FINAL REPORT

Sudbury Area Risk Assessment
Volume II

Appendix C:

Background Exposures

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SUDBURY AREA RISK ASSESSMENT
VOLUME II

APPENDIX C: BACKGROUND EXPOSURES

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APPENDIX C BACKGROUND EXPOSURES

The following appendix provides a detailed literature review of the various sources of data collected describing background exposures to each of the COCs for the HHRA of the Sudbury Soils Study. This data was then used in the HHRA to evaluate background exposures to a typical Ontario resident *versus* those exposures incurred by residents of the GSA. This data should be considered in conjunction with the estimated daily intake (EDI) information provided in Appendix D.

C-1.0 ARSENIC BACKGROUND EXPOSURE

C-1.1 Sources and Environmental Fate

C-1.1.1 Sources

Arsenic is naturally present in terrestrial and aquatic environments from weathering and erosion of rocks and soils. It is present in the earth's crust at an average concentration of 2 to 5 mg/kg (Tamaki and Frankenberger, 1992), but naturally arsenic-enriched bedrock is relatively common in areas of precious metal deposits. For example, high arsenic content has been reported in the soils, sediments and water of precious metal deposits in Northern Ontario, Quebec, New Brunswick and Nova Scotia (*e.g.*, Boyle *et al.,*1969; Brooks *et al.,* 1982; Bottomley, 1984).

The major anthropogenic sources of arsenic are base-metal and gold mines and smelting operations. Gold-milling operations and gold ore roasters discharge significant amounts of arsenic in their liquid effluents and air emissions. Weathering of waste rock and tailings also release significant amounts of arsenic into the environment, especially at abandoned base and precious metal mine sites where no leachate treatment systems are in place (Errington and Ferguson, 1987). The mining, smelting, milling and roasting of base and precious metals accounts for the majority of As_2O_3 present in the atmosphere. Other anthropogenic sources include pesticide use, wood preservation, coal-fired electricity generation, petroleum refining, antifouling paints and disposal (*e.g.*, incineration) of domestic and industrial wastes (Frank *et al.,* 1976; Henning and Konasewich, 1984; Evans *et al.,* 1985; van Voris *et al.,* 1985; PACE, 1983; Environment Canada, 1985; 1987; OME, 1988; Adams *et al.,* 1994). The glass and ceramics industries can also be sources of arsenic, as arsenic is utilized within these industries (WHO, 1981). Tobacco contains arsenic; and therefore, cigarettes smoking is a source of arsenic as well (WHO, 1981).

Arsenic is also released into the environment through natural processes: volcanic eruptions; forest fires; volatilization of methylarsenines from soil and decaying plant and animal material (Chilvers and Peterson, 1987; NRCC, 1978; Walsh *et al.,* 1979). Approximately one third of the atmospheric flux of arsenic is of natural origin (IPCS, 2001).

C-1.1.2 Environmental Fate and Speciation in Environmental Media

Due to its reactivity and mobility, arsenic cycles extensively through both biotic and abiotic components of terrestrial and aquatic systems, where it can undergo a variety of chemical and biochemical transformations, including oxidation, reduction, methylation and demethylation (Cullen and Reimer, 1989). The oxidation state of arsenic is the single most important factor controlling the solubility, mobility, environmental fate, bioavailability, and toxicity of its compounds (Masscheleyn *et al.,* 1991).

C-1.1.2.1 Atmosphere

The arsenic species present in the air are dependent on the sources and on reactions with other atmospheric substances. Most of the arsenic released to the air is in the form of arsenic trioxide (As_2O_3), which is the predominant species released from smelters, fossil fuel combustion, and mineral ore roasters. The trioxide rapidly sublimates in the atmosphere to form the gaseous species, As_4O_6 (Rabano *et al.,* 1989). This gaseous compound may be adsorbed or complexed to suspended particulate matter or it may condense to a solid upon cooling (Cullen and Reimer, 1989; Gagan, 1979). Volatile arsines and methylarsines are also released to the atmosphere by soil and aquatic microbial processes, where they are eventually oxidized (especially in the presence of sunlight) and bound to particulates, typically as methylated As(V) species (Parris and Brinckman, 1976; NRCC, 1978). The majority of atmospheric arsenic is associated with fine particulates (*i.e.*, less than 2.5 µm in diameter), with smaller percentages existing either in the vapour phase, or associated with coarse particulates (>2.5 µm in diameter) (Walsh *et al.,* 1979; Rabano *et al.,* 1989). The As_4O_6 species is believed to be the precursor for inorganic particulate-bound As(III) and As(V) species (Rabano *et al.,* 1989). The chemical mechanism is believed to be similar to the atmospheric reactions that occur with NO_x and SO_x compounds, in which weak acids NO, NO_2 and SO_2 react with alkaline coarse particles to form coarse particulate nitrate and sulfate (Rabano *et al.,* 1989). Inorganic As(III) and As(V) species (arsenites and arsenates) typically occur in the low ng/m^3 range in atmospheric particulate matter (Rabano *et al.,* 1989). Other chemical forms of arsenic found in the atmosphere in small quantities include metallic arsenic, and volatile organic arsenicals and their degradation products which result from pesticide applications. Arsenic is removed from the atmosphere *via* wet and dry deposition processes with an average atmospheric residence time of approximately nine days (Walsh *et al.,* 1979).

C-1.1.2.2 Surface Water and Groundwater

The most abundant species in natural waters are arsenite (As(III)) and arsenate (As(V)) (Bissen and Frimmel, 2003); however, arsenic speciation in surface waters is highly dependent upon pH and redox potential. When As_2O_3 (or As_4O_6) is deposited into aerobic surface waters, it rapidly hydrolyzes to form mobile As(III) species, principally AsO_3^{-3} (arsenite). Arsenite is relatively unstable in aerobic waters and is slowly oxidized to form less mobile As(V) species, principally the arsenates, $HAsO_4^{-2}$ and $H_2AsO_4^{-1}$ (CEPA, 1993). Under anaerobic conditions, arsenates are reduced to arsenite (Korte and Fernando, 1991; Masscheleyn *et al.,* 1991). In deep anoxic waters, insoluble arsenic sulfides are common, while in more shallow and oxygenated waters, As(V) species tend to predominate; As(III) species tend to predominate at mid-depths under reducing conditions (Seyler and Martin, 1989). Phytoplankton blooms in surface waters can result in the biochemical reduction of arsenates to arsenite, as well as the production of methylated arsenic species (Andreae, 1978). Since arsenic does not occur as a cation in fresh surface waters, it does not complex with humic or fulvic acids, nor does it form complexes with other common anions in water to an appreciable extent (Korte and Fernando, 1991).

The mobility of arsenic in aqueous environments is influenced by the pH value, the redox potential, and the presence of adsorbents (*e.g.,* oxides and hydroxides of Fe(III), Al(III), Mn(III/IV), humic substances and clay minerals) (Bissen and Frimmel, 2003). In general, dissolved arsenic is rapidly removed from the water column by biotic uptake, fixation by organic matter, adsorption onto iron or manganese hydroxides or clay particles, precipitation and co-precipitation (Nriagu, 1983). These removal mechanisms result in the majority of arsenic in surface waters being deposited in sediments.

The predominant chemical species in groundwater appear to be inorganic As(V) and to a lesser extent, As(III) (Masscheleyn *et al.,* 1991; Korte and Fernando, 1991). Groundwater normally contains higher arsenic concentrations than surface waters (Boyle and Jonasson, 1973). High groundwater arsenic concentrations may be caused by elevated arsenic content in bedrock, such as in a number of regions of Ontario, Quebec, New Brunswick and Nova Scotia (*e.g.*, Boyle *et al.,* 1969; Brooks *et al.,* 1982; Bottomley, 1984; Méranger *et al.,* 1984a).

C-1.1.2.3 Soils and Sediments

Arsenic speciation in soil is influenced by complex interactions between pH, redox potential, organic content, iron oxyhydroxide (and other hydrous metal oxide) concentrations and soil particle size. The principal species present in soil are arsenites (As(III)), arsenates (As(V)), and methylated arsenicals from herbicide use (*e.g.*, monomethylarsonic acid, dimethylarsinic acid). The methylated arsenicals have soil half-lives ranging from 0.5 to 2.9 years but are eventually degraded to carbon dioxide and arsenate by soil microorganisms (Hiltbold, 1975). Some soil arsenic is lost to the atmosphere *via* the microbially-mediated volatilization of arsine and methylarsines (NRCC, 1978). However, soil microbial activity also results in arsenic inputs to the soil through the mobilization of arsenic present in rocks and minerals by microbial oxidation of sulfides and ferrous iron in these minerals to sulfate and ferric iron (Tamaki *et al.,* 1992).

The movement of arsenic species from soil to groundwater is dependent on the properties of the arsenic species, and soil properties such as pH, redox potential, organic content, cation exchange capacity, concentrations of iron oxyhydroxide (and other hydrous metal oxides), soil particle size, and concentrations of other chemicals in the soil (Bissen and Frimmel, 2003; CEPA, 1993). Most arsenic in soils is tightly bound to iron/manganese oxides and clay particles, which reduces the amount of arsenic that can leach into groundwater or be taken up by plants (CEPA, 1993). The use of phosphate fertilizers can result in the mobilization of otherwise tightly bound arsenic in soil (Peryea, 1991). Medium to fine-grained, well drained soils can retain arsenic for decades (Veneman *et al.,* 1983). Poorly drained soils do not retain arsenic as efficiently though, as flooding creates an anaerobic environment that results in the mobilization of arsenic (Masscheleyn *et al.,* 1991). Pantsar-Kallio and Manninen (1997) found that more inorganic As(III) and As(V) species were mobilized from sandy soils than from humic or clay soils. In general, inorganic arsenic species have been found to be highly mobile and leachable in sandy *versus* higher clay content soils (Walsh *et al.,* 1977). Pantsar-Kallio and Manninen (1997) also found that high pH values resulted in greater mobilization of inorganic arsenic than low pH values. However, over a pH range of three to nine, less than 2% of inorganic arsenic was mobilized, indicating that environmental pH changes would have to be drastic to result in the release of significant amounts of arsenic from the soil matrix. In all soil mobilization experiments conducted by the authors, As(V) species were the predominant species extracted from the soil types studied. In an earlier study, Masscheleyn *et al.,* (1991) found that alterations in the oxidation state of arsenic, brought about by changing redox potential and pH, greatly affected its solubility in soil. At high redox levels, arsenic solubility was low and 65 to 98% of the dissolved arsenic was present as As(V). High pH values or reducing conditions resulted in the release of substantial amounts of arsenic into solution; present mainly as As(III). Under moderately reduced conditions, arsenic solubility was mainly controlled by the dissolution of iron oxyhydroxides. Therefore, when arsenic-containing wastes are released to soil, consideration should be given to maintaining a high soil redox potential and nonalkaline conditions to minimize arsenic solubility and mobility (Masscheleyn *et al.,* 1991).

Sediments are a major long term sink for arsenic, with some studies suggesting sediment retention times of up to 100 years (Nriagu, 1983; Sutherland, 1989). However, some sediment-bound arsenic may be released into pore waters and the water column by organic decomposition processes, or dissolution of iron/manganese hydroxides under anaerobic conditions resulting from sediment reburial (Nriagu *et al.,* 1987; Belzile, 1988). In addition, arsenates can be reduced to arsenites in sediments, which are subsequently methylated by microorganisms to form methylarsinic acids. These can be further reduced to yield volatile methylarsines, which are eventually released to the atmosphere (Wade *et al.,* 1993). While the production of methylarsines in sediments occurs mainly under anaerobic conditions, there is some evidence that this process can also occur under aerobic conditions (Brinckman *et al.,* 1977). The processes that lead to the methylation of arsenic by aquatic microbial species are poorly understood (Anderson and Bruland, 1991); however, detoxification and/or energy generation have been suggested by several authors to be the driving force behind the biomethylation of arsenic (Mitchell and Barr, 1995).

C-1.1.2.4 Biota

The extensive biogeochemical cycling of arsenic results in its occurrence in virtually all living organisms. Although bioconcentration factors (BCFs) for aquatic organisms, including algae, crustaceans, and fish have been reported to be as high as several thousand, arsenic does not bioaccumulate to any great extent, nor does it biomagnify in either aquatic or terrestrial food webs (NRCC, 1978; Eisler, 1988a; Adams *et al.,* 1994). In freshwater aquatic plants, arsenic is mainly present as arseno-lipids, and to a lesser extent, arsenite and methylated As(V) species (Cullen and Reimer, 1989). Arseno-lipids, arseno-sugars, methanoarsenate, dimethylarsenate, and other methylated arsenicals account for 60 to 99% of the arsenic in marine algae and plants (Adams *et al.,* 1994; Cullen and Reimer, 1989). The principal arsenic compounds found in fish and other marine animals are arsenobetaine and arsenocholine (Lawrence *et al.,* 1986; Adams *et al.,* 1994). However, arsenic may also occur in fish tissues as inorganic forms (NRCC, 1978; ATSDR, 1997; CEPA, 1993). The proportion of arsenic in fish tissues that is inorganic has been reported to range from as low as 0.1% to as high as 41% (NRCC, 1978; Vaesson and van Ooik, 1989). It is important from a risk characterization perspective to determine the proportion of inorganic arsenic species that are present in fish as the inorganic forms are the most bioavailable and the most toxic. Complexed organic arsenic species are not readily bioavailable and are more readily eliminated than the inorganic forms. As a result, organic arsenic species are generally considered to be of low toxicity.

Arsenic is present in methylated forms in some terrestrial plants and animals (Nissen and Benson, 1982; NRCC, 1978). Generally, arsenic does not accumulate to high levels in terrestrial plants, as reduced plant growth and other forms of phytotoxicity will occur before arsenic can accumulate to any significant extent (Bennett, 1981). However, some plants are quite tolerant of arsenic in soil (*e.g.*, grapes, corn, carrots, tomatoes, cabbage, tobacco) (Walsh *et al.,* 1977). Furthermore, plant uptake of arsenic is in competition with phosphorus uptake; thus arsenic accumulation is usually restricted as most soils contain greater amounts of phosphorus than arsenic (Adams *et al.,* 1994). On a relative basis, the highest concentrations of arsenic in terrestrial plants tend to occur in plant roots, with intermediate levels occurring in vegetative tissues and the lowest levels in plant reproductive tissues (Walsh *et al.,* 1977).

C-1.1.2.5 Foods

Due to the extensive cycling of arsenic through biotic and abiotic components of terrestrial and aquatic systems, it is not surprising that arsenic has been detected in most foods consumed by humans. The chemical form of arsenic in various foodstuffs varies considerably. For example, much of the arsenic in fish is present in a highly complexed form that is not readily bioavailable, or as organoarsenicals (*e.g.*, arsenobetaine, arsenocholine) that are rapidly excreted from the body. Arsenosugars are found in seaweed, oysters and mussels (Le, 1999). Soluble inorganic As(III) and As(V) species are the most bioavailable of the arsenic species and are of primary toxicological concern in humans. Based on limited data, the percentage of inorganic arsenic in various foods has been reported to typically range from 0 to 1% in saltwater fish, 5% in vegetables, 10 to 15% in freshwater fish, 15% in potatoes, and fruits, 73% in apple juice, 35 to 43% in rice, 49 to 69% in cereals, flour and breads, 15 to 41% in poultry, and as much as 75 to 100% in milk, dairy products, and meats (Weiler, 1987; OME, 1987). Organic forms of arsenic predominate in fish, vegetables and fruits. For a typical mixed diet, approximately 20% of the estimated daily dietary intake of arsenic is inorganic (Borum and Abernathy, 1994). A study by Yost *et al.,* (1998) suggests that inorganic arsenic may account for 21 to 40% of the total arsenic present in a mixed diet, and that population exposure to inorganic arsenic through the ingestion of food may be greater than previously believed. It has been estimated that the percentage of inorganic arsenic is approximately 75% in meats, 65% in poultry, 75% in dairy products, and 65% in cereals (IPCS, 2001; Yost *et al*., 1998); while in fruits, vegetables and seafood the percentage of inorganic arsenic is only 10, 5% and 0 to 10%, respectively (IPCS, 2001). Schoof *et al*. (1999) measured total and inorganic arsenic in samples of 40 food items expected to provide at least 90% of the dietary inorganic arsenic intake in the U.S. Although the food samples were collected in Texas, the authors expect that their arsenic concentration data are representative of typical concentrations in foods throughout the U.S. The ratio of inorganic arsenic to total arsenic was calculated based on reported mean concentrations for each food item, and is presented in Table C.1.0. Note that ratios were calculated only for those food items where both total and inorganic arsenic were detected at concentrations above the method detection limit.

Table C.1.0 Proportions of inorganic arsenic in selected foods, calculated based on mean concentrations measured by Schoof *et al.* (1999)

Food Item	Total Arsenic (ng/g wet wt.)	Inorganic Arsenic (ng/g wet wt.)	Ratio
Fish and Shellfish [a]	**~160 to 2360**	**n.d.**	**--**
Meat, Poultry and Eggs [a]	**~14 to 86**	**n.d.**	**--**
Rice			
Rice	303	73.7	0.24
Cereals, Grains and Baked Goods			
Corn meal	38.6	4.4	0.11
Flour	39.1	10.9	0.28
Fruits and Fruit Juices			
Apple juice	7.6	2.8	0.37
Grapes	10.2	3.6	0.35
Grape juice	58.2	9.2	0.16
Watermelon	40.2	8.9	0.22
Root Vegetables			
Carrots	7.3	3.9	0.53
Onions	9.6	3.3	0.34
Other Vegetables			
Cucumber	9.6	4.1	0.43
Peas	4.3	4.5	1 [b]
Spinach	5.1	6.1	1 [b]
Sugars and Sweets			
Beet sugar	12.2	3.5	0.29
Cane sugar	23.8	4.4	0.18
Nuts			
Peanut butter	43.6	4.7	0.11

n.d. Non-detect (concentrations were below the method detection limit)

[a] Although levels of total As in these food items are detectable, concentrations of inorganic As were below the method detection limit and a quantitative ratio could not be calculated; however, it can be qualitatively stated that nearly all of the As present in these foods is inorganic.

[b] Calculated ratios for these food items exceed 1 because the reported mean concentrations of inorganic arsenic exceed those of total arsenic.

Vélez and Montoro (1998) caution against extrapolating data on arsenic speciation in fresh seafood to processed (*e.g.,* frozen, canned or salted) seafood, since arsenobetaine may not be the dominant species in processed seafood and dimethylarsinic acid is present with a higher mean content in processed *versus* fresh products.

C-1.2 Background Exposure Concentrations in Ontario and Canada

C-1.2.1 Background Concentrations in Air

A U.S. study found air concentrations of arsenic in indoor public places of <0.1 to 1 ng/m^3 (mean of 0.4 ng/m^3, and <0.13 ng/m^3 in places with and without environmental tobacco smoke, respectively (Landsberger and Wu, 1995). Table C.1 provides a summary of arsenic air concentrations from various sampling locations across Canada.

Table C.1 Ontario and Canadian Background Arsenic Concentrations in Air

Location	Description	Concentration	References
Canada (urban)	annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994 to 2004	range: nd to 0.231 µg/m^3 mean: 0.00135 µg/m^3	Dann, 2005 pers. comm.
Canada (rural)	annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994 to 2004	range: nd to 0.0131 µg/m^3 mean: 0.000850 µg/m^3	Dann, 2005 pers. comm.
Canada	major urban centres	mean: 0.001 µg/m^3 (in PM10)	CCME, 1997
Canada	major urban centres (1983 to 1984 data)	range: <0.003 to 0.013 µg/m^3	EAG, 1984
Windsor, Ontario	indoor (home and office) samples of personal air taken 1991 to 1992	range: nd to 2.6 ng/m^3 mean: 0.8 ng/m^3	Bell *et al.*, 1994
Windsor, Ontario	outdoor (residential and commercial neighbourhoods) samples of personal air taken 1991 to 1992	range: 0.4 to 3.3 ng/m^3 mean: 1.3 ng/m^3	Bell *et al.*, 1994
Windsor, Ontario	6 samples of ambient air taken in 1992	range: 0.4 to 5.4 ng/m^3 mean: 2.5 ng/m^3	Bell *et al.*, 1994
Windsor, Ontario	1987 to 1988 air data	range: 0.001 to 0.004 µg/m^3	Environment Canada, 1988
Canada	11 Canadian cities and one rural location (1985 to 1990 data)	range: <0.0005 to 0.017 µg/m^3 (24 h average) mean: 0.001 µg/m^3 (most cities)	Dann, 1990; Environment Canada, 1990
Toronto, Ont. Area	arsenic concentration of airborne particulates from 1982 to 1984	range: 0.04 to 0.15 µg/m^3 mean: 0.08 µg/m^3	Brzezinska–Paudyn *et al.,* 1986
North America	typical ranges for urban and rural areas	urban range: 0.002 to 0.22 µg/m^3 rural range: 0.001 to 0.007 µg/m^3	Schroeder *et al.,* 1982
British Columbia	mean from 3 stations between 1995 and 1998	mean: 0.497 ng/m^3 range: 0 to 8.95 ng/m^3	Dryfhout-Clark, 2004

C-1.2.2 Background Concentrations in Surface Water and Groundwater

Arsenic concentrations in fresh waters vary considerably according to the geologic composition of the watershed, and the extent of anthropogenic input (Le, 1999). Background arsenic concentrations in fresh surface water, groundwater, drinking water and precipitation are presented in Table C.2 to C.5 respectively. Tremblay and Gobeil (1990) noted that arsenic concentrations increased with increasing salinity.

Table C.2 Ontario and Canadian Background Arsenic Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 10 µg/L mean: 0.89 µg/L	Clubb, 2005, pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 21.7 µg/L mean: 0.72 µg/L	Clubb, 2005, pers. comm.
Lake Superior	47 water samples	range: <0.1 to 1.0 µg/L mean: 0.23 µg/L	Traversy *et al.*, 1975
Lake Huron	91 water samples	range: 0.1 to 0.8 µg/L mean: 0.44 µg/L	Traversy *et al.*, 1975
Georgian Bay	64 water samples	range: <0.1 to 0.7 µg/L mean: 0.35 µg/L	Traversy *et al.*, 1975
Lake Erie	17 water samples	range: <0.1 to 0.6 µg/L mean: 0.25 µg/L	Traversy *et al.*, 1975
Lake Ontario	24 water samples	range: 0.6 to 1.2 µg/L mean: 0.91 µg/L	Traversy *et al.*, 1975
Great Lakes Basin Rivers	108 water samples	range: <0.1 to 1.4 µg/L mean: 0.26 µg/L	Traversy *et al.*, 1975
St. Mary's River	160 water samples	range: <0.1 to 1.0 µg/L mean: 0.37 µg/L	Traversy *et al.*, 1975
St. Lawrence River	132 water samples	range: <0.1 to 1.0 µg/L mean: 0.61 µg/L	Traversy *et al.*, 1975
Moira Lake, Ontario	sampled from 1987 to 1988; past mining activity in area	range: 4 to 94 µg/L mean: 43 µg/L	Azcue *et al.*, 1994
St. Lawrence Estuary	samples taken at various locations[a]	range: 0.5 to 1.4 µg/L	Tremblay and Gobeil, 1990
Saguenay Fjord	samples taken at various locations[a]	range: 0.1 to 1.4 µg/L	Tremblay and Gobeil, 1990
Bowron Lake, British Columbia	samples taken in 1992; reference lake with no nearby mining activity	range: <0.2 to 0.42 µg/L mean: 0.26	Azcue *et al.*, 1994
British Columbia	samples taken in 1992 from a lake near an abandoned gold mine	range: <0.2 to 0.3 µg/L mean: 0.25	Azcue *et al.*, 1994
Various Lakes, NWT	sampled in 1975; near gold mining activity	range: 700 to 5,500 µg/L	Wagemann *et al.*, 1978
Various subarctic lakes	sampled in 1991; near gold mining activity	range: 64 to 530 µg/L mean: 270 µg/L	Bright *et al.*, 1996

Table C.2 Ontario and Canadian Background Arsenic Concentrations in Fresh Surface Water

Location	Description	Concentration	References

[a] Samples of varying salinity (0 to 31 g/L) showed As increasing with salinity.

Table C.3 Ontario and Canadian Background Arsenic Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 10.1 µg/L mean: 0.79 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standard[a]	25 µg/L	MOE, 2004
Southeastern Ontario	survey of shallow groundwater supplies	<50 µg/L	Michel, 1990
Saskatchewan	study of well water supplies	>20 µg/L in 13% of samples [b] >100 µg/L in one sample	Thompson *et al*., 1999

[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

[b] Wells with high arsenic levels were geographically near to one another.

Table C.4 Ontario and Canadian Background Arsenic Concentrations in Drinking Water

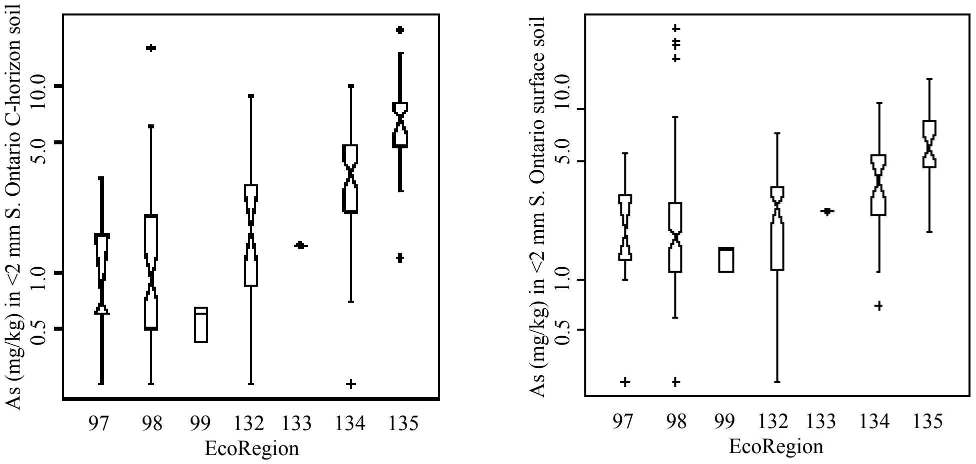
Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 15 µg/L mean: 0.73 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 9.5 µg/L mean: 0.68 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 8.3 µg/L mean: 0.45 µg/L	Clubb, 2005 pers. comm.
Canada	Ontario drinking water supplies	<5 µg/L	Subramanian and Méranger, 1984; OME, 1989
Canada	Domestic and imported bottled water samples from across Canada	range: <1 to 48 µg/L mean: 3 µg/L	Dabeka *et al.*, 1992

Table C.5 Ontario and Canadian Background Arsenic Concentrations in Precipitation

Location	Description	Concentration	References
Various locations	53 rainwater samples throughout Great Lakes Basin	range: <0.1 to 2.5 µg/L mean: 0.72 µg/L	Traversy *et al.*, 1975
Toronto, Etobicoke, Oakville, North York, Kingston, Ont.	Fresh snow samples (particulate matter); filtered snow samples from 1983 to 1984	fresh snow range: 10 to 50 µg/L filtered snow range: 15 to 50 µg/L	Brzezinska-Paudyn *et al.*, 1986

C-1.2.3 Background Concentrations in Soils and Sediment

Background concentrations of arsenic in soil are typically 1 to 40 µg/g (mean of 5 µg/g) (Beyer and Cromartie, 1987; Eckel and Langlery, 1988; U.S. EPA, 1982a; NAS, 1977). Generally, soils of granitic origins are low in arsenic (approximately 4 µg/g), while soils of sedimentary origins may be as high as 20-30 µg/g (Yan-Chu, 1994). Table C.6 summarizes background concentrations of arsenic in Canadian soils. Concentrations of arsenic in soils from across Southern Ontario are plotted in Figure C-1, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005).



EcoRegions:

97	Lake Timiskaming Lowland, n = 17	133	Frontenac Axis, n = 1
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 112	134	Manitoulin-Lake Simcoe, n = 89
99	Southern Laurentians, n = 3	135	Lake Erie Lowlands, n = 42
132	St. Lawrence Lowlands, n = 30		

Figure C-1 Tukey Boxplots, by EcoRegion in Southern Ontario, of Arsenic in C-horizon (70 to 100 cm) and Surface (top 25 cm) Soils

Table C.6 Ontario and Canadian Background Arsenic Concentrations in Soil

Location	Description	Concentration	References
Ontario	typical range surface soil concentrations	14 mg/kg (agricultural land use) 17 mg/kg (all other land uses)	MOEE, 1994
Canada	uncontaminated soils across Canada	range: 4.8 to 13.6 mg/kg <10 mg/kg (average urban and agricultural concentrations)[a]	Kabata-Pendias and Pendias, 1992 Environment Canada, 1996
Ottawa	garden soil, n = 50, collected winter 1993 from 10 Ottawa neighbourhoods	2.99 mg/kg	Rasmussen *et al*., 2001
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~1 to 60 mg/kg mean: ~ 5 mg/kg OTR_{98}: 11 mg/kg	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~1 to 30 mg/kg mean: 5.7 mg/kg OTR_{98}: 17 mg/kg	MOEE, 1994
Ontario	upper-limit of background[c]	14 to 17 mg/kg	MOE, 2004
Ontario	uncontaminated agricultural soils	range: 1.1 to 16.7 mg/kg	Frank *et al.,* 1976
South-western Ontario	untreated agricultural soils	range: 1.1 to 8.6 mg/kg	Miles, 1968
Canada	uncontaminated soil	<15 mg/kg usually average: 7 mg/kg	NRCC, 1978
Ontario	uncontaminated soils	range: 1.1 to 8.6 mg/kg	Walsh and Keeney, 1975
Southern Ontario	urban area; top 5 cm of soil; 1974	range: 2.7 to 41 mg/kg mean: 9.8 mg/kg	Temple *et al*., 1977
Southern Ontario	<700 m from secondary lead smelter; top 5 cm of soil; 1974	range: 4.7 to 2,000 mg/kg mean: 107 mg/kg	Temple *et al*., 1977
Toronto	near secondary lead smelter; top 1 cm of soil	range of means: 17.9 to 3,007 mg/kg	Dolan *et al*., 1990
Manitoba	surface peat soils sampled 1982-84	range: 1 to 19.6 mg/kg mean: 4 mg/kg	Zoltai, 1988
Alberta	acid sulphate soil, soil horizons E-C	range: 1.5 to 45 mg/kg	Dudas, 1984

[a] Environment Canada (1996) reports that most urban and agricultural soil concentrations are in the 4 to 6 mg/kg range.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

[c] Value was derived from the Ontario Typical Range values and is representative of the upper limits of typical province-wide background concentrations in soils that are not contaminated by point sources.

The U.S. EPA (2003) compiled mean background concentrations of arsenic in soil for each state, and reported values ranging from 1.4 µg/g in Delaware to 16 µg/g in Tennessee. Generic background concentrations of arsenic in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.7).

Table C.7 Generic Background Concentrations of Arsenic in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

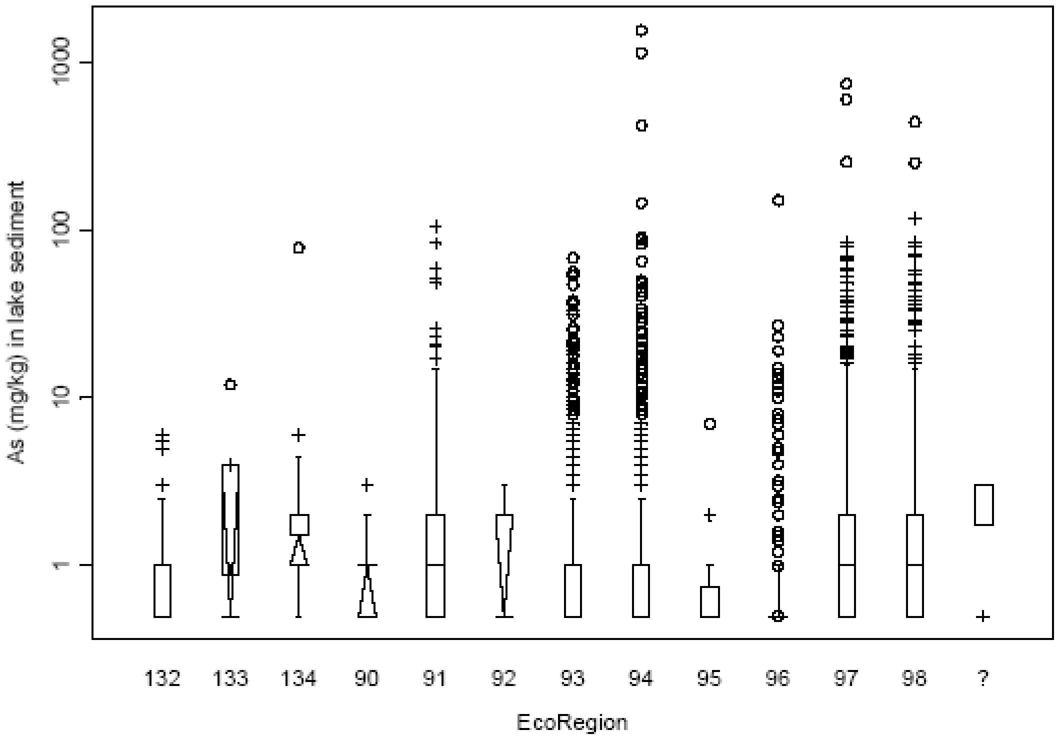
Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	2.1 to 22.0	8.2
Chernozems and dark prairie soils	1.9 to 23	8.8
Clay and clay-loamy soils	1.7 to 27.0	7.7
Forest soils	1.5 to 16.0	6.5
Lateritic soils		
Light desert soils	1.2 to 18.0	6.4
Light loamy soils	0.4 to 31.0	7.3
Loess and soils on silt deposits	1.9 to 16.0	6.6
Low Humic Gley soils and humus groundwater podzols		
Organic light (or rich) soils	<0.1 to 48.0	5.0
Sandy and lithosols on sandstone		
Silty prairie soils	2.0 to 12.0	5.6
Soils on glacial till and drift	2.1 to 12.0	6.7
Soils on lacustrine deposits		
Soils over granites and gneisses	0.7 to 15.0	3.6
Soils over limestones and calcareous rocks	1.5 to 21.0	7.8
Soils over volcanic rocks (or ash)		
Various soils	1.0 to 93.2	7.0
Western Alluvial soils		

Table C.8 summarizes background concentrations of arsenic in dust.

Table C.8 Ontario and Canadian Background Arsenic Concentrations in Dust

Location	Description	Concentration	References
Ottawa	housedust, n = 50, collected winter 1993 from 10 Ottawa neighbourhoods	4.9 mg/kg	Rasmussen *et al*., 2001
Ottawa	street dust, n = 50, collected winter 1993 from 10 Ottawa neighbourhoods	1.0 mg/kg	Rasmussen *et al*., 2001
Halifax, Nova Scotia	street dusts; 2 samples	range: 5.9 to 8.9 mg/kg	Fergusson and Ryan, 1984

An estimated upper limit for arsenic levels in lake sediment from non-mineralized background areas is approximately 10 to 15 mg/kg (Garrett, 2005). A plot of concentrations of arsenic in lake sediments is presented in Figure C-2 below, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes. However the extent does underestimate the full range of natural background when mineral occurrences are present in the region (Garrett, 2005). Table C.9 summarizes background concentrations of arsenic in sediment.



EcoRegions:

90	Lac Seul Upland, n = 41
91	Lake of the Woods, n = 2,118
92	Rainy River, n = 29
93	Thunder Bay-Quetico, n = 1,483
94	Lake Nipigon, n = 3,003
95	Big Trout Lake, n = 27
96	Abitibi Plains, n = 2,045
97	Lake Timiskaming Lowland, n = 5,065
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 4,279
132	St. Lawrence Lowlands, n = 71
133	Frontenac Axis, n = 10
134	Manitoulin-Lake Simcoe, n = 128
?	Unclassified, n = 3

Figure C-2 Tukey Boxplots, by EcoRegion in Ontario, of Arsenic in Sediment from Deep Centre-lake Basins, below the Surface Gyttja

Table C.9 Ontario and Canadian Background Arsenic Concentrations in Sediments

Location	Description	Concentration	References
Lake Ontario	surficial sediments sampled in 1998	range: non-detect to 47.2 mg/kg	Marvin *et al*., 2003
Lake Ontario	pre-colonial background from deep sediments	<5 mg/kg	Marvin *et al*., 2003
Ontario	upper limit of normal for lake sediment from non-mineralized background areas	10 to 15 mg/kg	Garrett, 2005
Lake Erie	surficial sediments, sampled in 1997-98	range: non-detect to 18.6 mg/kg	Painter *et al*., 2001
Lake Erie, West Basin	pre-colonial background from deep sediments	5.8 mg/kg	Painter *et al*., 2001
Lake Erie, Centre Basin	pre-colonial background from deep sediments	7.1 mg/kg	Painter *et al*., 2001
Lake Erie, East Basin	pre-colonial background from deep sediments	6.8 mg/kg	Painter *et al*., 2001
Ontario	Background Site Condition Standard[a]	6 mg/kg	MOE, 2004
Lake Superior	15 sediment samples	range: 0.5 to 8.0 mg/kg mean: 2.03 mg/kg	Traversy *et al.,* 1975
Lake Huron	10 sediment samples	range: 0.8 to 4.5 mg/kg mean: 2.33 mg/kg	Traversy *et al.,* 1975
Lake Erie	10 sediment samples	range: 2.0 to 5.5 mg/kg mean: 3.2 mg/kg	Traversy *et al.,* 1975
Lake Ontario	8 sediment samples	range: 1.5 to 14 mg/kg mean: 4.1 mg/kg	Traversy *et al.,* 1975
Lake Superior	north shore surficial sediments	<20 mg/kg	Friske, 1985
Ontario lakes	14 lakes sampled in Ontario	<20 mg/kg	Johnson, 1987
NWT lakes	lake sediments impacted by gold mining	<3,500 mg/kg	Wagemann *et al*., 1978
Various subarctic lakes	lake sediment impacted by gold mining	range: 1,043 to 3,090 mg/kg mean: 1,716 mg/kg[b]	Bright *et al*., 1996
Bowron Lake, British Columbia	reference lake sampled in 1992	range: 16 to 23 mg/kg mean: 19 mg/kg	Azcue *et al*., 1994
British Columbia	sediment from gold mining impacted lake	range: 80 to 1,104 mg/kg mean: 382 mg/kg	Azcue *et al*., 1994

a Value is within the range of measured background sediment in the 1993 Sediment Guidelines.

b Samples were taken from the top 10 cm of sediment. Total dissolved arsenic levels in porewater ranged from 800 to 5,170 µg/L (0.7% organic arsenic).

C-1.2.4 Background Concentrations in Biota and Foods

Background concentrations of arsenic in living organisms are generally <1 µg/g wet weight (Eisler, 1994). Tables C.10 through C.11 summarize background concentrations in Canadian fish (freshwater), biota.

Table C.10 Ontario and Canadian Background Arsenic Concentrations in Biota

Location	Description	Concentration	References
Lake Erie	31 freshwater fish sampled	range: 0.03 to 0.12 mg/kg ww mean: 0.07 mg/kg ww	Traversy *et al.,* 1975
Lake Ontario	12 freshwater fish sampled	range: 0.04 to 0.1 mg/kg ww mean: 0.07 mg/kg ww	Traversy *et al.,* 1975
Remote areas	freshwater fish uncontaminated water bodies	typical range: <0.1 to 0.4 mg/kg ww	Moore and Ramamoorthy, 1984
St. Lawrence River	mussels	2.8 to 8.6 mg/kg, dry weight	Metcalfe-Smith, 1994
NWT	zooplankton from lake impacted by gold mining	700 to 2,400 mg/kg	Wagemann *et al*., 1978
Remote areas	aquatic plants - uncontaminated water bodies	typical: <10 mg/kg dry weight	Moore and Ramamoorthy, 1984
Lake Ontario watershed	aquatic plants -area contaminated with mine effluent	<1,200 mg/kg dry weight	Mudroch and Capobianco, 1979
NWT	aquatic plants -lake historically impacted by gold mining	150 to 3,700 mg/kg	Wagemann *et al*., 1978
Northern Quebec	hares and martins (muscle tissue)	< 0.05 mg/kg	Langlois and Langlis, 1995
Canadian Arctic	polar bears (liver tissue)	0.07 mg/kg dry weight	Nostrom *et al*., 1986
Northern Canada	*Sphagnum fuscum* moss (various un-impacted sites)	mean background: 0.66 mg/kg dry weight	Glooschenko and Arafat, 1988
Northern Canada	*Sphagnum fuscum* moss (various mining and smelting areas)	>3 to 31 mg/kg dry weight	Glooschenko and Arafat, 1988
Southern Ontario	Grass (urban site < 700 m from a secondary lead smelter)	5.8 mg/kg	Temple *et al*., 1977
Southern Ontario	tree and shrub foliage (urban site < 700 m from a secondary lead smelter)	7.4 mg/kg	Temple *et al*., 1977
Southern Ontario	plant samples (urban control site	<1 mg/kg	Temple *et al*., 1977

Table C.11 summarizes background As concentrations in Canadian foods sampled from typical points-of-purchase (*e.g.*, grocery store).

Table C.11 Typical Total Arsenic Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fish and seafood				
Fish and shellfish	Port Colborne	186 food samples [c,d]	mean: 1,600	JWEL, 2004
Fish and shellfish	6 Canadian cities btw 1985 and 1988	total arsenic in samples collected [b]	mean: 1662.46 max: 4830.0	Dabeka *et al.* 1993
Marine fish	Canada	marine fish sold for human consumption	range: 400 to 118,000	DNHW, 1983
Fish (saltwater)	Ontario	total arsenic concentrations and % inorganic	1100 to 4000 (1% inorganic) average: 2550 [a]	OME, 1987
Fish (freshwater)	Ontario	total arsenic concentrations and % inorganic	140 (15% inorganic) [a]	OME, 1987
Shrimp	Ontario	total arsenic concentrations and % inorganic	650 (16% inorganic) [a]	OME, 1987
Meat / poultry products				
Meat, Poultry and eggs	Port Colborne	186 food samples	mean: 30.6 max: 43	JWEL, 2004
Meat and poultry	Canada, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 24.3 max: 536.0	Dabeka *et al*., 1993
Meat and poultry	Canada	sold for human consumption	range: non-detect to 440	DNHW, 1983
Red meat	Ontario	total arsenic concentrations and % inorganic	13 to 26 (100% inorganic) [a]	OME, 1987
Poultry	Ontario	total arsenic concentrations and % inorganic	21 to 23 (41% inorganic) [a]	OME, 1987
Meats	Canada, Ottawa-Hull area	food purchased	50	Smith, 1971
Milk and dairy products				
Milk and milk Products	Port Colborne	186 food samples	mean: 21 max: 24	JWEL, 2004
Vanilla ice cream	Ontario	total arsenic concentrations and % inorganic	16 (26% inorganic) [a]	OME, 1987
Milk and dairy products	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 3.8 max: 26.0	Dabeka *et al*., 1993
Dairy	Canada, Ottawa-Hull area	food purchased	200	Smith, 1971

Table C.11 Typical Total Arsenic Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Rice				
Cooked rice	Ontario	total arsenic concentrations and % inorganic	230 to 240 (43% inorganic) [a]	OME, 1987
Rice cereal, dry	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 284.1 max: 365	Dabeka *et al.*, 1993
Cereals, grains and baked goods				
Cereals, grains and baked goods	Port Colborne	186 food samples	mean: 18.5 max: 28	JWEL, 2004
Cereals and baked goods	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 24.5 max: 365	Dabeka *et al.*, 1993
Cereals	Ontario	total arsenic concentrations and % inorganic	230 to 300 (49% inorganic) [a]	OME, 1987
Bread	Ontario	total arsenic concentrations and % inorganic	mean: 24 (50% inorganic) [a]	OME, 1987
Pastry flour	Ontario	total arsenic concentrations and % inorganic	11 (69% inorganic) [a]	OME, 1987
Cereals	Canada; Ottawa-Hull area	food purchased	50	Smith, 1971
Fruits and fruit juices				
Fruits and fruit Juices	Port Colborne	186 food samples	mean: 14.9 max: 37	JWEL, 2004
Fruit and fruit juices	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 4.5 max: 37	Dabeka *et al.*, 1993
Apple juice	Ontario	total arsenic concentrations and % inorganic	12 (73% inorganic) [a]	OME, 1987
Garden fruits	Canada, Ottawa-Hull area	food purchased	20	Smith, 1971
Fruits	Canada, Ottawa-Hull area	food purchased	<100	Smith, 1971
Root vegetables				
Potatoes	Port Colborne	186 food samples	mean: 18.5	JWEL, 2004

Table C.11 Typical Total Arsenic Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Root vegetables	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 7.8	Dabeka *et al*., 1993
Root vegetables	Canada, Ottawa-Hull area	food purchased	<20	Smith, 1971
Potatoes	Canada, Ottawa-Hull area	food purchased	<100	Smith, 1971
Other vegetables				
Other vegetables	Port Colborne	186 food samples	mean: 1.16 max: 2.7	JWEL, 2004
Vegetables	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 7.0 max: 84.0	Dabeka *et al*., 1993
Leafy vegetables	Canada, Ottawa-Hull area	food purchased	<100	Smith, 1971
Legumes	Canada, Ottawa-Hull area	food purchased	<20	Smith, 1971
Fats and oils				
Fats, oils, nuts and Seeds	Port Colborne	186 food samples	mean: 38.5 max: 54	JWEL, 2004
Fats and oils	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 19.0 max: 57.0	Dabeka *et al*., 1993
Sugars and sweets				
Sugars and sweets	Port Colborne	186 food samples	mean: 35.7 max: 48	JWEL, 2004
Sugar and candies	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 10.9 max: 105	Dabeka *et al*., 1993
Sugar products	Canada, Ottawa-Hull area	food purchased	80	Smith, 1971
Miscellaneous				
Miscellaneous	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 12.5 max: 41.0	Dabeka *et al*., 1993
Beverages				
Alcoholic beverages	Port Colborne	186 food samples	mean: 6.9	JWEL, 2004

Table C.11 Typical Total Arsenic Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Non-alcoholic beverages	Port Colborne	186 food samples	mean: 9.7	JWEL, 2004
Beverages	6 Canadian cities, btw 1985 and 1988	total arsenic in samples collected [b]	mean: 3.0 max: 9.0	Dabeka *et al*., 1993
Tea	Ontario	total arsenic concentrations and % inorganic	35 (26% inorganic) [a]	OME, 1987
Drinks	Canada, Ottawa-Hull area	food purchased	20	Smith, 1971

[a] All food samples in this study were comprised of one homogenized sample, analyzed in duplicate or triplicate, except for saltwater fish and apple juice. Percent inorganic arsenic was calculated by dividing measured average inorganic concentration in foods by the average measured total arsenic concentration.

[b] All food samples in this study were prepared as for normal consumption and then homogenized.

[c] Includes replicates and duplicates

[d] 97% of all food data is below the MDL (50 ng/g dw). All food items analyzed as dry weight and then converted to wet weight using moisture content (measured by laboratory). Samples detected at, or below, the MDL were assumed to be ½ the detection limit.

C-1.3 Estimated Canadian Daily Intakes

C-1.3.1 Dietary Intake

Utilizing age and sex-specific food consumption rate data for 112 food categories representative of the Canadian diet, Yost *et al.,* (1998) took the percentage of inorganic arsenic in the foods analyzed by OME (1987) and multiplied by the corresponding food concentrations reported by Dabeka *et al.,* (1993) to estimate total Canadian dietary intake of inorganic arsenic for three age/sex classes: (children ages 1 to 4; women ages 20 to 39; men ages 20 to 39). Consumption data were provided by the Nutrition Canada Survey of Department of Health and Welfare, Canada (Yost *et al.,* 1998). The total daily dietary intake of inorganic arsenic for these three classes was 4.8, 8.1, and 12.7 µg/day, respectively (Yost *et al.,*1998). The average daily intake for all classes combined was 8.3 µg/day. Based on their analysis of the OME (1987) data, the authors concluded that as much as 21 to 40% of total dietary arsenic is present as the soluble inorganic forms. This suggests that dietary intake of inorganic arsenic may be higher than previously believed (Yost *et al.,* 1998).

Dabeka *et al.,* (1993) had previously estimated daily Canadian dietary intakes for total arsenic, averaged over six Canadian cities, to range from 14.9 µg/day (F and M children aged 1 to 4), 29.9 µg/day (F and M children aged 5 to 11), 31.7 and 40.9 µg/day (12 to 19 yr old F and M, respectively), 34.1 and 59.2 µg/day (20-39 yr old F and M, respectively), 52.8 and 43 µg/day (40 to 65 yr old F and M, respectively), and 25.8 and 35.7 µg/day (>65 yr old F and M, respectively). The overall average estimated daily dietary intake for the entire Canadian population was 38.1µg/day. An earlier estimate of daily arsenic intake from food was reported to range from 2.6 to 101µg/day for total arsenic in adults, with an average intake of 16.7 µg/day (Dabeka *et al.,*1987). However, this study was based on limited data and only estimated daily arsenic intake for male and female adults. The data from Dabeka *et al.,* (1987) as well as 1980s or earlier data from other countries was previously used to estimate the daily intake of inorganic arsenic from food (GCDWQ, 1996); a dietary EDI of approximately 10.5 µg/day was estimated. Despite the limitations of the data used to derive this estimate, it is in agreement with the average daily inorganic arsenic intake for all age classes recently estimated by Yost *et al.,* (1998) to be 8.3 µg/day. The estimated chronic daily intake of 11 µg/day from a typical Ontario background diet (Fleming and Kuja, 1998) is also in close agreement with the estimates of Yost *et al.,* (1998), and GCDWQ (1996). Table C.12 summarized the studies on dietary intake rates of As.

Breast fed infants generally do not consume large quantities of fish and seafood, the major source of dietary arsenic exposure for the general population, and Grandjean *et al.* (1995) found no major transfer of arsenobetaine, the main form of arsenic in fish and seafood, from mothers who are heavy fish and seafood consumers to breast milk.

Table C.12 Dietary Intake Rates for Arsenic

Species	Intake Rate	Comments	Reference
Total As	1 to 4 yr: 14.9 µg/day 5 to 11 yr: 29.9 µg/day 12 to 19 M: 40.9 µg/day 20 to 39 M: 59.2 µg/day 40 to 65 M: 43.0 µg/day >65 M: 35.7 µg/day 12 to 19 F: 31.7 µg/day 20 to 39 F: 34.1 µg/day 40 to 65 F: 52.8 µg/day >65 F: 25.8 µg/day	total dietary As intake rates based on 1985 to 1988 concentrations in foods	Dabeka *et al*., 1993
Total As	16.7 µg/d, or 0.26 µg/kg/d	total dietary As intake by Canadians, based on duplicate diets collected in 1981 from 24 adults in 5 cities	Dabeka *et al*., 1987

Table C.12 Dietary Intake Rates for Arsenic

Species	Intake Rate	Comments	Reference
Total As	infant: 21.5 µg/day preschool child:27.6 µg/day adult: 52.6 µg/day	total dietary As intake rates; based on FDA 1992 Total Diet Survey	Borum and Abernathy, 1994
Inorganic As	preschool child: 4.8 µg/day women (20-39): 8.1 µg/d men (20-39): 12.7 µg/day	dietary intake of inorganic As by Canadians, based on limited speciation data, and total As data in Dabeka *et al.*, 1993	Yost *et al*., 1998
Inorganic As	adult: 10.9 to 14 µg/day	based on FDA 1992 Total Diet Survey and info on % inorganic As in foods from Weiler (1987)	Borum and Abernathy, 1994
Total As	<0.02 to 2.4 µg/kg body weight/day	for all age groups	CEPA, 1993
Inorganic As	<0.02 to 2.0 µg/kg body weight/day	for all age groups	CEPA, 1993

C-1.3.2 Relative Contributions of Exposure Pathways to Total Exposure

Soluble inorganic As(III) and As(V) species are the most bioavailable and toxicologically significant arsenic species to humans. Organic arsenic species are rapidly metabolized and eliminated by the body and are generally of low toxicity to humans (Le *et al.*, 1993; 1994). Humans may be exposed to inorganic arsenic in ambient air, drinking water, soil, and food. Ingestion of inorganic arsenic in food and drinking water constitute the main exposure pathways for the general population (CCME, 1997; CEPA, 1993). In infants and small children, ingestion of dirt is a more important route of exposure to inorganic arsenic than drinking water (CEPA, 1993).

The total average daily intake of inorganic arsenic by Canadians from all environmental sources (uncontaminated areas) was estimated to range from 0.1 to 2.6 µg/kg body weight/day, with the greatest exposure occurring in infants and young children (CEPA, 1993). The total EDI values, in µg/kg body weight/day for all age classes assessed in CEPA (1993) were 0.1 to 2.6 (0 to 5 yrs); 0.3 to 2.4 (0.5 to 4 yrs); 0.2 to 2.1 (5 to 11 yrs); 0.1 to 1.3 (12 to 19 yrs); and 0.1 to 0.7 (20 to 70 yrs). Cigarette smoking was estimated to contribute an additional 0.01 to 0.04 µg/kg body weight/day in adolescents and adults (CEPA, 1993). It should be noted that these estimates were based on environmental data collected before 1991, and the assumption that 37% of the arsenic content of foods was inorganic. Thus, these estimates may change slightly if the recent daily Canadian dietary intakes of inorganic arsenic and estimates of inorganic arsenic content from Yost *et al.* (1998) as well as environmental concentrations specific to Ontario, were to be incorporated into the calculations used in CEPA (1993).

U.S. data indicate that food exposure contributes approximately 92.8% of the total arsenic exposure, while drinking water contributes 7% (Adams *et al.,* 1994). Of the food total arsenic exposure, roughly 90% is attributed to the consumption of seafood, and the remaining 10% to all other foods (Adams *et al.,* 1994). However, most arsenic in seafood is in an organic form, either as arsenobetaine or arsenocholine; thus the contribution to arsenic toxicity from seafood consumption is not directly related to consumption rates alone.

Drinking water exposure varies considerably depending on geological conditions, especially if groundwater is used as the raw drinking water source. Arsenic intakes from drinking water for typical adults average about 5 µg/day (CEPA, 1993; U.S. EPA, 1982b). High levels of groundwater arsenic have been found to occur in a number of regions where bedrock arsenic content is elevated (*e.g.*, Boyle *et al.,*1969; Brooks *et al.,* 1982; Bottomley, 1984; Méranger *et al.,* 1984a). In these areas, intake from drinking water may be as high as 10 to 100 µg/day (ATSDR, 2000).

Soil and air exposures typically contribute only 0.01 and 0.2% of the total arsenic exposure, respectively (Adams *et al.,* 1994). Canadian data indicates that approximately 0.4 to 3% of the total daily exposure to inorganic arsenic is from soil/dust ingestion for all age classes, with infants and young children receiving as much as 4 to 9% of their total daily intake through this route (CCME, 1997; CEPA, 1993). Inhalation as an exposure route is insignificant for the general population, with the possible exception of smokers, who may incur as much as 10% of their total daily inorganic arsenic exposure from smoking (CCME, 1997; CEPA, 1993). However, a recent study failed to find increased levels of arsenic in the lungs of smokers *versus* non-smokers (Kraus *et al*., 2000). Dermal exposure to arsenic *via* direct contact is minor due to the low dermal bioavailability of arsenic (U.S. EPA, 1984).

Meacher *et al*. (2002) estimated the daily inorganic arsenic intake of U.S. adults from food, water, soil ingestion and inhalation of airborne particles. The mean relative contributions to intake from food were 53.0 and 56.3% for females and males, respectively. Drinking water contributed 45.3 and 42.2%, for women and men respectively. Ingestion of soil contributed 1.3 and 1.1% for women and men, respectively. The contribution from inhalation exposure was 0.4% for both genders (Meacher *et al*., 2002).

The Windsor Air Quality Study found the following breakdown of inhalation exposure to trace metals: 60% from indoor air in the home, 18% from air in the office, and 22% from outdoor air (exposure while commuting was not considered) (Bell *et al.*, 1994).

C-1.4 Indices of Human Exposure

Indices of chronic human arsenic exposure include measurements of the arsenic content of hair, urine, blood, and nails. Blood is not generally considered a reliable index as arsenic is rapidly cleared from the blood; therefore blood analysis is of little value in assessing human arsenic exposure and intoxication, except perhaps in the identification of arsenic as a cause of acute poisoning (Hindmarsh and McCurdy, 1986). Concentrations of arsenic in blood provide a record of only the previous few hours of exposure; therefore they are not suitable for use as a biomarker of exposure.

Urine analysis is considered a reliable index of recent (*i.e.*, one to three days) exposure only, due to the rapid and efficient excretion of arsenic in the urine (Hindmarsh and McCurdy, 1986). The determination of inorganic arsenic (iAs), MMA (V) and DMA in urine is the current method of choice for biological monitoring of workers exposed to inorganic arsenic, as this method is less influenced by organoarsenicals that are of marine origin (Lauwerys and Hoat, 2001). As the majority of arsenic elimination by the body occurs through the kidney, urinary arsenic concentrations are generally considered to be a valid biomarker of exposure. However, for poorly absorbed arsenic compounds, urinary levels will only mirror the amount absorbed and will not reflect the total intake (Gerhardsson and Skerving, 1996). Concentrations of arsenic in urine provide a record of the amount of arsenic absorbed over the previous one to three days; therefore, they can be used as a biomarker of recent exposure.

Data on arsenic concentrations in nails are limited; therefore, nail arsenic concentrations have not been validated as a reliable index of exposure. In addition, it is unclear whether nail arsenic reflects only internal exposure to arsenic, or if it reflects both external and internal exposure (Hindmarsh and McCurdy, 1986). Gerharrdsson and Skerving (1996) reported that there is a high potential for external contamination of nails, which limits the usefulness of nail analysis in biological exposure monitoring.

Some studies have found that hair arsenic is an unreliable index, due to difficulties in distinguishing internally acquired and externally deposited arsenic, and uncertainties about how arsenic in bloodstream enters hair (Young and Rice, 1944; Hindmarsh and McCurdy, 1986; Gerhardsson and Skerving, 1996). It has been suggested that ingested arsenic may enter hair *via* sweat and/or sebaceous secretions and remain attached to hair for the remainder of that hair's life (Hindmarsh and McCurdy, 1986). Regardless of whether arsenic enters hair from the bloodstream or is deposited from the surrounding atmosphere, it tends to accumulate mostly on the outer surface of a hair. Although a number of studies have shown no clear relationship between hair arsenic levels and severity of toxicity (based on clinical manifestation), and environmental arsenic exposure, it has been concluded by some authors that hair arsenic levels can be reliably used as approximate indicators of chronic exposure and toxicity, providing that external arsenic contamination can be largely excluded (Hindmarsh and McCurdy, 1986). To date, exposure levels resulting in measurable increases in hair arsenic have not been defined, and there are presently no available critical limit values for arsenic (and other trace elements) in hair (Wilhelm and Idel, 1996). Therefore, hair analysis is considered by some to be suitable only as a screening tool for large populations where there is continuous exposure to arsenic *via* food and water (Wilhelm and Idel, 1996; Gerhardsson and Skerving, 1996).

It should be noted that a number of factors can confound estimates of arsenic exposure, making it difficult to attribute particular sources of arsenic contamination to measured arsenic concentrations in human tissues or fluids. Key confounding variables reported in the literature include: age, seafood consumption, geographic region, tobacco smoking, drinking, occupation, and sex (Gebel *et al.,* 1998; Pollisar *et al.,* 1990; Arbouine and Wilson, 1992; Bencko, 1995). In particular, age and seafood consumption tend to correlate positively with urinary arsenic levels (Gebel *et al.,* 1998).

Table C.13 summarized background As concentration in human biological tissues and fluids.

Table C.13 Background Arsenic Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Hair	not specified	normal hair concentration	0.25 to 0.88 µg/g	Benramdane *et al.*, 1999
Hair	not specified	nonoccupationally exposed individuals	<2 mg/kg	Valentine *et al.*, 1979
Hair	not specified	nonoccupationally exposed individuals	<1 mg/kg	Hewitt *et al.*, 1995
Whole blood	U.S.	50 female non-smokers from uncontaminated areas	mean: 1.5 µg/L	Kagey *et al.*,1977
Blood	not specified	normal blood concentration	1.5 to 2.5 µg/L	Benramdane *et al.*, 1999
Blood	not specified	nonoccupationally exposed individuals	typical range: 1 to 4 µg/L	Bencko and Symon, 1977
Urine	Europe	normal concentrations	<10 µg/L	Gerhardsson and Skerving, 1996

Table C.13 Background Arsenic Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Urine	World-wide	expected range of values in an ostensibly unexposed population	<100 µg/L	WHO, 1980
Urine	U.S.	upper limit of background or normal concentrations	20 µg/L	ATSDR, 1997
Urine	not specified	normal urine concentration	20 to 50 µg/L	Benramdane *et al.*, 1999
Urine	Japan	nonoccupationally exposed individuals	>50 µg/L	Yamato, 1988
Urine	Vietnam	Vietnamese urbanites (2 day abstinence from seafood prior to sampling)	62.4 ± 11.6 µg/L	Dang *et al.*, 1999

C-2.0 COBALT BACKGROUND EXPOSURE

C-2.1 Sources and Environmental Fate

C-2.1.1 Sources

Cobalt occurs naturally in the earth's crust, and hence in soil, seawater and some surface and groundwaters (ATSDR, 2004a). Cobalt is released into the atmosphere by both natural and anthropogenic processes, with the amount released naturally slightly exceeding anthropogenic releases (ATSDR, 2004a). The natural sources of cobalt are windblown soil, seawater spray, marine biogenic emissions, volcanic eruptions and forest fires (ATSDR, 2004a). Human activities that release cobalt into the environment include fossil fuel and waste combustion, vehicular and aircraft exhausts, processing of cobalt and cobalt-containing alloys, copper and nickel smelting and refining, and the manufacture and use of cobalt chemicals and phosphate fertilizers (Barceloux, 1999a; Lantzy and Mackenzie, 1979; Nriagu, 1989; Smith and Carson, 1981). The radioactive forms of cobalt, $_{60}$Co and $_{58}$Co, may be released from nuclear activities (ATSDR, 2004a).

C-2.1.2 Environmental Fate and Speciation in Environmental Media

C-2.1.2.1 Atmosphere

Cobalt and its compounds are non-volatile, and are released to the atmosphere only in particulate form (ATSDR, 2004a). The principle form of emitted cobalt from combustion sources is thought to be the oxide, while arsenides and sulphides may be released from mining and ore processing (Schroeder *et al.,* 1987). It is not known whether cobalt undergoes any atmospheric transformations (ATSDR, 2004a). Cobalt released to air will be transferred to land or surface waters *via* wet or dry deposition at a distance from its point of release determined by its form, particle size and density, and meteorological conditions (ATSDR, 2004a). Coarse particles with aerodynamic diameters >2 µm are generally deposited with 10 km of the point of emission, while smaller particles may travel longer distances (ATSDR, 2004a).

C-2.1.2.2 Surface Water and Groundwater

Soluble cobalt may remain in solution and be transported in dissolved form with water currents, it may precipitate as carbonates and hydroxides or with mineral oxides, it may be absorbed to particles and sediment, or complexed with humic acids (ATSDR, 2004a). pH and other factors influence these processes, and at low pH the proportion of dissolved cobalt will be higher (ATSDR, 2004a). For many metals movement of suspended solids is the chief mode of transport in aqueous systems; however, with cobalt this amount can vary greatly as cobalt is released to water (ATSDR, 2004a). There are conflicting models to predict the equilibrium levels of cobalt species in fresh water (*e.g.,* Mantoura *et al*., 1978; Smith and Carson, 1981). Neither of these models seem to be generally accepted.

C-2.1.2.3 Soils and Sediments

Soils and sediments are sinks for cobalt as it is strongly adsorbed to metal oxides, crystalline minerals and organic matter; however, cobalt can be released from soils and sediments under certain conditions (ATSDR, 2004a). pH is an important factor affecting migration of cobalt between water and sediment; the proportion of dissolved cobalt is increased with decreased pH (ATSDR, 2004a). The mobility of cobalt in soil is inversely related to how strongly it is adsorbed by soil components (ATSDR, 2004a).

The speciation of cobalt in soil or sediment depends on the nature of the substrate, the concentration of chelating/complexing agents, pH, and redox potential of the soil (ATSDR, 2004a). Dissolved cobalt may be absorbed by ion exchange and other mechanisms, or may complex with fulvic acids, humic acids or other organic ligands (ATSDR, 2004a). Cobalt may be released from soils when they are flooded or when soil pH is decreased (ATSDR, 2004a). Bacterial activity can also affect the mobility of cobalt by mediating reactions or by lowering soil pH (ATSDR, 2004a).

C-2.1.2.4 Biota and Foods

Cobalt may be taken up from soil by plants, with a transfer coefficient generally between 0.01 and 0.3; but translocation of cobalt within the plant from roots to above ground parts is not significant in most soils (ATSDR, 2004a). Cobalt levels generally decrease with increasing trophic levels in a food chain (Smith and Carson, 1981). Cobalt is an essential element, and in order for the dietary requirements of grazing animals to be met, soils should contain greater than 3 mg/kg, yielding corresponding concentrations in plant tissues greater than 0.1 mg/kg (ATSDR, 2004a). Cobalt is subject to bioaccumulation in aquatic and marine environments; however, cobalt in fish is largely concentrated on the skin and in viscera, as opposed to the edible parts of the fish (ATSDR, 2004a).

Cobalt is an essential nutrient and a component of vitamin B-12. However, vitamin B-12 constitutes only a very small fraction of cobalt intake and most ingested cobalt is in the inorganic form (ATSDR, 2004a). Cobalt is found in the highest concentrations in grains and vegetables, particularly, green leafy vegetables, with the lowest concentrations in dairy products, refined cereals and sugar (Barceloux, 1999a). Analysis conducted as part of the Canadian Total Diet Study found the highest concentrations of cobalt in the following food categories: grains and baked goods; fats, oils and nuts; and, sugar, candy and desserts (Dabeka and McKenzie, 2005 pers. comm.; HC, 2004a; Dabeka and McKenzie, 1995).

C-2.2 Background Exposure Concentrations in Ontario and Canada

C-2.2.1 Background Concentrations in Air

Reported background concentrations of cobalt in air are provided in Table C.14

Table C.14 Ontario and Canadian Background Cobalt Concentrations in Air

Location	Description	Concentration	References
Canada (rural)	annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994 to 2004	range: nd to 0.00414 µg/m^3 mean: 0.000911 µg/m^3	Dann, 2005 pers. comm.
Canada (urban)	annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994 to 2004	range: nd to 0.00822 µg/m^3 mean: 0.000877 µg/m^3	Dann, 2005 pers. comm.
Canada	ambient levels at urban sites	range: 1 to 7.9 ng/m^3	Schroeder *et al.*, 1987
British Columbia	mean from 3 stations between 1995 and 1998	mean: 0.0258 ng/m^3 range: 0 to 0.559 ng/m^3	Dryfhout-Clark, 2004

C-2.2.2 Background Concentrations in Surface Water and Groundwater

Reported background concentrations of cobalt in surface water, groundwater, drinking water and precipitation are provided in Tables C.15 to C.17, respectively. No data were found for background cobalt concentrations in rainwater.

Table C.15 Ontario and Canadian Background Cobalt Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 25.0 µg/L mean: 0.15 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 7.8 µg/L mean: 0.22 µg/L	Clubb, 2005 pers. comm.

Table C.16 Ontario and Canadian Background Cobalt Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 8.2 µg/L mean: 0.17 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standards[a]	0.9 µg/L	MOE, 2004

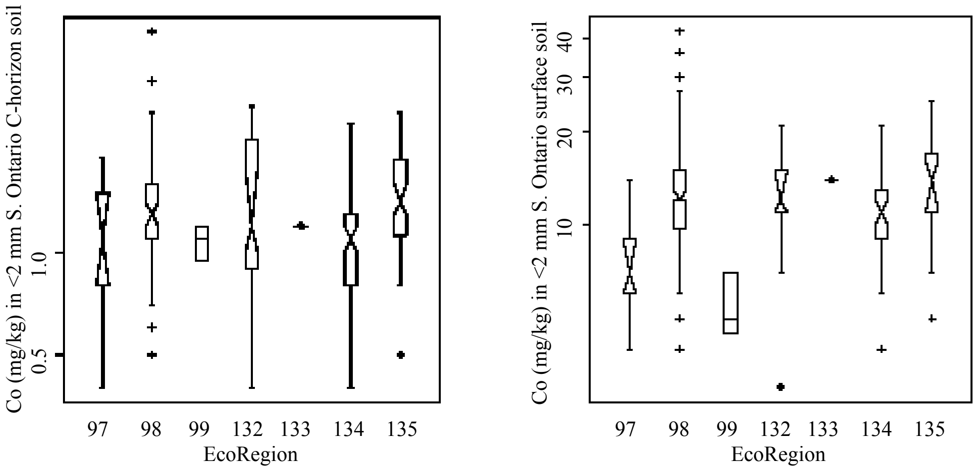
[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

Table C.17 Ontario and Canadian Background Cobalt Concentrations in Drinking Water

Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 6.2 µg/L mean: 0.16 µg/L	Clubb, 2005 pers. comm
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 9.0 µg/L mean: 0.13µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 22.0 µg/L mean: 0.15 µg/L	Clubb, 2005 pers. comm.

C-2.2.3 Background Concentrations in Soils and Sediment

Concentrations of cobalt in soils from across Southern Ontario are plotted in Figure C-3, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005). Reported background concentrations of cobalt in soil and dust are provided in Tables C.18 and C.19, respectively.



EcoRegions:

97	Lake Timiskaming Lowland, n = 17
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 112
99	Southern Laurentians, n = 3
132	St. Lawrence Lowlands, n = 30
133	Frontenac Axis, n = 1
134	Manitoulin-Lake Simcoe, n = 89
135	Lake Erie Lowlands, n = 42

Figure C-3 Tukey Boxplots, by EcoRegion in Southern Ontario, of Cobalt in C-horizon (70-100 cm) and Surface (top 25 cm) Soils

Table C.18 Ontario and Canadian Background Cobalt Concentrations in Soil

Location	Description	Concentration	References
Ottawa	garden soil, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	8.18 mg/kg	Rasmussen *et al*., 2001
Ontario	upper-limit of background[a]	19 mg/kg (agricultural land use) 21 mg/kg (all other land uses)	MOE, 2004
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~2 to 19 mg/kg mean: 7.6 mg/kg OTR_{98}: 17 mg/kg	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~2 to 19 mg/kg mean: ~ 7 mg/kg OTR_{98}: 16 mg/kg	MOEE, 1994
Canada	uncultivated, uncontaminated soils, remote from ore bodies	range: 5 to 50 mg/kg mean: 21 mg/kg	McKeague and Wolynetz, 1980
Appalachians (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=45	18 mg/kg	McKeague and Wolynetz, 1980
Canadian Shield	uncultivated, uncontaminated soils, remote from ore bodies, n=12	19 mg/kg	McKeague and Wolynetz, 1980
St. Lawrence Lowlands	uncultivated, uncontaminated soils, remote from ore bodies, n=40	24 mg/kg	McKeague and Wolynetz, 1980
Interior Plains (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=34	15 mg/kg	McKeague and Wolynetz, 1980
Cordillerans (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=19	34 mg/kg	McKeague and Wolynetz, 1980

[a] Value was derived from the Ontario Typical Range values and is representative of the upper limits of typical province-wide background concentrations in soils that are not contaminated by point sources.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

Table C.19 Ontario and Canadian Background Cobalt Concentrations in Dust

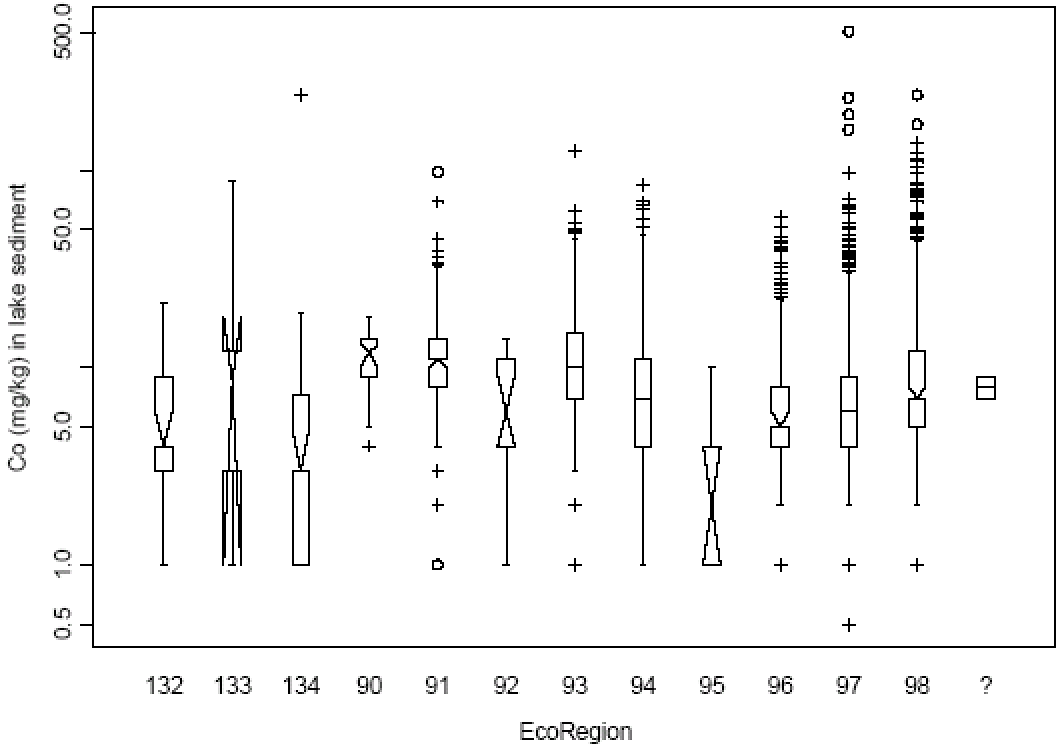
Location	Description	Concentration	References
Ottawa	household dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	8.40 mg/kg	Rasmussen *et al*., 2001
Ottawa	street dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	8.02 mg/kg	Rasmussen *et al*., 2001

The U.S. EPA (2003) compiled mean background concentrations of cobalt in soil for each state, and reported values ranging from 1.6 mg/kg dry weight in Florida to 18 mg/kg dry weight in Washington. Generic background concentrations of cobalt in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.20).

Table C.20 Generic Background Concentrations of Cobalt in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	3 to 20	9.0
Chernozems and dark prairie soils	3 to 15	7.5
Clay and clay-loamy soils	3 to 30	8.0
Forest soils	5 to 20	10.0
Lateritic soils		
Light desert soils	3 to 20	10.0
Light loamy soils	3 to 30	7.5
Loess and soils on silt deposits	3 to 30	11.0
Low Humic Gley soils and humus groundwater podzols	0.3 to 3.1	1.0
Organic light (or rich) soils	3 to 10	6.0
Sandy and lithosols on sandstone		
Silty prairie soils	3 to 15	7.5
Soils on glacial till and drift	5 to 15	7.5
Soils on lacustrine deposits		
Soils over granites and gneisses	3 to 15	6.0
Soils over limestones and calcareous rocks	3 to 20	9.5
Soils over volcanic rocks (or ash)		
Various soils	3 to 50	10.5
Western Alluvial soils		

An estimated upper limit for background variation in cobalt levels in lake sediment is approximately 40 mg/kg (Garrett, 2005). Concentrations of cobalt in lake sediments from across Southern Ontario are plotted in Figure C-4, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes. However, the whiskers underestimate the full range of natural background when mineral occurrences are present in the region (Garrett, 2005). Reported background concentrations of cobalt in sediment are provided in Table C.21.



EcoRegions:

90	Lac Seul Upland, n = 41
91	Lake of the Woods, n = 2,118
92	Rainy River, n = 29
93	Thunder Bay-Quetico, n = 1,483
94	Lake Nipigon, n = 3,003
95	Big Trout Lake, n = 27
96	Abitibi Plains, n = 2,045
97	Lake Timiskaming Lowland, n = 5,065
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 4,279
132	St. Lawrence Lowlands, n = 71
133	Frontenac Axis, n = 10
134	Manitoulin-Lake Simcoe, n = 128
?	Unclassified, n = 3

Figure C-4 Tukey Boxplots, by EcoRegion in Ontario, of Cobalt in Sediment from Deep Centre-lake Basins, below the Surface Gyttja

Table C.21 Ontario and Canadian Background Cobalt Concentrations in Sediments

Location	Description	Concentration	References
Ontario	Background Site Condition Standard [a]	50 mg/kg	MOE, 2004

[a] Value is within the range of measured background sediment in the 1993 Sediment Guidelines.

C-2.2.4 Background Concentrations in Biota and Foods

No background concentrations of cobalt in fish, other aquatic biota, aquatic plants and terrestrial biota were found.

Reported background concentrations of cobalt in Canadian foods are provided in Table C.22.

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fish and seafood				
Fish and shellfish	Canada	unpublished data from the 2000 TDS	5.0 [a]	Dabeka and McKenzie, 2005 pers. comm
Fish and shellfish	8 Canadian cities: Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 7.69 max: 11.52	HC, 2004a
Fish and Shellfish	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 3.2[a]	JWEL, 2004
Fish	Canada, Montreal between 1986 and 1988	6 samples purchased	mean: 19.9 max: 29.4	Dabeka and McKenzie, 1995
Meat / poultry products				
Meat, poultry and eggs	Canada	unpublished data from the 2000 TDS	10.7 ng/g [a]	Dabeka and McKenzie, 2005 pers. comm
Meat, poultry and eggs	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 10.39 max: 40.96 (organ meats)	HC, 2004a

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Meat, poultry and eggs	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 14.2[a] max: 83 (organ meats)	JWEL, 2004
Meat and poultry	Canad, Montreal between 1986 and 1988	18 samples purchased in	mean: 8.7 max: 38.2	Dabeka and McKenzie, 1995
Meat, fish and poultry	Canada, Ottawa-Hull area in 1969	foods purchased	100	Méranger and Smith, 1972
Meat, fish and poultry	Canada, Winnipeg area in 1972	foods purchased	10	Kirkpatrick and Coffin, 1977
Milk and dairy products				
Dairy	Canada	unpublished data from the 2000 TDS	5.9[a]	Dabeka and McKenzie, 2005 pers. comm
Milk and milk products	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 7.42 max: 24.28	HC, 2004a
Milk and milk Products	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 2.0[a] max: 9.4	JWEL, 2004
Milk and milk products	Canada, Montreal between 1986 and 1988	13 samples purchased	mean: 5.2 max: 19.8	Dabeka and McKenzie, 1995
Milk and dairy	Canada, Ottawa-Hull area in 1969	foods purchased	60	Méranger and Smith, 1972
Milk and dairy	Canada, Winnipeg area in 1972	foods purchased	20	Kirkpatrick and Coffin, 1977
Infant Formula				
Infant formula	Canada	unpublished data from the 2000 TDS	2.1[a]	Dabeka and McKenzie, 2005 pers. comm
Infant formula	Canada, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 4.01 max: 5.27	HC, 2004a
Ready to use, milk based	Canada	33 samples	median: 0.40 max: 0.99	Dabeka, 1989
Ready to use, soy based	Canada	16 samples	median: 2.27 max: 5.2	Dabeka, 1989
Concentrated, milk based	Canada	34 samples	median: 1.57 max: 3.11	Dabeka, 1989
Concentrated, soy based	Canada	16 samples	median: 4.33 max: 11.8	Dabeka, 1989

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Powdered, milk based	Canada	36 samples	median: 4.96 max: 10.6	Dabeka, 1989
Powdered, soy based	Canada	28 samples	median: 20.0 max: 53	Dabeka, 1989
Cereals, grains and baked goods				
Cereal and grain products	Canada	unpublished data from the 2000 TDS	12.5[a]	Dabeka and McKenzie, 2005 pers. comm
Cereals, grains and baked goods	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 15.08 max: 69.83	HC, 2004a
Cereals, grains and baked goods	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 7.6[a] max: 25	JWEL, 2004
Bakery goods and cereals	Canada, Montreal between 1986 and 1988	24 samples purchased	mean: 17.9 max: 75.7	Dabeka and McKenzie, 1995
Cereals	Canada, Ottawa-Hull area in 1969	foods purchased	140	Méranger and Smith, 1972
Cereals	Canada, Winnipeg area in 1972	foods purchased	30	Kirkpatrick and Coffin, 1977
Fruits and fruit juices				
Fruit and fruit products	Canada	unpublished data from the 2000 TDS	7.4 [a]	Dabeka and McKenzie, 2005 pers. comm
Fruit and fruit products	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 10.26 max: 96.89	HC, 2004a
Fruits and fruit juices	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 3.1[a] max: 8.9	JWEL, 2004
Fruits and fruit juices	Canada, Montreal between 1986 and 1988	25 samples purchased	mean: 4.6 max: 18.1	Dabeka and McKenzie, 1995
Garden fruits	Canada, Ottawa-Hull area in 1969	foods purchased	<40	Méranger and Smith, 1972
Garden fruits	Canada, Winnipeg area in 1972	foods purchased	20	Kirkpatrick and Coffin, 1977
Fruits	Canada, Ottawa-Hull area in 1969	foods purchased	<40	Méranger and Smith, 1972

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fruits	Canada, Winnipeg area in 1972	foods purchased	20	Kirkpatrick and Coffin, 1977
Root vegetables				
Root vegetables	Canada	unpublished data from the 2000 TDS	7.4[a]	Dabeka and McKenzie, 2005 pers. comm
Root vegetables	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 17.70 max: 63.67	HC, 2004a
Potatoes	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 11.6[a]	JWEL, 2004
Potatoes	Canada, Ottawa-Hull area in 1969	foods purchased	<90	Méranger and Smith, 1972
Potatoes	Canada, Winnipeg area in 1972	foods purchased	20	Kirkpatrick and Coffin, 1977
Root vegetables	Canada, Ottawa-Hull area in 1969	foods purchased	<50	Méranger and Smith, 1972
Root vegetables	Canada, Winnipeg area in 1972	foods purchased	30	Kirkpatrick and Coffin, 1977
Other vegetables				
Other vegetables	Canada	unpublished data from the 2000 TDS	5.2[a]	Dabeka and McKenzie, 2005 pers. comm
Other vegetables	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 8.79 max: 17.32	HC, 2004a
Other vegetables	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 16.8[a] max: 43	JWEL, 2004
Vegetables	Canada, Montreal between 1986 and 1988	38 samples purchased	mean: 9.7 max: 70.2	Dabeka and McKenzie, 1995
Leafy vegetables	Canada, Ottawa-Hull area in 1969	foods purchased	<50	Méranger and Smith, 1972
Leafy vegetables	Canada, Winnipeg area in 1972	foods purchased	10	Kirkpatrick and Coffin, 1977
Legumes	Canada, Ottawa-Hull area in 1969	foods purchased	<50	Méranger and Smith, 1972

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Legumes	Canada, Winnipeg area in 1972	foods purchased	30	Kirkpatrick and Coffin, 1977
Mixed Foods				
Miscellaneous (including soups)	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 12.03 max: 17.58	HC, 2004a
Soups	Canada, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	foods collected	3.4[a]	HC, 2004a
Soups	Canada, Montreal between 1986 and 1988	4 samples purchased	mean: 6.1 max: <8.5	Dabeka and McKenzie, 1995
Miscellaneous	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 4.6 max: 9.1	Dabeka and McKenzie, 1995
Fats and oils				
Fats, oils and peanuts	Canada	unpublished data from the 2000 TDS	9.8 [a]	Dabeka and McKenzie, 2005 pers. comm
Fats, oils and peanuts	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 21.82 max: 51.79	HC, 2004a
Fats, oils, nuts and seeds	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 10.6[a] max: 37	JWEL, 2004
Fats and oils	Canada, Montreal between 1986 and 1988	3 samples purchased	mean: 16.1 max: 35.7	Dabeka and McKenzie, 1995
Fats and oils	Canada, Ottawa-Hull area in 1969	foods purchased	<40	Méranger and Smith, 1972
Fats and oils	Canada, Winnipeg area in 1972	foods purchased	10	Kirkpatrick and Coffin, 1977

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Sugars and sweets				
Sugar, candy and desserts	Canada	unpublished data from the 2000 TDS	26.7 [a]	Dabeka and McKenzie, 2005 pers. comm
Sugar, candy and desserts	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 13.53 max: 59.89	HC, 2004a
Sugars and sweets	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 35.7 [a] max: 48	JWEL, 2004
Sugar and candies	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 9.1 max: 37.6	Dabeka and McKenzie, 1995
Sugars	Canada, Ottawa-Hull area in 1969	foods purchased	190	Méranger and Smith, 1972
Sugars	Canada, Winnipeg area in 1972	foods purchased	40	Kirkpatrick and Coffin, 1977
Beverages				
Non-alcoholic drinks	Canada	unpublished data from the 2000 TDS	2.1[a]	Dabeka and McKenzie, 2005 pers. comm
Alcoholic drinks	Canada	unpublished data from the 2000 TDS	1.6 [a]	Dabeka and McKenzie, 2005 pers. comm
Non-alcoholic drinks	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 2.61 max: 6.9	HC, 2004a
Alcoholic drinks	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 2.77 max: 4.72	HC, 2004a
Alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 4.1 [a]	JWEL, 2004
Non-alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 0.2[a]	JWEL, 2004
Beverages	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 1.1 max: 3.5	Dabeka and McKenzie, 1995

Table C.22 Typical Total Cobalt Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Drinks	Canada, Ottawa-Hull area in 1969	foods purchased	<40	Méranger and Smith, 1972
Drinks	Canada, Winnipeg area in 1972	foods purchased	10	Kirkpatrick and Coffin, 1977

[a] Calculated from raw data in original study.

C-2.3 Estimated Canadian Daily Intakes

C-2.3.1 Dietary Intake

Food concentrations of cobalt are generally thought to be low; however, food is considered to be the largest source of exposure in the general population (ATSDR, 2004a). The food groups that provide the largest contributions to the dietary intake of cobalt of Canadians are bakery goods and cereals (29.8%), and vegetables (21.9%) (Barceloux, 1999a; Dabeka and McKenzie, 1995). Reported dietary intake rates for cobalt are provided in Table C.23.

Table C.23 Dietary Intake Rates of Cobalt

Gender	Age	Intake Rate	Comments	Reference
Both	0 to 1 mo	0.674 µg/kg/d	Average dietary intake rate for Canadians for Total Diet Study from 1993 to 1999	HC, 2004a
Both	2 to 3 mo	0.821 µg/kg/d		
Both	4 to 6 mo	0.697 µg/kg/d		
Both	7 to 9 mo	0.653 µg/kg/d		
Both	10 to 12 mo	0.625 µg/kg/d		
Both	1 to 4 y	0.656 µg/kg/d		
Both	5 to 11 y	0.493 µg/kg/d		
Male	12 to 19 y	0.350 µg/kg/d		
Male	20 to 39 y	0.279 µg/kg/d		
Male	40 to 64 y	0.240 µg/kg/d		
Male	65+ y	0.202 µg/kg/d		
Female	12 to 19 y	0.263 µg/kg/d		
Female	20 to 39 y	0.231 µg/kg/d		
Female	40 to 64 y	0.211 µg/kg/d		
Female	65+ y	0.184 µg/kg/d		
All	All	0.241 µg/kg/d		

C-2.3.2 Relative Contributions of Exposure Pathways to Total Exposure

Dietary exposure to cobalt is highly variable, but generally higher than intake from drinking water (ATSDR, 2004a). Other sources of exposure are considered negligible.

C-2.4 Indices of Human Exposure

In their review, ATSDR (2004a) report that biomonitoring data demonstrate a positive correlation between levels of occupational exposure to cobalt, and concentrations of cobalt in both urine and blood; however, they note that the correlations are more consistent for exposures to soluble cobalt compounds (metal, salts and hard metals). Reported background concentrations of cobalt in various human tissues and fluids are provided in Table C.24.

Table C.24 Background Cobalt Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Breast milk	Canada	milk collected from 43 mothers in the 1st 3 months of lactation in Newfoundland between 1988 and 93	0 to 6 µg/L	Friel *et al.*, 1999
Blood	U.S.	sample of 1,007 1999 NHANES participants, aged 6 yr or older, selected to be representative of the U.S.	geometric mean: 0.36 µg/L of urine; or 0.33 µg/g creatinine	CDC, 2001
Blood	not specified	unexposed humans	0.5 to 1.9 µg/L	Alexandersson, 1988; Ichikawa *et al.*, 1985
Blood	Italy	population of healthy Italians	Range: 0.01 to 0.91 µg/L Mean: 0.39 µg/L	Minoia *et al.*, 1990
Blood	not specified	male mean reference value	2.96 ± 1.93 nmol/L	Christensen and Poulson, 1994
Blood	not specified	female mean reference value	4.25 ± 2.19 nmol/L	Christensen and Poulson, 1994
Serum	Italy	population of healthy Italians	Range: 0.08 to 0.4 µg/L Mean: 0.21 µg/L	Minoia *et al.*, 1990
Urine	not specified	mean estimated values	0.1 to 0.3 µg/L	IARC, 1991
Urine	not specified	unexposed humans	0.4 to 20 µg/L	Alexandersson, 1988; Ichikawa *et al.*, 1985

Table C.24 Background Cobalt Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Urine	Italy	population of healthy Italians	Range: 0.18 to 0.96 µg/L Mean: 0.57 µg/L	Minoia *et al.*, 1990
Urine	not specified	mean estimated values	0.1 to 2 µg/L	IARC, 1991
Urine	not specified	male mean reference value	0.91 ± 0.69 nmol/mmol	Christensen and Poulson, 1994
Urine	not specified	female mean reference value	1.67 ± 1.71 nmol/mmol	Christensen and Poulson, 1994
Urine	U.S	healthy U.S residents	1.84 µg/L	Paschal *et al.*, 1998

C-3.0 COPPER BACKGROUND EXPOSURE

C-3.1 Sources and Environmental Fate

C-3.1.1 Sources

Copper and copper compounds are naturally present in the earth's crust (ATSDR, 2004b). Natural sources of copper releases are windblown dust, forest fires, volcanic eruptions, biogenic processes and sea spray (ATSDR, 2004b). Anthropogenic sources of emissions to air include nonferrous metal production, wood production, iron and steel production, waste incineration, industrial applications, coal combustion, nonferrous metal mining, oil and gasoline combustion, and phosphate fertilizer manufacture (ATSDR, 2004b). The major sources of anthropogenic release to land are mining operations, agriculture, sewage sludge and solid waste (ATSDR, 2004b). Copper compounds are released to water in wastewater discharges, and may also be directly applied to water as algacides (ATSDR, 2004b).

C-3.1.2 Environmental Fate and Speciation in Environmental Media

C-3.1.2.1 Atmosphere

Copper is released to the atmosphere either as particulate matter, or adsorbed to particulates (ATSDR, 2004b). Emissions from combustion processes may be in the form of the oxide, elemental copper, and adsorbed copper (ATSDR, 2004b). Copper smelters are expected to emit copper sulphate (ATSDR, 2004b). Emissions from steel manufacturing and in fly ash from oil-fired power plants and open-hearth steel mills may include cupric oxide (Graedel 1978; Perwak *et al*., 1980). Combustion processes tend to emit copper as fine particles (<1 µm), while copper associated with larger particles tends to be from windblown soil and dust (Schroeder *et al*., 1987).

Copper is removed from the atmosphere by bulk deposition, dry deposition, in-cloud scavenging and washout (Schroeder *et al*., 1987). The source characteristics, particle size, turbulence and wind velocity determine the removal rate and distance travelled of atmospheric copper (ATSDR, 2004b). The fine particulate copper associated with combustion sources may remain in the troposphere for seven to 30 days, and may be transported long distances (Perwak *et al*., 1980).

C-3.1.2.2 Surface Water and Groundwater

Copper enters surface waters mostly associated with particulate matter (ATSDR, 2004b). Most copper in natural waters is in the Cu(II) state, and is complexed or tightly bound to organic matter, with little

present in the free or readily exchangeable form (ATSDR, 2004b). A significant fraction of copper discharged into natural waters is adsorbed within one hour (Harrison and Bishop, 1984). In most natural waters, the chemical conditions controlling complexation, adsorption and precipitation are such that the level of free Cu(II) is extremely low, even at relatively high copper concentrations (ATSDR, 2004b). Under the pH and carbonate conditions typical of natural waters, most Cu(II) is present as carbonate complexes (Stiff, 1971). The particulate forms of copper include precipitates, insoluble organic complexes and copper adsorbed to mineral solids (ATSDR, 2004b).

C-3.1.2.3 Soils and Sediments

Copper is naturally present in soils, and may be enriched near smelters, mining operations and combustion sources (ATSDR, 2004b). Most copper deposited on the soil will be adsorbed in the top 5 or 10 cm of the soil (ATSDR, 2004b). Sandy soils with low pH have the greatest potential for leaching (ATSDR, 2004b). There is potential for copper that is bound to organic and inorganic matrices to be released into pore water (ATSDR, 2004b). Above a pH of five, absorption of copper from pore water on to soil components becomes is significant, whereas at pHs below five, copper largely remains in pore water and is therefore, mobile in soil (Perwak *et al.*, 1980). However, the precise situation depends on the physical and chemical interactions with soil components (ATSDR, 2004b).

Sediment is an important sink and reservoir for copper (ATSDR, 2004b). The form of copper in sediment is determined by site-specific conditions (ATSDR, 2004b). In aerobic sediments copper is usually bound to organics and iron oxides, although it is occasionally predominantly associated with carbonates (ATSDR, 2004b). Copper is reduced in anaerobic sediments and insoluble salts of Cu(I) are formed (ATSDR, 2004b).

C-3.1.2.4 Biota and Foods

Copper is an essential nutrient for plants; therefore it is taken up from the soil in a process that is actively regulated (Clemens, 2001). Studies in terrestrial environments have shown no or little evidence of bioaccumulation and biomagnification of copper (ATSDR, 2004b). In aquatic systems, copper is bioconcentrated, but there is little evidence of biomagnification (ATSDR, 2004b; Perwak *et al.*, 1980).

Copper is an essential micronutrient and is found in all foods (ATSDR, 2004b). Typical food items that are high in copper include shellfish, organ meats (*e.g.*, liver and kidney), legumes, and nuts (ATSDR, 2004b; Dabeka and McKenzie, 2005, pers. comm.; Dabeka and McKenzie, 1995).

C-3.2 Background Exposure Concentrations in Ontario and Canada

C-3.2.1 Background Concentrations in Air

Reported background concentrations of copper in air are provided in Table C.25.

Table C.25 Ontario and Canadian Background Copper Concentrations in Air

Location	Description	Concentration	References
Canada (rural)	Annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994 to 2004	range: nd to 0.0758 µg/m^3 mean: 0.00598 µg/m^3	Dann, 2005 pers. comm.
Canada (urban)	Annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994 to 2004	range: nd to 0.783 µg/m^3 mean: 0.0105 µg/m^3	Dann, 2005 pers. comm.
Canada (urban)	Median PM10 concentrations from 11 urban stations across Canada, 1986 to 1993	mean: 0.009 µg/m^3	CEPA/FPAC WGAQOG, 1999
Canada (urban)	Values from literature survey	17 to 500 ng/m^3	Schroeder *et al.*, 1987
British Columbia	Mean from 3 stations between 1995 and 1998	mean: 3.88 ng/m^3 range: 0 to 46.3 ng/m^3	Dryfhout-Clark, 2004, pers. comm

C-3.2.2 Background Concentrations in Surface Water and Groundwater

Reported background concentrations of copper in surface water, groundwater, drinking water and precipitation are provided in Tables C.26 to C.28, respectively.

Table C.26 Ontario and Canadian Background Copper Concentrations in Fresh Surface Water

Location	Description	Concentration	References

Table C.26 Ontario and Canadian Background Copper Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 431.0 µg/L mean: 7.54 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 870 µg/L mean: 8.29 µg/L	Clubb, 2005 pers. comm.
Canada	Acid sensitive lakes	range: 1 to 8 ppb	Reed and Henningson, 1984
Lake Superior	11 samples taken at depths up to 251m	range: 629 to 834 ppb mean: 756 ppb	Nriagu *et al*., 1996
Lake Erie	11 samples taken at depths up to 55m	range: 703 to 1,061 ppb mean: 870 ppb	Nriagu *et al*., 1996
Lake Ontario	9 samples taken at depths up to 145m	range: 540 to 1,098 ppb mean: 830 ppb	Nriagu *et al*., 1996

Table C.27 Ontario and Canadian Background Copper Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 756.0 µg/L mean: 3.62 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standards[a]	2.5 µg/L	MOE, 2004

[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

Table C.28 Ontario and Canadian Background Copper Concentrations in Drinking Water

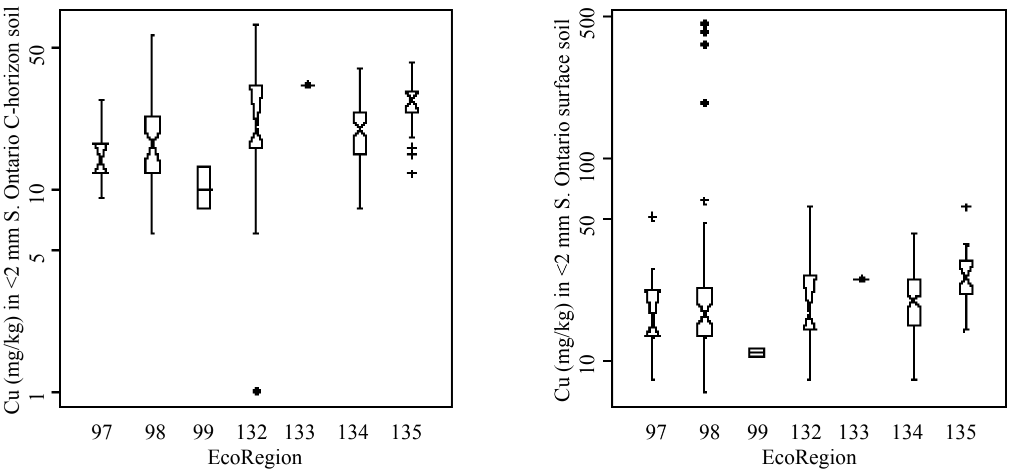
Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 2,930.0 µg/L mean: 147.72 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 3,700.0 µg/L mean: 65.33 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 7,000.0 µg/L mean: 93.45 µg/L	Clubb, 2005 pers. comm.

Table C.29 Ontario and Canadian Background Copper Concentrations in Precipitation

Location	Description	Concentration	References
Southern Ontario	Average concentration in rain in 1982	1.57 ppb	Chan *et al.*, 1986
Central Ontario		1.36 ppb	
Northern Ontario		1.58 ppb	

C-3.2.3 Background Concentrations in Soils and Sediment

Concentrations of copper in soils from across Southern Ontario are plotted in Figure C-4, where the extent of the whiskers provides an estimate of background range for each Ecoregion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005). Reported background concentrations of copper in soil and dust are provided in Tables C.29 to C.31, respectively.



EcoRegions:

97 Lake Timiskaming Lowland, n = 17
98 Algonquin-Lake Nipissing (includes Sudbury region), n = 112
99 Southern Laurentians, n = 3
132 St. Lawrence Lowlands, n = 30
133 Frontenac Axis, n = 1
134 Manitoulin-Lake Simcoe, n = 89
135 Lake Erie Lowlands, n = 42

Figure C-5 Tukey Boxplots, by EcoRegion in Southern Ontario, of Copper in C-horizon (70-100 cm) and Surface (top 25 cm) Soils.

Table C.30 Ontario and Canadian Background Copper Concentrations in Soil

Location	Description	Concentration	References
Ottawa	garden soil, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	12.28 mg/kg	Rasmussen *et al.*, 2001
Ontario	upper-limit of background[a]	56 mg/kg (agricultural land use) 85 mg/kg (all other land use)	MOE, 2004
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~10 to 370 mg/kg mean: ~20 mg/kg OTR_{98}: 65 mg/kg	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~10 to 90 mg/kg mean: ~20 mg/kg OTR_{98}: 41 mg/kg	MOEE, 1994
Canada	uncultivated, uncontaminated soils, remote from ore bodies	range: 5 to 50 mg/kg mean: 22 mg/kg	McKeague and Wolynetz, 1980
Appalachians (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=45	17 mg/kg	McKeague and Wolynetz, 1980
Canadian Shield	uncultivated, uncontaminated soils, remote from ore bodies, n=12	11 mg/kg	McKeague and Wolynetz, 1980
St. Lawrence Lowlands	uncultivated, uncontaminated soils, remote from ore bodies, n=40	19 mg/kg	McKeague and Wolynetz, 1980
Interior Plains (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=34	21 mg/kg	McKeague and Wolynetz, 1980
Cordillerans (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=19	46 mg/kg	McKeague and Wolynetz, 1980

[a] Value was derived from the Ontario Typical Range values and is representative of the upper limit of typical province-wide background concentrations in soils that are not contaminated by point sources.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

Table C.31 Ontario and Canadian Background Copper Concentrations in Dust

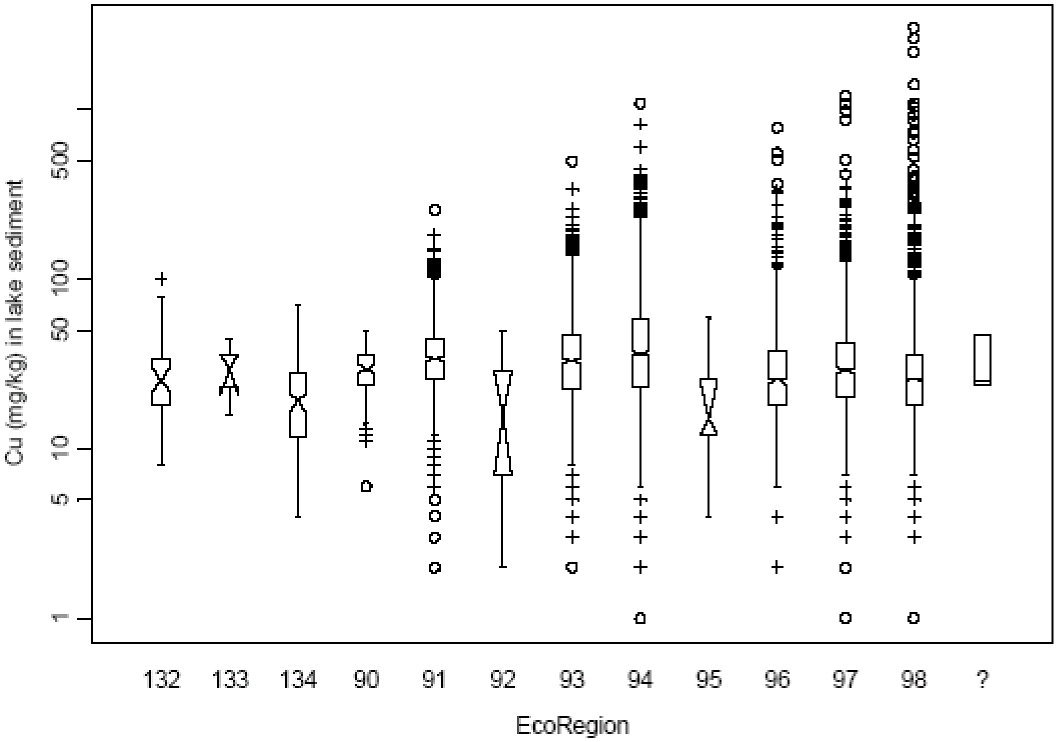
Location	Description	Concentration	References
Ottawa	Household dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	170.69 mg/kg	Rasmussen *et al*., 2001
Ottawa	Street dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	38.13 mg/kg	Rasmussen *et al*., 2001

The U.S. EPA (2003) compiled mean background concentrations of copper in soil for each state, and reported values ranging from 5.0 mg/kg dry weight in Delaware to 53 mg/kg dry weight in Oregon. Generic background concentrations of copper in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.32).

Table C.32 Generic Background Concentrations of Copper in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	5 to 50	27
Chernozems and dark prairie soils	10 to 70	27
Clay and clay-loamy soils	7 to 70	29
Forest soils	7 to 150	17
Lateritic soils		
Light desert soils	5 to 100	24
Light loamy soils	3 to 70	25
Loess and soils on silt deposits	7 to 100	25
Low Humic Gley soils and humus groundwater podzols		
Organic light (or rich) soils	1 to 100	15
Sandy and lithosols on sandstone		
Silty prairie soils	10 to 50	20
Soils on glacial till and drift	15 to 50	21
Soils on lacustrine deposits		
Soils over granites and gneisses	7 to 70	24
Soils over limestones and calcareous rocks	7 to 70	21
Soils over volcanic rocks (or ash)		
Various soils	3 to 300	26
Western Alluvial soils		

An estimated upper limit for background variation in copper levels in lake sediment is approximately 100 to 150 mg/kg, except for the Lake Nipigon EcoRegion where 300 mg/kg is more appropriate (Garrett, 2005). Concentrations of copper in sediment from across Southern Ontario are plotted in Figure C-6, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes. However the whiskers will underestimate the full range of natural background when mineral occurrences are present in the region (Garrett, 2005). Reported background concentrations of copper in sediment are provided in Table C.33.



EcoRegions:

90	Lac Seul Upland, n = 41
91	Lake of the Woods, n = 2,118
92	Rainy River, n = 29
93	Thunder Bay-Quetico, n = 1,483
94	Lake Nipigon, n = 3,003
95	Big Trout Lake, n = 27
96	Abitibi Plains, n = 2,045
97	Lake Timiskaming Lowland, n = 5,065
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 4,279
132	St. Lawrence Lowlands, n = 71
133	Frontenac Axis, n = 10
134	Manitoulin-Lake Simcoe, n = 128
?	Unclassified, n = 3

Figure C-6 Tukey Boxplots, by EcoRegion in Ontario, of Copper in Sediment from Deep Centre-lake Basins, below the Surface Gyttja.

Table C.33 Ontario and Canadian Background Copper Concentrations in Sediments

Location	Description	Concentration	References
Lake Ontario	surficial sediments sampled in 1998	range: 3.7 to 108.6 mg/kg	Marvin *et al*., 2003
Lake Ontario	pre-colonial background from deep sediments	50 mg/kg	Marvin *et al*., 2003
Lake Erie	surficial sediments, sampled in 1997 to 1998	range: 3.1 to 68.2 mg/kg	Painter *et al*., 2001
Lake Erie, West Basin	pre-colonial background from deep sediments	15.1 mg/kg	Painter *et al*., 2001
Lake Erie, Centre Basin	pre-colonial background from deep sediments	35.1 mg/kg	Painter *et al*., 2001
Lake Erie, East Basin	pre-colonial background from deep sediments	28.4 mg/kg	Painter *et al*., 2001
Ontario	Background Site Condition Standard[a]	16 mg/kg	MOE, 2004

[a] Value is within the range of measured background sediment in the 1993 Sediment Guidelines.

C-3.2.4 Background Concentrations in Biota and Foods

Reported background concentrations of copper in fish, other aquatic biota, aquatic plants and terrestrial biota were not found. Reported background concentrations of copper in Canadian foods are provided in Table C.34.

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fish and seafood				
Fish and shellfish	Canada	unpublished data from the 2000 TDS	992.4[a]	Dabeka and McKenzie, 2005 pers. comm
Fish and shellfish	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 811.68 max: 1972.4	HC, 2004a
Fish and shellfish	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 240[a]	JWEL, 2004

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Meat / poultry products				
Meat, poultry and eggs	Canada	unpublished data from the 2000 TDS	10,910.6 [a,b]	Dabeka and McKenzie, 2005 pers. comm
Meat, poultry and eggs	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 3495.75 max: 33372.87 (organ meats)	HC, 2004a
Meat, poultry and eggs	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 21,935[a] max: 170,000 (organ meats)	JWEL, 2004
Meat, fish and poultry	Canada, Ottawa-Hull area in 1969	foods purchased	1,490	Méranger and Smith, 1972
Meat, fish and poultry	Canada, Winnipeg area in 1972	foods purchased	1,130	Kirkpatrick and Coffin, 1977
Milk and dairy products				
Dairy	Canada	unpublished data from the 2000 TDS	221.0[a]	Dabeka and McKenzie, 2005 pers. comm
Milk and milk products	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 200.93 max: 843.13	HC, 2004a
Milk and milk Products	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 179 [a] max: 230	JWEL, 2004
Milk and dairy	Canada, Ottawa-Hull area in 1969	foods purchased	170	Méranger and Smith, 1972
Milk and dairy	Canada, Winnipeg area in 1972	foods purchased	190	Kirkpatrick and Coffin, 1977
Infant formula				
Infant formula	Canada	unpublished data from the 2000 TDS	783.5 [a]	Dabeka and McKenzie, 2005 pers. comm
Infant formula	Canada	137 food items	mean: 789.76 max: 817.44	HC, 2004a
Cereals, grains and baked goods				
Cereal and grain products	Canada	unpublished data from the 2000 TDS	1,367.0 [a]	Dabeka and McKenzie, 2005 pers. comm

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Cereals, grains and baked goods	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 1,300.04 max: 4,574.87	HC, 2004a
Cereals, grains and baked goods	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 1,006 [a] max: 1,700	JWEL, 2004
Cereals	Canada, Ottawa-Hull area in 1969	foods purchased	2,790	Méranger and Smith, 1972
Cereals	Canada, Winnipeg area in 1972	foods purchased	2,260	Kirkpatrick and Coffin, 1977
Fruits and fruit juices				
Fruit and fruit products	Canada	unpublished data from the 2000 TDS	814.2 [a]	Dabeka and McKenzie, 2005 pers. comm
Fruit and fruit products	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 911.28 max: 5,305.59	HC, 2004a
Fruits and fruit juices	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 687[a] max: 3,100 (dried fruits)	JWEL, 2004
Garden fruits	Canada, Ottawa-Hull area in 1969	foods purchased	900	Méranger and Smith, 1972
Garden fruits	Canada, Winnipeg area in 1972	foods purchased	810	Kirkpatrick and Coffin, 1977
Fruits	Canada, Ottawa-Hull area in 1969	foods purchased	520	Méranger and Smith, 1972
Fruits	Canada, Winnipeg area in 1972	foods purchased	540	Kirkpatrick and Coffin, 1977
Root vegetables				
Root vegetables	Canada	unpublished data from the 2000 TDS	774.3[a]	Dabeka and McKenzie, 2005 pers. comm

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Root vegetables	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 839.74 max: 2,650.79	HC, 2004a
Potatoes	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 675[a]	JWEL, 2004
Potatoes	Canada, Ottawa-Hull area in 1969	foods purchased	2,530	Méranger and Smith, 1972
Potatoes	Canada, Winnipeg area in 1972	foods purchased	1,180	Kirkpatrick and Coffin, 1977
Root vegetables	Canada, Ottawa-Hull area in 1969	foods purchased	880	Méranger and Smith, 1972
Root vegetables	Canada, Winnipeg area in 1972	foods purchased	680	Kirkpatrick and Coffin, 1977
Other vegetables				
Other vegetables	Canada	unpublished data from the 2000 TDS	782.8[a]	Dabeka and McKenzie, 2005 pers. comm
Other vegetables	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 836.84 max: 3,715.39	HC, 2004a
Other vegetables	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 1,259[a] max: 4,300	JWEL, 2004
Leafy vegetables	Canada, Ottawa-Hull area in 1969	foods purchased	840	Méranger and Smith, 1972
Leafy vegetables	Canada, Winnipeg area in 1972	foods purchased	920	Kirkpatrick and Coffin, 1977
Legumes	Canada, Ottawa-Hull area in 1969	foods purchased	1,480	Méranger and Smith, 1972
Legumes	Canada, Winnipeg area in 1972	foods purchased	1,170	Kirkpatrick and Coffin, 1977

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Mixed Foods or Miscellaneous				
Miscellaneous (including soup)	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 1,528.76 max: 15,344.29 (seeds shelled)	HC, 2004a
Soups	Canada, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	foods collected	256 [a]	HC, 2004a
Fats and oils				
Fats, oils and peanuts	Canada	unpublished data from the 2000 TDS	1,276.3[a]	Dabeka and McKenzie, 2005 pers. comm
Fats, oils and peanuts	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 2,044.04 max: 5,911.07	HC, 2004a
Fats, oils, nuts and seeds	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 2,514[a] max: 9,800 (nuts and seeds)	JWEL, 2004
Fats and oils	Canada, Ottawa-Hull area in 1969	foods purchased	1,890	Méranger and Smith, 1972
Fats and oils	Canada, Winnipeg area in 1972	foods purchased	1,560	Kirkpatrick and Coffin, 1977
Sugars and sweets				
Sugar, candy and desserts	Canada	unpublished data from the 2000 TDS	727.4[a]	Dabeka and McKenzie, 2005 pers. comm
Sugar, candy and desserts	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 647.06 max: 2,896.88	HC, 2004a

Table C.34 Typical Total Copper Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Sugars and sweets	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 487 [a] max: 1,400	JWEL, 2004
Sugars	Canada, Ottawa-Hull area in 1969	foods purchased	2,360	Méranger and Smith, 1972
Sugars	Canada, Winnipeg area in 1972	foods purchased	1,450	Kirkpatrick and Coffin, 1977
Beverages				
Non-alcoholic drinks	Canada	unpublished data from the 2000 TDS	56.1[a]	Dabeka and McKenzie, 2005 pers. comm
Non-alcoholic drinks	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 108.00 max: 193.32	HC, 2004a
Non-alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 35.4[a]	JWEL, 2004
Alcoholic drinks	Canada	unpublished data from the 2000 TDS	66.2[a]	Dabeka and McKenzie, 2005 pers. comm
Nlcoholic drinks	8 Canadian cities, Toronto, Montreal, Halifax, Winnipeg, Vancouver, Ottawa, Whitehorse and Calgary between 1993 and 1999	137 food items collected	mean: 88.5 max: 134.28	HC, 2004a
Alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 27.3[a]	JWEL, 2004
Drinks	Canada, Ottawa-Hull area in 1969	foods purchased	270	Méranger and Smith, 1972
Drinks	Canada, Winnipeg area in 1972	foods purchased	170	Kirkpatrick and Coffin, 1977

[a] Calculated from raw data in original study.

[b] High levels in the year 2000 data for meat, poultry and eggs can be largely attributed to the extremely high copper concentrations reported for organ meats. Organ meats were included in previous years' studies, but the average concentration in organ meats between 1993 and 1999 was four fold lower than the 2000 value. Values for meat, poultry and eggs, excluding organ meats, are 1006 and 1,342 ng/g for 1993 to 1999 and 2000, respectively.

C-3.3 Estimated Canadian Daily Intakes

C-3.3.1 Dietary Intake

The recommended limit for dietary intake of copper is 10 to 12 mg/day for adults (WHO, 1996). ATSDR (2004b) noted that dietary intake of copper can be elevated by regular consumption of certain foods, including shellfish, organ meats, legumes and nuts; however, the only food likely to elevate dietary intake above the WHO limit is shellfish. Regular consumption of shellfish could increase dietary intake by 5.7 to 136 mg/day (above that of the general U.S. population) (ATSDR, 2004b). Reported Canadian dietary intake rates for copper are provided in Table C.35.

Table C.35 Dietary Intake Rates for Copper

Gender	Age	Intake Rate	Comments	Reference
Both	0 to 1 mo	62.025 µg/kg/d	Average dietary intake rate for Canadians for Total Diet Study from 1993 to 1999	HC, 2004a
Both	2 to 3 mo	77.494 µg/kg/d		
Both	4 to 6 mo	41.391 µg/kg/d		
Both	7 to 9 mo	49.592 µg/kg/d		
Both	10 to 12 mo	39.785 µg/kg/d		
Both	1 to 4 y	45.742 µg/kg/d		
Both	5 to 11 y	36.309 µg/kg/d		
Male	12 to 19 y	25.084 µg/kg/d		
Male	20 to 39 y	21.140 µg/kg/d		
Male	40 to 64 y	17.496 µg/kg/d		
Male	65+ y	14.289 µg/kg/d		
Female	12 to 19 y	18.831 µg/kg/d		
Female	20 to39 y	17.423 µg/kg/d		
Female	40 to 64 y	14.961 µg/kg/d		
Female	65+ y	13.364 µg/kg/d		
All	All	17.651 µg/kg/d		

C-3.3.2 Relative Contributions of Exposure Pathways to Total Exposure

In the general population, the highest copper exposure comes from food (2 mg/day) and drinking water (0.15 mg/day) (ATSDR, 2004b). The contribution made by water distribution systems (*i.e.,* copper plumbing) to copper intake from drinking water is of special concern (ATSDR, 2004b). Copper intake through inhalation is much less significant (0.1 to 4.0 µg/day) (ATSDR, 2004b). Dermal exposure may also result from the use of copper fungicides and algacides (ATSDR, 2004b).

The inhalation exposure of children to copper is expected to be similar to that of adults; however, exposure through oral routes may be different due to differences in diet and behaviour (ATSDR, 2004b).

C-3.4 Indices of Human Exposure

Background concentrations of copper in various human tissues and fluids are provided in Table C.36.

Table C.36 Background Copper Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Blood	Italy	healthy nonoccupationally exposed workers	0.8 to 1.6 mg/L	Minoia *et al*., 1990
Breast milk	Canada	milk collected from 43 mothers in the 1st 3 months of lactation in Newfoundland between 1988 and 1993	0.21 to 0.57 mg/L	Friel *et al*., 1999
Serum	unknown	female	120 µg/g dw	Georgopoulos *et al*., 2001; Scheinberg, 1979; Sternlieb and Scheinberg, 1977
Serum	unknown	male	109 µg/g dw	
Serum	unknown	newborn	36 µg/g dw	
Serum	unknown	normal mean level	1.1 mg/L	Versieck and Cornelis, 1989; Trebig and Schaller, 1984
Serum	Italy	healthy nonoccupationally exposed workers	0.6 to 1.37 mg/L	Minoia *et al*., 1990
Urine	unknown	normal mean level	15 to 36 µg/24 hr	Versieck, 1985
Urine	Unknown	mean urinary daily excretion	20 µg/hr	Trebig and Schaller, 1984

C-4.0 LEAD BACKGROUND EXPOSURE

C-4.1 Sources and Environmental Fate

C-4.1.1 Sources

Lead is a naturally occurring element found in the earth's crust, mostly as the ore galena (PbS), and in all other environmental media; however, anthropogenic processes are responsible for the majority of lead in the environment (ATSDR, 1999). Combustion of leaded gasoline, which was banned in Canada in 1990 (except for racing fuel) (HC, 2004c; EC, 2002) and in the U.S. in 1996, was once the primary source of anthropogenic releases to the atmosphere (ATSDR, 1999). Currently, the major contributors to total atmospheric lead releases are industrial releases from nonferrous smelters, battery plants, chemical plants, and releases from old lead-based paint (ATSDR, 1999). Releases from lead-based paints are often confined to the immediate vicinity of the painted surface, but deterioration or removal of the paint can lead to high localized concentrations of lead in air and in dust on exposed surfaces (ATSDR, 1999). Cigarettes smoking and second-hand smoke are also sources of inhalation exposure to lead (WHO, 1977).

The largest releases of lead to water are from the steel and iron industries, and from lead production and processing operations (ATSDR, 1999). Solid wastes concentrated in landfills, including solder, weights, ballast, waste from ore production, iron and steel production and ammunition use, are important sources of releases to soil (ATSDR, 1999).

C-4.1.2 Environmental Fate and Speciation in Environmental Media

C-4.1.2.1 Atmosphere

The principal forms of lead particle emissions from mines and smelters are the lead-sulphur compounds ($PbSO_4$, $PbO{\cdot}PbSO_4$ and PbS) (U.S. EPA, 1986). The chemistry of lead in the atmosphere is unclear, and it is not known how the chemical composition of lead changes during dispersion; however inorganic lead in the atmosphere is present primarily in particulate form as $PbSO_4$ and $PbCO_3$ (ATSDR, 1999; U.S. EPA, 1986). Particulates are removed from the atmosphere *via* wet and dry deposition, after being transported distances up to thousands of kilometres (ATSDR, 1999). The time to deposition, and hence the distance traveled by particulates, is determined principally by particle size, with smaller particles travelling longer distances (ATSDR, 1999).

C-4.1.2.2 Surface Water and Groundwater

The stable ionic species of lead in natural waters is the divalent form (Pb^{2+}) (ATSDR, 1999). Lead has a tendency to form low-solubility compounds with major anions, and in surface waters, the solubility of lead is limited by the pH and dissolved salt content of the water (ATSDR, 1999). Above a pH of 5.4, poorly soluble lead carbonates are formed and precipitate out of solution (U.S. EPA, 1979). Below pH 5.4, lead sulphate limits the concentration of lead in solution (U.S. EPA, 1979). In water with high dissolved salt content (*i.e.,* in hard water) the total solubility of lead is severely limited (ATSDR, 1999). Dissolved lead concentrations in most surface and ground waters are low, due to the formation of compounds with low water solubilities that precipitate out of the water column (*e.g.,* hydroxides, carbonates, sulphates and phosphates) (Mundell *et al.*, 1989). Precipitated lead may be sedimented, or, in fast flowing rivers, transported some distance. Lead may be microbially methylated to tetramethyl lead in anaerobic sediments, and if the overlying water is also anaerobic it may volatilize into the atmosphere (U.S. EPA, 1979).

C-4.1.2.3 Soils and Sediments

Lead is a minor component of natural soils. Additional lead is added to soils *via* wet and dry deposition (likely as $PbSO_4$ and $PbCO_3$) and *via* surface water flow (ATSDR, 1999). Since the sale of leaded gasoline was banned, emissions of organic tetraalkyl lead compounds have dropped significantly; however, the deposited organolead compounds and their transformation products still remain in soil (ATSDR, 1999). Data suggest that the transformation products of tetraethyl and tetramethyl lead are the highly water soluble trialkyl lead oxides, which may be subject to leaching (ATSDR, 1999; U.S. EPA, 1985b).

The availability and mobility of lead increases in acid soils, due to the prevalence of ionic lead (Pb^{2+}) and ion pairs (*e.g.,* $PbSO_4^0$) (Reddy *et al.*, 1995). At near neutral pH, dissolved organic carbon-lead complexes predominate, but as pH increases further, the level of dissolved lead declines (Reddy *et al.*, 1995). Most lead in soils is strongly absorbed, and does not leach into surface water or groundwater (U.S. EPA, 1986; NSF, 1977); however, it may be transported in surface waters *via* erosion of lead-containing soils (ATSDR, 1999). Given its relative immobility, the principal factor in determining the concentration of lead in soils is the rate of atmospheric deposition (ATSDR, 1999).

C-4.1.2.4 Biota and Foods

Lead enters the terrestrial food chain *via* deposition on to plant and soil surfaces, followed by biological uptake (ATSDR, 1999). Lead may be taken up from soil *via* the root system, by direct foliar uptake, and by surface deposition of particulates (ATSDR, 1999). Generally, the greatest body burdens of lead are found in the oldest organisms.

In aquatic systems, lead concentrations are usually highest in benthic organisms and algae, and lowest in high trophic level predators (ATSDR, 1999). Plants and animals bioconcentrate lead, but biomagnification of lead has not been observed (ATSDR, 1999). A review of BCF factors in aquatic biota found the following median values: 42 in fish, 536 in oysters, 500 in insects, 725 in algae, and 2,570 in mussels (Eisler, 1988c). Depuration of lead is relatively rapid, with half lives of tetramethyl lead in rainbow trout of 30 to 45 hours (Eisler, 1988c).

Due to it past use, lead is found in most food items (ATSDR, 1999). Due to the phasing out of leaded gasoline sales in the early 1980s, and the virtual elimination of the use of lead-soldered cans for food storage, lead concentrations in environmental media and food are generally much lower today than in the 1970s and 1980s (ATSDR, 1999). Typical foods that are high in lead are processed foods, for example, soups and frozen dinners (Dabeka and McKenzie, 2005 pers. comm.; HC, 2004a; Dabeka and McKenzie, 1995; 1992). Lead is also found in comparably high concentrations in sugars and candies (Dabeka and McKenzie, 2005 pers. comm.).

C-4.2 Background Exposure Concentrations in Ontario and Canada

The following tables present typical background concentrations of lead in environmental media from areas that are not influenced by either a major anthropogenic or natural source of lead contamination.

It should be noted that lead concentrations in environmental media and biological tissues/fluids are generally much lower today than in the 1970s and 1980s, due to the phasing out of leaded gasoline sales, and the virtual elimination of the use of lead-soldered cans for food storage (ATSDR, 1999). In addition, older Canadian diet studies (and presumably other studies in which lead was measured in various media) used analytical techniques that may not have been sensitive enough for the purpose (Dabeka *et al.*, 1987). The detection limit for lead used in the 1987 study by Dabeka *et al*. was two to three orders of magnitude more sensitive than in previous work. For these reasons, caution should be used in applying older lead data to current situations.

C-4.2.1 Background Concentrations in Air

Unleaded gasoline was introduced in Canada in 1975, and sale of leaded gasoline for use in cars was banned in 1990 (HC, 2004c). Between 1973 and 1985, lead concentrations in Canadian air dropped by 76%, and lead concentrations in the ambient air of most Canadian cites is currently below detection limits (HC, 2004c). Reported background concentrations of lead in air are provided in Table C.37.

Table C.37 Ontario and Canadian Background Lead Concentrations in Air

Location	Description	Concentration	References
Canada (rural)	Annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994 to 2004	range: nd to 0.028 µg/m^3 mean: 0.0038 µg/m^3	Dann, 2005 pers. comm.
Canada (urban)	Annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994 to 2004	range: nd to 0.42 µg/m^3 mean: 0.0045 µg/m^3	Dann, 2005 pers. comm.
Canada (urban)	Median PM10 concentrations from 11 urban stations across Canada, 1986 to 1993	mean: 0.043 µg/m^3	CEPA/FPAC WGAQOG, 1999
Windsor, Ontario	Indoor (home and office) samples of personal air taken 1991 to 1992	range: 0.7 to 47.1 ng/m^3 mean: 9.0 ng/m^3	Bell *et al*., 1994
Windsor, Ontario	Outdoor (residential and commercial neighbourhoods) samples of personal air taken 1991 to 1992	range: 2.9 to 29.2 ng/m^3 mean: 13.0 ng/m^3	Bell *et al*., 1994
Windsor, Ontario	6 samples of ambient air taken in 1992	range: 5.4 to 30.5 ng/m^3 mean: 16.0 ng/m^3	Bell *et al*., 1994
Canada	Geometric mean from stations across Canada	geom. mean: <0.1 µg/m^3	HC, 1992
British Columbia	Mean from 3 stations between 1995 and 1998	mean: 3.58 ng/m^3 range: 0 to 29.2 ng/m^3	Dryfhout-Clark, 2004, pers. comm
Not specified	Large cities	2 to 4 µg/m^3	WHO, 1989
Not specified	Suburban areas	<0.2 µg/m^3	WHO, 1989

C-4.2.2 Background Concentrations in Surface Water and Groundwater

Reported background concentrations of lead in surface water and groundwater are provided in Tables C.38 and C.39, respectively.

Table C.38 Ontario and Canadian Background Lead Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 66.0 µg/L mean: 0.38 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 49.0 µg/L mean: 0.64 µg/L	Clubb, 2005 pers. comm.
U.S.	50,000 surface water stations	mean: 3.9 µg/L	Eckel and Jacob, 1988
U.S.	lakes	6 to 34 µg/L	HSDB, 2000
Worldwide	lakes and rivers	average concentration: 2 µg/kg	Eisler, 1988c
Not specified		0.1 mg/L	Kopp and Kroner, 1970
Not specified	unpolluted areas	1 µg/L	Zukovickaja *et al.*, 1966

Table C.39 Ontario and Canadian Background Lead Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 37.0 µg/L mean: 0.29 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standards[a]	1 µg/L	MOE, 2004

[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

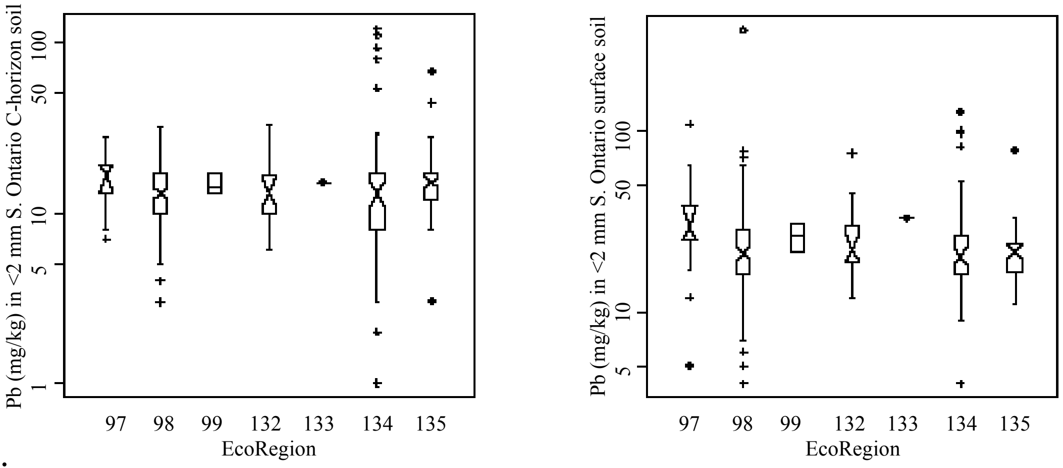
Lead is a component of many solders, fluxes and pipes; therefore, drinking water may become contaminated with lead as it passes through the distribution system or building plumbing. A U.S. survey of households, schools and office buildings, with corroded plumbing, found lead levels in tap water ranging from 10 to 30 µg/L, resulting from leaching of lead (U.S. EPA, 1989). Reported concentrations of lead in Ontario and Canadian drinking water are provided in Table C.40. Background concentrations of lead in precipitation were not found.

Table C.40 Ontario and Canadian Background Lead Concentrations in Drinking Water

Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 120.0 µg/L mean: 2.08 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 460.0 µg/L mean: 2.92 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 332.0 µg/L mean: 2.54 µg/L	Clubb, 2005 pers. comm.
Canada	survey of bottled water purchased in 1990 (water from both Canadian and imported sources, available in Canada)	range: <0.001 to 0.074 µg/g mean: 0.0026 µg/g	Dabeka *et al.*, 1992
Canada	71 municipalities - untreated water	mean: <1 µg/L range: <1 µg/L to 65 µg/L	Méranger *et al.*, 1979; 1981
Ontario	64 municipalities	mean: 4 µg/L range: <1 to 48 µg/L	HC, 1992
Montreal, PQ	18 homes; tap water	range: 0.25 to 2.76 µg/L median: 0.65 µg/L	Méranger *et al.*, 1984b
Canada	5 cities	median: 2 µg/L	Dabeka *et al.*, 1987
Ontario	1 week composites from 40 homes at 7 locations	range: 1.1 to 30.7 µg/L median: 4.8 µg/L	HC, 1992

C-4.2.3 Background Concentrations in Soils and Sediment

The earth's crust contains an average of 16 mg/kg of lead (U.S. EPA, 1980). Concentrations of lead in soils from across Southern Ontario are plotted in Figure C-7, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005). Reported background concentrations of lead in soil and dust are provided in Tables C.41 and C.42, respectively.



EcoRegions:

97	Lake Timiskaming Lowland, n = 17	133	Frontenac Axis, n = 1
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 112	134	Manitoulin-Lake Simcoe, n = 89
99	Southern Laurentians, n = 3	135	Lake Erie Lowlands, n = 42
132	St. Lawrence Lowlands, n = 30		

Figure C-7 Tukey Boxplots, by EcoRegion in Southern Ontario, of Lead in C-horizon (70-100 cm) and Surface (top 25 cm) Soils

Table C.41 Ontario and Canadian Background Lead Concentrations in Soil

Location	Description	Concentration	References
Ottawa	garden soil, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	42 mg/kg	Rasmussen *et al*., 2001
Ontario	upper-limit of background[a]	55 to 120 mg/kg	MOE, 2004
Not specified	natural lead content of soil (due to crustal rock - *i.e.*, galena)	<10 to 30 mg/kg	ATSDR,1993
Canada	background levels for total lead	mean: 12 mg/kg	Nriagu, 1978
Canada	normal agricultural soil	<1 to 12 mg/kg	Warren *et al.*, 1970
Ontario	296 agricultural soils	mean: 46 mg/kg range: 1.5 to 888 mg/kg	Frank *et al.*, 1976
Ontario	neutral pH soils from heavily hunted upland areas influenced by lead shot sampled in 2000	range: 3 to 199 mg/kg mean: 69 mg/kg	Holdner *et al*., 2004
St. Thomas, Ontario	acid (5.5) pH soils from heavily hunted upland areas influenced by lead shot	max: 6,700 mg/kg	Emerson, 1994
Canada	cropped soils	average: 14 mg/kg	CCME, 1999
Alberta	agricultural soils near settlements	range: 2 - 28 mg/kg mean: 9 mg/kg	CCME, 1999

Table C.41 Ontario and Canadian Background Lead Concentrations in Soil

Location	Description	Concentration	References
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~7 to 110 µg/g mean: ~35 µg/g OTR_{98}: 98 µg/g	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~7 to 75 µg/g mean: ~20 µg/g OTR_{98}: 45 µg/g	MOEE, 1994
Canada	uncultivated, uncontaminated soils, remote from ore bodies	mean: 20 ppm range: 5 to 50 ppm	McKeague and Wolynetz, 1980
Appalachians (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=45	21 ppm	McKeague and Wolynetz, 1980
Canadian Shield	uncultivated, uncontaminated soils, remote from ore bodies, n=12	21	McKeague and Wolynetz, 1980
St. Lawrence Lowlands	uncultivated, uncontaminated soils, remote from ore bodies, n=40	25	McKeague and Wolynetz, 1980
Interior Plains (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=34	15	McKeague and Wolynetz, 1980
Cordillerans (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=19	16	McKeague and Wolynetz, 1980
Worldwide	average	16,000 µg/kg	Eisler, 1988c
Worldwide		10 mg/kg range: 2 to 200 mg/kg	Demayo *et al*., 1982

[a] Value was derived from the Ontario Typical Range values and is representative of the upper limits of typical province-wide background concentrations in soils that are not contaminated by point sources.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

Table C.42 Ontario and Canadian Background Lead Concentrations in Dust

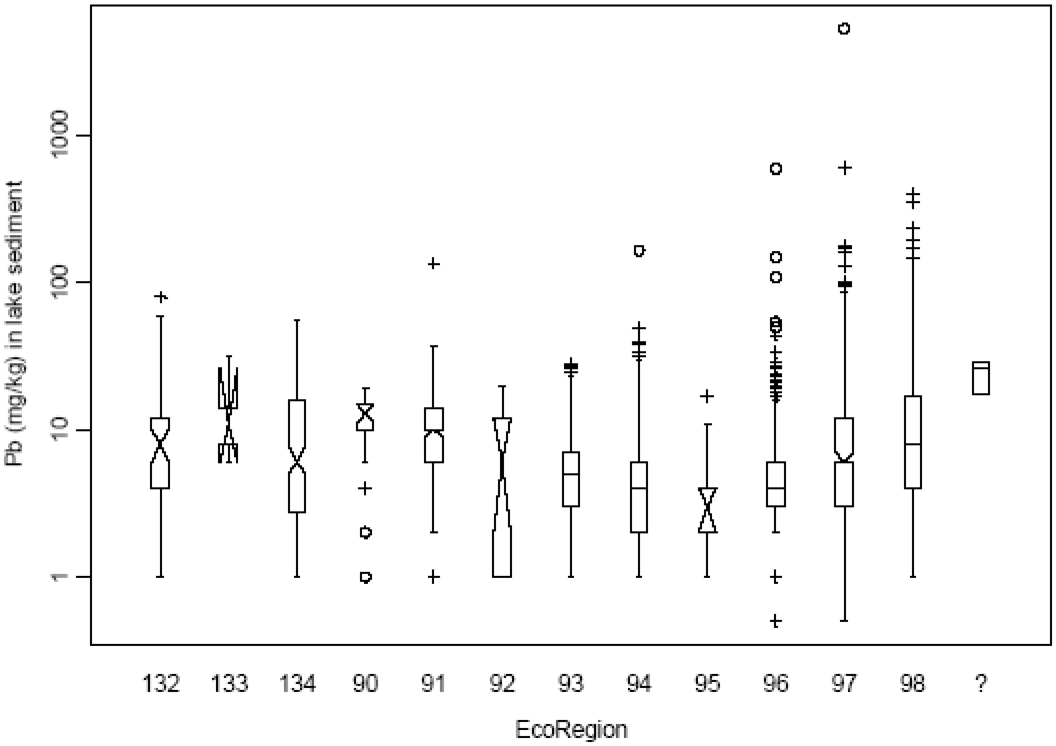
Location	Description	Concentration	References
Ottawa	Household dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	233 mg/kg	Rasmussen *et al*., 2001
Ottawa	Street dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	33 mg/kg	Rasmussen *et al*., 2001
Toronto	House dust from a location not near to any point sources	845 mg/kg	Roberts *et al.,* 1974

In the U.S., reported state mean background concentrations of lead in soil range from 5.0 mg/kg (Connecticut and South Carolina) to 39 mg/kg (Illinois) (U.S. EPA, 2003). Generic background concentrations of lead in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.43).

Table C.43 Generic Background Concentrations of Lead in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	10 to 30	18
Chernozems and dark prairie soils	10 to 70	19
Clay and clay-loamy soils	10 to 70	22
Forest soils	10 to 50	20
Lateritic soils	NA	NA
Light desert soils	10 to 70	23
Light loamy soils	<10 to 50	20
Loess and soils on silt deposits	10 to 30	19
Low Humic Gley soils and humus groundwater podzols	NA	NA
Organic light (or rich) soils	10 to 50	24
Sandy and lithosols on sandstone	NA	NA
Silty prairie soils	10 to 30	21
Soils on glacial till and drift	10 to 30	17
Soils on lacustrine deposits	NA	NA
Soils over granites and gneisses	10 to 50	21
Soils over limestones and calcareous rocks	10 to 50	22
Soils over volcanic rocks (or ash)	NA	NA
Various soils	<10 to 70	26
Western Alluvial soils	NA	NA

Lead shows considerable variability in background levels in lake sediment; however, an estimated upper limit for background variation is approximately 20 to 50 mg/kg (Garrett, 2005). A plot of concentrations of lead in lake sediments is presented in Figure C-8 below, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes. However, the whiskers can underestimate the full range of natural background when mineral occurrences are present in the region (Garrett, 2005). Reported background concentrations of lead in sediment are provided in Table C.44.



EcoRegions:

90	Lac Seul Upland, n = 41
91	Lake of the Woods, n = 2,118
92	Rainy River, n = 29
93	Thunder Bay-Quetico, n = 1,483
94	Lake Nipigon, n = 3,003
95	Big Trout Lake, n = 27
96	Abitibi Plains, n = 2,045
97	Lake Timiskaming Lowland, n = 5,065
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 4,279
132	St. Lawrence Lowlands, n = 71
133	Frontenac Axis, n = 10
134	Manitoulin-Lake Simcoe, n = 128
?	Unclassified, n = 3

Figure C-8 Tukey Boxplots, by EcoRegion in Ontario, of Lead in Sediment from Deep Centre-lake Basins, below the Surface Gyttja

Table C.44 Ontario and Canadian Background Lead Concentrations in Sediments

Location	Description	Concentration	References
Lake Erie	surficial sediment samples collected 1997-1998	range: 4.4 to 104.3 mg.kg	Painter *et al*., 2001
Lake Erie, West Basin	pre-colonial background from deep sediments	13.2 mg/kg	Painter *et al*., 2001
Lake Erie, Centre Basin	pre-colonial concentrations from deep sediments	22.7 mg/kg	Painter *et al*., 2001
Lake Erie, East Basin	pre-colonial concentrations from deep sediments	18.6 mg/kg	Painter *et al*., 2001
Lake Ontario	surficial sediment samples collected 1998	range: 5.2 to 196.6 mg/kg	Marvin *et al*., 2003
Lake Ontario	pre-colonial background from deep sediments	15 mg/kg	Marvin *et al*., 2003
Ontario	Background Site Condition Standard[a]	31 mg/kg	MOE, 2004
Worldwide	average	47,000 µg/kg	Eisler, 1988c

[a] Value is within the range of measured background sediment in the 1993 Sediment Guidelines.

C-4.2.4 Background Concentrations in Biota and Foods

Reported background concentrations of lead in fish, aquatic plants and terrestrial biota are provided in Tables C.45 to C.47 respectively.

Table C.45 Ontario and Canadian Background Lead Concentrations in Fish (Freshwater)

Location	Description	Concentration	References
U.S.	112 stations (ppm wet weight) from 1979 to 1981	geom. mean: 0.17 to 0.19 mg/kg ww range: 0.1 to 6.73 mg/kg ww	HSDB, 2000
U.S.	National Contaminant Biomonitoring Program for 1984 to 1985; 315 composite samples of whole fish from 109 stations nationwide	geom. mean: 0.11 max:4.88 85th%ile: 0.22 (all in mg/kg ww)	HSDB, 2000
not specified	Fish and seafood	0.2 to 2.5 mg/kg	Schroeder and Balassa, 1961

Table C.46 Ontario and Canadian Background Lead Concentrations in Aquatic Plants

Location	Description	Concentration	References
Chesapeake Bay	Not specified	2.2 to 18.9 mg/kg dry weight	HSDB, 2000

Table C.47 Ontario and Canadian Background Lead Concentrations in Terrestrial Biota

Biota	Location	Description	Concentration (mg/kg ww)	Reference
Caribou	Northern Quebec	mean concentrations in tissues of 317 caribou harvested by Inuit hunters 1994 to 1996	muscle: 0.05 mg/kg kidneys: 0.26 mg/kg liver: 0.95 mg/kg	Robillard *et al.*, 2002
Woody plants	not near a point source	leaves and twigs	2.5 mg/kg	HSDB, 2000
Pasture grass	not near a point source		1.0 mg/kg	HSDB, 2000
Cereals	not near a point source		0.1 to 1.0 mg/kg	HSDB, 2000
Birds	not specified	livers of 28 species; no known lead exposure	0.3 to 7 mg/kg ww	HSDB, 2000

For multiple reasons, the concentration of lead in food has gradually declined over a number of years; therefore, older data should be interpreted with caution. Reported background concentrations of lead in Canadian foods are provided in Table C.48.

Table C.48 Typical Lead Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fish and seafood				
Fish and shellfish	Canada	mean of 4 food composites	mean: 3.0	Dabeka and McKenzie, 2005 pers. comm.
Fish and shellfish	8 Canadian cities sampled in 1993 to 1999	137 food items	mean: 10.68 max: 20.69	HC, 2004a
Fish	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 19.3 max: 72.8	Dabeka and McKenzie, 1995
Fish	Canada, Ottawa/Hull region, Ottawa/Hull area	2 x 105 food composites sampled	mean: 21.2	Dabeka and McKenzie, 1992
Meat / poultry products				
Meat, poultry and eggs	Canada sampled in 2000	mean of 14 food composites	mean: 5.2	Dabeka and McKenzie, 2005 pers. comm.
Meat, poultry and eggs	8 Canadian cities sampled in 1993 to 1999	137 food items	mean: 13.11 max: 35.33	HC, 2004a

Table C.48 Typical Lead Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Meat and poultry	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 20.2 max: 523.4	Dabeka and McKenzie, 1995
Canned luncheon meat	5 Canadian cities sampled in 1986 to 1988		mean: 163	Dabeka and McKenzie, 1995
Meat and poultry	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 18.5	Dabeka and McKenzie, 1992
Milk and dairy products				
Milk and milk products	Canada	mean of 12 food composites	mean: 2.8	Dabeka and McKenzie, 2005 pers. comm.
Milk and milk products	8 Canadian cities	137 food items	mean: 4.87 max: 14.22	HC, 2004a
Milk and milk products	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 7.7 max: 44.7	Dabeka and McKenzie, 1995
Milk and Dairy Products	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 6.58	Dabeka and McKenzie, 1992
Infant formula	Canada	mean of 2 food composites	mean: 1.6	Dabeka and McKenzie, 2005 pers. comm.
Infant formula	Canada	137 food items	mean: 3.7 max: 4.99	HC, 2004a
Infant formula (ready-to-use)	Canada	49 samples	mean: 1.58 max: 6.08	Dabeka, 1989
Infant formula (concentrated)	Canada	50 samples	mean: 3.67 max: 75.3	Dabeka, 1989
Infant formula (powdered)	Canada	64 samples	mean: 12.56 max: 57.3	Dabeka, 1989
Evaporated milk (lead-free solder)	Canada	8 samples	mean: 2.83 max: 5.17	Dabeka, 1989
Evaporated milk (lead-soldered)	Canada	13 samples	mean: 94.9 max: 300	Dabeka, 1989
Cereals, grains and baked goods				
Cereal/grain products and baked goods	Canada	mean of 21 food composites	mean: 7.5	Dabeka and McKenzie, 2005 pers. comm.
Cereals, grains and baked goods	8 Canadian cities	137 food items	mean: 11.94 max: 33.51	HC, 2004a
Bakery goods and cereals	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 13.7 max: 66.4	Dabeka and McKenzie, 1995

Table C.48 Typical Lead Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Bakery goods and cereals	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 23.5	Dabeka and McKenzie, 1992
Fruits and fruit juices				
Fruit and fruit products	Canada	mean of 20 food composites	mean: 6.9	Dabeka and McKenzie, 2005 pers. comm.
Fruit and fruit Products	8 Canadian cities	137 food items	mean: 11.10 max: 63.97	HC, 2004a
Fruits and fruit juice	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 44.4 max: 372.7	Dabeka and McKenzie, 1995
Canned and raw cherries	5 Canadian cities sampled in 1986 to 1988		mean: 203	Dabeka and McKenzie, 1995
Canned citrus	5 Canadian cities sampled in 1986 to 1988		mean: 126	Dabeka and McKenzie, 1995
Fruits and fruit juices	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 60.7	Dabeka and McKenzie, 1992
Root vegetables				
Root vegetables	Canada	mean of 6 food composites	mean: 5.6	Dabeka and McKenzie, 2005 pers. comm.
Root vegetables	8 Canadian cities	137 food items	mean: 5.46 max: 9.41	HC, 2004a
Other vegetables				
Other vegetables	Canada	mean of 15 food composites	mean: 4.7	Dabeka and McKenzie, 2005 pers. comm.
Other vegetables	8 Canadian cities	137 food items	mean: 9.38 max: 35.65	HC, 2004a
Vegetables	5 Canadian cites sampled in 1986 to 1988	113 composites of 39 foods	mean: 24.4 max: 331.7	Dabeka and McKenzie, 1995
Canned beans	5 Canadian studies sampled in 1986 to 1988		mean: 158	Dabeka and McKenzie, 1995
Vegetables	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 29.3	Dabeka and McKenzie, 1992
Fats and oils				
Fats, oils and peanut butter	Canada	mean of 4 food composites	4.6	Dabeka and McKenzie, 2005 pers. comm.

Table C.48 Typical Lead Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fats, oils and peanuts	8 Canadian cities	137 food items	mean: 18.20 max: 23.88	HC, 2004a
Fats and oils	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 9.6 max: 19.7	Dabeka and McKenzie, 1995
Fats and Oils	Canada, Ottawa/Hull region	2 x 105 food composites sampled in 1985 in Ottawa/Hull area	mean: 8.1	Dabeka and McKenzie, 1992
Sugars and sweets				
Sugar, candy and desserts	Canada	mean of 9 food composites	mean: 18.0	Dabeka and McKenzie, 2005 pers. comm.
Sugar, candy and desserts	8 Canadian cities	137 food items	mean: 8.17 max: 17.72	HC, 2004a
Sugar and candies	5 Canadian cites sampled in 1986 to 1988	113 composites of 39 foods	mean: 18.3 max: 111.6	Dabeka and McKenzie, 1995
Sugar and candies	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 32.8	Dabeka and McKenzie, 1992
Beverages				
Non-alcoholic drinks	Canada	mean of 4 food composites	mean: 1.5	Dabeka and McKenzie, 2005 pers. comm.
Alcoholic drinks	Canada	mean of 2 food composites	mean: 9.0	Dabeka and McKenzie, 2005 pers. comm.
Non-alcoholic drinks	8 Canadian cities	137 food items	mean: 1.64 max: 2.83	HC, 2004a
Alcoholic drinks	8 Canadian cities	137 food items	mean: 15.51 max: 29.46	HC, 2004a
Beverages	5 Canadian cites sampled in 1986 to 1988	113 composites of 39 foods	mean: 9.9 max: 88.8	Dabeka and McKenzie, 1995
Beverages	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 47.4	Dabeka and McKenzie, 1992
Other				
Miscellaneous	8 Canadian cities	137 food items	mean: 55.37 max: 704.48 (Frozen beef dinner)	HC, 2004a
Miscellaneous	5 Canadian cites sampled in 1986 to 1988	113 composites of 39 foods	mean: 41.7 max: 178.9	Dabeka and McKenzie, 1995

Table C.48 Typical Lead Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Soups	5 Canadian cities sampled in 1986 to 1988	113 composites of 39 foods	mean: 15.5 max: 48.7	Dabeka and McKenzie, 1995
Soups	Canada, Ottawa/Hull region in 1985	2 x 105 food composites sampled	mean: 26.3	Dabeka and McKenzie, 1992

C-4.3 Estimated Canadian Daily Intakes

C-4.3.1 Dietary Intake

Caution should be used in applying older dietary intake data to current situations for several reasons:

- Emissions and environmental concentrations of lead have decreased significantly following the phase-out and ban of sales of leaded gasoline for use in road vehicles (1990 in Canada, 1996 in the U.S.) (ATSDR, 1999; HC, 2004c);
- Insufficiently sensitive analyses were used to determine the lead content of Canadian foods prior to 1987 (Dabeka *et al.*, 1987); and,
- According to one study, the concentration of lead in canned foods purchased in Canada decreased significantly (by 38%) during the period of 1985 to 1988, and by 1988 virtually all canned foods packaged in Canada were packed in lead-free cans, but analysis of one food item from a lead-soldered can in an older study could contribute 0.31 µg/kg/d to estimates of dietary intake (HC, 2004c; Dabeka and McKenzie, 1995; Dabeka *et al.*, 1987).

Dabeka and McKenzie (1995) reported a 60% decrease in Canadians' intake of lead from foods between 1981 and 1986 to 1988. Reported dietary intakes of lead are provided in Table C.49.

Table C.49 Dietary Intake Rates of Lead

Species	Age and Gender Group	Intake Rate	Comments	Reference
Total lead	0 to 1 mo, MandF	0.445 µg/kg/d	Average daily intakes of Canadians from the Total Diet Study 1993 to 1999. Studies were conducted in Montreal, Halifax,	HC, 2004c
	2 to 3 mo, MandF	0.543 µg/kg/d		
	4 to 6 mo, MandF	0.418 µg/kg/d		
	7 to 9 mo, MandF	0.454 µg/kg/d		
	10 to 12 mo, MandF	0.496 µg/kg/d		
	1 to 4 yr, MandF	0.492 µg/kg/d		
	5 to 11 yr, MandF	0.368 µg/kg/d		

Table C.49 Dietary Intake Rates of Lead

Species	Age and Gender Group	Intake Rate	Comments	Reference
	12 to 19 yr, F	0.198 µg/kg/d	Winnipeg, Vancouver, Ottawa and Toronto.	
	12 to 19 yr, M	0.250 µg/kg/d		
	20 to 39 yr, F	0.185 µg/kg/d		
	20 to 39 yr, M	0.223 µg/kg/d		
	40 to 65 yr, F	0.168 µg/kg/d		
	40 to 65 yr, M	0.205 µg/kg/d		
	65+ yr, F	0.144 µg/kg/d		
	65+ yr, M	0.162 µg/kg/d		
	all	0.189 µg/kg/d		
Total lead	0 to 1 yr	16.5 µg/d	intake from food and water	Dabeka and McKenzie, 1988
Total lead	adult	53.8 µg/d, or 0.80 µg/kg/d	24 hr duplicate diet study, 24 adults, 5 Cnd cities	Dabeka *et al.*, 1987
Total lead	1 to 4 yr	1.1 µg/kg/d		HC, 1992
Total lead	adult	0.75 µg/kg/d		HC, 1992
Total lead	1 to 4 yr, MandF	15 µg/d	food items purchased in 5 Canadian cities between 1984 and 1986	Dabeka and McKenzie, 1995
	5 to 11 yr, MandF	20 µg/d		
	12 to 19 yr, F	21 µg/d		
	12 to 19 yr, M	26 µg/d		
	20 to 39 yr, F	24 µg/d		
	20 to 39 yr, M	33 µg/d		
	40 to 65 yr, F	23 µg/d		
	40 to 65 yr, M	30 µg/d		
	65+ yr, F	20 µg/d		
	65+ yr, M	24 µg/d		
	all	24 µg/d		
Inorganic lead		child: 2.9 µg/d adult: 7.2 µg/d	estimated intake from drinking water, based on a Pb concentration of 4.8 µg/L and daily water intakes of 0.6 L and 1.5 L (child and adult, respectively)	HC, 1992

C-4.3.2 Relative Contributions of Exposure Pathways to Total Exposure

ATSDR (1999) stated that exposure of the general population to lead is most likely to occur through ingestion of contaminated food and drinking water, and by the inhalation of lead particulates in ambient air, with inhalation accounting for only a small portion of total exposure. The CDC (2001) concluded that the most common source of lead exposure for children is deteriorated lead paint, while the most common source for adults is occupational exposure.

The estimated daily intake of inorganic lead from air alone is 0.36 µg/d and 1.2 µg/d for a Canadian two-year old and adult, respectively (HC, 1992). The total daily intake from air, water, food, dust and dirt combined is 29.5 µg/d and 63.7 µg/d for a Canadian two-year old and adult, respectively (HC, 1992).

The Windsor Air Quality Study found the following breakdown of inhalation exposure to trace metals: 60% from indoor air in the home, 18% from air in the office, and 22% from outdoor air (exposure while commuting was not considered) (Bell *et al*., 1994).

C-4.4 Indices of Human Exposure

Reported background concentrations of lead in various human tissues and fluids are provided in Table C.50.

Table C.50 Background Lead Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Blood	not specified	families of non-exposed workers	6.2 LTC/dL	Kaye *et al*., 1987
Blood	general	blood lead level considered elevated in children under 6	10 µg/dL	CDC, 2001
Blood	U.S.	1 yr and older, geometric mean (n = 3,189)	1.6 µg/dL	CDC, 2001
Blood	U.S.	1 to 5 yr, geometric mean (n = 254)	2.0 µg/dL	CDC, 2001
Blood	U.S.	6 to 11 yr, geometric mean (n = 419)	1.3 µg/dL	CDC, 2001
Blood	U.S.	12 to 19 yr, geometric mean (n = 868)	1.0 µg/dL	CDC, 2001
Blood	U.S.	20 to 39 yr, geometric mean (n = 595)	1.4 µg/dL	CDC, 2001
Blood	U.S.	40 to 59 yr, geometric mean (n = 471)	1.9 µg/dL	CDC, 2001
Blood	U.S.	60+ yr, geometric mean (n = 582)	2.5 µg/dL	CDC, 2001
Breast milk	Canada	210 human milk samples	mean: 1.04 µg/kg range: <0.05 - 15.8 µg/kg geom. mean: 0.566 µg/kg median: 0.55 µg/kg	Dabeka *et al.*, 1988
Breast milk	Newfoundland	samples from 1st 3 months of lactation from mothers of premature (n=24) and full-term (n=19) babies, btw 1988 and 1993	range: 0 to 4 µg/L	Friel *et al*., 1999
Breast milk	not specified		12 ug/L and < 5 ug/L	HSDB, 2000

Table C.50 Background Lead Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Brain cortex	not specified	50 adult males	mean: 0.1 mg/kg wet wt range: 0.02 to 0.8 mg/kg;	HSDB, 2000
Basal ganglia	not specified	50 adult males	range: 0.04 to 0.2 mg/kg.	HSDB, 2000
Body burden	U.S.	average adult in the U.S.	not less than 100 mg and not more than 300 mg	HSDB, 2000

C-5.0 NICKEL BACKGROUND EXPOSURE

C-5.1 Sources and Environmental Fate

C-5.1.1 Sources

Natural sources of nickel emissions to air are soil dust, sea salt, forest fires and particulate exudates from vegetation (CEPA, 1994). During Canadian summers, soil dust and vegetation are the predominant natural sources of nickel, except in coastal areas where sea spray may be more important (EC/HC, 1994). Anthropogenic emissions of nickel exceed natural emissions (ATSDR, 2003a; Nriagu and Pacyna, 1988). The largest anthropogenic sources of nickel are fossil fuel combustion, nickel mining and smelting, but virtually every industry will emit heavy metals, including nickel, in high temperature processes (McGrath, 1995; Wilson *et al*., 1998).

C-5.1.2 Environmental Fate and Speciation in Environmental Media

Very little quantitative information on the speciation of nickel in environmental media is available (CCME, 2004). Nickel concentrations are generally reported as total nickel (CCME, 2004).

C-5.1.2.1 Atmosphere

The form of nickel emitted depends on the source. Emissions of nickel from smelting operations and fossil fuel combustion are predominantly in the form of nickel sulphate, subsulphide and oxide (Gilman and Ruckerbauer, 1962; Henry and Knapp, 1980). Nickel species associated with combustion, incineration, smelting and refining are complex nickel oxides, nickel sulphate and metallic nickel (U.S. EPA, 1985a). Nickel emitted from more specialized industries is commonly in the forms of nickel silicate, nickel subsulphide and nickel chloride (U.S. EPA, 1985a). Nickel of anthropogenic origins is reported to enter the atmosphere as particulate matter in the 0.1 to 2 µm size range, while nickel from natural sources has a larger size, 2 to 10 µm (Beijer and Jernelov, 1986). The species of nickel which are probably present in the atmosphere are soil minerals, nickel oxide and nickel sulphate (Schmidt and Andren, 1980).

Due to the generally small size of the particulate matter, nickel has a relatively long atmospheric residence time. Schmidt and Andren (1980) estimated a residence time of five to eight days, and Schroeder *et al*. (1987) estimated an atmospheric half life for submicron particles of as long as 30 days. Monitoring data show that nickel can be transported far from its source (Pacyna and Ottar, 1985).

C-5.1.2.2 Surface Water and Groundwater

Concentrations of nickel in surface waters are generally low (ATSDR, 2003a). In aerobic waters at environmental pH, the dominant form of nickel is the hexahydrate $Ni((H_2O)_6^{2+}$ ion (Richter and Theis, 1980). Above pH 9.5, $Ni(OH)_2^0$ is the dominant species (ATSDR, 2003a). A small proportion of nickel forms complexes with anions, such as OH^-, SO_4^{2-}, and Cl^- (ATSDR, 2003a). Nickel is mobile in natural waters in both aqueous and particulate forms (CCME, 2004). The factors affecting the fate, transport and bioavailability of nickel in natural waters are pH, redox potential, ionic strength, type and concentration of organic and inorganic ligands, and the presence of solid surfaces for adsorption (Semkin, 1975; Callahan *et al*., 1979; Snodgrass, 1980). Lowering the pH or increasing the concentrations of organic ligands may result in desorption of nickel from sediment or suspended particulates into the water column (Callahan *et al*., 1979). Data suggest that very little nickel is present in Canadian lakes in suspended solids (CCME, 2004).

C-5.1.2.3 Soils and Sediments

In soils, over 50% of the nickel present may be associated with the residual fraction, approximately 20% may be associated with iron and manganese oxides, most of the remainder is bound up with the carbonate fraction, and only minimal amounts are associated with the exchangeable and organic fractions (Hickey and Kittrick, 1984; McGrath, 1995). The adsorption of nickel to soil is affected by site-specific factors including pH, soil texture, bulk density, organic matter, clay minerals, hydroxides and groundwater flow; but the primary factor determining the distribution of nickel between the solid and solution phases of soil is pH (ATSDR, 2003a; Sunderman and Oskarsson, 1988). Most soils have a high affinity for nickel, and once it is sorbed, it is difficult to desorb (Bowman *et al.,* 1981); however, at pH values below 6.5, solubility is increased, nickel is mobilized and concentrations in pore water increase (Sunderman and Oskarsson, 1988). Nickel in sediment may be either strongly bound or in a removable form (ATSDR, 2003a).

C-5.1.2.4 Biota and Foods

The available data do not suggest biomagnification of nickel in freshwater or terrestrial food chains, despite the fact that algae, macrophytes and some terrestrial plants accumulate nickel (CCME, 2004; ATSDR, 2003a).

Nickel can be detected in most foods. In general, nuts, oatmeal, chocolate, legumes, and grains and grain products are high in nickel concentrations (ATSDR, 2003a). In particular, nickel has been found in high concentrations in peanuts, peanut butter and other nuts (*e.g.*, JWEL, 2004; Dabeka and McKenzie, 1995).

C-5.2 Background Exposure Concentrations in Ontario and Canada

C-5.2.1 Background Concentrations in Air

Reported background concentrations of nickel in air are provided in Table C.51.

Table C.51 Ontario and Canadian Background Nickel Concentrations in Air

Location	Description	Concentration	References
Ontario	mean concentration in 1,410 samples of PM10 collected from 27 stations in cities and towns across Ontario in 2001	6.2 ng/m^3	MOE, 2002
Canada (rural)	annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994-2004	range: nd to 0.00690 μg/m^3 mean: 0.00109 μg/m^3	Dann, 2005 pers. comm.
Canada (urban)	annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994-2004	range: nd to 0.408 μg/m^3 mean: 0.00197 μg/m^3	Dann, 2005 pers. comm.
Canada	background concentration for both PM10 and PM2.5	4 ng/m^3	CCME, 2004
Canada (urban)	median PM10 concentrations from 11 urban stations across Canada, 1986 to 1993	range: non-detect to 0.020 μg/m^3	CEPA/FPAC WGAQOG, 1999
Windsor, Ontario	indoor (home and office) samples of personal air taken 1991-1992	range: 0.3 to 9.3 ng/m^3 mean: 1.2 ng/m^3	Bell *et al.*, 1994
Windsor, Ontario	outdoor (residential and commercial neighbourhoods) samples of personal air taken 1991-1992	range: 0.4 to 8.7 ng/m^3 mean: 2.1 ng/m^3	Bell *et al.*, 1994
Windsor, Ontario	6 samples of ambient air taken in 1992	range: 1.1 to 7.2 ng/m^3 mean: 3.0 ng/m^3	Bell *et al.*, 1994
British Columbia	mean from 3 stations between 1995 and 1998	mean: 0.724 ng/m^3 range: 0 to 10.9 ng/m^3	Dryfhout-Clark, 2004, pers. comm

C-5.2.2 Background Concentrations in Surface Water and Groundwater

Reported background concentrations of nickel in surface water, groundwater, and drinking water are provided in Table C.52 to C.54, respectively. Background concentrations of nickel in precipitation were not found.

Table C.52 Ontario and Canadian Background Nickel Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 150.0 µg/L mean: 2.09 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 99.0 µg/L mean: 1.34 µg/L	Clubb, 2005 pers. comm.
Great Lakes	baseline data (not background)	0.76 to 0.88 µg/L	Chapman and Wang, 2000
Canada	representative background concentration for Canadian Shield-type lakes	1.8 µg/L	Doyle *et al*., 2003
Ontario	19 samples from 6 reference sites between 1998 and 2003, selected to represent ambient concentrations	range: <1 to 4 µg/L mean: 1 µg/L	Boyd, 2004 pers. comm.

Table C.53 Ontario and Canadian Background Nickel Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 34.0 µg/L mean: 1.09 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standards[a]	25 µg/L	MOE, 2004

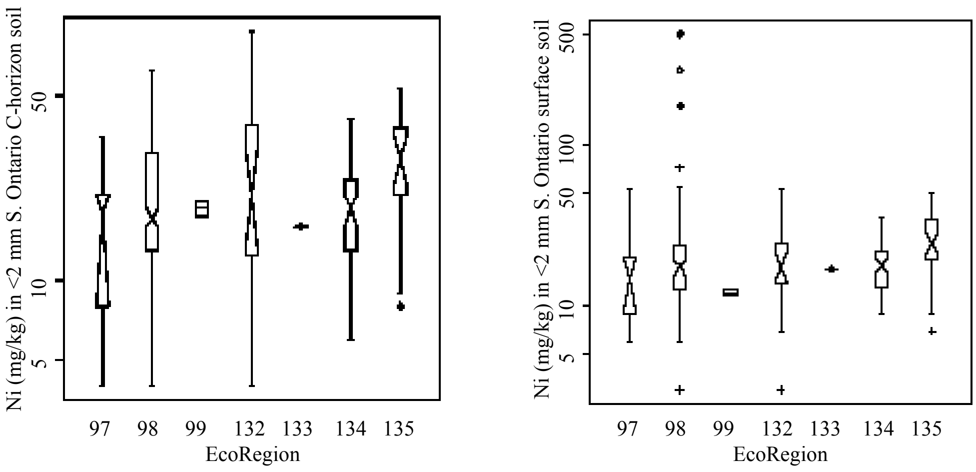
[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

Table C.54 Ontario and Canadian Background Nickel Concentrations in Drinking Water

Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 347.0 µg/L mean: 1.76 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 6,100.0 µg/L mean: 6.01µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 1,150.0 µg/L mean: 2.97 µg/L	Clubb, 2005 pers. comm.

C-5.2.3 Background Concentrations in Soils and Sediment

Concentrations of nickel in soils from across Southern Ontario are plotted in Figure C-9, where the extent of the whiskers provides an estimate of background range for each Ecoregion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005). Reported background concentrations of nickel in soil and dust are provided in Tables C.55 and C.56, respectively.



Ecoregions:

97 Lake Timiskaming Lowland, n = 17
98 Algonquin-Lake Nipissing (includes Sudbury region), n = 112
99 Southern Laurentians, n = 3
132 St. Lawrence Lowlands, n = 30
133 Frontenac Axis, n = 1
134 Manitoulin-Lake Simcoe, n = 89
135 Lake Erie Lowlands, n = 42

Figure C-9 Tukey Boxplots, by Ecoregion in Southern Ontario, of Nickel in C-horizon (70-100 cm) and Surface (top 25 cm) Soils

Table C.55 Ontario and Canadian Background Nickel Concentrations in Soil

Location	Description	Concentration	References
Ottawa	garden soil, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	15.9 mg/kg	Rasmussen *et al.*, 2001
Ontario	upper-limit of background[a]	43 mg/kg (agricultural land use) 43 mg/kg (all other land uses)	MOE, 2004
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~5 to 35 mg/kg mean: ~15 mg/kg OTR_{98}: 32 mg/kg	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~3 to 55 mg/kg mean: ~15 mg/kg OTR_{98}: 38 mg/kg	MOEE, 1994
Canada	uncultivated, uncontaminated soils, remote from ore bodies	range: 5 to 50 mg/kg mean: 20 mg/kg	McKeague and Wolynetz, 1980
Appalachians (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=45	18 mg/kg	McKeague and Wolynetz, 1980
Canadian Shield	uncultivated, uncontaminated soils, remote from ore bodies, n=12	12 mg/kg	McKeague and Wolynetz, 1980
St. Lawrence Lowlands	uncultivated, uncontaminated soils, remote from ore bodies, n=40	18 mg/kg	McKeague and Wolynetz, 1980
Interior Plains (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=34	18 mg/kg	McKeague and Wolynetz, 1980
Cordillerans (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=19	40 mg/kg	McKeague and Wolynetz, 1980
Central and Southern Ontario	total nickel in 296 A horizon samples	mean: 24.98 µg/g range: 3 to 500 µg/g	Sharpe and Rasmussen, 1996
Central and Southern Ontario	total nickel in 296 C horizon samples	mean: 22.34 µg/g range: 4 to 87 µg/g	Sharpe and Rasmussen, 1996
Ottawa area	total nickel in 19 samples from 2 agricultural fields at depths of 0 to 20 cm	mean: 36 µg/g range: 26 to 46 µg/g	Wang, 2004
Ottawa area	total nickel in 20 samples from 2 agricultural fields at depths of 50 to 65 cm	mean: 72 µg/g range: 54 to 87 µg/g	Wang, 2004

[a] Value was derived from the Ontario Typical Range values and is representative of tge upper limits of typical province-wide background concentrations in soils that are not contaminated by point sources.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

Table C.56 Ontario and Canadian Background Nickel Concentrations in Dust

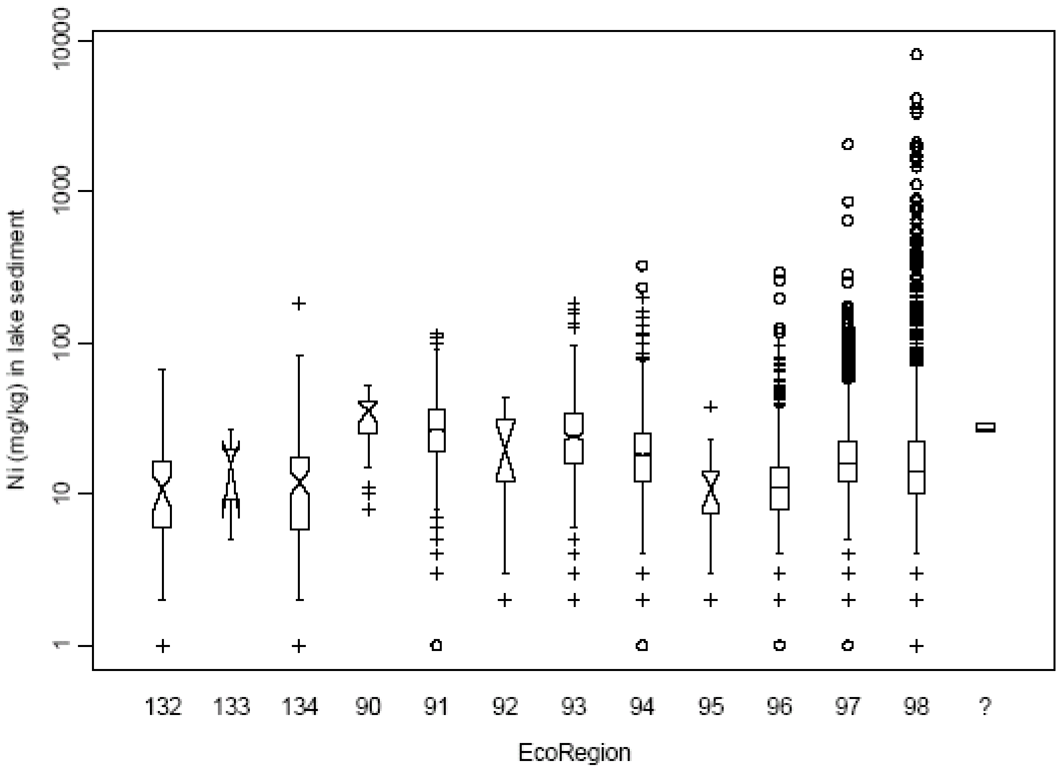
Location	Description	Concentration	References
Ottawa	household dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	53.6 mg/kg	Rasmussen *et al.*, 2001
Ottawa	street dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	14.8 mg/kg	Rasmussen *et al.*, 2001

The U.S. EPA (2003) compiled mean background concentrations of nickel in soil for each state, and reported values ranging from 3.8 mg/kg dry weight in New Jersey to 48 mg/kg dry weight in California. Generic background concentrations of nickel in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.57).

Table C.57 Generic Background Concentrations of Nickel in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	7 to 50	19.0
Chernozems and dark prairie soils	7 to 70	19.5
Clay and clay-loamy soils	5 to 50	20.5
Forest soils	7 to 100	22.0
Lateritic soils		
Light desert soils	7 to 150	22.0
Light loamy soils	5 to 200	22.0
Loess and soils on silt deposits	5 to 30	17.0
Low Humic Gley soils and humus groundwater podzols		
Organic light (or rich) soils	5 to 50	12.0
Sandy and lithosols on sandstone		
Silty prairie soils	<5 to 50	16.0
Soils on glacial till and drift	10 to 30	18.0
Soils on lacustrine deposits		
Soils over granites and gneisses	<5 to 50	18.5
Soils over limestones and calcareous rocks	<5 to 70	18.0
Soils over volcanic rocks (or ash)		
Various soils	<5 to 150	18.5
Western Alluvial soils		

An estimated upper limit for background variation in nickel levels in lake sediment is approximately 80 to 90 mg/kg (Garrett, 2005). Concentrations of nickel in sediments from lakes across Ontario are plotted in Figure C-10, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes; however it underestimates the full range of natural background when mineral occurrences are present in the region (Garrett, 2005). Reported background concentrations of nickel in sediment are provided in Table C.58.



EcoRegions:

90	Lac Seul Upland, n = 41
91	Lake of the Woods, n = 2,118
92	Rainy River, n = 29
93	Thunder Bay-Quetico, n = 1,483
94	Lake Nipigon, n = 3,003
95	Big Trout Lake, n = 27
96	Abitibi Plains, n = 2,045
97	Lake Timiskaming Lowland, n = 5,065
98	Algonquin-Lake Nipissing (includes Sudbury region), n = 4,279
132	St. Lawrence Lowlands, n = 71
133	Frontenac Axis, n = 10
134	Manitoulin-Lake Simcoe, n = 128
?	Unclassified, n = 3

Figure C-10 Tukey Boxplots, by EcoRegion in Ontario, of Nickel in Sediment from Deep Centre-lake Basins, below the Surface Gyttja

Table C.58 Ontario and Canadian Background Nickel Concentrations in Sediments

Location	Description	Concentration	References
Lake Ontario	surficial sediments sampled in 1998	range: 7.5 to 100.2 mg/kg	Marvin *et al*., 2003
Lake Ontario	pre-colonial background from deep sediments	43 mg/kg	Marvin *et al*., 2003
Lake Erie	surficial sediments, sampled in 1997 to 1998	range: 7.9 to 63.5 mg/kg	Painter *et al*., 2001
Lake Erie, West Basin	pre-colonial background from deep sediments	27.6 mg/kg	Painter *et al*., 2001
Lake Erie, Centre Basin	pre-colonial background from deep sediments	45.9 mg/kg	Painter *et al*., 2001
Lake Erie, East Basin	pre-colonial background from deep sediments	35.5 mg/kg	Painter *et al*., 2001
Ontario	Background Site Condition Standard	16 mg/kg	MOE, 2004
Lake Ontario	background sediments	42 to 48 µg/g	Murdoch *et al*., 1988
Lake Erie	background sediments	10 to 76 µg/g	Murdoch *et al*., 1988
Lake Huron	background sediments	30 to 51 µg/g	Murdoch *et al*., 1988
Lake Michigan	background sediments	20 µg/g	Murdoch *et al*., 1988
Lake Superior	background sediments	24 to 70 µg/g	Murdoch *et al*., 1988
Canada	background concentrations based on 70,000 samples collected over 20 years	range: 5 to 50 µg/g median: 15 µg/g	Friske, 1993

C-5.2.4 Background Concentrations in Biota and Foods

Reported background concentrations of nickel in fish are provided in Tables C.59. Background concentrations for other aquatic biota, aquatic plants and terrestrial biota were not found.

Table C.59 Ontario and Canadian Background Nickel Concentrations in Fish (Freshwater)

Location	Description	Concentration	References
Lake Erie (Wheatley and Port Stanley)	15 walleye collected in 1996	non-detect (DL = 0.02 mg/kg) in the majority of samples	Trivedi, 2004 pers. comm.
Lake Huron (French River)	20 walleye collected 1995 to 1996	0.052 mg/kg	Trivedi, 2004 pers. comm.
Lake Ontario (Bay of Quinte-Lennox)	42 walleye collected 1995 to 2002	non-detect (DL = 0.02 or 0.05 mg/kg) in the majority of samples	Trivedi, 2004 pers. comm.

Reported background concentrations of total nickel in Canadian foods are provided in Table C.60.

Table C.60 Typical Total Nickel Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Fish and seafood				
Fish and shellfish	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 37	JWEL, 2004
Fish	Canada, Montreal between 1986 and 1988	6 samples purchased	mean: 125[a] max: 232[a]	Dabeka and McKenzie, 1995
Fish and shellfish	1991 to 2002 Over 36 Cities across US	6459 total food samples	mean: 40 max: 105	U.S. FDA, 2004
Meat / poultry products				
Meat, poultry and eggs (w/ organ meats)	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 14.5 max: 31	JWEL, 2004
Meat, poultry and eggs (w/out organ meats	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 15.7 max: 31.0	JWEL, 2004
Meat and poultry	Canada, Montreal between 1986 and 1988	18 samples purchased	mean: 385[a] max: 2,521[a]	Dabeka and McKenzie, 1995
Meat, poultry and eggs	1991 to 2002 Over 36 Cities across US	6,459 total food samples	mean: 39 max: 116	U.S. FDA, 2004
Organ meats	1991 to 2002 Over 36 Cities across US	6,459 total food samples	mean: 1	U.S. FDA, 2004
Meat, fish and poultry	Canada, Winnipeg area in 1972	foods purchased	240	Kirkpatrick and Coffin, 1977
Milk and dairy products				
Milk and milk products	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 20.5 max: 91	JWEL, 2004
Milk and milk products	Canada, Montreal between 1986 and 1988	13 samples purchased	mean: 63[a] max: 323[a]	Dabeka and McKenzie, 1995
Milk and milk products	1991 to 2002 Over 36 Cities across US	6,459 total food samples	mean: 15 max: 101 (chocolate shake)	U.S. FDA, 2004
Milk and dairy	Canada, Winnipeg area in 1972	foods purchased	90	Kirkpatrick and Coffin, 1977

Table C.60 Typical Total Nickel Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Infant formula				
Milk based	Canada	ready to use	5.8 to 28.9 µg/L	Dabeka, 1989
Soy based	Canada	ready to use	31.2 to 187 µg/L	Dabeka, 1989
Infant formula	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 11 max: 23	U.S. FDA, 2004
Cereals, grains and baked goods				
Cereals, grains and baked goods	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 106[a] max: 320	JWEL, 2004
Bakery goods and cereals	Canada, Montreal between 1986 and 1988	24 samples purchased	mean: 256[a] max: 1,273[a]	Dabeka and McKenzie, 1995
Cereals, grains and baked goods	1991 to 2002 Over 36 Cities across U.S.	6459 total food samples	mean: 243 max: 2.270 (oat ring cereal)	U.S. FDA, 2004
Cereals	Canada, Winnipeg area in 1972	foods purchased	330	Kirkpatrick and Coffin, 1977
Fruits and fruit juices				
Fruits and fruit juices	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 30.9[a] max: 130	JWEL, 2004
Fruits and fruit juices	Canada, Montreal between 1986 and 1988	25 samples purchased	mean: 123[a] max: 505[a]	Dabeka and McKenzie, 1995
Fruits and fruit juices	1991-2002 Over 36 Cities across U.S.	6459 total food samples	mean: 85 max: 423	U.S. FDA, 2004
Garden fruits	Canada, Winnipeg area in 1972	foods purchased	540	Kirkpatrick and Coffin, 1977
Fruits	Canada, Winnipeg area in 1972	foods purchased	150	Kirkpatrick and Coffin, 1977
Root vegetables				
Potatoes	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 75[a]	JWEL, 2004
Root vegetables	1991-2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 91 max: 224	U.S. FDA, 2004

Table C.60 Typical Total Nickel Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Potatoes	Canada, Winnipeg area in 1972	foods purchased	180	Kirkpatrick and Coffin, 1977
Root vegetables	Canada, Winnipeg area in 1972	foods purchased	220	Kirkpatrick and Coffin, 1977
Other vegetables				
Other vegetables	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 173[a] max: 430	JWEL, 2004
All vegetables	Canada, Montreal between 1986 and 1988	38 samples purchased	mean: 195[a] max: 982[a]	Dabeka and McKenzie, 1995
Other vegetables	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 145 max: 698	U.S. FDA, 2004
Garden vegetables	Canada, 1 rural garden in Fredericton, NB	lettuce, beet tops, carrots and potatoes sampled	means: 500 to 1,500 (dw)	Pilgrim and Schroeder, 1997
Garden vegetables	Canada, 9 urban gardens in 2 New Brunswick cities	beet tops sampled	means: 1,200 to 3,100 (dw)	Pilgrim and Schroeder, 1997
Radishes	Canada, rural gardens in N. Manitoba	sampled	500 to 700	Yee, 2004
Garden produce	Canada, rural gardens in N. Manitoba	potatoes, carrots, turnips, strawberries, blueberries and mossberries sampled	<100	Yee, 2004
Leafy vegetables	Canada, Winnipeg area in 1972	foods purchased	190	Kirkpatrick and Coffin, 1977
Legumes	Canada, Winnipeg area in 1972	foods purchased	500	Kirkpatrick and Coffin, 1977

Table C.60 Typical Total Nickel Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Mixed foods				
Soups	Canada, Montreal between 1986 and 1988	4 samples purchased	mean: 291[a] max: 689[a]	Dabeka and McKenzie, 1995
Miscellaneous	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 101[a] max: 213[a]	Dabeka and McKenzie, 1995
Mixed foods and soups	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 131 max: 213	U.S. FDA, 2004
Fats and oils				
Fats and oils	Port Colborne	186 food samples (includes replicates and duplicates)	Range: 15 to 57	JWEL, 2004
Nuts and seeds	Port Colborne	186 food samples (includes replicates and duplicates)	Range: 31 to 2,000	JWEL, 2004
Fats and oils	Canada, Montreal between 1986 and 1988	3 samples purchased	mean: 566[a] max: 1,467[a]	Dabeka and McKenzie, 1995
Fats and oils	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 27 max: 91	U.S. FDA, 2004
Nuts	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 1,449 max: 3,030	U.S. FDA, 2004
Fats and oils	Canada, Winnipeg area in 1972	foods purchased	1,500	Kirkpatrick and Coffin, 1977
Sugars and sweets				
Sugars and Sweets	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 107[a] max: 310 (candy)	JWEL, 2004
Sugar and candies	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 143[a] max: 577[a]	Dabeka and McKenzie, 1995
Sugars and sweets	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 174 max: 979	U.S. FDA, 2004
Sugars	Canada, Winnipeg area in 1972	foods purchased	300	Kirkpatrick and Coffin, 1977

Table C.60 Typical Total Nickel Concentrations in Canadian Foods

Food Type	Location	Description	Concentration (ng/g ww)	Reference
Beverages				
Alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 11.5[a]	JWEL, 2004
Non-alcoholic beverages	Port Colborne	186 food samples (includes replicates and duplicates)	mean: 6.0[a]	JWEL, 2004
Beverages	Canada, Montreal between 1986 and 1988	7 samples purchased	mean: 16[a] max: 52[a]	Dabeka and McKenzie, 1995
Alcoholic beverages	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 8 max: 25	U.S. FDA, 2004
Non-alcoholic beverages	1991 to 2002 Over 36 Cities across U.S.	6,459 total food samples	mean: 10 max: 39	U.S. FDA, 2004
Drinks	Canada, Winnipeg area in 1972	foods purchased	140	Kirkpatrick and Coffin, 1977

[a] Stainless steel cookware was used extensively in the preparation and cooking of samples, and may have contributed to the reported nickel concentrations.

C-5.3 Estimated Canadian Daily Intakes

C-5.3.1 Dietary Intake

There is evidence that nickel may leach from new steel cooking pots and utensils during preparation of acidic foods (IARC, 1990), which may lead to increased nickel intake while the steel item is new. Concern has been expressed (*i.e.*, JWEL, 2004) with the interpretation of the nickel concentrations in the food analyzed in the Canadian Total Food Study (*i.e.*, Dabeka and McKenzie, 1995). The food samples were prepared using new stainless steel frying and roasting pans. Food was analyzed before and after cooking and the results indicated that significant nickel contamination occurred, particularly by roasting some of the meat samples (Dabeka and McKenzie, 1995). Jacques Whitford (JWEL, 2004) conducted an extensive literature review and a series of experiments to explore the role of cooking with stainless steel utensils on the leaching of nickel into food samples. Their review revealed that significant nickel is leached during cooking; however, this contamination decreases to negligible amounts after the first few uses of the utensil (JWEL, 2004). They also conducted a screening-level cooking study with a well-used stainless steel frying pan and ceramic pan. This study demonstrated that the foods were not contaminated by nickel during normal preparation and cooking (use of "well used" stainless steel pan) (JWEL, 2004). Thus, they concluded that contamination of the food items in the Dabeka and McKenzie (1995) study does not appropriately characterize the long term contribution of nickel to the general public from cooking using stainless steel utensils. Reported dietary intakes of nickel are provided in Table C.61.

Table C.61 Dietary Intake Rates of Nickel

Gender	Age	Intake Rate	Comments	Reference
Both	All	4.4 to 22.1 µg/kg/d	intake range for the general population, intake for infants greater than for adults	CEPA, 1994
Both	All	153 µg/d	dietary exposure of 176 participants in the NHEXAS Arizona study	O'Rourke *et al*., 1999
Male	>18 y	163 µg/d	dietary exposure of 55 participants in the NHEXAS Arizona study	O'Rourke *et al*., 1999
Female	>18 y	157 µg/d	dietary exposure of 86 participants in the NHEXAS Arizona study	O'Rourke *et al*., 1999
Both	<18 y	125 µg/d	dietary exposure of 35 participants in the NHEXAS Arizona study	O'Rourke *et al*., 1999
Both	All	0.374 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Both	Non-nursing Infants	0.870 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Both	1 to 6 y	0.669 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Both	7 to 12 y	0.425 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Male	13 to 19 y	0.324 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Male	20 to 54 y	0.342 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Male	≥55 y	0.369 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Female	13 to 19 y	0.281 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Female	20 to 54 y	0.350 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002
Female	≥55 y	0.368 µg/kg/d	intake rate for U.S. population using the DEPM model and data from the Combined National Residue Database	Moschandreas *et al*., 2002

C-5.3.2 Relative Contributions of Exposure Pathways to Total Exposure

The general population is exposed to nickel in ambient air, water and food (ATSDR, 2003a). The greatest source of exposure for the general population is through food (ATSDR, 2003a). Additional exposures (0.12 to 0.15 µg/kg/d) may be received through cigarette smoke (ATSDR, 2003a). Other potential sources of nickel exposure are contaminated intravenous fluids, dialysis, and leaching and corrosion of nickel from prostheses (ATSDR, 2003a).

The Windsor Air Quality Study found the following breakdown of inhalation exposure to trace metals: 60% from indoor air in the home, 18% from air in the office, and 22% from outdoor air (exposure while commuting was not considered) (Bell *et al.*, 1994).

C-5.4 Indices of Human Exposure

Sunderman (1993) concluded that serum and urine nickel levels are the most useful biomarkers of nickel exposure in humans. Reported background concentrations in various human tissues and fluids are provided in Table C.62.

Table C.62 Background Nickel Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Blood	Italy	Healthy Italian population	Range: 1.3 to 3.3 µg/L Mean: 2.3 µg/L	Minoia *et al.*, 1990
Blood	unknown	Mean reference values	<0.05 to 3.8 µg/L	Herber, 1999
Breast milk	Canada	milk collected from 43 mothers in the 1st 3 months of lactation in Newfoundland between 1988 and 93	0 to 28 µg/L	Friel *et al.*, 1999
Plasma	unknown	adults nonoccupationally exposed	< 10 µg/L	Hogetveit *et al.*, 1978
Plasma	unknown	not specified	0.3 to 0.6 µg/L	Versieck and Cornelis, 1989
Serum	unknown	levels in serum of 30 individuals not occupationally exposed	range: <0.05 to 1.05 µg/L mean: 0.34 µg/L	Barceloux, 1999b
Serum	unknown	average for the general population	0.2 µg/L	Templeton *et al.*, 1994

Table C.62 Background Nickel Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Serum	unknown	normal concentration	Range: 0.05 to 0.23 μg/L Mean: 0.14 μg/L	Nixon *et al.*, 1989
Serum	Italy	healthy Italian population	Range: 0.24 to 2.8 μg/L Mean: 1.2 μg/L	Minoia *et al.*, 1990
Serum	unknown	mean reference values	0.14 to 0.63 μg/L	Herber, 1999
Urine	unknown	levels in urine of individuals not occupationally exposed	<2 μg/L max: 9 to 10 μg/L	Barceloux, 1999b
Urine	unknown	average for the general population	1 to 3 μg/L	Templeton *et al.*, 1994
Urine	unknown	adults nonoccupationally exposed	<5 μg/L	Ader and Stoeppler, 1977
Urine	unknown	nonoccupationally exposed subjects	<2 μg/g creatinine	Oliveira *et al.*, 2000; Minoia *et al.*, 1990
Urine	unknown	mean reference values	0.9 to 3.2 μg/L	Herber, 1999
Fingernails	Japan, India, Canada and Poland		1.1 to 3.9 ppm	Takagi *et al.*, 1988
Hair	Japan, India, Canada and Poland		0.26 to 2.70 ppm	Takagi *et al.*, 1986

C-6.0 SELENIUM BACKGROUND EXPOSURE

C-6.1 Sources and Environmental Fate

C-6.1.1 Sources

Selenium is released into the environment from both natural and anthropogenic sources (ATSDR, 2003b). Natural sources of selenium releases to the environment include weathering of selenium-containing rocks, volcanic eruptions and microbial action (ATSDR, 2003b). The largest anthropogenic source of selenium releases is coal fly ash from the burning of coal (ATSDR, 2003b). Other human activities that result in selenium releases are oil combustion, selenium refining, base metal smelting and refining, mining and milling, end product (*e.g.,* semiconductors) manufacturing, and municipal solid waste incineration (ATSDR, 2003b).

C-6.1.2 Environmental Fate and Speciation in Environmental Media

Selenium is stable in the environment in four oxidations states (-2, 0, +4 and +6) and its behaviour in the environment is strongly influenced by its oxidation state, which is dependent in turn on environmental conditions such as pH, pE and biological activity (ATSDR, 2003b).

C-6.1.2.1 Atmosphere

The most common forms of selenium in air are selenium dioxide, methyl selenide and dimethyl selenide (ATSDR, 2003b). Hydrogen selenide is volatile and partitions into air, but it is so reactive in air that it is rapidly oxidized to elemental selenium by sulphur dioxide (ATSDR, 2003b; NAS, 1976b). Dimethyl selenide and methyl selenide are also volatile, but these species persist in the atmosphere (ATSDR, 2003b). Selenium compounds released to the atmosphere as particulates can be removed by both wet and dry deposition to soils or surface waters (ATSDR, 2003b).

C-6.1.2.2 Surface Water and Groundwater

Surface waters receive selenium *via* wet and dry deposition, surface runoff and subsurface drainage (ATSDR, 2003b). Both selenates (+6) and selenites (+4) are water soluble and can be found in natural waters, while neither the heavy metal selenides (-2) nor elemental selenium are water soluble (ATSDR, 2003b). Between pH 3.5 and 9 the principal selenite present is the diselenite ion, and the dominant selenate is SeO_4^{2-} (ATSDR, 2003b). Selenite can be rapidly reduced to elemental selenium under acidic conditions (NAS, 1980). Sodium selenate is highly water soluble and does not adsorb to particulates, therefore it is highly mobile in the aquatic environment (ATSDR, 2003b). Bacteria and cyanobacteria take up selenate from water by reducing it to elemental selenium, and they also transform soluble selenium species into volatile alkyl compounds (Bender *et al*., 1991).

C-6.1.2.3 Soils and Sediments

The level of selenium in soils is largely controlled by the selenium content of the parent rock materials (NAS, 1976a), although wet and dry deposition also contribute to selenium levels (ATSDR, 2003b). Heavy metal selenides and selenium sulfides predominate in acidic soils and in soils with high organic matter content (ATSDR, 2003b). They, along with elemental selenium, are insoluble and immobile in soil (ATSDR, 2003b; NAS, 1976b). Sodium and potassium selenites dominate in neutral, well-drained mineral soils (ATSDR, 2003b). In alkaline, well-oxidized soils, the highly mobile selenates are the major species (ATSDR, 2003b). In soils, microorganisms can methylate elemental selenium and inorganic selenium compounds (Doran, 1982; Fishbein, 1983; Shamberger, 1981). Microbially methylated compounds will partition into the atmosphere (ATSDR, 2003b).

C-6.1.2.4 Biota and Foods

Selenates and selenites are both soluble in water, are bioavailable and can be accumulated by plants; however, selenates are preferred over selenites, and are readily taken up by plants and converted into organic compounds (*e.g.,* selenomethionine, selenocysteine, dimethyl selenide and dimethyl diselenide) (ATSDR, 2003b; Baňuelos and Meek, 1990). Selenium bioaccumulates in aquatic organisms and may also biomagnify (ATSDR, 2003b).

The most important pathway for selenium exposure for the general public is food, followed by water, then air (ATSDR, 2003b). Selenium is a micronutrient and is found in many food items. Selenium supplements are available that generally contain 10 to 25 µg Se/tablet as inorganic selenium or selenomethionine, although some tablets with up to 200 µg/tablet are available (Goodman *et al*. 1990). In general, fish and seafood, and meats contain the highest concentrations of selenium, cereals have intermediate levels, and fruits and vegetables generally contain the lowest levels (ATSDR, 2003b). Brazil nuts contain extremely high levels of selenium since they grow in the foothills of the Andes Mountains, where the soils are high in selenium (Secor and Lisk, 1989).

C-6.2 Background Exposure Concentrations in Ontario and Canada

C-6.2.1 Background Concentrations in Air

Reported background concentrations of selenium in air are provided in Table C.63.

Table C.63 Ontario and Canadian Background Selenium Concentrations in Air

Location	Description	Concentration	References
Canada (rural)	annual arithmetic means of PM2.5 samples from 38 urban stations across Canada, 1994 to 2004	range: nd to 0.00870 μg/m^3 mean: 0.00116 μg/m^3	Dann, 2005 pers. comm.
Canada (urban)	annual arithmetic means of PM2.5 samples from 8 rural stations across Canada, 1994 to 2004	range: nd to 0.0292 μg/m^3 mean: 0.000947 μg/m^3	Dann, 2005 pers. comm.
Canada (urban)	median PM10 concentrations from 11 urban stations across Canada, 1986 to 1993	range: non-detect to 0.001 μg/m^3	CEPA/FPAC WGAQOG, 1999
Windsor, Ontario	indoor (home and office) samples of personal air taken 1991 to 1992	range: nd to 3.3 ng/m^3	Bell *et al*., 1994
Windsor, Ontario	outdoor (residential and commercial neighbourhoods) samples of personal air taken 1991 to 1992	range: nd to 5.2 ng/m^3 mean: 1.9 ng/m^3	Bell *et al*., 1994
Windsor, Ontario	6 samples of ambient air taken in 1992	range: 0.5 to 2.6 ng/m^3 mean: 1.2 ng/m^3	Bell *et al*., 1994
British Columbia	mean from 3 stations between 1997 and 1998	mean: 0.629 ng/m^3 range: 0 to 42.0 ng/m^3	Dryfhout-Clark, 2004, pers. comm
U.S.	estimated average concentration	<<10 ng/m^3	NAS, 1976a

C-6.2.2 Background Concentrations in Surface Water and Groundwater

Reported background concentrations of selenium in surface water, groundwater, drinking water and precipitation are provided in Table C.64 to C.66, respectively. Background concentrations of selenium in precipitation were not found.

Table C.64 Ontario and Canadian Background Selenium Concentrations in Fresh Surface Water

Location	Description	Concentration	References
Ontario	Mean levels in raw lake water from 90 sampling pts for 82 Ontario water works	range: nd to 9.0 µg/L mean: 0.88 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in raw river water from 51 sampling pts for 46 Ontario water works	range: nd to 9.0 µg/L mean: 0.88 µg/L	Clubb, 2005 pers. comm.

High selenium concentrations in water are more likely to occur in irrigation return waters, seeps, springs and shallow wells where seleniferous soils may contribute to the selenium content of water, and under unusual geologic conditions, selenium concentrations in groundwater may reach as high as 0.60 mg/L (ATSDR, 2003b; Glover *et al.*, 1979).

Table C.65 Ontario and Canadian Background Selenium Concentrations in Groundwater

Location	Description	Concentration	References
Ontario	Mean levels in raw ground water from 61 sampling pts for 55 Ontario water works	range: nd to 14.0 µg/L mean: 1.20 µg/L	Clubb, 2005 pers. comm.
Ontario	Background Site Condition Standards[a]	5 µg/L	MOE, 2004

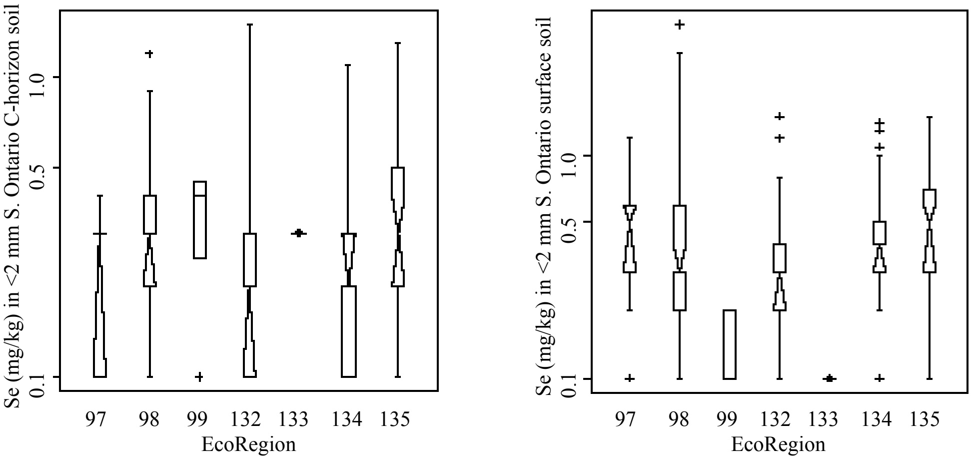
[a] The value selected for the Standard is within the range of measured groundwater data from the 1998 Drinking Water Surveillance Program, and is considered generally achievable in site situations typical of background.

Table C.66 Ontario and Canadian Background Selenium Concentrations in Drinking Water

Location	Description	Concentration	References
Ontario	Mean levels in drinking water from 89 sampling pts in the distribution systems of 54 Ontario water works drawing groundwater	range: nd to 19.9 µg/L mean: 1.36 µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 82 sampling pts in the distribution systems of 160 Ontario water works drawing lake water	range: nd to 8.5 µg/L mean: 1.11µg/L	Clubb, 2005 pers. comm.
Ontario	Mean levels in drinking water from 90 sampling pts in the distribution systems of 50 Ontario water works drawing river water	range: nd to 8.0 µg/L mean: 1.08µg/L	Clubb, 2005 pers. comm.

C-6.2.3 Background Concentrations in Soils and Sediment

Concentrations of selenium in soils from across Southern Ontario are plotted in Figure C-11, where the extent of the whiskers provides an estimate of background range for each EcoRegion that is not affected by outliers (+ near outlier; o far outlier) due to natural or anthropogenic processes (Garrett, 2005). Reported background concentrations of selenium in soil, dust and sediments are provided in Tables C.67 and C.68. Background selenium concentrations were not found for sediments.



EcoRegions:
97 Lake Timiskaming Lowland, n = 17
98 Algonquin-Lake Nipissing (includes Sudbury region), n = 112
99 Southern Laurentians, n = 3
132 St. Lawrence Lowlands, n = 30
133 Frontenac Axis, n = 1
134 Manitoulin-Lake Simcoe, n = 89
135 Lake Erie Lowlands, n = 42

Figure C-11 Tukey Boxplots, by EcoRegion in Southern Ontario, of Selenium in C-horizon (70-100 cm) and Surface (top 25 cm) Soils.

Table C.67 Ontario and Canadian Background Selenium Concentrations in Soil

Location	Description	Concentration	References
Ottawa	garden soil, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	0.6 mg/kg	Rasmussen *et al*., 2001
Ontario	upper-limit of background[a]	1.4 to 1.9 mg/kg	MOE, 2004
Ontario	Ontario Typical Range[b] - old urban parkland	OTR: ~0.125 to 2.5 mg/kg mean: ~0.5 mg/kg OTR_{98}: 1.3 mg/kg	MOEE, 1994
Ontario	Ontario Typical Range[b] - rural parkland	OTR: ~0 to 2 mg/kg mean: ~0.375 mg/kg OTR_{98}: 0.93 mg/kg	MOEE, 1994
Canada	uncultivated, uncontaminated soils, remote from ore bodies	range: 0.03 to 2 mg/kg mean: 0.26 mg/kg	McKeague and Wolynetz, 1980
Appalachians (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=45	0.24 mg/kg	McKeague and Wolynetz, 1980
Canadian Shield	uncultivated, uncontaminated soils, remote from ore bodies, n=12	0.18 mg/kg	McKeague and Wolynetz, 1980
St. Lawrence Lowlands	uncultivated, uncontaminated soils, remote from ore bodies, n=40	0.24 mg/kg	McKeague and Wolynetz, 1980
Interior Plains (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=34	0.31 mg/kg	McKeague and Wolynetz, 1980
Cordillerans (Canada)	uncultivated, uncontaminated soils, remote from ore bodies, n=19	0.30 mg/kg	McKeague and Wolynetz, 1980

[a] Value was derived from the Ontario Typical Range values and is representative of the upper limits of typical province-wide background concentrations in soils that are not contaminated by point sources.

[b] Ontario Typical Ranges (OTRs) represent the expected range of concentrations of contaminants in surface soil from areas in Ontario not subjected to the influence of known point sources of emissions. The OTR_{98} represents an upper limit of normal. OTR and mean values were estimated from graphs. These values apply to the land use and soil type in Ontario for which they were developed. The soil type is all soils except loamy sand, sand and soils with organic carbon content >17%.

Table C.68 Ontario and Canadian Background Selenium Concentrations in Dust

Location	Description	Concentration	References
Ottawa	household dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	1.0 mg/kg	Rasmussen *et al*., 2001
Ottawa	street dust, n=50, collected winter 1993 from 10 Ottawa neighbourhoods	0.4 mg/kg	Rasmussen *et al*., 2001

In the U.S., reported state mean background concentrations of selenium in soil range from 0.2 mg/kg (California) to 1.9 mg/kg (Massachusetts) (U.S. EPA, 2003). Generic background concentrations of selenium in soil based on soil type were compiled by Kabata-Pendias and Pendias (1985) and are presented as generic values that may be applied to any area of the U.S. (RAIS, 2004) (see Table C.69).

Table C.69 Generic Background Concentrations of Selenium in Soil by Soil Type (Kabata-Pendias and Pendias, 1985)

Soil Type	Range (ppm)	Mean (ppm)
Alluvial soils	<0.1 to 2.0	0.5
Chernozems and dark prairie soils	<0.1 to 1.2	0.4
Clay and clay-loamy soils	<0.1 to 1.9	0.5
Forest soils	<0.1 to 1.6	0.4
Lateritic soils	0.02 to 2.5	1.05
Light desert soils	<0.1 to 1.1	0.5
Light loamy soils	0.02 to 1.2	0.33
Loess and soils on silt deposits	0.02 to 0.7	0.26
Low Humic Gley soils and humus groundwater podzols	--	--
Organic light (or rich) soils	<0.1 to 1.5	0.3
Sandy and lithosols on sandstone	--	--
Silty prairie soils	<0.1 to 1.0	0.3
Soils on glacial till and drift	0.2 to 0.8	0.4
Soils on lacustrine deposits	--	--
Soils over granites and gneisses	<0.1 to 1.2	0.4
Soils over limestones and calcareous rocks	0.1 to 1.4	0.19
Soils over volcanic rocks (or ash)	--	--
Various soils	<0.1 to 4.0	0.31
Western Alluvial soils	--	--

C-6.2.4 Background Concentrations in Biota and Foods

Reported background concentrations of selenium in terrestrial biota are provided in Tables C.70. Background concentrations in other biota were not found.

Table C.70 Ontario and Canadian Background Selenium Concentrations in Terrestrial Biota

Type	Genus	Description	Concentration	Reference
Primary accumulator	*Astragalus* *Oonopsis* *Stanelya* *Xylorhiza* *Machaeranthera*	grasses and herbaceous plants that accumulate Se	100 to 100,000 mg/kg dw	Rosenfeld and Beath, 1964

Table C.70 Ontario and Canadian Background Selenium Concentrations in Terrestrial Biota

Type	Genus	Description	Concentration	Reference
Secondary accumulator	*Astor* *Gatierreaia* *Atriplex* *Grindelia* *Castillaja* *Comandra*	grasses and herbaceous plants that accumulate Se to a lesser degree	25 to 100 mg/kg dw	Rosenfeld and Beath, 1964
Non-accumulator	--	most other plants	<25 mg/kg dw	Rosenfeld and Beath, 1964

In general, meats contain the highest concentrations of selenium, cereals have intermediate levels, and fruits and vegetables generally contain the lowest levels (ATSDR, 2003b). Reported background concentrations of selenium in Canadian foods are provided in Table C.71.

Table C.71 Typical Selenium Concentrations in Canadian Foods

Food Type	Location	Description	Concentration	Reference
Fish and seafood				
Fish and seafood	U.S., 1991 to 2004	mean of fish and seafood samples collected; 5 different foods	mean: 388 ng/g ww[a]	U.S. FDA, 2004
Meat / poultry products				
Meat, poultry and eggs	U.S., 1991 to 2004	mean of meat *etc*. samples collected; 23 different foods	mean: 268 ng/g ww[a]	U.S. FDA, 2004
Milk and dairy products				
Dairy	U.S., 1991 to 2004	mean of dairy samples collected; 17 different foods	mean: 64 ng/g ww[a]	U.S. FDA, 2004
Infant formula	U.S., 1991 to 2004	mean of dairy samples collected; 2 different foods	mean: 20 ng/g ww[a]	U.S. FDA, 2004
Cereals, grains and baked goods				
Cereals, grains and baked goods	U.S., 1991 to 2004	mean of cereal *etc*. samples collected; 33 different foods	mean: 130 ng/g ww[a]	U.S. FDA, 2004
Fruits and fruit juices				
Fruit and fruit juices	U.S., 1991 to 2004	mean of fruit samples collected; 28 different foods	mean: 0.8 ng/g ww[a]	U.S. FDA, 2004
Root vegetables				
Root vegetables	U.S., 1991 to 2004	mean of root vegetable samples collected; 16 different foods	mean: 3.2 ng/g ww[a]	U.S. FDA, 2004

Table C.71 Typical Selenium Concentrations in Canadian Foods

Food Type	Location	Description	Concentration	Reference
Other vegetables				
All types of vegetables	U.S., 1991 to 2004	mean of vegetables samples collected; 45 different foods	mean: 10 ng/g ww[a]	U.S. FDA, 2004
Fats and oils				
Fats, oils and peanuts	U.S., 1991 to 2004	mean of samples collected; 9 different foods	mean: 28 ng/g ww[a]	U.S. FDA, 2004
Sugars and sweets				
Sugar, desserts and candy	U.S., 1991 to 2004	mean of samples collected; 24 different foods	mean: 29 ng/g ww[a]	U.S. FDA, 2004
Beverages				
Alcoholic beverages	U.S., 1991 to 2004	means of samples collected; 4 different foods	mean: 0.8 ng/g ww[a]	U.S. FDA, 2004
Non-alcoholic beverages	U.S., 1991 to 2004	means of samples collected; 9 different foods	mean: 0.6 ng/g ww[a]	U.S. FDA, 2004
Other				
Mixed foods (*e.g.*, soup, casserole, pizza)	U.S., 1991 to 2004	mean of mixed food samples collected; 28 different foods	mean: 120 ng/g ww[a]	U.S. FDA, 2004

[a] Analyses were performed on foods that prepared as they would be consumed (*i.e.*, table-ready foods).

Means were calculated from raw data in original study.

Selenium is not one of the elements evaluated in the Canadian Total Diet study; therefore, U.S. data were reported.

C-6.3 Estimated Canadian Daily Intakes

C-6.3.1 Dietary Intake

The RDA for selenium is 0.055 mg/d for men and women (NAS, 2000). Selenium supplements are available that generally contain 10 to 25 µg Se/tablet as inorganic selenium or selenomethionine, although some tablets with up to 200 µg/tablet are available (Goodman *et al*., 1990). Reported dietary intake rates of selenium are provided in Table C.72.

Table C.72 Dietary Intake Rates of Selenium

Gender	Age	Intake Rate	Comments	Reference
Both	All	114 µg/d	Intake rate for U.S. population based on NHANES III (data collected 1988 to 1994)	U.S. DHHS, 2002
Male	<6 y	134 µg/d		
Male	6 to 11 y	102 µg/d		
Male	12 to 19 y	140 µg/d		
Male	20 to 59 y	153 µg/d		
Male	≥60 y	118 µg/d		
Female	<6 y	94 µg/d		
Female	6 to 11 y	90 µg/d		
Female	12 to 19 y	93 µg/d		
Female	20 to 59 y	102 µg/d		
Female	≥60 y	87 µg/d		

C-6.3.2 Relative Contributions of Exposure Pathways to Total Exposure

The most important pathway for selenium exposure for the general public is food, followed by water, then air (ATSDR, 2003b). For workers in the metals industry, health services, mechanics and painters, occupational exposure to selenium may be more important than exposure *via* other routes (ATSDR, 2003b).

The Windsor Air Quality Study found the following breakdown of inhalation exposure to trace metals: 60% from indoor air in the home, 18% from air in the office, and 22% from outdoor air (exposure while commuting was not considered) (Bell *et al*., 1994).

Children are exposed to selenium by the same pathways as adults, the primary source of exposure being food (ATSDR, 2003b).

C-6.4 Indices of Human Exposure

Although the biological significance of selenium in the blood and urine is not yet fully established, monitoring selenium levels in human biological tissues may indicate exposure (Lauwerys and Hoet, 2001). Selenium concentration in the plasma (or serum) and urine reflect short-term exposure, while erythrocyte concentrations reflect intake over a 120 day period. Whole blood may be representative of long-term exposure as under normal exposure selenium is found at higher concentrations in the erythrocytes (Lauwerys and Hoet, 2001). Reported background concentrations of selenium in various human tissues and fluids are provided in Table C.73.

Table C.73 Background Selenium Concentrations in Human Biological Tissues and Fluids

Tissue or Fluid Type	Location	Description	Concentration	References
Blood	U.S.	levels in whole blood of residents from 19 U.S. cities	range: 0.10 to 0.34 mg/L mean: 0.21 mg/L	Barceloux, 1999c
Blood	U.S	estimated levels in serum based on data collected 1988 to 1994 in NHANES III	Males all ages: 0.126 mg/L 12 to 19 y: 0.121 mg/L 20 to 59 y: 0.127 mg/L ≥60 y: 0.126 mg/L Females all ages: 0.123 mg/L 12 to 19 y: 0.121 mg/L 20 to59 y: 0.123 mg/L ≥60 y: 0.125 mg/L	U.S. DHHS, 2002
Blood	South Dakota (U.S.)	mean value	221 to 640 µg/L	Whanger *et al.*, 1988
Blood	South Dakota and Wyoming (U.S.)	mean value	187 to 560 µg/L	Swanson *et al.*, 1990
Blood	Belgium	Belgian subjects	33 to 181 µg/L	Lauwerys, 1999
Hair	U.S	general population	0.57 ± 0.4 µg/g	ATSDR, 1989
Serum	various locations	nonoccupationally exposed subjects	15 to 360 µg/L	Alfthan and Neve, 1996
Serum/Plasma	Italy	Italian healthy population	56 to 106 µg/L	Minoia *et al.*, 1990
Toenails	unknown	mean concentrations	0.78 ± 0.17 ppm	Bukkens *et al.*, 1990
Toenails	unknown	mean concentrations	12 µg/g	Swanson *et al.*, 1990
Toenails	unknown	mean concentrations	1.5 ± 0.55 µg/g	Longnecker *et al.*, 1996
Urine	unknown	unoccupationally exposed subjects	1 to 200 µg/L	Lauwerys, 1999
Urine	unknown	normal concentrations	< 30 µg/L	Robberecht and Deelstra, 1984
Urine	Italy	healthy Italian population	2.1 to 30.9 µg/L	Minoia *et al.*, 1990

C-7.0 REFERENCES

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