated and reported, were in the range of 4 to 360 mg Cr(VI)/kg (ATSDR 2012). Case reports of brief high exposures to Cr(VI) via inhalation indicate effects on the respiratory and GI systems, including irritation and skin ulcerations (Cohen 2009). Sensitization and allergic contact dermatitis have been reported in workers and, to a lesser extent, in the general population. Little information is available on acute toxic effects from Cr(III); however, contact dermatitis has been reported, particularly in workers (Cohen 2009).

Most chronic and subchronic toxicity studies in experimental animals have been carried out for oral exposure, and for Cr(VI) rather than Cr(III). The most influential chronic and subchronic studies with respect to the development of soil quality guidelines are the National Toxicology Program (NTP) rat and mouse drinking studies (NTP 2007; 2008), involving exposures to Cr(VI), as well as the NTP (2010) rat and mouse dietary studies involving exposures to Cr(III). In general, chemical-related effects associated with Cr(III) oral exposure did not demonstrate toxicity at the doses evaluated. On the other hand, oral exposure to Cr(VI) was determined to cause GI tract lesions in rats and mice, as well as squamous cell carcinoma in the oral mucosa in rats and cancer of the small intestine in mice. The most sensitive effect (i.e., the effect occurring at the lowest dose) was diffuse hyperplasia in the small intestine of mice (NTP 2008). Health Canada (HC 2016), based on an analysis of evidence relevant to the Cr(VI) mode of action, considers diffuse hyperplasia of the small intestine to be a precursor of tumour formation caused by Cr(VI).

With respect to inhalation, a limited number of subchronic studies of Cr(III) and Cr(VI) in experimental animals have shown respiratory tract lesions (Glaser *et al*. 1985; 1990; US EPA 2010; ATSDR 2012). No studies on chronic exposure to Cr(III) via inhalation were identified and only a limited number have been carried out for Cr(VI). These indicate that Cr(VI) is carcinogenic to experimental animals, resulting in significant increases in lung tumours (Steinhoff *et al*. 1986).

In humans, non-neoplastic respiratory lesions and respiratory cancers have been reported in epidemiological studies of workers exposed to airborne Cr(VI) (Mancuso *et al*. 1975; 1997; Crump *et al*. 2003; Gibb *et al*. 2000*a*; *b*). Non-cancer effects on the respiratory system include nasal lesions, throat irritation, rhinitis and decreased pulmonary function reported in people employed in chrome plating and chromate production. The key concern identified in epidemiological studies was elevated incidence of lung cancer in workers exposed to Cr(VI) (chromate production workers).

The toxicological reference values (TRVs) for Cr(III), retained by different authoritative health organizations, include TRVs for threshold effects resulting from oral and inhalation exposures. For Cr(VI), TRVs for threshold effects resulting from oral exposure and TRVs for both threshold and non-threshold effects associated with inhalation have been developed.

With respect to Cr(III), the US EPA (1998b) provided an oral reference dose (RfD) that is based on the absence of effects at the highest dose tested in a rat study (Ivankovic and Preussman 1975). Although the US EPA completed their assessment prior to the NTP (2010) chronic oral exposure study on Cr(III), the RfD is consistent with the findings of this later study and remains the most relevant toxicological reference value (TRV) of those published by authoritative health agencies. Based on the results of a subchronic inhalation exposure study in rats (Derelanko *et al*. 1999), ATSDR (2012) provided a minimal risk level (MRL) of 0.1 $\mu g/m^3$ for protection of non-cancer effects resulting from intermediate duration inhalation exposures. This TRV is considered the most appropriate for evaluating chronic inhalation risks of Cr(III).

With respect to Cr(VI), Health Canada (HC 2016) derived a tolerable daily intake (TDI) of 2.2 µg/kg bw/d, based on the NTP (2008) study, for protection against non-cancer effects (gastrointestinal lesions). A mode of action analysis indicates that this TRV would also protect against cancer (HC 2016). Based on respiratory lesions observed in rats (Glaser *et al*. 1990), US EPA (1998a) derived a reference concentration (RfC) of 0.1 $\mu g/m^3$ for protection against non-

cancer effects resulting from inhalation exposures. Health Canada (EC and HC 1994) derived an inhalation unit risk of 0.076 $(\mu g/m^3)^{-1}$ based on lung cancer incidence among workers at an Ohio chromate production plant (Mancuso 1975).

Guideline Derivation

Soil Quality Guideline for Environmental Health

Environmental soil quality guidelines ($SoQG_{ES}$s) are derived following CCME (1996), and detailed derivations are provided by Environment Canada (1999). They 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 the 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 $SoQG_E$.

For residential or parkland and commercial land uses, the soil quality guideline for soil contact is recommended as the $SoQG_E$.

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

Total Chromium (EC 1999)

In the case of Cr(T), the $SoQG_E$ for agricultural and residential or 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 $SoQG_E$ is based on the soil contact guideline (Table 5). The Cr(T) $SoQG_E$ can be used to address Cr(III) contamination, as most soils contain predominantly Cr(III), unless a specific Cr(VI) source is identified, in which case speciated soil analysis is recommended.

Hexavalent Chromium (EC 1999)

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 $SoQG_E$ based on soil contact for plants (Table 6).

Soil Quality Guidelines for Human Health

In the derivation of human health soil quality guidelines ($SoQG_{HH}$) for chromium, it was necessary to identify TRVs (tolerable concentration (TC), tolerable daily intake (TDI), and an inhalation unit risk (IUR)) for inhalation exposure (Table 4). The $SoQG_{HH}$ is based on the most sensitive receptor designated for each land use.

Table 4. Toxicological reference values for chromium

Species	TDI (threshold oral and dermal) µg/kg bw/d	TC (threshold inhalation) µg/m^3	IUR (non-threshold inhalation) (µg/m^3)$^{-1}$
Cr(III)	1500	0.1	Not applicable
Cr(VI)	2.2	0.1	7.6×10^{-2}

CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection (Table 5 and Table 6). An off-site migration check was completed to ensure that concentrations of chromium at one site would not cause concentrations on an adjacent site to exceed guideline values for a site with a more restrictive SoQG. Since no appreciable bioconcentration or biomagnification of chromium is anticipated, a produce, meat and milk check was not performed. No guideline for the protection of potable groundwater ($SoQG_{PW}$) was derived because the procedure for derivation of $SoQG_{PW}$ is not applicable to inorganic substances (CCME 2006). Since chromium is not expected to volatilize under ambient environmental conditions, no guidelines for the protection of indoor air quality or soil vapours were calculated.

The lowest of the calculated human health guidelines and check values is recommended as the $CSoQG_{HH}$. The $CSoQG_{HH}$s for Cr(III) and Cr(VI) are therefore based on protection against cancer risks via the inhalation of soil particles for all land uses when applying an incremental lifetime cancer risk (ILCR) of 10^{-6}. The $CSoQG_{HH}$ is also based on the protection against cancer risks via inhalation or for industrial land uses for an ILCR of 10^{-5}. For agricultural, residential or parkland, and commercial land uses where an ILCR of 10^{-5} is applied, the $CSoQG_{HH}$ is based on ingestion and dermal exposure, as these are more sensitive than the inhalation-based $CSoQG_{PI}$ for these land uses (Table 5 and Table 6).

Soil Quality Guidelines for Trivalent Chromium, Hexavalent Chromium and Total Chromium

Chromium occurs in the environment in the following two forms: Cr(III) and Cr(VI). In soil, it occurs primarily as Cr(III) unless the soils have been polluted with Cr(VI)-contaminated wastes. Since Cr(III) and Cr(VI) have different effects on human health, human health-based soil quality guidelines were derived for each form. Current practices favour the analysis of Cr(T) in soil, while

Cr(VI) is only measured in cases where there is a known or suspected Cr(VI) source. Cr(T) data can be compared to the $SoQG_E$ for Cr(T) or the $SoQG_{HH}$ for Cr(III), because the majority of environmental Cr is expected to be present as Cr(III) compounds. SoQG for Cr(T) are expected to be protective of sites where Cr(VI) accounts for only a small component of Cr species. Analytical measurement of Cr(VI) in soil is strongly recommended for any site potentially contaminated by activities involving Cr(VI).

For human health, the speciated data for Cr(III) and non-speciated Cr(T) data should be compared to the Cr(III) SQG_{HH} (Table 5), while Cr(VI) data should be compared to the $SoQG_{HH}$ for Cr(VI) (Table 6).

For ecological receptors, speciated Cr(III) and non-speciated Cr(T) data should be compared to the $SoQG_E$ for Cr(T) (Table 5), while Cr(VI) data should be compared to the $SoQG_E$ for Cr(VI) (Table 6).

The soil quality guidelines Cr(III), Cr(T) and Cr(VI) are intended to be protective of both environmental and human health and are taken as the lower of the $SoQG_{HH}$ and the $SoQG_E$. The $CSoQG_{HH}$s presented herein are updated values, whereas the $CSoQG_E$s are those developed in 1997 and 1999 (CCME 1999).

Table 5. Soil quality guidelines and check values for trivalent chromium (Cr(III)) or total chromium (Cr(T)) (mg-kg^{-1})[2]

	Land use			
	Agricultural	**Residential/ Parkland**	**Commercial**	**Industrial**
Guideline[a]	**52**	**52**	**87**	**87**
Human health guidelines or check values (SQG_{HH}) Cr(III)[b]	26 000[n]	26 000[n]	86 000[p]	96 000[n]
Direct contact guidelines				
Ingestion and dermal (SQG_{DH})	57 000	57 000	86 000	1 000 000
Particulate inhalation (SQG_{DH-PI})[c]	26 000	26 000	96 000	96 000
Inhalation of indoor air check (SQG_{IAQ})[d]	NC	NC	NC	NC
Groundwater check (drinking water) (SQG_{PW})[e]	NC	NC	NC	NC
Produce, meat and milk check (SQG_{FI})[f]	NC	NC	-	-
Off-site migration check (SQG_{OM-HH})	-	-	370 000	370 000
Environmental health guidelines or check values				
SQG_E Cr(T)[g]	64	64	87	87
Soil contact guideline[h]	64	64	87	87
Soil and food ingestion guideline	NC[i]	-	-	-
Nutrient and energy cycling check	52	52	NC[j]	NC[j]
Off-site migration check (SQG_{OM-HH})	-	-	-	91
Groundwater check (aquatic life)[k]	NC	NC	NC	NC
Canadian Soil Quality Guidelines for the protection of human health (Cr(T)) (CCME 1997)[m]	220	220	630	2300

Notes: NC = not calculated; $SoQG_E$ = soil quality guideline for environmental health; $SoQG_{HH}$ = soil quality guideline for human health.

[a] Data are sufficient and adequate to calculate an $SoQG_E$ and an $SoQG_{HH}$ for this land use. Therefore, the soil quality guideline is the lower of the two (CCME 2006). SQG_{HH}s are derived for Cr(III), which is considered to dominate in most environmental media, except water. Soil concentrations of Cr(T) may be compared to the $SoQG_{HH}$ for Cr(III). $SoQG_E$ are based on the direct contact guideline, as derived in 1997 (CCME 1997). The original Cr(T) soil quality guideline and the interim soil quality criteria (CCME 1997) are superseded by the chromium soil quality guideline (CCME 2023) that represents the lowest value between the SQG_E (Cr(T)) and the SQG_{HH} (Cr(III)).

[b] The SQG_{HH} is set at the direct contact ingestion and dermal value ($SoQG_{DH}$) for all land uses because these are the lowest of the of the human health guidelines and check mechanisms for this land use.

[c] The inhalation pathway was developed separately due to the different toxic effects of chromium via the different routes of exposure.

[d] Applies only to volatile compounds and is not calculated for non-volatiles.

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

[f] Not calculated. Concerns about metal substances should be addressed on a site-specific basis.

[g] $SoQG_E$ for Cr(T) taken from CCME (1997).

[h] The 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.

[i] Data are insufficient or inadequate to calculate the food and soil ingestion guideline for this land use.

[j] Data are insufficient or inadequate to calculate the nutrient and energy cycling check for this land use.

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

[m] CCME $SoQG_{HH}$ (Cr(T) were developed in 1997 and published in 1999 (CCME 1999).

[n] Based on the $SoQG_{DH-PI}$ for inhalation exposures for threshold effects.

[p] Based on the $SoQG_{DH}$ for oral and dermal exposures for threshold effects.

[2] Cr(T) (unspeciated) should be compared to the values in Table 5 ($SoQG_{HH}$ for Cr(III) or $SoQG_E$ for Cr(T)). Likewise, for speciated results (i.e., when values are available for Cr(III)), they should be compared to the $SoQG_{HH}$ provided for Cr(III) or $SoQG_E$ provided for Cr(T).

Table 6. Soil quality guidelines and check values for hexavalent chromium (Cr(VI)) (mg-kg^{-1})

	Land use			
	Agricultural	Residential/ Parkland	Commercial	Industrial
Guideline[a]	**0.4**	**0.4**	**1.4**	**1.4**
Human health guidelines/check values[b]				
SQG_{HH}				
ILCR 10^{-6}	18[h]	18[h]	18[h]	18[h]
ILCR 10^{-5}	70[i]	70[i]	110[i]	170[h]
Direct contact guideline				
Ingestion and dermal ($SoQG_{DH}$)	70	70	110	1400
Particulate inhalation ($SoQG_{DH-PI}$)[c]				
10^{-6} ILCR	18	18	18	18
10^{-5} ILCR	170	170	170	170
Threshold	26 000	26 000	96 000	96 000
Inhalation of indoor air check ($SoQG_{IAQ}$)[d]	NC	NC	NC	NC
Groundwater check (drinking water) ($SoQG_{PW}$)[e]	NC	NC	NC	NC
Produce, meat and milk check ($SoQG_{FI}$)[f]	NC	NC	-	-
Off-site migration check ($SoQG_{OM-HH}$)				
Non-cancer and 10^{-6} ILCR			250	250
Non-cancer and 10^{-5} ILCR	-	-	990	990
Provisional environmental health guidelines or check values ($PSoQG_E$)[g]	0.4	0.4	1.4	1.4
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 check (SQG_{OM-HH})	-	-	-	NC
Groundwater check (aquatic life)	NC	NC	NC	NC

Notes: NC = not calculated; ILCR = incremental lifetime cancer risk; $SoQG_E$ = soil quality guideline for environmental health; $SoQG_{HH}$ = soil quality guideline for human health.

[a] Data are sufficient and adequate to calculate an $SoQG_{HH}$ for this land use but only a provisional $SoQG_E$ ($PSoQG_E$). Therefore, the soil quality guideline is the lower of the two (CCME 2006). $PSQG_E$ are based on the direct contact guideline, as derived in 1999 (CCME 1999). The original chromium soil quality guideline derived in 1999 (based on $SoQG_E$ only) are superseded by this chromium soil quality guideline (CCME 20XX).

[b] For an ILCR of 1 in 1 000 000, the $SoQG_{HH}$ is set at the direct contact particulate inhalation value ($SoQG_{DH-PI}$) for non-threshold effects for all land uses because these are the lowest of the human health guidelines and check mechanisms for this land use. For an ILCR of 1 in 100 000, the $SoQG_{HH}$ for agricultural, residential or park and commercial land uses is set at the direct contact guideline for ingestion and dermal exposures ($SoQG_{DH}$), while the $SoQG_{HH}$ for industrial land uses is set at the direct contact particulate inhalation value ($SoQG_{DH-PI}$) for non-threshold effects.

[c] The inhalation pathway was developed separately due to the different toxic effects of chromium via the different routes of exposure.

[d] Applies only to volatile compounds and is not calculated for non-volatiles.

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

[f] Not calculated. Concerns about metal substances should be addressed on a site-specific basis.

[g] Data are insufficient or inadequate to calculate any of the environmental health guidelines or check values. However, there are sufficient and adequate data to calculate provisional $SoQG_E$s. The $SoQG_E$s for Cr(VI) is taken from CCME (1999 update).

[h] Based on the $SoQG_{DH-PI}$ for inhalation exposures for non-threshold effects.

[i] Based on the $SoQG_{DH}$ for oral and dermal exposures for threshold effects.

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