



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

**Nickel  
2015**

This fact sheet provides Canadian soil quality guidelines for nickel for the protection of environmental and human health (Table 1). A supporting criteria document is also available (CCME 2015). This guideline applies to nickel forms that include soluble (i.e., nickel in the form of chloride, sulphate and nitrate) and insoluble forms (i.e., nickel as sulphide and oxide). Nickel present as refinery dust or in other forms not listed above (such as nickel subsulphide or nickel carbonyl) is not addressed in this guideline and would require a separate assessment.

## Background Information

Nickel (Ni), is a hard but brittle, silvery white metal which possesses high thermal and electrical conductivities. Powdered nickel is reactive and may spontaneously ignite in air (ATSDR 2005). Nickel (CAS #7440-02-0) is a transition element of Group VIIIa of the Periodic Table, with an atomic number of 28 and an atomic weight of 58.693, a melting point of 1455°C, a boiling point of 2913°C and a specific density of 8.9 g/cm<sup>3</sup> at 25°C (Haynes 2011). Nickel exhibits magnetism (less magnetic than iron) (Cotton and Wilkinson 1988).

Although nickel can exist in oxidation states of -1, 0, +1, +2, +3 and +4, the most common valence state in the environment is Ni(II) (otherwise noted as Ni<sup>2+</sup>) (ATSDR 2005). Ni<sup>2+</sup>, with an ionic radius

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

	Land use			
	Agricultural	Residential/ Parkland	Commercial	Industrial
<b>Guideline<sup>a</sup></b>	<b>45</b>	<b>45</b>	<b>89</b>	<b>89</b>
SQG <sub>HH</sub> Non-Cancer and 10 <sup>-6</sup> ILCR Limiting pathway for SQG <sub>HH</sub>	200 Ingestion and dermal contact	200 Ingestion and dermal contact	310 Ingestion and dermal contact	1000 Particulate inhalation
SQG <sub>HH</sub> Non-Cancer and 10 <sup>-5</sup> ILCR Limiting pathway for SQG <sub>HH</sub>	200 Ingestion and dermal contact	200 Ingestion and dermal contact	310 Ingestion and dermal contact	2500 Off-site migration
SQG <sub>E</sub> Limiting pathway for SQG <sub>E</sub>	45 Soil contact	45 Soil contact	89 Soil contact	89 Soil contact
Guideline derived in 1999 (original Ni SQG)	50	50	50	50
Interim soil quality guideline criterion (CCME 1991)	150	100	500	500

**Notes:** SQG<sub>E</sub> = soil quality guideline for environmental health; SQG<sub>HH</sub> = soil quality guideline for human health. ILCR = incremental lifetime cancer risk.

<sup>a</sup>Data are sufficient and adequate to calculate a SQG<sub>HH</sub> and an SQG<sub>E</sub>. Therefore the soil quality guideline is the lower of the two (CCME 2006). The original nickel soil quality guideline derived in 1999 (based on SQG<sub>E</sub> only) and the interim soil quality criteria (CCME 1991) are superseded by the 2015 nickel soil quality guideline CCME (2015).

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. Use of some values listed may not be permitted at the generic level in some jurisdictions. The reader should consult the appropriate jurisdiction before application of the values.

close to those of iron, magnesium, copper and zinc, can replace essential metals in metallo-enzymes and, thus, cause disruptions in metabolic pathways (McGrath 1995).

In the environment, nickel can be found in a variety of inorganic and organic compounds, depending on such factors as the medium considered and ambient environmental conditions. In water,  $\text{Ni}^{2+}$  forms a number of compounds of varying solubilities with sulphate, nitrate, chloride, hydroxide and carbonate. Elemental nickel is insoluble in water (Cotton and Wilkinson 1988; WHO 1991).

Nickel is a commercially viable natural resource in Canada with industrial activities focussed in nickel mining, smelting and refining. Canada exports nickel and nickel products to over 70 countries worldwide (NRCan 2009) and is one of the top five producers of nickel in the world, responsible for approximately 10% of global nickel production (USGS 2011). Metallic nickel, sold in the form of cathodes, pellets, powders, briquettes, rondelles and coinage, is used in approximately 3000 alloys that have more than 250 000 applications (MAC 1991). For example, nickel-containing stainless steel is employed by chemical and food processing industries and in the medical profession. Iron-nickel alloys are also important materials for the electric industry while nickel-copper alloys are used in shipbuilding.

Nickel compounds are also useful in various industries (IPCS 1991). Nickel carbonate hydroxide is employed in plating and catalysis; nickel carbonate is an important electric component; anhydrous nickel chloride is used as an adsorbent in certain gas masks and in nickel plating; nickel hydroxide is an electrode material; nickel oxide is an important raw material in metallurgical operations for smelting and alloy-producing processes; nickel sulphate can be a catalyser or employed in electrolyte solution and jewellery; and nickel nitrate is employed by nickel-plating and nickel-containing battery industries (WHO 1991).

Nickel is naturally released into the Canadian surface waters, sediments and soils by weathering and erosion of geological materials (i.e. bedrock) (Painter *et al.* 1994; NRCC 1981). Natural sources of airborne nickel include soil dust, sea salt, volcanoes, forest fires and particulate exudates from vegetation (Warren and Delavault 1954; Schmidt and Andren 1980; NRCC 1981; Richardson *et al.* 2001). Sea spray may be a major contributor to atmospheric nickel in coastal areas. Forest fires can be short-term but intense sources (Havas and Hutchinson 1983).

In addition, nickel enters the aquatic environment in effluents and leachates as well as through atmospheric deposition from anthropogenic releases (Environment Canada (EC) 1994). Primary base metal production represents an important anthropogenic source in Canada (Environment Canada and Health Canada (EC and HC) 1994). Other major emitters were facilities in the mining, smelting, petroleum refining and manufacturing industries (EC 2007). Some minor atmospheric releases have also been attributed to the alloy production and the scrap reprocessing industries, to the incineration of municipal garbage and sewage sludge, to the manufacture of cement, to coke oven and cooling tower operations and to the mining/milling of asbestos (Jacques 1987; WHO 1991; EC and HC 1994).

Globally, the largest anthropogenic releases are from fossil fuel (predominantly coal and oil) combustion and nickel mining and smelting (McGrath 1995). Virtually every industry will emit heavy metals via high temperature processes into the atmospheric, aquatic and terrestrial ecosystems (Wilson

*et al.* 1998).

Anthropogenic nickel is found in a variety of compounds. The predominant form in nickel refineries is the relatively inert high-temperature green nickel oxide, whereas black nickel oxides are more chemically active. More complex and reactive nickel oxides are often formed as by-products of industrial processes, such as the processing of sulphidic ores (nickel subsulphide (Ni<sub>3</sub>S<sub>2</sub>) and nickel sulphide (NiS)) (Goodman 2011).

Data on Canadian nickel concentrations in air as PM<sub>2.5</sub> (particulate matter less than 2.5 µm in diameter) were provided by Environment Canada from the National Air Pollution Surveillance (NAPS). Based on ambient air samples collected across Canada from 2003 to 2009 from NAPS, the overall mean of urban and rural stations was 0.94 ng/m<sup>3</sup> (HC 2011). Mean and median concentrations were found to be very similar for both rural and urban areas.

Higher concentrations in total suspended particulates (TSP) have been reported in the vicinity of industrial sources of nickel (Brecher *et al.* 1989; Dobrin and Potvin 1992; OMOE 1992).

Rasmussen *et al.* (2007) found that median nickel PM<sub>2.5</sub> and PM<sub>10</sub> levels in rural Ontario homes were slightly higher (0.7 and 1.5 ng/m<sup>3</sup>, respectively) in comparison to urban homes (0.6 and 1.0 ng/m<sup>3</sup>) in Ottawa. In rural areas, median outdoor air PM<sub>2.5</sub> concentrations were slightly higher (1.0 ng/m<sup>3</sup>) than indoor air concentrations (0.7 ng/m<sup>3</sup>) but there was no difference between outdoor and indoor air concentrations measured in urban homes (0.6 ng/m<sup>3</sup>) (Rasmussen *et al.* 2006).

Fergusson and Kim (1991) reported that the median concentration of nickel in house dust from various cities around the world was 40 mg/kg. Rasmussen *et al.* (2008) reported a median total nickel concentration of 41 µg/g in house dust based on dust samples collected from 22 residential homes in Ottawa, Ontario.

Nickel is naturally present in soils as a result of chemical and mechanical weathering of rock to form soil. Nickel is present in granites, sandstones and limestones in concentrations ranging from 5 to 20 mg/kg, but it can occur in high concentrations in ultramafic and mafic bedrock and soils overlying naturally enriched bedrock. Based on the distribution of nickel-enriched mafic and ultramafic bedrock in Canada, areas of naturally nickel-enriched soil likely exist throughout most of Canada (with the possible exception of the St. Lawrence River lowlands and the southern plain regions of Alberta and Saskatchewan) (Doyle 1991).

For the purpose of this soil quality guideline, a mean total nickel concentration of 26.8 mg/kg calculated from background till data (excluding areas of nickel enriched rocks and nickel bearing mineral occurrences) compiled by the Geological Survey of Canada (Rencz *et al.* 2006; Grunsky 2010) is considered to be representative of typical nickel concentrations in background soils in Canada.

Concentrations of nickel in surface waters in Canada are typically below 2 µg/L. The reported range of concentrations for uncontaminated fresh waters in Canada is 1 to 10 µg/L, (NRCC 1981; Moore and Ramamoorthy 1984; Leger 1991).

Based on Ni concentrations in drinking water from Ontario, Saskatchewan and Newfoundland and Labrador, an average concentration of 2.9 µg/L (n=12 251) was calculated (HC 2011). The data are based on Ni concentrations in treated water from the Ontario Drinking Water Surveillance Program

(DWSP) from 1998 to 2007, drinking water from Saskatchewan from 2000 to 2009 and tap water concentrations of Ni taken from public water supplies in Newfoundland and Labrador sampled from January 2000 to June 2009 (HC 2011).

Concentrations of nickel in sediments from Canadian lakes varied from <10 to >4000 mg/kg dw (Bradley and Morris 1986; Bodo 1989). Background concentrations in Canadian freshwater sediments range from 2 to 50 mg/kg dw (Moore and Ramamoorthy 1984; Arafat and Nriagu 1986; Jackson 1988; Bodo 1989). Nickel in stream sediments collected in 2004 from 20 ecoregions in the Yukon ranged from 16.31 to 111.1 mg/kg and median concentrations ranged from 8 to 38 mg/kg (Garrett 2004).

Various researchers have reported nickel concentrations measured in garden vegetables, fruits, fish, shellfish and wildlife. This information is summarised in CCME (2015).

### **Environmental Fate and Behaviour in Soil**

Due to its use and release into the environment, nickel is distributed in the atmosphere, water, sediment, soils, and biota worldwide. The global distribution and the persistence of this metal suggests that cycling represents the most important process affecting nickel since an element cannot be degraded in the environment. As such, the fate of nickel is dependent on many physiochemical and biological factors that influence cycling among biotic and abiotic components of the environment. The most important of these factors are pH and the presence and abundance of organic materials, hydroxides, clay minerals, cations and complexing ligands (NRCC 1981). Nickel has a high affinity for negatively charged surfaces associated with clay minerals, hydroxides, organic compounds and carbonates. Consequently, it tends to be removed rapidly from solution. Although surface soils and aquatic sediments may act as temporary sinks for nickel, changes in environmental conditions have the potential to remobilise and transport it to other compartments of the ecosystem.

### **Behaviour and Effects in Biota**

#### *Soil Microbial Processes*

The toxicity of nickel to microorganisms in soil varies among a variety of soil types. Enhancement of clay content in soil increases its cation exchange capacity (CEC) and protects against nickel toxicity. Increasing soil pH was also reported to decrease the toxicity of nickel to several microorganisms such as eubacteria, actinomycetes, yeasts and fungi (Babich and Stotzky 1982). Effect concentrations for soil microbial processes range from 6.6 to more than 1000 mg/kg (CCME 2015).

The addition of 294 mg Ni/kg to soil (as NiCl<sub>2</sub>) reduced nitrification and nitrogen mineralisation by 17% (Liang and Tabatabai 1977; 1978). A concentration of 1000 mg/kg reduced nitrogen mineralisation by 36% and nitrification by 68% (Giashuddin and Cornfield 1978).

Carbon mineralisation was also affected by the addition of nickel to soils. Carbon mineralisation decreased after a 2 to 6 week exposure to 10 mg Ni/kg of NiSO<sub>4</sub> (the lowest exposure concentration tested) in sandy soil (Cornfield 1977). Brookes and McGrath (1984) reported a reduction in carbon mineralisation by 55% at nickel concentrations as low as 6.6 mg/kg in a sandy loam with unreported pH. In contrast, Bhuiya and Cornfield (1972) reported a 24% reduction in carbon mineralisation with a soil concentration as high as 1000 mg/kg.

### *Terrestrial Plants*

Nickel is essential for plant growth (Dixon *et al.* 1975; Brown *et al.* 1987a; 1987b; Aller *et al.* 1990; Salt *et al.* 2002); however, relatively high concentrations can have adverse effects on plants.

Several authors have reported that nickel can affect the iron status of plants (Khalid and Tinsley 1980; Adriano 2001). Toxicity may also be caused by nickel accumulating in cell cytoplasm and binding to cell components; nickel-tolerant plants are capable of flushing nickel from the cytoplasm to vacuoles (Salt *et al.* 2002). Effect levels are normally below 80 mg/kg dry weight (dw) of plant, but effects have been reported in tolerant plants containing up to 1000 mg/kg dw tissues (Brooks 1980; Cox and Hutchinson 1981; Kabata-Pendias and Pendias 1984). Symptoms of injury were observed for a variety of vegetables containing as little as 15 to 95 mg Ni/kg dw in plant tops (Frank *et al.* 1982). For example, Bazzaz *et al.* (1974) reported that inhibition of photosynthesis and transpiration in sunflowers depended on the nickel concentration in leaves and the exposure period.

Nickel toxicity to plants can be significantly affected by soil pH, with lower pH resulting in higher toxicity (Weng *et al.* 2004; Li *et al.* 2011). In a study of 16 European soils, soil cation exchange capacity was found to be the best soil property predictor for nickel toxicity to barley and tomato (Rooney *et al.* 2007). Some studies have shown that soil texture also affects nickel phytotoxicity; for example, clover was found to be more nickel-tolerant in fine soils than coarse soils (Elmosly and Abdel-Sabour 1997). Toxicity may also be affected by soil nutrients; for example, one study found that nickel was less toxic to sunflowers if both nitrate and ammonium were supplied than if only nitrate was supplied (Zornoza *et al.* 1999).

### *Terrestrial Invertebrates*

Effect levels ranged from 20 to 40 000 mg/kg for two earthworm species (*Eisenia foetida* and *Lumbricus rubellus*). Using the same test (growth rate) and the same organism (*Eisenia foetida*), Malecki *et al.* (1982) reported effects of nickel acetate, nickel carbonate, nickel chloride, nickel nitrate, and nickel sulphate at concentrations ranging between 200 and 500 mg/kg while an effect level for nickel oxide, the least soluble, was as high as 40 000 mg/kg. Using a contact test (filter paper), Neuhauser *et al.* (1985) found similar results indicating that each of the soluble nickel salts tested (acetate, chloride, nitrate and sulphate) was not significantly different from any of the others. This contrasts with nematodes, for which nickel chloride has been observed to be more toxic than nickel nitrate (Peredney and Williams 2000).

The toxicity of soil nickel to earthworms also depends on the influence of soil factors determining its bioavailability to earthworms. Concentration factors of heavy metals in earthworms were negatively correlated with the soil pH and CEC (Ma 1982).

### *Vertebrates, Birds and Other Wildlife*

Mammals and birds are capable of accumulating nickel, and dietary exposure is probably the most important route under most circumstances. Upon ingestion, the absorption of nickel is influenced by many factors including solubility of the nickel compound, dose, age and diet. The absorption often results in relatively low bioaccumulation factors. Studies in rats, dogs and mice indicate that only 1 to 10% of orally-administered nickel (Ni, NiCl<sub>2</sub> and NiSO<sub>4</sub>) is absorbed by the gastrointestinal tract from diet or drinking water (Ho and Furst 1973; Schroeder *et al.* 1974; Ambrose *et al.* 1976).

Numerous studies on rats (Whanger 1973), ducks (Cain and Pafford 1981), livestock (O'Dell *et al.* 1971; Spears *et al.* 1986) and wild mammals and birds (Rose and Parker 1983; Outridge and Scheuhammer 1993) have shown that nickel accumulates in the kidney of animals and birds after it is absorbed and distributed in the body.

Animals have a high capability to eliminate absorbed nickel. The majority of nickel that is absorbed by animals is eliminated in urine. Feces appear to be the most important routes of elimination for unabsorbed nickel. Tedeschi and Sunderman (1957) noted that dogs excreted 90% of ingested nickel in feces and 10% in urine.

No avian or mammalian species are known to biomagnify nickel in the environment. Studies comparing nickel concentrations in wildlife and their food reported that concentrations were either similar in different trophic levels or even declined with increasing trophic level (Scanlon 1987; Beyer and Miller 1990). Similarly, nickel concentrations measured in mouse carcasses from a wetland were less than the detection limit of 0.6 mg/kg, despite higher nickel concentrations being measured in food sources (Torres and Johnson 2001a); concentrations were also much lower than those predicted using published bioaccumulation models (Torres and Johnson 2001b).

### **Health Effects in Humans and Experimental Animals**

High levels of exposure to nickel have been associated with a wide variety of effects that may include adverse gastrointestinal and neurological effects in various studies in both laboratory animals and people (mostly industrial workers) (ATSDR 2005). Nevertheless, the key concerns of health agencies are the potential effects of nickel on the developing fetus and respiratory cancer (EU 2004; HC 1996; US EPA 1996; WHO 2000; 2007; EC 2001).

In a study by SLI (2000), developmental effects (increased perinatal mortality and post-implantation loss) were noted in rats exposed to nickel sulphate during gestation. Based on this study, the Danish Environmental Protection Agency (DEPA) identified a No Observed Adverse Effect Level (NOAEL) of 1.1 mg/kg bw/day for perinatal lethality (EU 2004). Both WHO (2007) and EU (2008) used the NOAEL identified by the DEPA re-analyses of the SLI (2000) data and the NOAEL of 1.1 mg/kg bw/day was used to develop the human health-based soil quality guideline (CCME 2015). Using an uncertainty factor of 100 (10-fold for interspecies differences and 10-fold for intraspecies differences), the Tolerable Daily Intake (TDI) for nickel was estimated to be 11 µg Ni/kg bw/day.

With respect to cancer, there is adequate epidemiological evidence indicating that nickel may act as a carcinogen via the inhalation route. In an epidemiological cohort study, Doll *et al.* (1990) provided evidence that exposure to high concentrations of "soluble", "oxidic", or "sulphidic" nickel resulted in increased mortality of workers due to lung and nasal cancer. Based on this study, Health Canada (1996) estimated TC<sub>05</sub> of 40 µg Ni/m<sup>3</sup> (tumourigenic concentration resulting in a 5% increase in tumour incidence) for exposure to combined oxidic, sulphidic and soluble nickel. In the calculation of cancer potency, Health Canada (1996) reported that lung cancer was a more sensitive endpoint than nasal cancer. This TC<sub>05</sub> corresponds to a unit risk value of 1.3 x 10<sup>-3</sup> µg Ni/m<sup>3</sup> and risk specific concentrations of 0.0008 µg/m<sup>3</sup> for an incremental lifetime cancer risk of 1 x 10<sup>-6</sup> and of 0.008 µg/m<sup>3</sup> for an incremental lifetime cancer risk of 1 x 10<sup>-5</sup>.

Non-cancer effects associated with inhalation of nickel include lung lesions such as alveolitis, chronic lung inflammation, alveolar macrophage hyperplasia and atrophy of the nasal olfactory

epithelium (NTP 1996a; 1996b). An inhalation tolerable concentration (TC) of 0.02 µg Ni/m<sup>3</sup> for both nickel sulphate and nickel oxide was adopted based on a weight of evidence approach using information from Environment Canada and Health Canada (1994), ATSDR (2005) and European Commission (2001; 2007).

### **Guideline Derivation**

Canadian soil quality guidelines are derived for different land uses following the process outlined in CCME (2006) using different receptors and exposure scenarios for each land use (Table 1). Detailed derivations for these soil quality guidelines are provided in CCME (2015).

#### *Soil Quality Guidelines for Environmental Health*

Environmental soil quality guidelines (SQG<sub>E</sub>) are primarily based on soil contact using data from toxicity studies on plants and invertebrates. In the case of agricultural land, soil and food ingestion toxicity data for mammalian and avian species are included to protect foraging livestock and wildlife. To provide a broader scope of protection, a nutrient and energy cycling check is calculated for all land uses to protect critical microbial processes. For commercial and industrial land uses, an off-site migration check is also calculated to prevent contamination of adjacent and more sensitive land uses. The soil contact and nutrient and energy cycling guidelines are applicable to soils within the pH range of 4.0 to 8.6, as the toxicological studies upon which these guidelines are based were conducted within this pH range.

Soil quality guidelines for the protection of aquatic life, livestock watering, or irrigation water, were not derived because these guidelines apply to soluble organic contaminants only. Concerns about soil based inorganic contaminants impacting water resources should be addressed on a site-specific basis.

For agricultural land use, the lower of the soil quality guideline for soil contact, soil and food ingestion, or nutrient and energy cycling is recommended as the SQG<sub>E</sub>. Therefore, the SQG<sub>E</sub> for agricultural land use is based on soil contact (Table 2).

For residential/parkland land use for contaminants that do not bioaccumulate and/or biomagnify (e.g., nickel), the SQG<sub>E</sub> is based on the lower of the soil quality guideline for soil contact or nutrient and energy cycling. Therefore, the SQG<sub>E</sub> for residential/parkland land use is based on soil contact (Table 2).

For commercial and industrial land uses, the lower of the soil quality guideline for soil contact or nutrient and energy cycling is recommended as the SQG<sub>E</sub>. The SQG<sub>E</sub> may also be modified by the environmental off-site migration check. The SQG<sub>E</sub> for commercial and industrial land uses are based on soil contact (Table 2).

#### *Soil Quality Guidelines for Human Health*

Human health soil quality guidelines (SQG<sub>HH</sub>) for nickel require consideration of both the non-carcinogenic and carcinogenic properties of nickel. For protection of non-cancer effects, the development of Canadian soil quality guidelines is typically based on 20% of the residual tolerable daily intake (i.e., 20% x [TDI minus the Estimated Daily Intake or EDI]); however, in the case of nickel, the EDI is greater than the TDI and this calculation results in a residual TDI that is a negative value for agricultural, residential/parkland and commercial land use. In these cases, a

provisional SQG<sub>HH</sub> is typically set at the background soil concentration (CCME 2006). Alternatively, the SQG<sub>HH</sub> can be based on an exposure that is the lower of either (i) 10% of the EDI; or (ii) 20% of the TDI (CCME 2015). In the case of nickel, the SQG<sub>HH</sub> was developed based on 10% of the EDI.

Since nickel may act as a carcinogen via the inhalation route, the development of SQG<sub>HH</sub> also considered the protection against cancer risks for soil-based airborne dust particles that can be inhaled. Specifically, non-threshold (carcinogenic) substances require the development of SQG<sub>HH</sub> that employ a critical risk-specific dose (RsD), based on incremental lifetime cancer risks (ILCRs) from exposure to nickel in soil via inhalation of airborne dust. For all land uses, the adult was chosen as the receptor when considering lifetime cancer risk. Some jurisdictions in Canada have adopted an “essentially negligible” ILCR of  $1 \times 10^{-5}$  (or 1 in 100 000) for managing risks of carcinogenic substances, while other jurisdictions use an ILCR of  $1 \times 10^{-6}$  (or 1 in 1 000 000). In light of this, soil quality guideline calculations were undertaken using both a  $1 \times 10^{-5}$  and  $1 \times 10^{-6}$  ILCR.

Various check mechanisms are applied, if relevant, to the preliminary human health soil quality guidelines in order to provide them with a broader scope of protection, such as the potential to adversely impact groundwater, agricultural crops and livestock.

The SQG<sub>HH</sub> derived for nickel for the protection of non-cancer effects are: 200 mg/kg for residential/parkland use and agricultural land use, 310 mg/kg for commercial land use and 2500 mg/kg for industrial land use based on a check mechanism for off-site migration of eroded soil deposited from commercial and industrial land use onto adjacent agricultural land. For the protection of cancer risks (i.e., via inhalation of fugitive dust), the human health-based soil quality guidelines for nickel are: 10 000 mg/kg for all land uses based on an incremental lifetime cancer risk (ILCR) of  $1 \times 10^{-5}$ . For an ILCR of  $1 \times 10^{-6}$ , the human health-based soil quality guideline for the inhalation of fugitive dust is 1000 mg/kg for all four land uses. Consequently, the non-cancer endpoints were the most conservative values and were used as the SQG<sub>HH</sub> for all land uses except for industrial sites that require protection of cancer risks at an ILCR of  $1 \times 10^{-6}$ .

The SQG<sub>HH</sub> is set at the lowest of the human health guidelines and checks. Based on this, the overall SQG<sub>HH</sub> derived for agricultural and residential/parkland uses is 200 mg/kg, and 310 mg/kg for commercial land use, based on direct contact. For industrial land use the SQG<sub>HH</sub> are 2500 mg/kg, based on the off-site migration check when an ILCR of  $10^{-5}$  is selected and 1000 mg/kg, based on an ILCR of  $10^{-6}$ .

A check mechanism for produce, meat and milk was not carried out, since the produce, meat and milk check pertains to substances that are expected to bioconcentrate or biomagnify. It is noted that the SQG<sub>HH</sub> above are considered to be protective at most sites; however certain exposure pathways have not been evaluated in the development of the SQG<sub>HH</sub>. More specifically, the SQG<sub>HH</sub> have not evaluated garden produce consumption or drinking water consumption (see footnotes in Table 2). The SQG derivation did not identify a dermal toxicity reference value which would be protective of people with dermal allergies to nickel, and the oral toxicity reference value which is used in the equations does not account for this endpoint.

### **Soil Quality Guidelines for Nickel**

The soil quality guidelines are intended to be protective of both environmental and human health. The soil quality guidelines are the lower of the  $SQG_E$  and  $SQG_{HH}$ . For all land use categories, the soil quality guideline for nickel is based on the  $SQG_E$  (Table 1). The interim soil quality criteria (CCME 1991) and previous soil quality guidelines for nickel (EC 1999) are replaced by the SQGs recommended here.

CCME (2006) provides guidance on potential modifications to the recommended soil quality guideline when setting site-specific objectives.

Table 2. Soil Quality Guidelines for Nickel (mg/kg)

Guideline	Land use			
	Agricultural	Residential/ Parkland	Commercial	Industrial
	45 <sup>a</sup>	45 <sup>a</sup>	89 <sup>a</sup>	89 <sup>a</sup>
Human health guidelines/check values				
SQG <sub>HH</sub> Non-Cancer and 10 <sup>-6</sup> ILCR	200	200	310	1000 <sup>b</sup>
SQG <sub>HH</sub> Non-Cancer and 10 <sup>-5</sup> ILCR	200	200	310	2500 <sup>c</sup>
Direct contact guideline (ingestion and dermal)	200	200	310	5100
Direct contact guideline (particulate inhalation) <sup>d</sup>				
10 <sup>-6</sup> ILCR	1000	1000	1000	1000
10 <sup>-5</sup> ILCR	10 000	10 000	10 000	10 000
Threshold	5300	5300	19 000	19 000
Groundwater check (drinking water)	NC <sup>e</sup>	NC <sup>e</sup>	NC <sup>e</sup>	NC <sup>e</sup>
Produce, meat and milk check	NC <sup>f</sup>	NC <sup>f</sup>	-	-
Off-site migration check	-	-	2500	2500
Environmental health guidelines/check values				
SQG <sub>E</sub>	45	45	89	89
Soil contact guideline	45	45	89	89
Soil and food ingestion guideline	528	-	-	-
Nutrient and energy cycling check	171	171	235	235
Off-site migration check	-	-	287	287
Groundwater check (aquatic life)	NC <sup>e</sup>	NC <sup>e</sup>	NC <sup>e</sup>	NC <sup>e</sup>
Guideline derived in 1999 (original Ni SQG)	50	50	50	50
Interim Soil Quality Criteria (CCME 1991)	150	100	500	500

**Notes:** NC = not calculated; SQG<sub>E</sub> = soil quality guideline for environmental health; SQG<sub>HH</sub> = soil quality guideline for human health; ILCR = incremental lifetime cancer risk. The dash indicates a guideline/check value that is not part of the exposure scenario for this land use and therefore is not calculated.

<sup>a</sup>Data are sufficient and adequate to calculate a SQG<sub>E</sub> and SQG<sub>HH</sub> for this land use. Therefore the soil quality guideline is the lower of the two (CCME 2006). The original nickel soil quality guideline derived in 1999 (based on SQG<sub>E</sub> only) and the interim soil quality criteria (CCME 1991) are superseded by the nickel soil quality guideline (CCME 2015).

<sup>b</sup>The SQG<sub>HH</sub> is set at the non-threshold guideline for particulate inhalation because it is the lowest of the of the human health guidelines and check mechanisms for this land use at an ILCR of 1 in 1 000 000.

<sup>c</sup>The SQG<sub>HH</sub> is set at the off-site migration check value because it is the lowest of the human health guidelines and check values for this land use at an ILCR of 1 in 100 000.

<sup>d</sup>Inhalation pathway was developed for combined soluble, oxidic and sulphidic nickel.

<sup>e</sup>Applies to organic compounds and is not calculated for metal substances. Concerns about metal substances should be addressed on a site specific basis.

<sup>f</sup>Applies to non-polar organic compounds and is not calculated for metal substances. Concerns about metal substances should be addressed on a site specific basis.

## References

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