SUDBURY AREA RISK ASSESSMENT

CHAPTER 9.0
REGIONAL DISTRIBUTION OF CHEMICALS OF CONCERN IN THE STUDY AREA

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9.0 REGIONAL DISTRIBUTION OF CHEMICALS OF CONCERN IN THE STUDY AREA

9.1 Overview of Distribution of the Chemicals of Concern in Surface Soils

A primary objective of the regional soil survey was to measure the spatial distribution (geographic area) of metals in surface (0 to 5 cm) soils to determine the potential "footprint" of particulate airborne emissions from the Sudbury smelters. The analytical methods and detection limits for the 2001 Soils Study were described in Chapter 7. Comments on the distribution of the COC are provided below.

A series of maps are provided that illustrate the concentration of each of the COC (As, Co, Cu, Ni, Pb, Se) in surface soils to a distance of approximately 20 km from the smelter centres. Although the actual soil sampling extended over a vast area approximately 200 km x 200 km, the major influence of the smelters is much more localized. The CEM (2004) report suggested that the concentrations of individual metals along a concentration gradient indicated the effects of smelter emissions relative to regional background approximately 120 km from downtown Sudbury. Detailed maps illustrating the wider patterns and extent of soil metal distribution are provided in the CEM (2004) report.

In general, elevated concentrations of metals were centred on the three historic smelting centres of Coniston, Copper Cliff and Falconbridge. This is clearly illustrated in Figures 9-1 to 9-6.

For illustrative purposes in the soil distribution maps (Figures 9-1 to 9-6), computer-based approaches to show "soil contours" of metal concentration have intentionally not been used. There are several approaches available (*e.g.,* kriging) whereby the computer can generate soil metal contours via interpolation and extrapolation of the available data. While these approaches do provide visually appealing maps and may be useful to demonstrate general trends (*i.e.,* as in the CEM 2004 report), the resultant maps can also be somewhat misleading. For example, broad areas between sampling locations may or may not contain the same metal concentrations as their "neighbour" samples.

Therefore, we have chosen to map each individual soil sample location, and colour code the sample with individual colours representing a different range of concentrations depending on the particular element. In general, metal concentrations less than the MOE Table A criteria values for residential land use and coarse soils are shown with round white symbols. As the concentration increases, the symbol colour changes from yellow, to green, to orange and finally to purple. The exceptions to this colour scheme are Pb and Se, where only samples > Table A are shown in purple. The symbols also increase slightly in size with increasing concentration to emphasize the trends. There is a different range of concentrations for each element.

Arsenic

The distribution of As is illustrated in Figure 9-1. It is apparent that large portions of the Sudbury area between the smelters of Copper Cliff and Falconbridge contain soils with As concentrations <20 mg/kg (Table A value for residential land use and coarse soils). This may be attributed to residents importing, vertically mixing or amending soil in their yards. This pattern also appears for the other COC. Soils containing As concentrations between 20 to 50 mg/kg are also widespread throughout the study area. Soils with As values between 50 to 200 mg/kg (orange symbols) are relatively localized within a few kilometres of the smelters. Soils with As levels more than 200 mg/kg (10x the Table A value) occur only in the town of Falconbridge.

Cobalt

Elevated concentrations of Co in surface soils are not widely distributed throughout the study area (Figure 9-2). Soils with Co concentrations above Table A for residential land use and coarse soils are primarily confined to the immediate vicinity of the three smelting centres of Copper Cliff, Coniston and Falconbridge.

Copper

The soil concentrations of Cu are elevated above Table A for residential land use and coarse soils over a relatively wide area (Figure 9-3). As for arsenic, many locations within the City Centre have Cu levels below Table A. This can likely be attributed to importing, amending or vertically mixing soils in residential or park properties. Soils with copper concentrations up to 1000 mg/kg (green symbols) are distributed up to 20 to 25 km from the smelting centres in a south-east direction (*i.e.*, primary downwind). Copper concentrations over 2000 mg/kg are confined to the immediate vicinity of the Copper Cliff and Falconbridge smelters.

Nickel

The distribution of Ni levels in surface soils very closely resembles the pattern of Cu (Figure 9-4). As for arsenic, many locations within the City Centre have Ni levels below Table A for residential land use and coarse soils. This can likely be attributed to importing, amending or vertically mixing soils in residential or park properties.

Lead

The distribution of Pb in surface soils is somewhat more patchy than the other elements (Figure 9-5). Soils containing Pb above Table A for residential land use and coarse soils (200 mg/kg) are primarily confined to the three smelting centres, with the largest density of these samples in close proximity to the Copper Cliff smelter. This issue is discussed in much more detail in Appendix D (Lead as a COC) of this Volume. However, there are a couple of samples containing Pb above 200 mg/kg in the City Centre. These elevated soil samples may be due to smelting activities or possibly other sources of Pb. Samples containing 100 – 200 mg/kg are primarily situated between the smelting centres, with samples containing 50-100 mg/kg being more widespread.

Selenium

The soil concentrations of Se are generally low throughout the study area (Figure 9-6). The primary exception is soil samples in the immediate vicinity of Copper Cliff which are elevated above the Table A value for residential land use and coarse soils (10 mg/kg).

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Figure 9-1 Regional Distribution of Arsenic in 2001 Soil Samples

Soil Depth 0-5 cm

Falconbridge

Coniston

Copper Cliff

144

17

69

N

W

E

S

Greater Sudbury Boundary

Arsenic Concentration (mg/kg)

- < 20 (MOE Table A Guideline)
- 20 - 50
- 50 -200
- > 200

Scale 1:160,000

0 *5 Km*

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Figure 9-2 Regional Distribution of Cobalt in 2001 Soil Samples

Soil Depth 0-5 cm

Falconbridge

Coniston

Copper Cliff

144

17

69

N

W

E

S

Greater Sudbury Boundary

Cobalt Concentration (mg/kg)

- < 40 (MOE Table A Guideline)
- 40 - 80
- 80 - 150
- > 150

Scale 1:160,000

0 *5 Km*

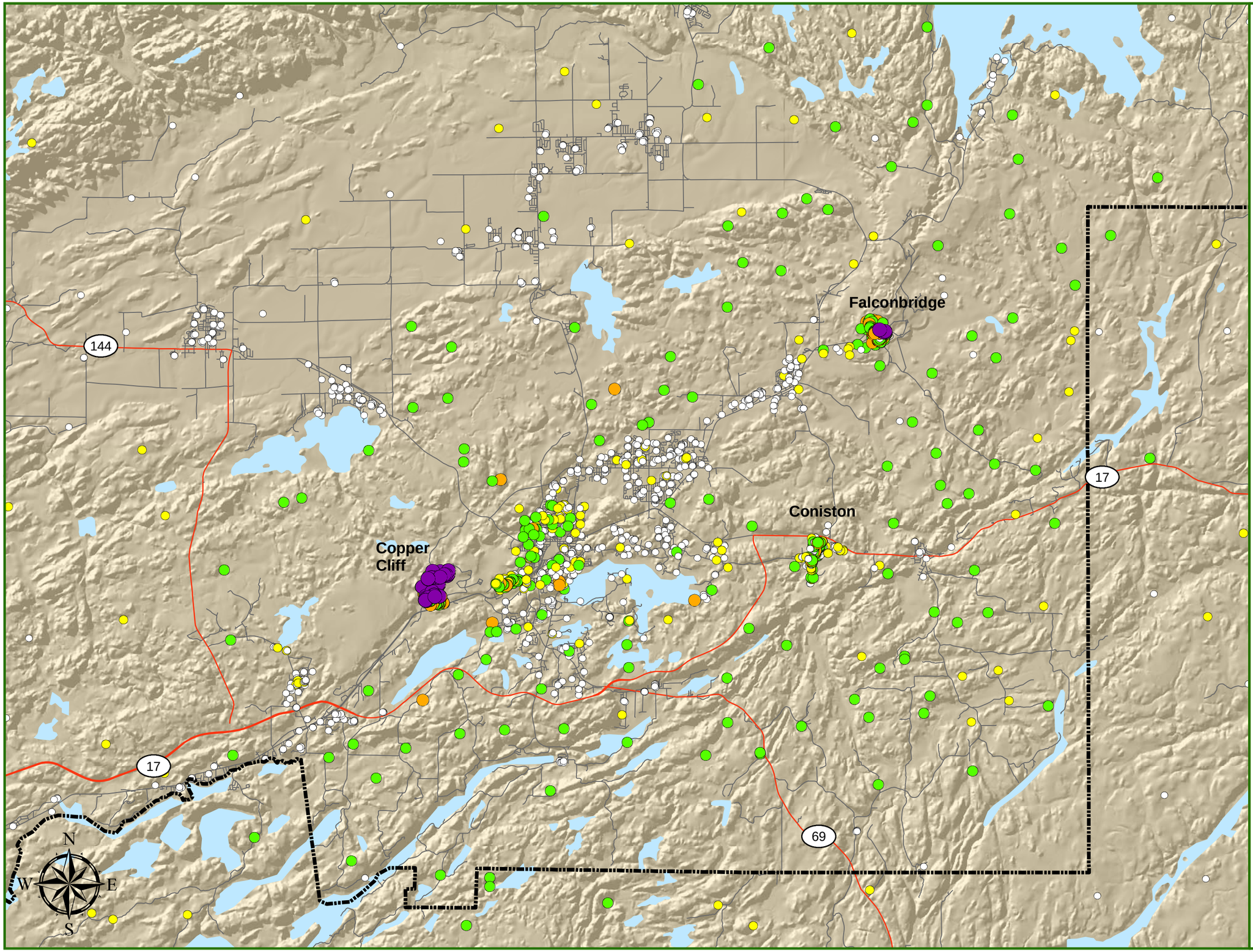

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Figure 9-3 Regional Distribution of Copper in 2001 Soil Samples

Soil Depth 0-5 cm

Greater Sudbury Boundary

Copper Concentration (mg/kg)

- < 150
- 150 - 300
- 300 - 1000
- 1000 - 2000
- > 2000

(MOE Table A Guideline is 225 mg/kg)

Scale 1:160,000

0 — *5 Km*

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Figure 9-4 Regional Distribution of Nickel in 2001 Soil Samples

Soil Depth 0-5 cm

Falconbridge

Copper Cliff

Coniston

144

17

17

69

Greater Sudbury Boundary

Nickel Concentration (mg/kg)

- < 150 (MOE Table A Guideline)
- 150 - 300
- 300 - 1000
- 1000 - 2000
- > 2000

N
W
E
S

Scale 1:160,000

0 *5 Km*

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Figure 9-5 Regional Distribution of Lead in 2001 Soil Samples

Soil Depth 0-5 cm

Falconbridge

Copper Cliff

Coniston

144

17

17

69

N

W

E

S

Greater Sudbury Boundary

Lead Concentration (mg/kg)

- < 50
- 50 - 100
- 100 - 200
- > 200 (MOE Table A Guideline)

Scale 1:160,000

0 *5 Km*

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Figure 9-6
Regional Distribution of Selenium in 2001 Soil Samples

Soil Depth 0-5 cm

Falconbridge

Coniston

Copper Cliff

144

17

69

N

W

E

S

Greater Sudbury Boundary

Selenium Concentration (mg/kg)

- < 5
- 5 - 10
- > 10 (MOE Table A Guideline)

Scale 1:160,000

0 *5 Km*

9.2 Background Soil Metal Levels

As part of the 2001 regional soil survey, the CEM also sampled soils to a depth of greater than 80 cm wherever possible to obtain samples assumed to be unaffected by recent industrial activities (CEM, 2004). These parent material samples were collected from 70% (254) of the sites visited during the rural/remote sampling program. Approximately 254 samples at depth were collected, representing the first known attempt to establish pre-industrial levels of metals in Sudbury regional soils (CEM, 2004).

Table 9.1 Summary of the concentration of major and trace elements in parent soil materials (n = 254)

Parameter	Arithmetic Mean	Range	95th UCL	Standard Error	Standard Deviation	Shield Soils[(a)]	MOE Table F[(b)]
			(%)				
Al	1.78	0.21 - 9.1	1.9	0.067	1.07	6.7	NG
Ca	0.78	0.1 - 5.8	0.8	0.067	1.11	1.8	NG
Fe	2.27	0.21 - 7.8	2.4	0.068	1.09	2.5	NG
Mg	0.67	0.04 - 3.8	0.7	0.034	0.54	0.53	NG
			(mg/kg)				
As	1.11	<dl - 98	4.1	n/a	6.5	n/a	17
Ba	98.4	13 - 390	120.4	n/a	80.5	n/a	NG
Be	0.15	<dl - 1.1	0.4	n/a	0.2	n/a	NG
Cd	<dl	<dl	<dl	n/a	n/a	n/a	1
Cr	56.4	12 - 130	59.1	1.63	26.04	19	71
Co	8.9	2 - 38	9.5	0.29	4.64	19	21
Cu	26.4	<dl - 270	28.8	1.73	27.65	12	85
Mn	293	23 - 1800	342.9	11.35	180.8	417	NG
Mo	0.11	<dl - 3.1	0.8	0.03	0.46	n/a	2.5
Ni	36.1	8.5 - 163	41.9	1.32	21.0	12	43
Pb	5.9	1 - 47	7	0.24	3.85	20	120
Se	0.06	<dl - 2	0.06	0.02	0.31	0.18	1.9
Sr	43.8	11 - 80	45.7	1.08	17.27	n/a	NG
V	43.3	6.7 - 220	47.4	1.29	20.61	n/a	91
Zn	29.7	5.4 - 160	31.9	1.16	18.5	57	160
pH (n = 35)	5.6	3.7 – 7.8	NC	0.15	0.9	n/a	n/a

Based on values for 254 samples; pH reported for subset of 35 samples; data from CEM (2004)
NG = no guideline available
NC = not calculated
n/a = not available
<dl = below detection limit
(a) Values for soils of the Canadian Shield (McKeague *et al.* 1979)
(b) Table F considered Ontario background concentrations

The concentration of Cd was below the method detection limit for all soil samples collected at depth. Summary statistics for the COC in parent material samples are provided in Table 9.2. It is noteworthy that concentrations of Cu, Ni and As in some samples exceeded the generic Table A criteria for residential land use and coarse soils. Otherwise, the concentrations of these elements in the deeper soils representing parent material were generally quite low.

Table 9.2 Summary of total COC levels (mg/kg) in parent material samples (n = 254 sites) from the Sudbury region

	As	Co	Cu	Ni	Pb	Se
Range	<dl - 98	2 - 38	<dl - 270	8.5 - 163	1 - 47	<dl - 2
Mean	1.11	8.9	26.4	36.1	5.9	0.06
95th UCL	4.1	9.5	28.8	41.9	7	0.06

Based on values for 254 sample sites; data from CEM (2004)
<dl = below minimum detection limit

Table 9.3 provides a summary of mean metal concentration by soil depth for samples collected under the regional soil survey. The results are consistent with the MOE findings in that the surface (0 to 5 cm) soil layer contained, on average, higher concentrations of each of the six COC (see also Section 9.3). This indicates atmospheric deposition as the likely major contributor of metals to the soils in the Sudbury area.

Another approach to determine if a metal concentration was derived from natural or anthropogenic (human) sources is the calculation of an Enrichment Factor (EF). The EF is a ratio of the metal concentration normalized against aluminium as a reference element. Aluminium was selected as it is relatively immobile in the soil and there is no indication that industrial sources contributed to aluminium in Sudbury soils (CEM, 2004). An EF from 0.5 to 2.0 was considered within the range of normal variability, while EFs above 2.0 may be considered indicative of anthropogenic input.

The data provided in Table 9.3 suggest that at least five of the COC; As, Cu, Ni, Pb, and Se, demonstrate EFs in surface soil considerably greater than 2.0.

Table 9.3 Mean concentration (mg/kg) of metals from all layers of all sites sampled, along with calculated enrichment factor (EF).

Depth	As	Co	Cu	Ni	Pb	Se
0 - 5 cm	14.81	12.45	261.4	263.1	49.98	2.19
5 - 10 cm	9.72	7.17	101.2	81.5	14.96	0.60
10 - 20 cm	3.80	7.30	49.7	50.6	8.90	0.17
EF (C– 0-5)	13.3	1.4	9.9	7.3	8.5	37.1

Comparison with MOE Table A and Table F values

Additional summary statistics for the parent material samples are provided in Table 9.4. The 95th percentile represents the value in the dataset that exceeds 95% of the samples, and is less than 5% of the samples, when data are arranged from lowest to highest. The parent material summary statistics are compared with MOE Table A values for residential land use and coarse soils and Table F values for all land uses other than agriculture. Table F values are generally considered to represent 'background' concentrations of chemicals in Ontario soils, and are based on the Ontario Typical Ranges for soils (MOEE, 1993).

Table 9.4 Comparison of MOE Table A and Table F values with Sudbury parent soil material summary results (mg/kg).

Parameter	Table A[(a)]	Table F[(b)]	Sudbury Parent Material[(c)]	
			Average	95th UCL
Al	NV	NV	1,7800	35,350
As	20	17	1.11	6
Ba	750	210	98.4	260
Be	1.2	1.2	0.15	0.8
Cd	12.0	1.0	<mdl	<mdl
Ca	NV	NV	780	11,700
Cr	750	71	56.4	100
Co	40	21	8.9	17
Cu	225	85	26.4	60
Fe	NV	NV	2,270	40,000
Pb	200	120	5.9	11
Mg	NV	NV	670	14,000
Mn	NV	NV	293	597
Mo	40	2.5	0.11	1.5
Ni	150	43	36.1	66
Se	10	1.9	0.06	NV
Sr	NV	NV	43.8	68.7
V	200	915	43.3	76
Zn	600	160	29.7	61.4

NV indicates no value or criterion

<mdl = below minimum detection limit

(a) Table A: for potable water, residential land use and coarse soils; applicable to surface soils with pH range of 5.0-9.0, and subsurface soils with pH range of 5.0-11.0 (MOE, 1997)

(b) Table F: Ontario background soil concentrations for land uses other than agriculture (MOE, 1997)

(c) Data from CEM (2004). Sample size = 254

The soils in the Sudbury region are formed on primarily coarse textured tills and glaciofluvial materials which are mineralogically dominated by quartz and feldspars, with minor amounts of heavy and clay minerals. As the heavy and clay mineral fraction are the sources for the metals of interest to the current studies, it is not surprising to observe that both the mean concentration and 95th percentile of most elements measured in the parent material are less than the generic Ontario background level (Table F values). In fact, the only two elements that have 95th percentile values greater than Table F are Cr and Ni, perhaps reflecting some incorporation of local metal-rich bedrock in the glacial detritus of the soil parent materials.

Although the bedrock in the Sudbury basin is known to be locally highly mineralized, this is not reflected in higher background soil concentrations relative to the Ontario generic criteria, possibly because of dilution with upstream rock materials due to glaciation. Further, the base metal-rich mineral phases hosted in the sulphide-rich units of the regional bedrocks are relatively soft, and may thus have been finely comminuted and dissolved from the surficial materials as a result of glacial activity and weathering. In fact, the true natural "background" surface soil metal concentrations in the mineralized areas of the Sudbury basin are similar to those documented in other regions of the Canadian Shield region. Further detailed discussion of the parent material methodology, results and interpretation are provided in CEM (2004). The results of the parent material analysis and comparison with Table F indicate that background metal concentrations in the Sudbury area are not higher than levels considered as background for other parts of Ontario.

9.3 Vertical Metal Profiles in Urban Soils

To examine evidence of atmospheric deposition of metals from the smelters, the MOE collected soil core profiles at 14 undisturbed locations in the Sudbury area. Undisturbed areas were chosen because development and landscaping in urban areas have altered most soils, both physically and chemically, through the processes of adding, grading, removing, mixing and/or other activities that may have occurred repeatedly over time. Undisturbed soils provide a better picture of atmospheric deposition.

The results are presented in Table 9.5. The data show that the highest concentrations of each of the six COC occur within the surface (0 to 5 cm) layer, and generally decrease with depth. This information indicates that atmospheric deposition is the likely prominent source of metals to soils in the study area.

Table 9.5 Mean metal concentrations (mg/kg)* in urban-undisturbed natural soil profiles (n = 14 samples per depth)

Soil depth (cm)	As	Co	Cu	Ni	Pb	Se
0-5	29	37	660	983	63	1.9
5-10	8.9	13	168	191	18	1.0
10-20	3.5	10	52	69	8	0.7

n = number of samples collected

9.4 Conclusion

The data in the three accompanying reports provide detailed analytical results for 20 inorganic parameters from about 8,400 samples from almost 1,200 locations, making it one of the most comprehensive soil surveys conducted in Canada. The data show localized areas containing elevated soil levels of six parameters; namely arsenic, cobalt, copper, nickel, lead and selenium. These areas are generally centered on the City of Greater Sudbury in the vicinity of the three smelting centres of Copper Cliff, Coniston and Falconbridge. Concentrations of the elements are generally higher in surface soils (0 to 5 cm) than deeper soil layers, indicating that atmospheric deposition from the smelters is the primary source of metals to the soils.

The soils data and other information will be incorporated into the ongoing human health and ecological risk assessments being conducted as part of the Sudbury Soils Study. These risk assessments are designed to determine if metal levels in the Sudbury environment pose unacceptable risk to either humans or ecological receptors (*e.g.*, plants and wildlife) in the area.

9.5 References

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