SUMMARY REPORT:
2001 SUDBURY SOILS DATA

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ABBREVIATIONS

CEM Centre for Environmental Monitoring, Laurentian University

COC Chemical of Concern

EC Environment Canada

MOE Ontario Ministry of the Environment

As Arsenic

Co Cobalt

Cu Copper

Pb Lead

Ni Nickel

Se Selenium

1.0 PREFACE

This report summarizes the results of three separate sampling programs conducted simultaneously in 2001 as part of the Sudbury Soils Study. These are:

1. Urban soil survey of residential properties, schools and parks
2. Regional soil survey of rural and undisturbed sites
3. Soil survey in the community of Falconbridge

The three surveys were conducted following the same sample collection and analytical procedures. Three volumes comprise the Sudbury Soils Study data report, each of which has been prepared and authored as follows:

- MOE, 2004. *City of Greater Sudbury 2001 Urban Soil Survey*. Ontario Ministry of the Environment Report No. SDB-008-3511-2003. (Volume I)
- CEM, 2004. *Metal levels in the soils of the Sudbury smelter footprint*. Report prepared by the Centre for Environmental Monitoring (CEM), Laurentian University, Sudbury. (Volume II)
- Golder Associates, 2001. *Town of Falconbridge soil sampling program, comprehensive Falconbridge survey*. Report prepared by Golder Associates Ltd., Sudbury, Ontario. (Volume III)

Copies of these reports are provided on CD ROM at the back of this report. The information collected in the 2001 soils survey represents a comprehensive documentation of the concentrations of 20 inorganic elements in soils in the Sudbury region. These elements include aluminium, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc. *Note:* Because of their chemical properties, arsenic and selenium are actually classified as metalloids; however, the generic term “metals” is used throughout this summary for simplicity.

These data provide the foundation for the Human Health and Ecological Risk Assessments currently being carried out for the City of Greater Sudbury and surrounding region. The results of the risk assessment studies will be provided at a later date in a series of separate reports.

2.0 INTRODUCTION AND BACKGROUND

The Sudbury Basin is an area rich in mineral deposits, particularly in the nickel and copper ores that have drawn people to the region for the past 125 years. Since 1971, the Ontario Ministry of the Environment (MOE) and Inco Ltd. have conducted soil sampling programs to determine the concentrations of metals in soils and vegetation across the Sudbury region. Those studies have demonstrated that there are areas in Sudbury with elevated metal levels in the soil. These areas are usually close to the historic smelting sites of Coniston, Falconbridge and Copper Cliff. Although these metals do occur naturally in all soils, the studies indicate that elevated metal concentrations in surface soil (the top 5 cm of soil) are the result of local mining, smelting and refining operations, including the original roast yards.

In 2001, the MOE released a report entitled *Metals in Soil and Vegetation in the Sudbury Area (Survey 2000 and Additional Historic Data)* (MOE 2001). The report reviewed and summarized the results of the previous 30 years of studies, comparing metal levels in local soils to the MOE's *Guideline for Use at Contaminated Sites in Ontario* (1996). The *Guidelines* are not legislated regulations; they also are not action levels – exceeding the *Guidelines* does not automatically mean that a clean-up is required (MOE, 2001). In Ontario, soil levels above the *Guidelines* indicate the need for more detailed study. Through this comparison, the MOE identified that concentrations of nickel, cobalt, copper and arsenic in Sudbury exceeded the *Guidelines*, and further investigation was needed.

In addition, the MOE review identified significant gaps in the existing data in terms of spatial coverage (geographic area) and changing methods over the 30 year period, making direct comparison of much of the data not possible. Therefore, the 2001 MOE report made two significant recommendations:

1. That a more detailed soil study be undertaken to fill data gaps; and,
2. That a human health and ecological risk assessment be undertaken.

Both Inco Ltd. and Falconbridge Ltd. voluntarily accepted these recommendations, and in 2001, the Sudbury Soils Study was established by a collaborative team including Inco Ltd., Falconbridge Ltd., the MOE, the Sudbury & District Health Unit, the City of Greater Sudbury, and the First Nations and Inuit Health Branch of Health Canada. These partners formed a Technical Committee to oversee the study.

A comprehensive soil sampling and analysis program was undertaken in the summer and fall of 2001. The sampling program was divided between the parties as follows:

- The MOE collected soil samples from schools, daycares, parks and beaches across the Sudbury area, and from 439 residential properties (referred to as the "urban" soils survey);
- Inco Ltd. and Falconbridge Ltd. retained the services of Laurentian University's Centre for Environmental Monitoring (CEM) to collect soil samples in more remote and undisturbed areas to determine the spatial extent (geographic area) of the smelter "footprint" and attempt to determine background concentrations of metals in the region (referred to as the "regional" soils survey)
- Falconbridge Ltd. retained the services of Golder Associates Ltd. to collect soil samples on properties owned by the company within the Town of Falconbridge, as well as some municipal and crown lands surrounding Falconbridge (referred to as the Falconbridge soils survey)

During the sampling program approximately 9,000 soil samples were collected from about 1,190 locations and analyzed for the 20 metals listed above. These data form the basis for the ongoing risk assessments. Soil samples were collected from different depths to provide a vertical profile of metal concentrations. In addition, numerous duplicate samples were collected for quality assurance and quality control purposes. Therefore, it is often not a simple matter to reconcile the number of samples collected and analyzed with the number of sampling locations.

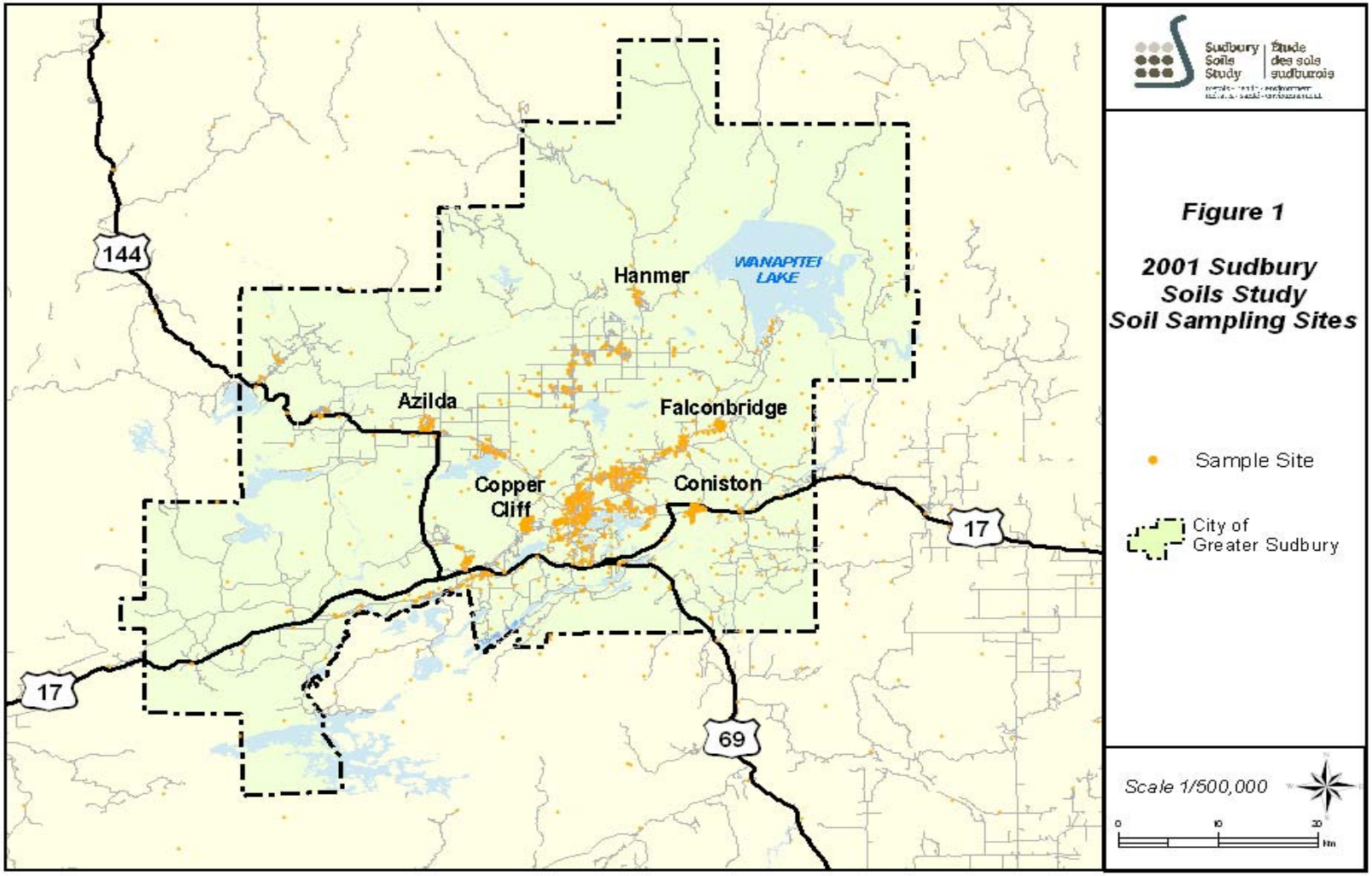
3.0 METHODS

3.1 Study Area

The study area for the Sudbury Soils Study is approximately 200 km x 200 km and encompasses the City of Greater Sudbury (Figure 1).

The CEM designed the regional soil sampling survey to collect data from rural and remote areas with undisturbed soils. The MOE designed and implemented the urban soil sampling program that focused on residential properties, schools and parks within the City of Greater Sudbury. Golder Associates designed the Town of Falconbridge soil sampling program to focus on properties owned by Falconbridge Ltd. as well as municipal and crown lands, including parkland and rural areas within the Town of Falconbridge. Details on the sampling programs, methodology and results are provided in Volumes I, II and III of this report (MOE, 2004; CEM, 2004; Golder Associates, 2001).

As the area sampled by the CEM covered the broadest geographical area, it is used to describe the boundaries of the study area. The approximate boundaries of the sampling area are shown in Figure 1, along with sampling locations for the soil surveys. At the scale of Figure 1, all sample locations are not apparent. The locations of individual sample locations are provided in the three individual reports.


Sudbury Soils Study
Étude des sols sudburois
Figure 1
2001 Sudbury Soils Study Soil Sampling Sites
Sample Site
City of Greater Sudbury
Scale 1/500,000
km
144
17
17
69
Hanmer
WANAPITEI LAKE
Azilda
Falconbridge
Copper Cliff
Coniston

3.2 Sampling Locations

3.2.1 Urban Soils Survey

For the urban soils survey, the MOE collected soil samples from four land uses: residential, schools, parks and agricultural. Three types of soil were sampled: soil, sand and gravel. The division of these three soil types are as follows:

Soil

- Urban Soil (developed, grassed areas)
- Urban Garden Soil (residential vegetable gardens)
- Agricultural Soil (commercial market garden and berry farms)
- Undisturbed Natural Soil (undeveloped, naturally vegetated areas)

Sand

- Play Sand (material used around play structures, brought in for landscaping purposes)
- Beach Sand (from parks with beaches, tends to be naturally occurring)

Gravel

- Crushed Stone (used in the infields of baseball diamonds, tends to be brought in for landscaping purposes)
- Playground Gravel (used in many school playgrounds, tends to be brought in for landscaping purposes)

Sand and gravel were collected because, unlike grass-covered urban soil, these can come into direct contact with skin, increasing the risk of exposure. Soil, play sand, crushed stone and gravel samples were collected from each school and daycare within the City of Greater Sudbury. Soil and sand samples were also collected from the major parks and sports complexes within the City of Greater Sudbury.

The goal of the MOE program was to sample about 10% of the houses in each area within the City of Greater Sudbury. The breakdown of residential sampling locations is as follows:

- Falconbridge: 51
- Coniston: 75
- Copper Cliff: 74
- City of Greater Sudbury: 239

In total, 6,734 soil samples were taken from 770 properties in City of Greater Sudbury. This included 16 commercial agriculture properties, 146 schools, 169 parks and the 439 residential properties detailed above.

In addition to soil sampling, the MOE conducted a preliminary sampling of vegetables and fruit grown within the City of Greater Sudbury. Samples were collected from residential gardens, commercial market gardens, commercial berry farms and wild blueberry patches. Sample types included root vegetables, fruit vegetables, leafy vegetables and berries. Samples were also collected from reference areas without elevated soil metal levels for comparison purposes. In total, 245 vegetable and fruit samples were taken from 52 residential gardens and agricultural operations in the 2001 MOE sampling program.

3.2.2 Regional Soils Survey

The regional soil sampling survey conducted by the CEM was developed using a randomly stratified sampling plan, centred on the three historical smelters in Copper Cliff, Coniston and Falconbridge, with the centre in the vicinity of the Copper Cliff smelter (CEM, 2004).

The final nested sampling grid covered an area approximately 200 km x 200 km in size (40,000 km^2). The sampling was centred on the three smelter areas of Copper Cliff, Falconbridge and Coniston. An imaginary grid was overlain on the entire area. The cells in the grid ranged in size from 2 to 16 km^2, with the smallest cells located closest to the zones of historical smelter impact. Soil samples were taken randomly from within each cell. Many of the soil sampling locations were remote and required helicopter access.

The primary purpose of the regional soil sampling survey was to determine the spatial area of soil metal levels affected by the Sudbury smelters. In addition, samples were taken at depths of 85 to 112 cm below surface to determine the natural "background" metal concentrations in Sudbury soils. This deep soil layer (parent material) was assumed to be unaffected by atmospheric deposition or other human sources.

In addition, the regional survey collected soil profiles, following the MOE protocol described below. Core samples were sectioned to collect soils from 0 to 5 cm, 5 to 10 cm, and 10 to 20 cm depth. This provided a detailed examination of the vertical distribution of metals in the surface soils. The CEM survey also made significant attempts to relate the geochemistry of surface soils to the bedrock mineralogy. In total, 386 sites were sampled as part of the regional soil survey.

3.2.3 Falconbridge Soils Survey

Sample locations were limited to properties owned by Falconbridge Ltd., as well as municipal and crown lands, to provide spatial coverage and representation of different terrain types including disturbed and natural (undisturbed) sites. A total of thirty-three (33) sites were sampled, including parks (3 sites), wooded areas (14 sites), residential yards (3 sites), schools (1 site), playgrounds (2 sites), grassy areas (4 sites), vacant lots (3 sites), gravel lots (1 site) and grass medians (2 sites). Soil samples were collected, prepared and analyzed following the MOE protocol described below.

3.3 Sampling Protocol

All soil samples were collected with a hand-held soil corer, with 15 to 30 soil cores collected per site. Samples were taken along a grid, "W" or "X" pattern at each location or property, to ensure even coverage of the property. Each soil core was divided into three depth intervals (0-5 cm, 5-10 cm and 10-20 cm). The 0-5 cm samples from one site were mixed together to form a composite sample to represent each location. The same process was followed to create separate 5-10 cm and 10-20 cm composite samples. A duplicate soil sample was collected by performing the soil sampling procedure a second time.

The regional study also sampled parent material to aid in determining normal background levels of metals for the Sudbury Basin. A Dutch auger was used to remove the top 60-80 cm of soil, then soil parent material was collected using a bucket auger, gathering 25 to 30 cm depth of soil, and the soil sampling depth was recorded (*e.g.* from 85 to 112 cm).

Figure 2. MOE staff conducting soil sampling, 2001.

3.4 Sample Analysis

Processing followed MOE Standard Operating Procedures, which included air drying and sieving the soil to obtain particles in the 2 mm size fraction, grinding the sample with a mortar and pestle to pass through a 355 µm sieve and then storing this ground material in glass jars.

All soil samples were analyzed by SGS-Lakefield Research Laboratories in Lakefield, Ontario, with additional analysis performed by the MOE laboratory for Quality Assurance/Quality Control (QA/QC). All soil samples were analyzed for the following elements:

aluminium (Al)	antimony (Sb)	arsenic (As)
barium (Ba)	beryllium (Be)	calcium (Ca)
cadmium (Cd)	cobalt (Co)	copper (Cu)
chromium (Cr)	iron (Fe)	magnesium (Mg)
manganese (Mn)	molybdenum (Mo)	nickel (Ni)
lead (Pb)	selenium (Se)	strontium (Sr)
vanadium (V)	zinc (Zn)	

One in ten samples was also analyzed for pH, electrical conductivity (EC) and total organic content (TOC).

3.5 Provincial Soil Quality Guidelines

To put some context to the values reported in this and other studies, metal concentrations in soils are often compared to the MOE Generic Soil Quality Guidelines described in the MOE document *Guideline for Use at Contaminated Sites in Ontario* (MOEE 1997). These guidelines were developed "to protect against adverse effects to human health, ecological health and the natural environment" (MOEE 1997).

The MOE *Guidelines* were established as the lowest concentration of a substance that is toxic to plants or animals, or the level to protect human health. Plant toxicity values are typically lower than those reported for animals or the protection of human health. Therefore, many of the generic metals criteria in the MOE *Guidelines* are based primarily on effects of these metals to sensitive plant species, such as wheat. Plant or animal based criteria were developed for: arsenic, boron, chromium, cobalt, copper, molybdenum, nickel, selenium, silver, zinc, barium, and vanadium. The *Guidelines* also apply to soil with pH range 5.0 to 9.0 for surface soils. It should be noted that Sudbury soils sometimes have pH less than 5.0, but generally not above 9.0.

The MOE *Guidelines* were developed to provide guidance for cleaning up contaminated sites, and are not legislated regulations. Furthermore, the guidelines are not action levels, where exceeding a particular guideline would indicate immediate risk or that remediation or clean-up is required. The significance of the *Guidelines* to the Sudbury area is to provide triggers to suggest the need for additional investigations (MOE, 2001). In fact, exceeding the generic *Guidelines* in soils collected up to the year 2000 initiated the entire Sudbury Soils Study.

3.6 Data Presentation and Screening in the Executive Summary

It is common practice in risk assessment to limit the number of chemicals being evaluated to those that represent the greatest potential concern in the area under consideration. The data screening process applies criteria to all the available data and identifies key "Chemicals of Concern" (COCs).

Following a review of existing soil quality data for the Sudbury area collected up to and including the year 2000, the MOE identified four potential COCs for the Sudbury Soils Study: copper, nickel, cobalt and arsenic. These were identified as those elements found in concentrations in Sudbury soils that exceeded the MOE Generic Soil Quality Guidelines.

In 2001, the Sudbury Soils Study Technical Committee developed three primary criteria to identify and select COCs for the detailed risk assessments:

1. The parameter must be above Table A or Table B guideline published in MOEE's *Guideline for Use at Contaminated Sites in Ontario* (MOEE, 1997), depending on whether the specific area under study has surface or well water sources for potable water;
2. The parameter must be present across the study area; and,
3. The parameter must scientifically show a significant contribution from the companies operations.

The combined results of the 2001 soils survey were merged into a comprehensive soils database and analyzed statistically. The comprehensive soils data were screened against the three criteria above. This screening process and the results of the combined database will be reported in a separate document as part of the Sudbury Soils Study. The data screening process is illustrated in Figure 3.

Soil concentrations were compared to the most protective guidelines. A potable water situation was assumed (Table A). In addition, the land use selected was residential/parkland, with coarse texture soils.

In addition to the four elements previously identified as potential COCs (nickel, copper, arsenic, cobalt), the screening exercise determined that lead and selenium also met the criteria for consideration as COCs.

The other parameters and elements measured in soils will also be considered as part of the Sudbury Soils Study risk assessments, but the primary focus is on these six COCs. For the purpose of this Summary, only information pertaining to the COCs is presented to illustrate trends between sampling areas.

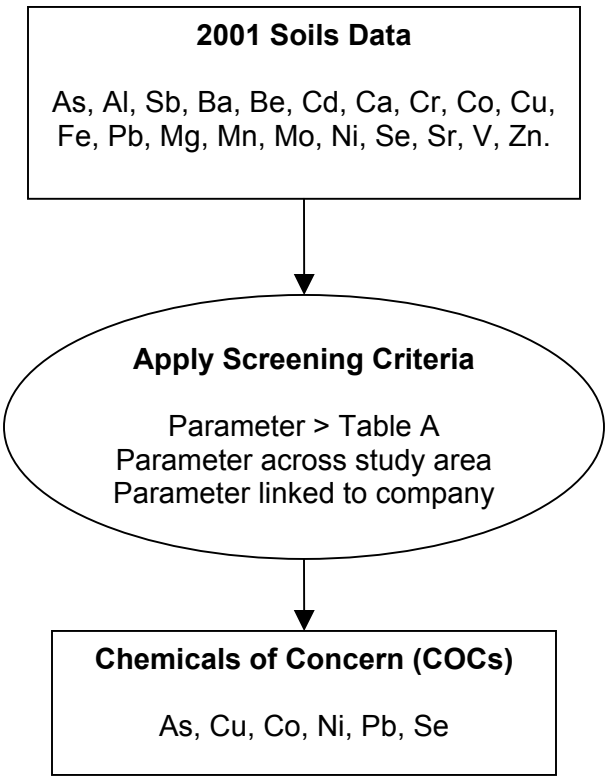


Figure 3. Data Screening Process for COC Selection

4.0 RESULTS

4.1 Urban Soils Survey (from MOE, 2004)

The objectives of the soil survey were to determine the following in the City of Greater Sudbury:

1. To provide a screening level assessment of metal concentrations in the upper 20 cm of soil;
2. To determine if there are localized areas of higher metal levels in the upper 20 cm of soil;
3. To determine if metal concentrations change with depth in the upper 20 cm of soil, to identify if element concentrations are related to aerial deposition from smelter emissions;
4. To determine the strength of relationships between metal concentrations and smelter emissions in the upper 20 cm of soil;
5. To identify metal concentrations in vegetables and fruit grown within the City of Greater Sudbury, to support exposure estimates for a Human Health Risk Assessment; and,
6. To identify additional work that may be appropriate to support the Human Health Risk Assessment and Ecological Risk Assessment based upon this screening level study.

For the purposes of discussion, the study area for the urban soil sampling was divided into 6 primary communities: Outer Sudbury, Inner Sudbury, Sudbury Core, Coniston, Falconbridge, and Copper Cliff. The MOE defines Outer Sudbury as a grouping of fourteen local communities, including Blezard Valley, Capreol, Chelmsford, Dowling, Hanmer, Levack, Naughton, Onaping Falls, Skead, Val Caron, Val Therese, Wahnapitae, Wanup and Whitefish (MOE, 2004).

Inner Sudbury is a grouping of three local communities and three geographic areas, including Azilda, Garson, Lively, Sudbury East, Sudbury New and Sudbury South. Sudbury East is defined as north of Ramsey Lake, east of Paris Street, and south of the Kingsway, including the neighbourhoods of Minnow Lake, Adamsdale, and Moonlight Beach. Sudbury New is defined as north of the Kingsway, east of Notre Dame, including the neighbourhoods of Barry Downe, New Sudbury, Nickledale, and San Francisco. Sudbury South is defined as south of Ramsey Lake, south of Lorne and York Streets, including the neighbourhoods of Robinson, Lockerby, Laurentian, and Lo-Ellen (MOE, 2004).

Sudbury Core is defined as being west of Notre Dame and north of Lorne and York Streets, including the neighbourhoods of Flour Mill, Gatchell, Little Britain, and Northern Heights. The communities of Copper Cliff, Coniston and Falconbridge made up their own groupings (MOE, 2004). A map depicting these groupings is provided in the MOE 2004 report.

Data summaries for each community are presented in Tables 4.1 to 4.6 by major land use: residential properties, schools and daycares, and parks. It is important to note that the sample sizes (n values) in Tables 4.1 to 4.6 represent all samples including duplicates, and not the number of sample locations. Therefore, the sample size in most cases will generally be much larger than the number of locations. For details on actual number of sites sampled within a community, refer to the full report.

Data from only the surface soils (0-5 cm depth) are presented in this Summary for ease of presentation to demonstrate trends between communities. Full details of the results for all soil depths are provided in MOE (2004).

4.1.1 Outer Sudbury

The majority of sampling sites in Outer Sudbury were either schools or parks with only 5 residential properties sampled. At the 0-5 cm depth, only 1 of the 284 samples had a soil value that exceeded the MOE Table A guideline (Table 4.1). A single park sample contained 151 mg/kg of nickel which is marginally over the guideline of 150 mg/kg. The levels of all other parameters were below the MOE guidelines.

Table 4.1. Summary concentrations[1] of select metals in surface soil (0-5cm depth) in Outer Sudbury by land use type

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	5	20	7	32	0.5
(n=12)[2]	mean	3.6	6	38	18	44	0.5
	max.	7	8	57	40	59	0.5
Schools and Daycare	min.	2.5	3	12	2	17	0.5
(n=95)	mean	3.6	6	40	18	52	0.6
	max.	8	12	97	170	120	1.2
Parks	min.	2.5	4	9	4	19	0.5
(n=177)	mean	3.6	6	34	13	50	0.5
	max.	16	22	74	66	151	1

1. All concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.2 Inner Sudbury

The sampling sites in Inner Sudbury were approximately half in residential properties and half in school or park properties (Table 4.2). At the 0-5 cm depth, nickel was the most elevated with 115 samples exceeding the MOE Table A guideline, and 19 copper, 4 arsenic, 1 lead and 2 cobalt samples that exceeded Table A out of a possible 675 samples. The maximum concentration of both nickel and copper observed was 1,400 mg/kg. Residential properties tended to have higher soil metal levels than schools or parks.

Table 4.2. Summary concentrations[1] of select metals in surface soil (0-5cm depth) in Inner Sudbury by land use type

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	4	20	4	30	0.5
(n=314)[2]	mean	5.5	9	106	23	124	0.7
	max.	30	41	1400	220	1400	6
Schools and Daycare	min.	2.5	3	11	2	16	0.5
(n=175)	mean	3.8	8	73	24	95	0.6
	max.	9	42	370	200	630	4
Parks	min.	2.5	4	13	3	25	0.5
(n=186)	mean	4.7	8	70	14	96	0.6
	max.	27	20	230	50	304	1

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.3 Sudbury Core

Sample locations in Sudbury Core included all three land uses, but with relatively fewer school sites. Within the 0-5 cm depth, nickel and copper levels exceeded the MOE Table A guideline in 205 and 139 samples, respectively. The maximum nickel level was 2,000 mg/kg, while the maximum copper value was 1,600 mg/kg (Table 4.3). In general, there were very few samples that exceeded the Table A guidelines for arsenic (12), lead (4) or cobalt (14) out of a possible 324 samples. Residential properties tended to have higher metal concentrations than in schools, daycares and parks.

Table 4.3. Summary concentrations[1] of select metals in surface soil (0-5 cm depth) in Sudbury Core by land use type

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	4	28	7	33	0.5
(n=184)[2]	mean	10	18	392	67	400	1.9
	max.	34	75	1600	320	2000	9
Schools and Daycare	min.	2.5	4	19	3	20	0.5
(n=45)	mean	4.5	9	129	20	140	0.9
	max.	14	28	530	75	660	4
Parks	min.	2.5	5	17	1	24	0.5
(n=95)	mean	4.7	11	134	21	162	0.8
	max.	32	55	950	101	1528	3.5

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.4 Coniston

The majority of sampling sites in the Coniston community were residential, with only a small number of parks (Table 4.4). At the 0-5 cm depth, the maximum nickel and copper concentrations were 1,900 and 1,200 mg/kg, respectively. Approximately one half (166) of the total number of samples (301) exceeded the Table A guideline for nickel, while 116 samples exceeded the copper guideline. Relatively few samples exceeded the criteria for arsenic (35), lead (6) and cobalt (23).

Table 4.4. Summary concentrations[1] of select metals in the surface soils (0-5 cm depth) in Coniston by land use type.

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	3	14	6	25	0.5
(n=287)[2]	mean	10	16	246	52	336	1.2
	max.	47	74	1200	400	1900	5
Parks	min.	2.5	4	8	2	16	0.5
(n=14)	mean	7.9	16	211	16	300	0.7
	max.	19	43	620	42	940	2

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.5 Falconbridge

The sampling sites in the Falconbridge community included all three land uses, but with relatively fewer school and park sites compared to residential sites. At the 0-5 cm depth the maximum nickel and copper concentrations were 3,700 and 3,000 mg/kg, respectively, with 191 samples that exceeded the Table A guideline for nickel and 178 samples that exceeded the copper guideline (Table 4.5). Arsenic levels in Falconbridge ranged from 2.5 to 300 mg/kg, which represented the highest arsenic values measured within the study area. A total of 184 soil samples exceeded the Table A arsenic guideline. Similarly, the highest levels of cobalt were observed in Falconbridge (maximum of 190 mg/kg) with 135 samples exceeding the soil guideline for cobalt. Very few samples exceeded criteria for lead (9) or selenium (1).

Table 4.5. Summary concentrations[1] of select metals in the surface soils (0-5 cm depth) in Falconbridge by land use type.

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	5	31	6	37	0.5
(n=199)[2]	mean	74	56	874	88	956	2.7
	max.	300	190	3000	370	3700	12
Schools and Daycare	min.	2.5	11	46	11	61	0.5
(n=3)	mean	2.5	12	57	17	97	0.5
	max.	2.5	13	66	21	120	0.5
Parks	min.	2.5	8	44	6	68	0.5
(n=3)	mean	34	34	456	31	601	1.7
	max.	84	130	1800	110	2500	4

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.6 Copper Cliff

The majority of sampling sites in the Copper Cliff community were residential, with only 1 school and a small number of parks. The highest concentrations of nickel (3,200 mg/kg), copper (5,600 mg/kg) and selenium (49 mg/kg) measured in the study were detected within Copper Cliff. Almost all of the 290 samples within the 0-5 cm depth layer exceeded the Table A guideline for nickel (280) and copper (280) (Table 4.6). In addition, the number of samples that exceeded the generic guidelines for arsenic, lead and cobalt were 90, 19 and 190, respectively.

Table 4.6. Summary concentrations[1] of select metals in the surface soils (0-5 cm depth) in Copper Cliff by land use type.

MOE Table A Soil Screening Criteria		As	Co	Cu	Pb	Ni	Se
		20	40	225	200	150	10
Land Use							
Residential	min.	2.5	6	65	10	71	0.5
(n=266)[2]	mean	18	33	1440	91	1017	7.8
	max.	72	100	5600	410	3200	49
Schools and Daycare	min.	6	11	250	11	250	1
(n=6)	mean	22	47	1587	60	1452	5.7
	max.	37	80	2900	100	2500	12
Parks	min.	2.5	9	250	13	205	1
(n=18)	mean	16	32	1274	45	959	5.4
	max.	63	100	4600	130	3649	22

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.7 Soil pH

Soil pH was analyzed on only one out of every ten samples collected during the 2001 urban soils survey. Therefore, there is an incomplete database to consider. However, the available data do illustrate some trends.

About 546 soil samples were analyzed for pH in the urban/residential soils collected within the city (MOE 2004). Of these, only 7 displayed pH < 5.0. Therefore, in the most densely populated areas low soil pH does not appear to be a concern.

These results suggest that the soils of many urban properties have likely been amended, resulting in higher pH compared with soils from the rural or remote locations.

4.1.8 Aerial Deposition

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 4.7. The data show that the highest concentrations of each of the six COCs occur within the surface (0-5 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 4.7. Mean metal concentrations[1] in urban-undisturbed natural soil profiles (n = 14 samples per depth)[2]

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

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected

4.1.9 Fruits and Vegetables

Collections included vegetables and fruit from residential gardens, commercial market gardens, commercial berry farms and wild blueberry patches. The results of the produce sampling were compared to areas without elevated soil metal levels. In total, 245 produce samples were taken from 52 residential gardens and agricultural operations. Data from residential gardens are provided in MOE (2004) but are difficult to put into context as there are very few provincial, federal or international human health guidelines specific to metals in vegetables and fruits that are available for direct comparative purposes. In addition, inherent limitations in the study design and problems with sample analytical procedures limit the reliability and usefulness of the vegetable and produce data collected in 2001.

4.1.10 Conclusions and Recommendations, Urban Soils Survey (from MOE, 2003)

All objectives for the study were met except for the identification of metal concentrations in vegetables and fruit. The MOE recommended that additional work be considered in the following areas:

- Further soil sampling, below 20 cm, to fully delineate the vertical extent of elevated metal concentrations within the town of Falconbridge;
- Bioaccessibility analysis for metals from soil samples from different soil types in each community (this would help estimate how much metal would be available to make its way into humans, plants or animals);
- Element concentrations in the fine fraction of the soil material, without grinding, should be determined in each community;
- Laboratory characterization of soil texture;
- Total organic content, pH, and conductivity should be measured for a large percentage of soil samples;
- Statistical analysis should be conducted on duplicate samples collected from each property to determine within-site and between-site sampling and analytical variability;
- Determination of accumulation and transport mechanisms responsible for differences in soil metal concentration profiles between elements and geographic locations;
- Completion of a comprehensive garden and commercial vegetables and fruit sampling program;
- Property owners should be informed that better washing of leafy vegetables would be recommended where elevated soil concentrations are found; and,
- The results of this study should be compared with previous research to fully assess short and long term data trends.

Many of these recommendations are being implemented as part of the Sudbury Soils Study.

4.2 Falconbridge Soils Survey (from Golder Associates, 2001)

Data for the 33 locations sampled by Golder Associates Ltd. in the town of Falconbridge are summarized in Table 4.8. In general, the results are similar to the findings of the MOE sampling program, although the mean and maximum concentrations are lower than those reported by the MOE (2004). The Table A generic soil quality guidelines were exceeded for five of the COCs, with selenium levels being generally quite low and below Table A values.

Table 4.8. Summary concentrations[1] of select metals in surface soils (0-5 cm depth) in Falconbridge (n = 66 samples)[2]

	As	Co	Cu	Pb	Ni	Se
MOE Table A Soil Screening Criteria	20	40	225	200	150	10
Min.	2.5	5.5	46	10	60	0.5
Mean	59.9	28.6	500.9	52.3	437.2	2.4
Max.	220	120	1600	220	1600	6

1. Concentrations expressed as mg/kg (parts per million) dry weight
2. n = number of samples collected

4.3 Regional Soils Survey (from CEM, 2004)

A primary objective of the Regional Soil Survey was to measure the spatial distribution (geographic area) of metals in surface (0-5 cm) soils to determine the potential "footprint" of particulate airborne emissions from the Sudbury smelters. Comments on the distribution of the COCs are provided below.

Elevated concentrations of metals were centred on the three historic smelting centres of Coniston, Copper Cliff and Falconbridge. Maximum arsenic values were observed in the vicinity of the Falconbridge smelter. The distribution of lead also shows deposition from the smelters, but to the south of Sudbury it also reflects an influence of parent material on lead concentrations in the surface layers. The distribution of copper, nickel and selenium show a classic wind-driven football-shaped pattern, primarily centred on the smelter complex at Copper Cliff, with the long axis in a SW to NE direction.

The concentrations of individual metals along a concentration gradient indicate the effects of smelter emissions to regional background approximately 120 km from downtown Sudbury. Detailed maps illustrating the patterns and extent of soil metal distribution are provided in the CEM (2004) report.

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 over 70% (254) of the sites visited during the rural/remote sampling program. Approximately 285 samples were collected, representing the first known attempt to establish pre-industrial levels of metals in Sudbury regional soils (CEM 2004).

Summary statistics for the parent material samples are provided in Table 4.9. It is noteworthy that some sample concentrations of copper, nickel and arsenic exceeded the generic Table A guidelines. Otherwise, the concentrations of these elements in the deeper soils representing parent material were generally quite low.

Table 4.9. Summary of total metal levels[1] in parent material samples (n = 254 sites)[2] from the Sudbury region

	As	Co	Cu	Pb	Ni	Se
Min.	<DL[3]	2	<DL	1	8.5	<DL
Mean	1.11	8.9	26.4	5.9	36.1	0.06
Max.	98	38	270	47	163	2

1. Concentrations expressed as mg/kg (parts per million) dry weight.
2. n = number of samples collected
3. <DL = below detection limit

Table 4.10 provides a summary of mean metal concentrations by soil depth for samples collected under the regional soil survey. The results are consistent with the MOE findings in that the surface (0-5 cm) soil layer contained, on average, higher concentration of each of the six COCs. 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 4.10 suggest that at least five of the COCs; As, Cu, Pb, Ni and Se, demonstrate EFs in surface soil considerably greater than 2.0.

Table 4.10. Mean concentration (mg/kg) of metals from all layers of all sites sampled in the Sudbury regional soil survey, along with calculated enrichment factor (EF).

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

4.3.1 Soil pH

Soil pH was analyzed on only one out of every ten samples collected during the 2001 regional soils survey. Therefore, there is an incomplete database to consider. However, the available data do illustrate some trends.

Approximately 280 samples were analyzed for pH within the regional or rural soil sample sites (CEM, 2004). Of these, 193 (68%) had pH< 5.0.

These results suggest that many of the soils from the rural or remote locations possess low pH. This is largely a natural situation, with some possible contribution from sulphur deposition.

4.3.2 Comparison with MOE Table A and Table F values

Additional summary statistics for the parent material samples are provided in Table 4.11. 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 and Table F values. Table F values are considered generic Ontario background levels and are based on the Ontario Typical Ranges for soils (MOEE, 1993).

Table 4.11. Comparison of MOE Table A and Table F values with Sudbury parent soil material summary results. Values expressed as mg/kg dry weight

Parameter	Table A[1]	Table F[2]	Sudbury Average	Parent Material[3] 95th percentile
Al	NV	NV	1780	35,350
As	20	17.0[4]	1.11	6.0
Ba	750	210[4]	98.4	260
Be	1.2	1.2[4]	0.15	0.8
Cd	12.0	1.0[4]	<DL	<DL
Ca	NV	NV	780	11,700
Cr	750	71	56.4	100
Co	40	21	8.9	17.0
Cu	225	85	26.4	60
Fe	NV	NV	2270	40,000
Pb	200	120	5.9	11.0
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	91[5]	43.3	76
Zn	600	160	29.7	61.4

NV indicates no value or guideline
<DL indicates value below detection limit
[1] Table A for potable water, residential land use and coarse soils
[2] Table F. Ontario background soil concentrations for land uses other than agriculture
[3] Data from CEM (2004). Sample size = 284
[4] Based on Upper Confidence Level of OTR_{98}

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 hosts 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 parameters that have 95th percentile values greater than Table F are chromium and nickel, 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 generic Ontario values, possibly because of dilution with upstream rock materials. 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 documented in the accompanying reports 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.

5.0 CONCLUSION

The data in the three accompanying reports provide detailed analytical results for 20 inorganic parameters from about 9,000 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 (0-5 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.

6.0 REFERENCES

CEM. 2004. Metal levels in the soils of the Sudbury smelter footprint. Report prepared by Centre for Environmental Monitoring (CEM), Laurentian University, Sudbury.

Golder Associates. 2001. Town of Falconbridge soil sampling program, comprehensive Falconbridge survey. Report prepared by Golder Associates Ltd., Sudbury, Ontario

MOE. 2004. City of Greater Sudbury 2001 Urban Soil Survey. Ontario Ministry of the Environment. Report No. SDB-008-3511-2003.