SUDBURY AREA RISK ASSESSMENT

CHAPTER 7.0
THE 2001 SOIL SURVEY

Table of Contents

Tables

Figures

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7.0 THE 2001 SOIL SURVEY

7.1 Background

As described earlier in Chapter 1 of this report, in 2001, the Ministry of the Environment (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* (MOE 1997). Through this comparison, the MOE identified that concentrations of arsenic, cobalt, copper, and nickel in Sudbury exceeded the *Guidelines*, and further investigation was needed.

The MOE review identified significant gaps in the existing data in terms of spatial coverage (geographic area). One of the primary recommendations stemming from the 2001 MOE report was that a more detailed and broader soil study be undertaken to fill data gaps.

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

- Vale Inco and Xstrata Nickel 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);
- The MOE collected soil samples from schools, daycares, parks and beaches across the Sudbury area, as well as from 439 residential properties (this is referred to as the "urban" soils survey);
- Xstrata Nickel 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 surrounding municipal and crown lands (referred to as the Falconbridge soils survey).

During the sampling program approximately 8,400 soil samples were collected from about 1,190 locations throughout the study area. Each sample was analyzed for 20 inorganic parameters as described in Section 7.2 below. 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.

Details on the sampling programs, methodology and results of the 2001 survey are provided in documents separate from this series of reports on the risk assessment. The three surveys were conducted following the same sample collection and analytical procedures. Three volumes comprise the 2001 Soils Survey 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 Ltd., 2001. *Town of Falconbridge soil sampling program, comprehensive Falconbridge survey*. Report prepared by Golder Associates Ltd., Sudbury, Ontario. (Volume III)

In addition, a 22-page Executive Summary was prepared by the SARA Group and released to the public July 21, 2004. Hard copies of the Executive Summary with Volumes I, II and III on CD-ROM are available at local Sudbury libraries and at the MOE Sudbury District Office. Complete hard copies of all the reports are available at the Main Branch Library on Mackenzie Street and at the MOE Sudbury District Office. Electronic copies of these three reports are provided on CD-ROM at the back of this document (as Appendix C). (Note: The 3 volumes of the 2001 Soil Survey are separate and different from the 3 volumes comprising the Sudbury Soils Study risk assessment of which this is Volume I.)

The CEM designed the regional soil sampling survey to collect data from rural and remote areas with undisturbed soils. The CEM study area was approximately 200 km x 200 km and encompassed the City of Greater Sudbury. The approximate boundaries of the sampling area are shown in Figure 7-1 along with sampling locations for the soil surveys. At the scale of Figure 7-1 all sample locations are not readily apparent.

This chapter provides a brief overview of the methods and results of the 2001 soil survey. The samples from these three sources were combined together into a database of soil metal concentrations in the Sudbury region which forms the basis of the risk assessment. For detailed information the interested reader is encouraged to refer to the three detailed reports referenced above. Chapter 8 describes the data screening process for the selection of the key Chemicals of Concern (COC) for the risk assessments. The broad spatial distribution of the COC in the study area is provided in Chapter 9, while Chapter 10 presents the distribution of the COC in the five Communities of Interest considered in the HHRA.

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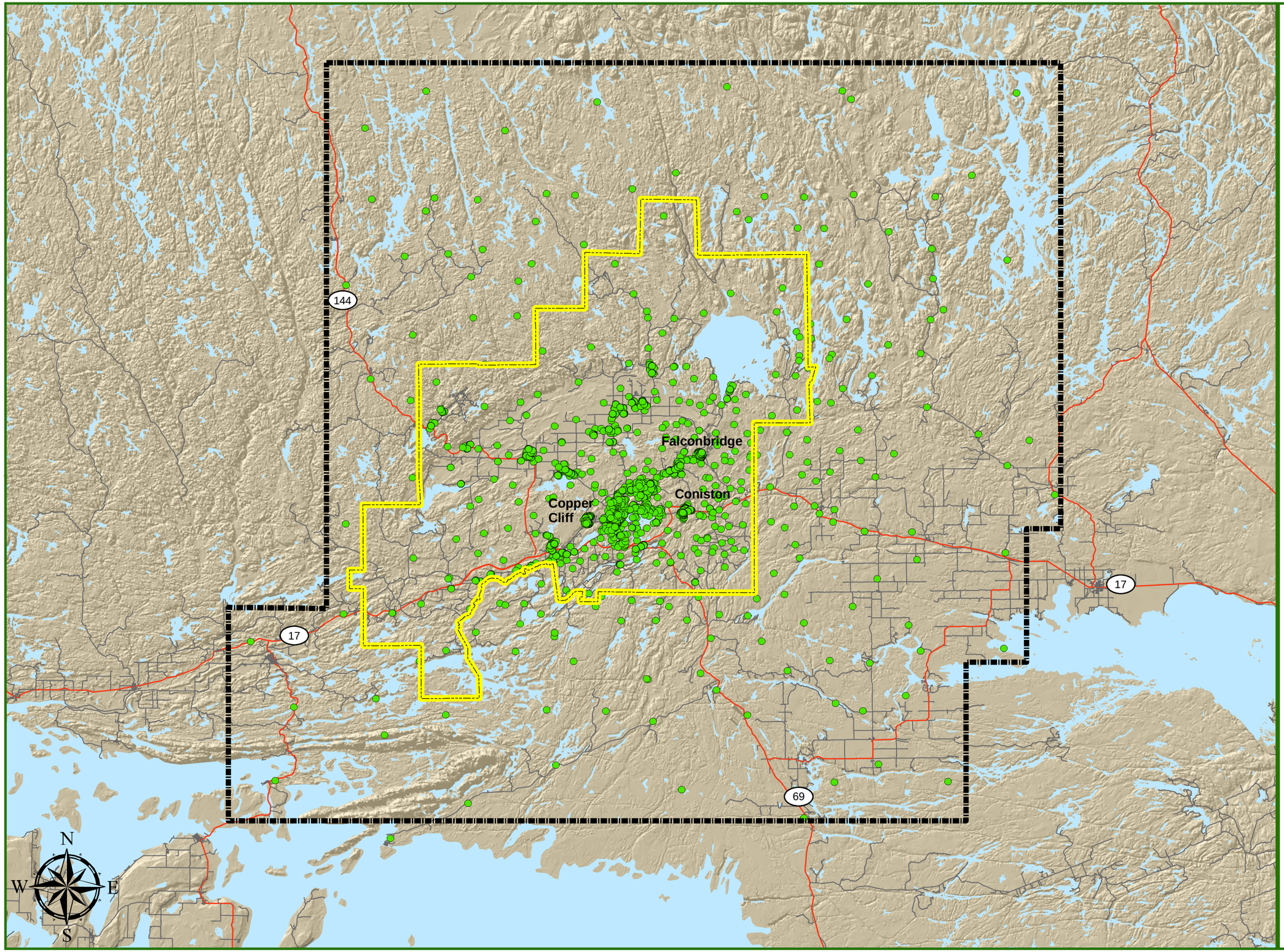
Figure 7-1
2001 Soil Sample Sites



Study Boundary Area

Greater Sudbury Boundary

Soil Samples 0-5cm

Scale 1:630,000

0 10 20 Km

7.2 Study Design

7.2.1 Regional Soil Survey

The primary purpose of the regional soil sampling survey was to determine the spatial area of soil metal levels affected by the Sudbury smelters. 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.

The final nested sampling grid covered an area approximately 200 km x 200 km in size (40,000 km^2). 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 regional survey collected soil cores 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.

A subset of samples was also taken at depth (*i.e.,* over 60 cm deep) 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.

7.2.2 Urban Soil 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 Copper Cliff, Coniston and Falconbridge, and a representative number of houses in the remainder of the City of Greater Sudbury. The breakdown of residential sampling locations in the risk assessment Communities of Interest 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.

7.2.3 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 33 sites were sampled, including parks (three sites), wooded areas (14 sites), residential yards (three sites), schools (one site), playgrounds (two sites), grassy areas (four sites), vacant lots (three sites), gravel lots (one site) and grass medians (two sites). Soil samples were collected, prepared and analyzed following the MOE protocol described below.

7.3 Methodology

7.3.1 Soil Sampling Protocol

All soil samples were collected with a hand-held soil corer, as shown in Figure 7-2, 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 to 5 cm, 5 to 10 cm and 10 to 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 to 10 cm and 10 to 20 cm composite samples. Duplicate composite soil samples were 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 to 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 7-2 MOE staff conducting soil sampling, 2001

7.3.2 Sample Preparation

Samples were delivered to the laboratory within 12 hours of collection. The sample bags were opened immediately, and the soil material was disaggregated to initiate air-drying to minimize chemical alteration due to anaerobic conditions within the sealed bags. The samples were then homogenized and further dried in weighed plastic containers to constant moisture, and weighed to enable bulk density calculation in order to quantify actual metal loadings to soils in subsequent data analysis.

The soil sample was then passed through a two mm mesh Fritsch Pulveriser, with the coarse material (>2 mm fraction) being weighed and stored for future analysis. The pulverized soil was split, using a stainless steel sample splitter, with a 200 g split being ground and sieved with 45 µm mesh and stored in labelled 250 ml plastic jars for shipment to the analytical facility.

Sample Analysis

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)

The prepared soil samples were analyzed at the Environmental Analytical Services Division of SGS Lakefield Research Ltd. according to Method #9-2-37 (June 2000). The sample was mixed thoroughly to ensure sub-samples would be homogenous. Between 0.5 and 0.505 g of the sample was weighed into a Teflon sleeve and was treated with 5 ml each of concentrated HNO_3 and HCl (*Aqua Regia)*. The vessels were placed in a MARS 5 MAW2 Microwave Oven, put through a heat cycle and allowed to cool to less than 60°C. The contents were poured into 50 ml volumetric flasks and diluted to volume with deionized water. The solutions were analyzed by a combination of Inductively-Coupled Plasma-Optical Emission Spectrometry (ICP-OES), Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS) and hydride generation atomic emission spectrometry (HG-AES).

Table 7.1 presents the mean Minimum Detection Limits (MDL) for these elements (taken from MOE 2004). The MDL is derived on an individual sample basis. The MDL is calculated using the Instrument Detection Limit (IDL), an experimentally based value which is the minimum level at which the instrument can detect the element. The IDL is used to calculate the real MDL for soil, biota and tissue

samples. Therefore, the MDLs are based on the actual mass of sample digested and the final volume. The calculation is as follows:

MDL=IDL x vol(digest)/mass(sample)

Every sample digested will have different weights making the MDLs reported differ slightly between samples. Dilutions resulting from high concentrations of metals or matrix effects may produce MDLs that differ by one or two orders of magnitude.

Table 7.1 Summary of Mean Minimum Detection Limits Achieved by SGS Lakefield Research Limited

	Concentration in Soil (mg/kg)
	Mean Minimum Detection Limit
aluminium (Al)	2.5
arsenic (As)	5
barium (Ba)	0.5
beryllium (Be)	0.5
calcium (Ca)	10
cadmium (Cd)	0.8
cobalt (Co)	1
chromium (Cr)	5
copper (Cu)	1
iron (Fe)	5
magnesium (Mg)	1
manganese (Mn)	2
molybdenum (Mo)	1.5
Nickel (Ni)	1
lead (Pb)	1
antimony (Sb)	0.8
selenium (Se)	1
Strontium (Sr)	10
vanadium (V)	2
zinc (Zn)	2.5

All values are presented in mg/kg

The soil profile samples were analyzed by energy dispersive X-ray fluorescence spectrometry using the EMMA system in the CEM laboratories. Approximately five g of the 45 µm mesh sample was placed in a plastic tube sealed with a Mylar sheet and irradiated for 120 seconds. Data reduction was completed with propriety software, with data accuracy and precision being checked with selected NIST SRM materials.

Originally, one in ten samples (10%) was analyzed for pH, electrical conductivity (EC) and total organic content (TOC). Subsequently, Laurentian University measured pH in all soils collected for the regional soil survey.

Quality Program

The soil samples were analyzed at SGS Lakefield Research Ltd., which is certified by the Standards Council of Canada (accredited ISO/IEC 17025 level) and the Canadian Association of Environmental Analytical Laboratories. The calibration and testing activities at Lakefield follow the requirements of the ISO/IEC 9000 series standards. According to the Lakefield Research Analytical Services Description of Quality Control and Accreditation, quality control measures include duplicate samples, spiked blanks, spiked replicates, reagent/instrument blanks, preparation control samples, certified reference material analysis and instrument control samples. The Lakefield SOP required that, internally, at least 20% of samples analyzed are quality control samples.

In addition to the laboratory QA/QC procedures, the CEM quality control program included submission of periodic splits of soil samples, and an analytical drift-monitoring sample collected from within the Sudbury region. This Internal Reference Material (IRM) was prepared from a 100 kg air-dried surface soil sample by sieving through the two mm mesh Fritsch Pulveriser, then through a 45 µm mesh sieve. The IRM sample was then tumbled for 24 hours to ensure homogenization, and bottled in 250 ml plastic jars for storage and submission for analysis. Blind CEM IRM samples were submitted for every 30 samples. Reported laboratory values are considered accurate if their reported value is ±10% of the “target” value of the blind reference material established by the analytical program.

Blind duplicates of the field samples were submitted every 20 samples. Reported laboratory values of the blind duplicate samples were considered precise and accurate if the values were within the 95% confidence intervals when plotted, with a slope of the regression line of the plotted data being between 0.95 and 1.05. The field duplicate accuracy and precision was evaluated in the same manner as the blind sample duplicates.

The overall QA/QC requirements of the Sudbury Soils Study meant that approximately 40% of all samples digested and analyzed were for data quality assessment and assurance, exclusive of the field duplicates which were required to allow for an assessment of landscape homogeneity. All IRM samples and duplicates were submitted in a randomized sequence relative to their duplicate, their geographic location, and their order of field collection. The laboratory analyses of duplicated splits of soil samples indicate very good reproducibility (precision). In general, there is also good agreement between the CEM laboratory analysis values and the reported values for the IRM. For the elemental analyses of the soil IRM, the majority of analyses fell within the ±10% criterion.

7.4 Overview of Results

Data from the three distinct soil surveys conducted in 2001 were provided to the SARA Group and were combined into a single integrated database in Microsoft Access format. The database is searchable using a range of variables and keyword locators for results presented by community, metal or soil depth, as well as spatial coordinates (UTMs).

Soil samples were collected from 26 distinct communities within the City of Greater Sudbury. These are shown in Figure 7-3. The City is also divided into six political Wards which are shown in Figure 7-3. Samples within the boundaries of the City but not within a specific community can be identified by Ward. The distribution of soil sampling locations by community is illustrated in Figure 7-4.

Summary statistics for the overall soil survey are provided in Table 7.2. Results for the Communities of Interest are described in more detail in Chapter 10. It is important to note that Table 7.2 includes results from the three surveys including properties near the smelters as well as remote sample locations. The table incorporates soils sampled to a maximum depth of 20 cm; it does not include any samples from greater than 20 cm. For example, the regional soil survey conducted by Laurentian University collected over 250 samples at depth (>80 cm) considered to represent regional background or parent material metal concentrations. A discussion of the distribution of the elements by depth and in parent material is provided in Chapter 9.

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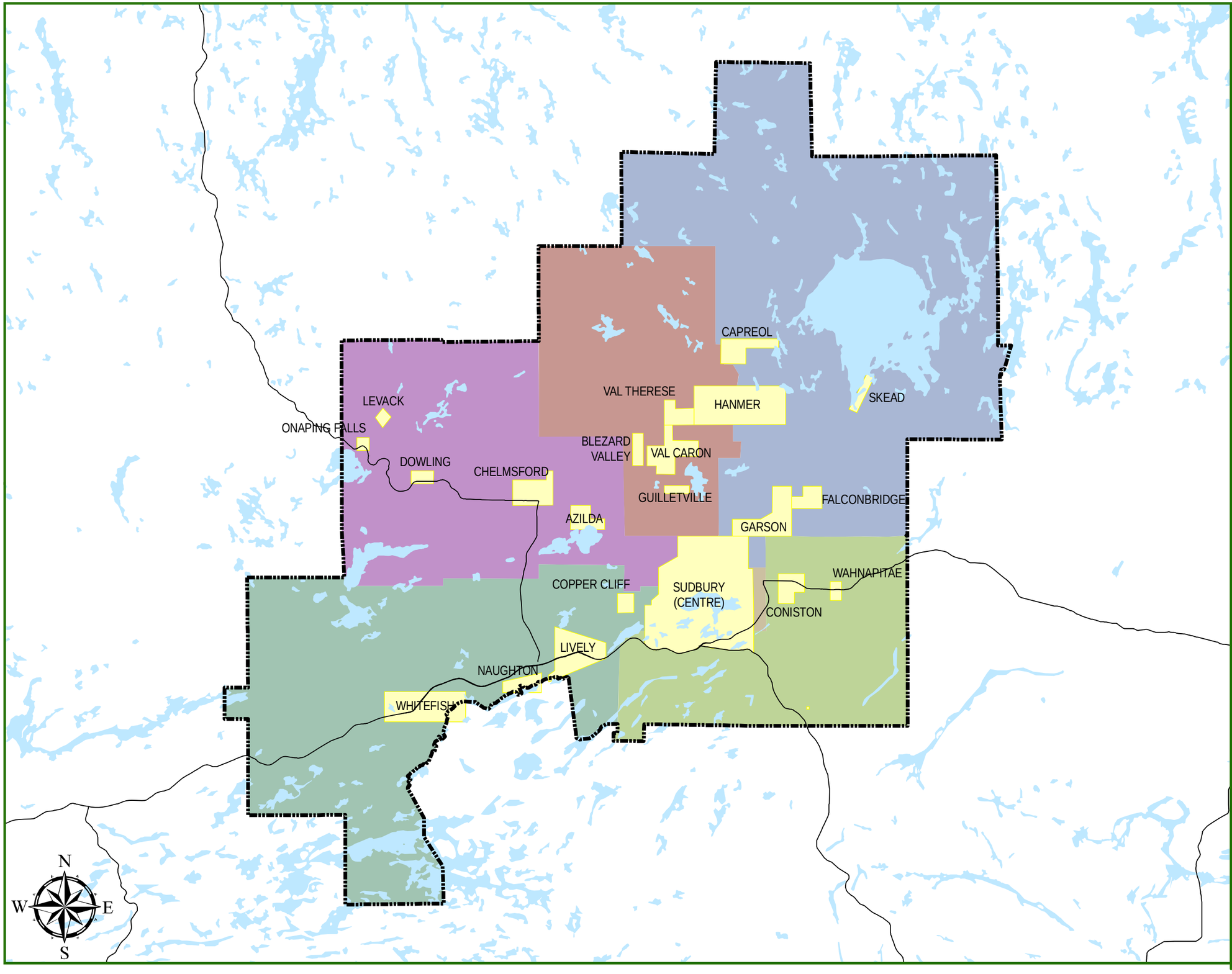
Figure 7-3
Community Boundary Index Map



Legend

- Greater Sudbury Boundary
- Community of Interest
- Other Communities
- Ward 1
- Ward 2
- Ward 3
- Ward 4
- Ward 5
- Ward 6

Scale 1:360,000

0 *10* *20 Km*

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Figure 7-4
Distribution of Soil Sample Locations by Community

Core Samples by Community

- Azilda
- Blezard Valley
- Capreol
- Chelmsford
- Coniston
- Copper Cliff
- Dowling
- Falconbridge
- Garson
- Guilletville
- Hanmer
- Levack
- Lively
- Naughton
- Onaping Falls
- Skead
- Sudbury (Centre)
- Val Caron
- Val Therese
- Wahnapitae
- Whitefish
- Ward 1
- Ward 2
- Ward 3
- Ward 4
- Ward 5
- Ward 6
- Remote

Greater Sudbury Boundary

N
W
E
S

Scale 1:360,000

0 10 20 Km

The concentrations of the six Chemicals of Concern (the selection of which is described in Chapter 8) across the study area (Table 7.2) can be summarized as follows:

Arsenic
The concentration of total As in the top 20 cm of soil ranged from 2.5 to 620 mg/kg, with a mean value of 16 mg/kg and a median value of 6 mg/kg. The upper 95th percentile concentration was 61 mg/kg.

Cobalt
The concentration of total Co in the top 20 cm of soil ranged from 1 to 190 mg/kg, with a mean value of 14 mg/kg, and a median value of 9 mg/kg. The upper 95th percentile concentration was 42 mg/kg.

Copper
The concentration of total Cu in the top 20 cm of soil ranged from 2.7 to 5600 mg/kg, with a mean value of 260 mg/kg and a median value of 80 mg/kg. The upper 95th percentile concentration was 1100 mg/kg.

Nickel
The concentration of total Ni in the top 20 cm of soil ranged from 7 mg/kg to 3700 mg/kg, with a mean value of 264 mg/kg, and a median value of 95 mg/kg. The upper 95th percentile concentration was 1100 mg/kg.

Lead
The concentration of total Pb in the top 20 cm of soil ranged from 1 to 790 mg/kg, with a mean value of 35 mg/kg, and a median value of 16 mg/kg. The upper 95th percentile concentration was 130 mg/kg.

Selenium
The concentration of total Se in the top 20 cm of soil ranged from 0.5 to 49 mg/kg, with a mean value of 2 mg/kg, and a median value of 0.5 mg/kg. The upper 95th percentile concentration was 5 mg/kg.

Table 7.2 Summary of 2001 soil survey results for 20 inorganic parameters.

	Concentration in Soil (mg/kg)				
N = 8148	**Minimum**	**Median**	**Average**	**Maximum**	**95th Percentile**
Al	2100	9800	10434	39000	18000
As	2.5	6	16	620	61
Ba	9.8	47	56	720	120
Be	0.25	0.25	0.61	2	0.25
Ca	470	4000	5165	250000	11000
Cd	0.4	0.4	1	6.7	1.8
Co	1	9	14	190	42
Cr	9	31	34	1100	56
Cu	2.7	80	260	5600	1100
Fe	4400	15000	16327	110000	26000
Mg	350	2800	3065	26000	5700
Mn	33	190	211	3300	360
Mo	0.75	0.75	1	21	1.8
Ni	7	95	264	3700	1100
Pb	1	16	35	790	130
Sb	0.4	0.4	0.48	8.1	1
Se	0.5	0.5	2	49	5
Sr	5	33	35	340	53
V	8	30	31	130	45
Zn	1.25	34	44	340	110

All values are presented in mg/kg
Sample size is from combined soils database
Soil depths combined : 0-5, 5-10, 0-20 cm