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

CYANIDE (FREE) 1997

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

Background Information

Cyanides make up a distinct group of compounds characterized by the presence of the group C≡N. Cyanide compounds may take many forms, including free cyanide, simple cyanides, complex cyanides (metallocyanides), and organic cyanides (nitriles). Free cyanide refers to the sum of molecular HCN and the cyanide anion, CN^-. Chemical names for HCN include hydrogen cyanide, hydrocyanic acid, and prussic acid. Hydrogen cyanide is a colourless, flammable liquid or gas. Gaseous hydrogen cyanide, which rarely occurs in nature, is lighter than air and diffuses rapidly. Hydrogen cyanide is a weak acid and remains largely in molecular form in aqueous solutions with a pH lower than 9.2. Above this pH, the molecule dissociates into H^+ and CN^-. Hydrogen cyanide is completely miscible with water (Towill et al. 1978; Eisler 1991). Impure liquid hydrogen cyanide may polymerize spontaneously and violently, so small quantities of sulphuric or phosphoric acid are generally added as stabilisers (Towill et al. 1978).

Considerable quantities of cyanide compounds are consumed by a variety of Canadian industries, and the demand has been increasing steadily (CPI 1992; Statistics Canada 1992). In Canada, cyanide compounds are primarily used for the extraction/recovery of precious metals (mainly gold) and electroplating; for the production of organic chemicals, plastics, and other

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

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**0.9**[a]	**0.9**[a]	**8.0**[a]	**8.0**[a]
SQG_{HH}	29	29	107	420
Limiting pathway for SQG_{HH}	Soil ingestion	Soil ingestion	Soil ingestion	Off-site migration
Provisional SQG_{HH}	NC[b]	NC[b]	NC[b]	NC[b]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
SQG_E	0.9	0.9	8.0	8.0
Limiting pathway for SQG_E	Soil contact	Soil contact	Soil contact	Soil contact
Provisional SQG_E	NC[c]	NC[c]	NC[c]	NC[c]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.5	10	100	100

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

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

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

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

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

synthetic materials; and for the synthesis of various inorganic compounds used by the electroplating industry (Montreal Engineering Company 1973; Scott 1989; CPI 1991, 1992; Eisler 1991).

Cyanide and cyanide compounds are present in air, water, soil, and food due to both natural and anthropogenic sources. Plants and other living organisms produce minute quantities of cyanide (Leduc 1984; Knowles 1988; Alström and Burns 1989; Davis 1991; Eisler 1991). Cyanogenic glycosides are widely distributed in more than 1000 species of food plants (notably cassava, peas, beans, and kernels of almonds) (Hulbert and Oehme 1968; Buck et al. 1973; Cade and Rubira 1982; Eisler 1991).

Although cyanide is ubiquitous in the environment, the highest environmental levels are found in the vicinity of combustion sources (automotive exhaust, fires, cigarette smoke, and solid waste incineration); in wastewaters from water treatment facilities, iron and steel plants, and organic chemicals industries; in landfills and associated groundwater; and in areas of road salt applications and runoff (Towill et al. 1978; Fiksel et al. 1981; ATSDR 1991).

Environmental Fate and Behaviour in Soil

The major processes affecting the transport and distribution of cyanide in soils are volatilization and biodegradation. Cyanide ions may also form complexes with heavy metals, particularly iron, and precipitate out of solution (Lagas et al. 1982; Chatwin 1989;). Hydrogen cyanide is not susceptible to photolysis in soils (Cicerone and Zellner 1983), but complex cyanides, such as ferrocyanides and ferricyanides, may rapidly photo-dissociate and release free cyanide when exposed to sunlight (Callahan et al. 1979; Fiksel et al. 1981; Meeussen et al. 1992). Cyanides may be adsorbed by several materials, including clays and biological solids (Cruz et al. 1974; Raef et al. 1977a, 1977b; Chatwin and Trepanowski 1987; Chatwin 1989). However, existing data indicate that the rate of hydrogen cyanide and metal cyanide adsorption in soils is not significant when compared with rates of volatilization and biodegradation (Raef et al. 1977b; Callahan et al. 1979; ATSDR 1991). Small amounts of cyanide in soil may be oxidized to cyanate (HCNO) (Chatwin 1989). The high volatility of cyanide and the action of soil microbes ensure that high levels of cyanide do not persist or accumulate in soil under natural conditions (Towill et al. 1978; Fuller 1984).

As with surface waters, cyanide must be present as hydrogen cyanide in order to volatilize from soils (Higgs 1992). The rate of volatilization from soils is complex and depends on many factors, including pH, cyanide solubility, hydrogen cyanide vapour pressure, free cyanide concentration, soil water content, soil sorptive properties, soil porosity, organic matter content, density and clay content, and atmospheric conditions such as barometric pressure, humidity, and temperature (Chatwin and Trepanowski 1987; Chatwin 1989). No quantitative data on the rate of cyanide volatilization from soils was available. Empirical studies on the partitioning of hydrogen cyanide between gas and solution phases in unsaturated soils showed that its migration through soil occurs mainly through gas diffusion. Hydrogen cyanide volatilization from unsaturated soils could account for up to 10% of total cyanide losses (Chatwin 1989). In acidic soils, volatilization becomes a significant removal process and may be the dominant mechanism for cyanide loss from soil surfaces (USEPA 1984; Rouse and Pyrih 1990).

Biodegradation, particularly in aerobic conditions, is expected to be an important cyanide process in soils (Towill et al. 1978). Cyanides may be degraded in the soil environment by a wide variety of microbes, including the fungi *Fusarium solani*, *Stemphylium loti*, and a *Pholiota* sp., and bacteria species such as *Corynebacterium, Arthrobacter, Bacillus, Thiobacillus, Pseudomonas, Klebsiella,* and *Escherichia* (Towill et al. 1978; Knowles 1988; Silva-Avalos et al. 1990). A strain of *Bacillus pumilus* from clay samples planted with flax was found to degrade a 0.1 $mol \cdot L^{-1}$ cyanide solution to carbon dioxide and ammonia (Knowles 1976).

Natural soil microflora have been demonstrated to convert cyanide to carbonate and ammonia (Strobel 1967). Cyanide present at low concentrations will be decomposed to ammonia, carbon dioxide, and nitrogen or nitrate under aerobic conditions, and to the ammonium ion, nitrogen, thiocyanate, and carbon dioxide under anaerobic conditions (Rouse and Pyrih 1990).

The mobility of cyanide compounds in soil depends on stability and dissociation characteristics of the compound, soil type, soil permeability, soil chemistry, and the presence of aerobic and anaerobic microorganisms (Fuller 1984; Higgs 1992). Experimental studies on the mobility of cyanide in saturated anaerobic soils have shown that aqueous simple cyanides and aqueous ferricyanides tend to be very mobile. Cyanides dissolved in leachate were found to move through soils much more slowly than those in aqueous solution as they tended to precipitate out as the relatively immobile compound Prussian Blue (Alesii and Fuller 1976; Fuller 1977, 1984). It should be noted, however, that although Prussian Blue tends to precipitate out in soils with pH >4, some of the compound remains in solution and may result in contamination of groundwater by iron cyanide (Meeussen et al. 1992). Copper, cobalt, zinc, and nickel-cyanide complexes were found to be relatively mobile in soils compared to iron and manganesecyanide complexes (Chatwin 1989; Higgs 1992).

Soil conditions increasing the mobility of cyanide include low pH, high negative soil charges, and low clay content. Neutral to alkaline pH, high clay content, high positive soil charges, and the presence of organic matter and iron or other metal oxides appear to increase the attenuation of cyanide in soils (Alesii and Fuller 1976; Fuller 1977, 1984). The presence of aerobic soil microbes is particularly important to the attenuation of cyanide since mobility under aerobic conditions is greatly reduced due to higher rates of biodegradation (Fuller 1984). Thus, cyanide leaching to groundwater is enhanced under anaerobic conditions.

Soils represent the major potential pathway for cyanide contamination of groundwater (Chatwin 1989). High concentrations of cyanide in landfill waste or industrial effluents present a hazard to both soil and groundwater since microbial degradation of the compound may be inhibited (Lagas et al. 1982; ATSDR 1991).

Behaviour and Effects in Biota

Soil Microbial Processes

Bacteria exposed to cyanide may exhibit decreased growth, altered cell morphology, decreased motility, mutagenicity, and altered respiration (Towill et al. 1978). Cyanide's toxicity to living cells is a result of three major mechanisms: strong chelation to metals in metallo-enzymes; reaction with keto compounds to form cyanohydrin derivatives of enzyme substrates; and reaction with Schiff-base intermediates during enzymic reactions to form stable nitrile derivatives (Solomonson 1981; Knowles 1988). Cyanide is a major inhibitor of the enzyme cytochrome oxidase as well as hemoproteins and other metal-containing oxidases or oxygenases. At concentrations of about 10^{-4} $mol \cdot L^{-1}$ or lower, cyanide is usually highly inhibitory to cytochrome oxidase while other enzymes require 10^{-4} to 10^{-2} $mol \cdot L^{-1}$ of cyanide for significant inhibition (Knowles 1976). Unacclimated mixed microbial populations are adversely affected by cyanide at concentrations of 0.3 mg $HCN \cdot kg^{-1}$. Acclimatized populations in activated sewage sludge may be unaffected by concentrations as high as 60 mg total $cyanides \cdot kg^{1}$ Towill et al. 1978).

Terrestrial Plants

Very few data were available on the uptake of cyanide from soil by plants. Cyanide levels in cyanogenic plants are partially determined by nutrient availability, physical stressors, and the growth stage of the plant (Buck et al. 1973; Cade and Rubira 1982; Eisler 1991). Consequently, cyanide concentrations in plants are difficult to correlate with levels in surrounding soil (Howe and Noble 1985). Dandelions, a non-cyanogenic plant, harvested from soils containing 11.3–16.2 $mg \cdot kg^{-1}$ of cyanide showed cyanide levels of 10.25 to 11.30 $mg \cdot kg^{-1}$, while control plants from soils containing 0.70 $mg \cdot kg^{-1}$ showed cyanide levels of 0.50 $mg \cdot kg^{-1}$. Laboratory tests demonstrated that dandelions grown in cyanide solutions and cyanide-containing mine effluents showed cyanide uptakes in proportion to the amount of cyanide in solution (Howe and Noble 1985). A BCF (ratio of cyanide in plant to cyanide in soil) of 0.8 can be calculated from the data on bush beans reported by Wallace et al. (1977).

The effects of cyanide on the seedling emergence of radishes *(Raphanus sativa)* and lettuce *(Lactuca sativa)* grown in an artificial soil were studied by Environment Canada (Environment Canada 1995a, 1995b). The average 3-d NOEC, LOEC, EC_{25}, and EC_{50} values for radish seedling emergence were 0.9, 1.9, 1.3, and 2.9 mg $CN^{-} \cdot kg^{-1}$ soil, respectively. The average 5-d NOEC, LOEC, EC_{25}, and EC_{50} values for lettuce seedling emergence were 5, 10, 7, and 13 mg $CN^{-} \cdot kg^{-1}$, respectively.

Terrestrial Invertebrates

Orchid weevils *(Orchidophilus aterrimus)* were resistant to cyanide at fumigating concentrations up to 4600 $mg \cdot L^{-1}$ (Hansen et al. 1991). Southern armyworm *(Spodoptera eridania)* larvae were demonstrated to be extremely resistant to cyanide, with 3-day-old larvae showing an ingested LD_{50} of 1492 mg $HCN \cdot kg^{-1}$, while levels of 23 mg $CN^{-} \cdot kg^{-1}$ soil resulted in significant earthworms mortality (Brattsten et al. 1983).

Soil invertebrate toxicity data, like toxicity data for soil microbes, are nearly nonexistent. In the only soil invertebrate toxicity study available, Environment Canada reported the effects of cyanide (applied as potassium cyanide) on the earthworm *Eisenia foetida* in an artificial soil. The average NOEC, LOEC, LC_{25}, and LC_{50}, values were reported at concentrations of 8, 15, 9, and 12 mg $CN^{-} \cdot kg^{-1}$ soil, respectively (Environment Canada 1995a, 1995b).

Livestock and Wildlife

Free cyanide is readily absorbed by terrestrial animals through inhalation, ingestion, and contact with skin and mucous membranes (Egekeze and Oehme 1980). The most frequent cause of cyanide poisoning in terrestrial animals, particularly livestock, is through ingestion of plants containing cyanogenic glycosides. Free cyanide is released from cyanogenic plants through mastication, digestion, and microbial degradation in the digestive system (Towill et al. 1978). Animals that eat rapidly are at greatest risk (Egekeze and Oehme 1980). Ruminants (e.g., cattle and sheep) tend to be more vulnerable to cyanogenic plants than nonruminants (e.g., horses and pigs), presumably as a result of the greater degradation of plant cells by bacterial enzymes (Cade and Rubira 1982; Reed 1984). Cyanide poisoning through the ingestion of cyanogenic plants is more prevalent under drought conditions since animals are less selective in choice of forage and plant production of cyanogenic glycosides is enhanced under stressful conditions (Buck et al. 1973; Towill et al. 1978; Eisler 1991). In addition to livestock, several bird species have been found dead after ingesting cyanogenic plants (Cameron 1972).

LD_{50}s for mammals and birds range from 1.43 to 11.15 mg $CN^-\cdot kg^{-1}$ bw. Detoxification is quite rapid. There is no evidence of cyanide bioaccumulation in any organisms. Low doses of cyanide are rapidly degraded to nontoxic products by most species, while large doses result in death (Towill et al. 1978).

Human and Experimental Animal Health Effects

The toxicity of cyanide will vary according to the route of exposure. Inhalation is the most rapid route of entry and results in the rapid onset of toxic effects. Ingestion of soluble salts results in lower absorption via the gut and a faster detoxification. The chemical form of cyanide will also affect toxicity. Hydrogen cyanide is the most toxic cyanide form, whereas a complex cyanide compound such as acetonitrile requires metabolism to release free cyanide, and thus the toxic effects may be delayed by as much as 12 h (Ballantyne 1984).

The rate of absorption of cyanide across the gastrointestinal mucosa is dependent of the pH, pKa, and the liposolubility of the cyanide compound. The rapid lethal effects observed following oral intakes of cyanide indicates that cyanides are readily absorbed from the gastrointestinal tract (Gosselin et al. 1976).

Because of their liposolubility, cyanides can rapidly penetrate the epidermis. Corrosive properties (to the skin) of some cyanides (such as KCN) can increase the rate of absorption (NIOSH 1976). In one instance, a worker wearing a respirator suffered severe cyanide poisoning within 5 min after spilling liquid HCN on his hands (Potter 1950).

Cyanides are rapidly absorbed following inhalation. In humans, a concentration of ≥2000 ppm is fatal in <1 min (Reiders 1971). Humans retain 58–77% of HCN in the lungs following inhalation (Landahl and Herrmann 1950).

Cyanides are distributed throughout the body following administration, and the detoxification process for cyanides occurs in various organs and tissues including nasal cavities, liver, and muscle (Dahl and Waruszewski 1989).

Gonzales and Sabatini (1989) described the mode of action of cyanide. It inhibits the final step of oxidative-phosphorylation of the cytochrome oxidase reaction by binding to cytochrome a-a_3 complex. Cyanide inhibits enzymes containing ferric iron and to a lesser extent enzymes containing ferrous iron. Iron is found in hemoglobin, and cyanide will react with hemoglobin to form cyanohemoglobin in small amounts. Death results from inhibition of cellular respiration.

Cyanide is extensively metabolized in the liver. The major pathway for detoxification of cyanide is via a mitochondrial enzyme, rhodanese. Cyanide is detoxified to form thiocyanate, which is excreted in the urine. The reaction forming thiocyanate is essentially irreversible (Way 1984). Estimates of the detoxification rates in humans vary from 0.5 $\mu g\cdot kg^{-1}$ per minute to 170 $\mu g\cdot kg^{-1}$ per minute (Bright and Marrs 1988).

Free cyanide is extremely toxic in acute doses via all routes of exposure. Most victims of acute cyanide poisoning (e.g., suicide attempts and accidental poisonings) die almost immediately. Fatal oral doses of cyanide compounds range from 0.5 to 3.5 mg $CN^-\cdot kg^{-1}$ bw, with most of the values between 0.5 and 1.0 $mg\cdot kg^{-1}$ (USEPA 1992). A fatal dermal dose for HCN was estimated at 100 $mg\cdot kg^{-1}$. Inhalation of gaseous cyanide is expected to be immediately fatal at concentrations of 270 ppm HCN (300 $\mu g\cdot L^{-1}$) and fatal after 30 min exposure to concentrations of 135 ppm (150 $\mu g\cdot L^{-1}$) (Hartung 1981).

Symptoms of acute cyanide poisoning include vomiting, unconsciousness, coma, respiratory failure, and metabolic acidosis. The central nervous system is the most sensitive endpoint of cyanide toxicity, partly because of its high metabolic demands. Several diseases have been associated with the chronic ingestion of small doses of cyanide, including tobacco amblyopia, retrobulbar neuritis with pernicious anaemia, Leber's optic atrophy, Nigerian nutritional ataxic, neuropathy, and sterility in women who are heavy smokers.

No cancer studies in animals and no epidemiological studies with carcinogenicity in humans have been reported. Cyanides have tested negative for mutagenicity and effects on DNA synthesis in vitro, except in a study where a marginally mutagenic response for HCN in *Salmonella typhimurium* strain TA100 without metabolic activation was reported.

The general Canadian population is exposed to free cyanide in ambient air, drinking water, soil, and food. Because of lack of adequate data, it was not possible to directly characterize Canadian exposure to free cyanide via the diet. Estimates of total daily intake of free cyanide via air, water and soil (but excluding food) ranged from $\geq 0.07\ \mu g \cdot kg^{-1}$ bw per day in adults to $\geq 0.11\ \mu g \cdot kg^{-1}$ bw per day in infants. Air appeared to be a significant source of free cyanide exposure. Cyanide exposure in smokers is likely to be significantly higher (500×) than that of the general population.

The U.S. Environmental Protection Agency (IRIS 1994) has recommended a chronic oral reference dose of $0.02\ mg \cdot kg^{-1}$ for CN^- and HCN, based on the Howard and Hanzal (1955) study and using an uncertainty factor of 100 (10 for intraspecies variation, 10 for interspecies variation) and a modifying factor of 5 (for the apparent difference of tolerance to cyanide depending on the mode of ingestion [gavage, drinking water, or in food]). This reference dose is adopted provisionally as a TDI by the Bureau of Chemical Hazards of Health Canada for the derivation of health soil quality guidelines for free cyanide at contaminated sites in Canada.

There are no data in humans or experimental animals upon which to base a conclusion regarding the carcinogenic potential of free cyanide. It is therefore "unclassifiable with respect to carcinogenicity in humans" (Group VI.B) according to the classification scheme employed at the Bureau of Hazardous Chemicals of Health Canada in 1994. Free cyanide is treated as a substance for which the critical effect is believed to have a threshold of exposure for setting human health soil quality guidelines.

Guideline Derivation

Canadian soil quality guidelines were derived for different land uses following the process outlined in CCME (1996a) using different receptors and exposure scenarios for each land use category. Detailed derivations for cyanide 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 nutrient energy cycling check is calculated as the soil quality guideline for soil contact. If the nutrient and energy cycling check is greater than the preliminary soil contact value, the preliminary soil contact value becomes the soil quality guideline for soil contact.

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

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

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

In the case of cyanide, there are insufficient data to calculate the nutrient and energy cycling check. Therefore, the soil contact guidelines are recommended as the SQG_{ES} for all land uses (Table 2).

Soil Quality Guidelines for Human Health

The free cyanide soil concentration, based on direct exposure from soil ingestion, has been approved by the Standards and Guidelines Rulings Committee of the Bureau of Chemical Hazards of Health Canada as a preliminary human health soil quality guideline (SQG_{HH}). However, the CCME recommends the application of various check mechanisms, when relevant, in order to provide a broader scope of protection. The lower of the soil ingestion guideline and any of the calculated checks is recommended as the SQG_{HH}.

Table 2. Soil quality guidelines and check values for free cyanide ($mg \cdot kg^{-1}$).

	Land use			
	Agricultural	**Residential/ parkland**	**Commercial**	**Industrial**
Guideline	**0.9**[a]	**0.9**[a]	**8.0**[a]	**8.0**[a]
Human health guidelines/check values				
SQG_{HH}	29[b]	29[b]	110[b]	420[b]
Soil ingestion guideline	29	29	110	2300
Inhalation of indoor air check	NC[c]	NC[c]	NC[c]	NC[c]
Off-site migration check	—	—	—	420
Groundwater check (drinking water)	NC[d]	NC[d]	NC[d]	NC[d]
Produce, meat, and milk check	NC[e]	NC[e]	—	—
Provisional SQG_{HH}	NC[f]	NC[f]	NC[f]	NC[f]
Limiting pathway for provisional SQG_{HH}	ND	ND	ND	ND
Environmental health guidelines/check values				
SQG_E	0.9[g]	0.9[g]	8.0[g]	8.0[g]
Soil contact guideline	0.9	0.9	8.0	8.0
Soil and food ingestion guideline	11	—	—	—
Nutrient and energy cycling check	NC[h]	NC[h]	NC[h]	NC[h]
Off-site migration check	—	—	—	14
Groundwater check (aquatic life)	NC[d]	NC[d]	NC[d]	NC[d]
Provisional SQG_E	NC[i]	NC[i]	NC[i]	NC[i]
Limiting pathway for provisional SQG_E	ND	ND	ND	ND
Interim soil quality criterion (CCME 1991)	0.5	10	100	100

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.

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

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

[c]Applies only to volatile organic compounds and is not calculated for free cyanide.

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

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

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

[g]The SQG_E is based on the soil contact guideline.

[h]Data are insufficient/inadequate to calculate the environmental nutrient and energy cycling check.

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

Therefore, the SQG_{HH}s 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 2).

Soil Quality Guidelines for Free Cyanide

For each land use category, the soil quality guideline is the lower of the SQG_{HH} and SQG_E. For all land uses, the soil quality guideline is the soil concentration calculated for the SQG_E, which is based on the soil contact guideline (Table 1).

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

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

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