LEAD AS A
CHEMICAL OF CONCERN

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SARA GROUP

HHRA/ERA Document
Lead as a Chemical of Concern
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EXECUTIVE SUMMARY

At the beginning of the Sudbury Soils Study, four Chemicals of Concern (COCs) were put forth by the Technical Committee (TC) for detailed evaluation in the Human Health Risk Assessment (HHRA) and Ecological Risk Assessment (ERA). These included arsenic, cobalt, copper and nickel. This recommendation was based on a review of historical soil quality data in the Sudbury area.

An extensive survey of soil quality in the Sudbury area was undertaken in 2001. Approximately 8150 soil samples were collected from over 1000 locations. The survey was undertaken by three different groups (Ontario Ministry of the Environment, Laurentian University and Golder Associates Ltd.) utilizing similar methodology. All samples were analyzed for 20 inorganic parameters by the same analytical laboratory.

For a compound to be considered as a COC in the risk assessment, it must fulfill 3 criteria established by the TC:

- Parameter must be above or equal to the Table A or Table B guidelines published in the MOE's Guideline for Use at Contaminated Sites in Ontario (1997), depending on whether the specified study area has surface or well water sources for potable water;
- Parameter must be present across the study area; and,
- Parameter must scientifically show origin from smelter operations.

The results of the 2001 survey were screened against these three criteria to identify whether any additional COCs should be considered for the risk assessments.

Analytical results from the Ontario Ministry of the Environment (MOE) survey were made available to the SARA Group in 2003. The SARA Group screened the MOE dataset against the three criteria above, and it was determined that lead (Pb) met all three. In July, 2003, the SARA Group recommended to the TC that Pb be considered a COC for the Sudbury Soils Study based on review of the partial dataset.

Analytical results from Laurentian University and Golder Associates Ltd. were later made available to the SARA Group. These results were integrated with the MOE data into one combined comprehensive soils database.

This document reports on the screening of the combined database to confirm that Pb should be considered as a COC for the Sudbury Soils Study. The results are:

- A small proportion of soil samples (1.6%, or 129 of 8148) had concentrations of lead that were greater than or equal to the generic soil quality guideline (200 mg/kg).
- Lead is present across the study area. However, the majority of samples that meet or exceed the guideline are located in the vicinity of the smelters at Copper Cliff, Coniston and Falconbridge.
- There is strong statistical and particle characterization evidence that links at least some of the Pb in soils to the smelter operations.

In summary, the SARA Group confirms the earlier recommendation that Pb should be considered a COC for the Sudbury Soils Study.

SARA GROUP

SUDBURY AREA RISK ASSESSMENT
LEAD AS A CHEMICAL OF CONCERN

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1.0 BACKGROUND

The Request for Proposal (RFP) for the Sudbury Soils Study identified four Chemicals of Concern (COCs) for the risk assessment: nickel (Ni), copper (Cu), cobalt (Co) and arsenic (As). This initial set of COCs was established by the Technical Committee based on historical sampling data and the Ontario Ministry of the Environment (MOE) 2001 report entitled *Metals in Soil and Vegetation in the Sudbury Area (Survey 2000 and Additional Historic Data).*

Three selection criteria were developed by the Technical Committee to identify a metal (or metalloid) as a potential COC for the Sudbury Soil Study. All three criteria must be satisfied to identify additional substances as COCs. The three criteria are:

- Parameter must be above or equal to the Table A or Table B guidelines published in the MOE's *Guideline for Use at Contaminated Sites in Ontario* (1997), depending on whether the specified study area has surface or well water sources for potable water;
- Parameter must be present across the study area; and,
- Parameter must scientifically show origin from smelter operations.

Phase 1 of the Sudbury Soils Study included the collection and analysis of approximately 8100 additional soil samples in 2001. These samples were collected by the Ontario Ministry of the Environment (MOE), Laurentian University and Golder Associates Ltd. Each sample was analyzed for a suite of 20 inorganic parameters. Results from these three sampling programs were reported separately.

Analytical results from the MOE sampling program (about 6700 samples) were provided to the SARA Group early in 2003 for review. These data were screened against the three criteria above, and it was determined that lead (Pb) met all three criteria. As a result, the SARA Group recommended that lead be considered a COC to the Technical Committee in July, 2003. That recommendation, however, was based only on the MOE soil survey data, and not the complete dataset that was eventually developed for the Sudbury Soils Study.

Analytical results from Laurentian University and Golder Associates were later made available to the SARA Group (Spring 2004). All sampling results were integrated into a single combined soils database. This complete database was then screened against the above three criteria to determine if any other substances should be considered as COCs for the Sudbury Soils Study.

This document reports on the screening of the entire combined soils database for the confirmation of lead as a COC. In addition, characterization studies using scanning electron microscope (SEM) were undertaken in 2003 and early 2004 by the Geosciences Laboratory, Ministry of Northern Mines and Development, in Sudbury, to further determine if the Sudbury smelters could be linked as a source of lead in Sudbury soils. The report from the Geosciences Lab was provided to the Technical Committee in June, 2004. This submission also summarizes the findings of that report.

2.0 METHODOLOGY

To evaluate whether lead meets the criteria as a COC, data from three sources were incorporated into a combined database and reviewed by the SARA Group. One source of data was the results of a comprehensive soil monitoring program conducted in the Sudbury area in 2001 by the MOE. These results are presented in a report entitled *City of Greater Sudbury 2001 Urban Soil Survey* (MOE, 2004). The MOE sampling stations established in this study were in predominantly urban areas. The second data source was provided by Laurentian University and consisted of samples collected in rural and remote areas within the Greater Sudbury area in 2001. The third dataset was collected in the Falconbridge area by Golder Associates Ltd. All sampling programs followed the same protocol, which included the collection of composite samples comprising a minimum of fifteen cores taken at three depths (0-5 cm, 5–10 cm and 10–20 cm), with most samples taken in duplicate.

The databases were combined, and the concentrations of lead in all soil samples compared to the MOE's *Guideline for Use at Contaminated Sites in Ontario* (1997), specifically Table A values. The Table A soil guidelines are effects-based and were derived to protect both human health and the natural environment, whichever is potentially affected at the lowest observed effect concentration (LOEC).

The MOE guideline level derived for lead is 200 mg/kg in Table A for industrial or residential sites. For agricultural sites, it is recommended that lead concentrations be less than 2 mg/kg where there is a possibility that vegetation may be consumed by livestock.

For lead to be classified as a COC three criteria need to be met:

- Criterion 1: Are lead concentrations above or equal to MOE's Table A?
- Criterion 2: Is lead present across the study area?
- Criterion 3: Can it be shown that elevated levels of lead are the result of smelter operations in the study area?

To evaluate Criterion 1, the combined database was compared to Table A guidelines as published in the MOE's Guideline for Use at Contaminated Sites in Ontario (MOE, 1997).

To evaluate Criterion 2, the location of lead values above 200 mg/kg (Table A guidelines) were plotted across the study area.

To evaluate Criterion 3, statistical analysis was performed to determine if elevated lead levels in soil were related to smelter operations in the study area. In addition, samples of soil and smelter stack filters were submitted for Scanning Electron Microscope (SEM) analysis to better characterize the form of lead in the samples.

3.0 DETERMINATION OF CRITERIA

3.1 Criterion 1

Parameter must be equal to or above the Table A or Table B guidelines published in the MOE's *Guideline for Use at Contaminated Sites in Ontario* (1997), depending on whether the specified study area has surface or well water sources for potable water.

The concentration of lead in Sudbury soils ranged from 1.0 to 790 mg/kg (n = 8148*). The median and mean values were 16.0 and 35 mg/kg, respectively. The 95th percentile was 130 mg/kg.

Lead was present at equal to or above the MOE Table A guideline (200 mg/kg) in a total of 129 soil samples; this included 125 urban soil samples collected by the MOE, 1 remote sample collected by Laurentian University and 3 samples collected by Golder Associates Ltd. in the Town of Falconbridge.

Further analysis of the combined database determined the spatial and depth variation between the samples containing elevated lead levels. This analysis considered:

- 6532 samples taken from 1531 sites (located on 633 properties) (MOE);
- 1422 samples taken from 369 sites (Laurentian University); and,
- 194 samples taken from 33 sites (Golder Associates Ltd.).

These results show that lead fulfills Criterion 1 for 129 (1.6%) of 8148 soil samples.

3.2 Criterion 2

Parameter must be present across study area.

To determine the distribution of soil samples with lead concentrations greater than the MOE Table A guideline, the easting and northing location of each sample was plotted (Figure 3-1). Figure 3-1 confirms that the samples with elevated lead levels occur throughout the study area, but elevated lead levels are primarily in the vicinity of the Inco smelter at Copper Cliff.

Lead levels above or equal to the MOE Table A guideline were present at 25 properties in Copper Cliff, 13 properties in Falconbridge, four in Sudbury Core, two in Sudbury South, one in Sudbury East, one in Gatchell, six in Coniston and one in Capreol (Table 3.1).

About half of the properties (47%) with lead in excess of or equal to the Table A guideline are located in Copper Cliff; 25% are in Falconbridge; 11% are in Coniston; and 17% are located in other areas (Gatchell, Sudbury Core, Sudbury East, Sudbury South and Capreol).

The concentration of lead in samples above or equal to the Table A guideline in Copper Cliff ranged from 200 mg/kg to 610 mg/kg. The concentration in Falconbridge ranged from 200 mg/kg to 790 mg/kg. The concentration in Sudbury Core ranged from 200 mg/kg to 470 mg/kg. The lead concentration in Sudbury East ranged from 220 mg/kg to 310 mg/kg, while the four samples from Sudbury South ranged from 200 mg/kg to 270 mg/kg (Table 3.1).

The results of the analysis show that lead fulfills Criterion 2; it exists within the study area, although elevated levels are predominantly in the Copper Cliff area.

Table 3.1 Summary of Properties with Samples Containing Lead Above MOE Table A Value (200 mg/kg)

Community	# Properties Above Table A	Lead Range (mg/kg)
Capreol	1	214
Coniston	6	200-400
Copper Cliff	25	200-610
Falconbridge	13	200-790
Gatchell	1	200-320
Sudbury (Core)	4	200-470
Sudbury (East)	1	220-310
Sudbury (South)	2	200

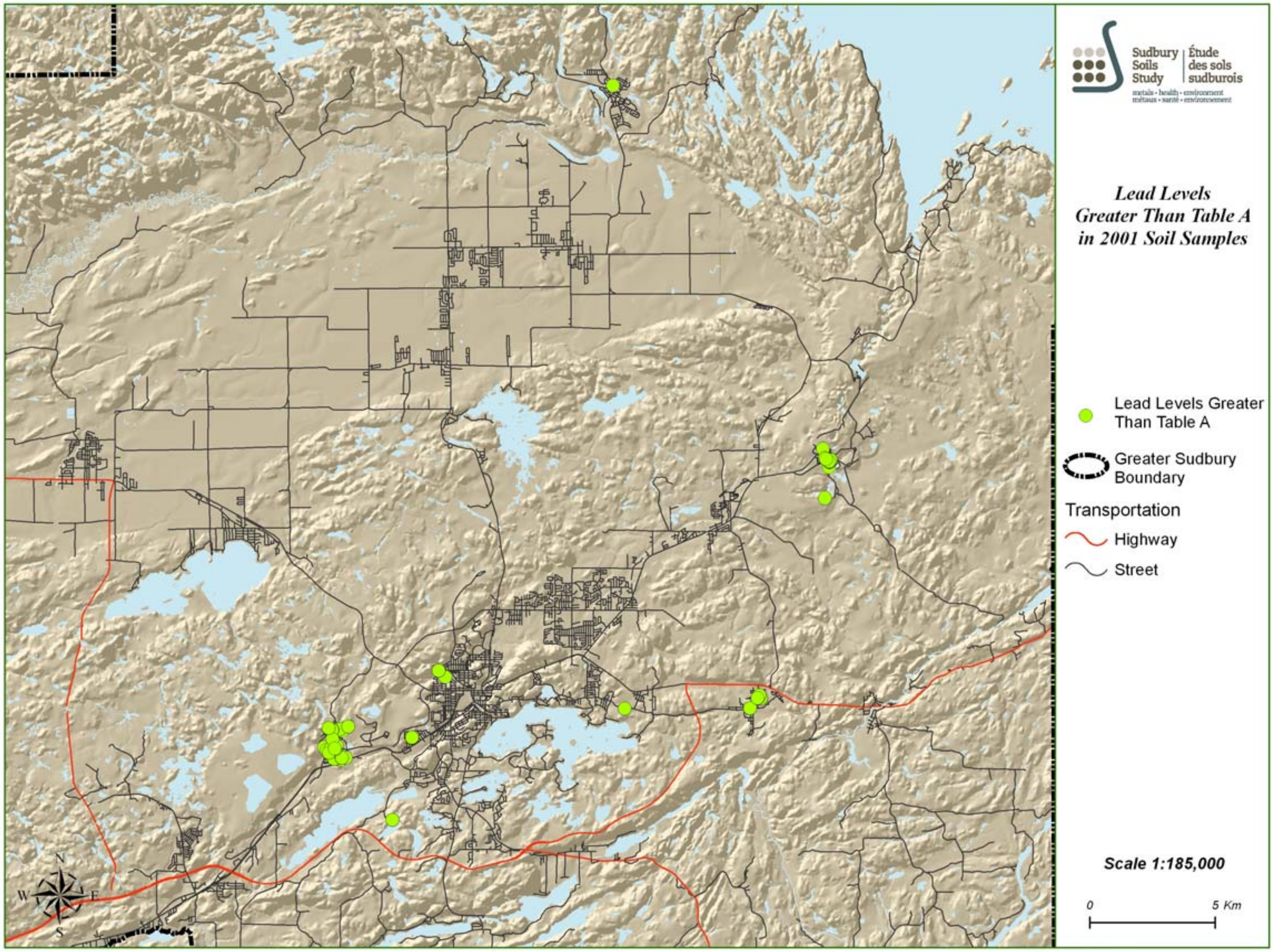

Figure 3-1 Distribution of soil samples with lead concentrations >200 mg/kg

3.3 Criterion 3

Parameter must scientifically show origin from smelter operations.

Lead is known to occur in association with copper and is one of the by-products of copper refining. A two variable regression and correlation analysis was performed to evaluate the possible relationship between concentration of lead and distance from the smelter within a defined radius (10 km for Copper Cliff, 5 km for Coniston and Falconbridge due to the close proximity of these two smelters). The relationship between lead in soils and distance is illustrated for the three smelter communities of Copper Cliff, Falconbridge and Coniston in the following scatter diagrams.

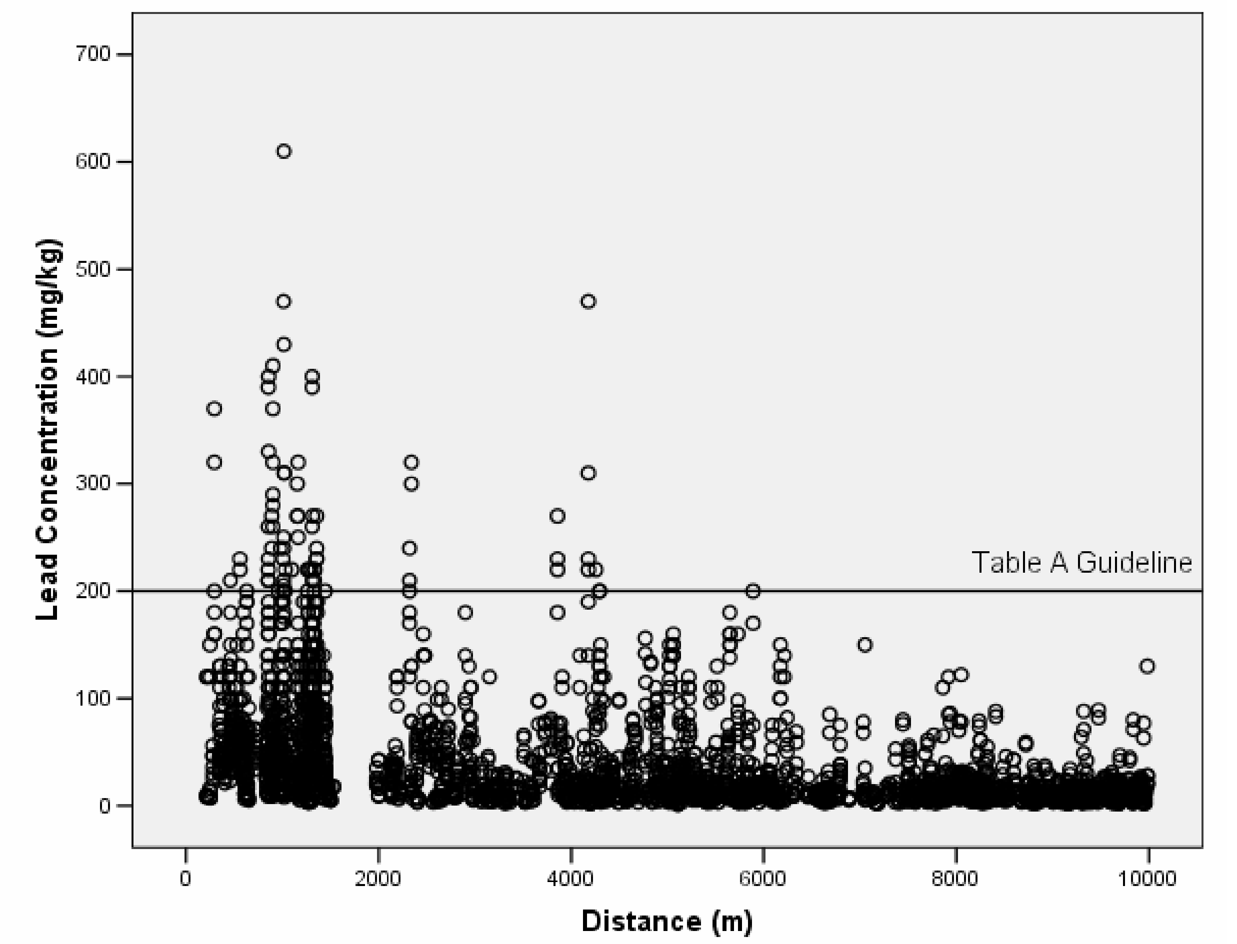

Figure 3-2 Lead Concentration vs. Distance within a 10 km Radius from the Copper Cliff Smelter in all samples, all depths

Figure 3-2 indicates that all of the samples containing lead above the MOE Table A value occurred at a distance of less than 6000 m from the Copper Cliff smelter.

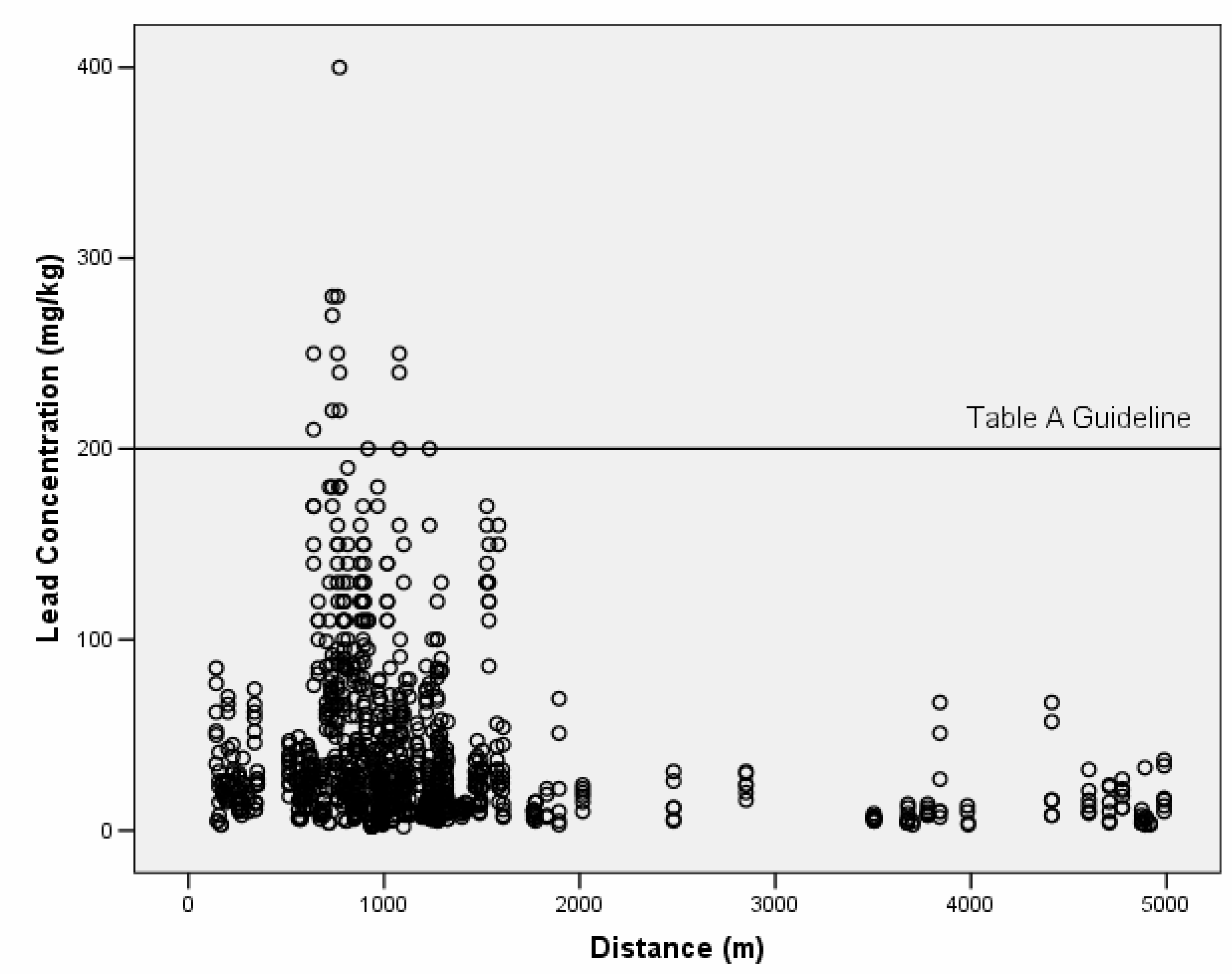

Figure 3-3 Lead Concentration vs. Distance within a 5 km Radius from the Coniston Smelter in all samples, all depths

Figure 3-3 indicates that in the Coniston area, all of the samples containing lead over the MOE Table A value occurred at a distance of less than 2000 m from the Coniston smelter.

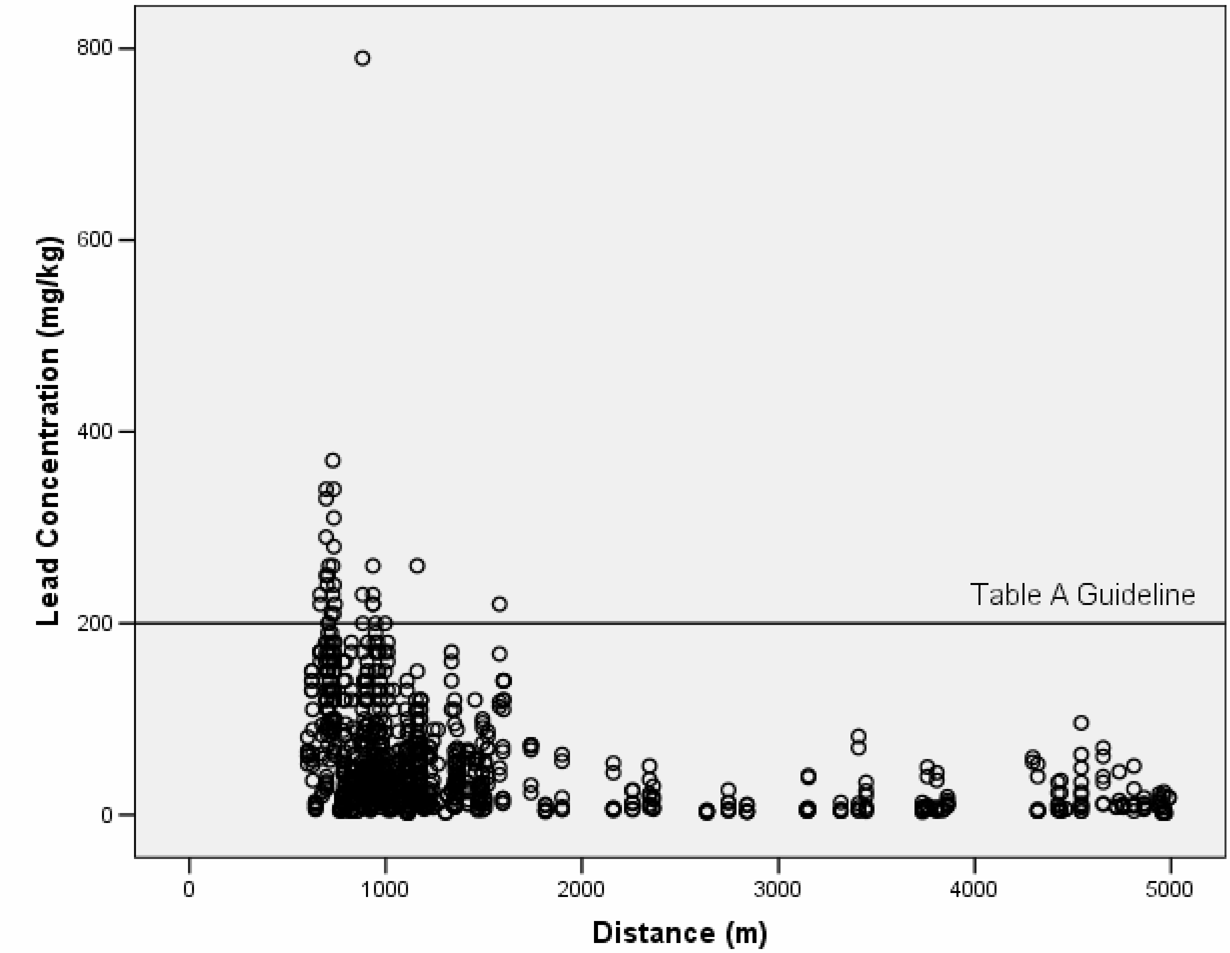

Figure 3-4 Lead Concentration vs. Distance within a 5 km Radius from the Falconbridge Smelter in all samples, all depths

Figure 3-4 indicates that in the Falconbridge area, samples containing lead over the MOE Table A value occurred at a distance of less than 2000 m from the Falconbridge smelter.

3D representations of lead levels versus distance from the smelters are provided in Figures 3-5 to 3-7. The UTM coordinates of all points within a defined radius (10 km for Copper Cliff, 5 km for Coniston and Falconbridge due to the close proximity of these two smelters) of the smelters were plotted.

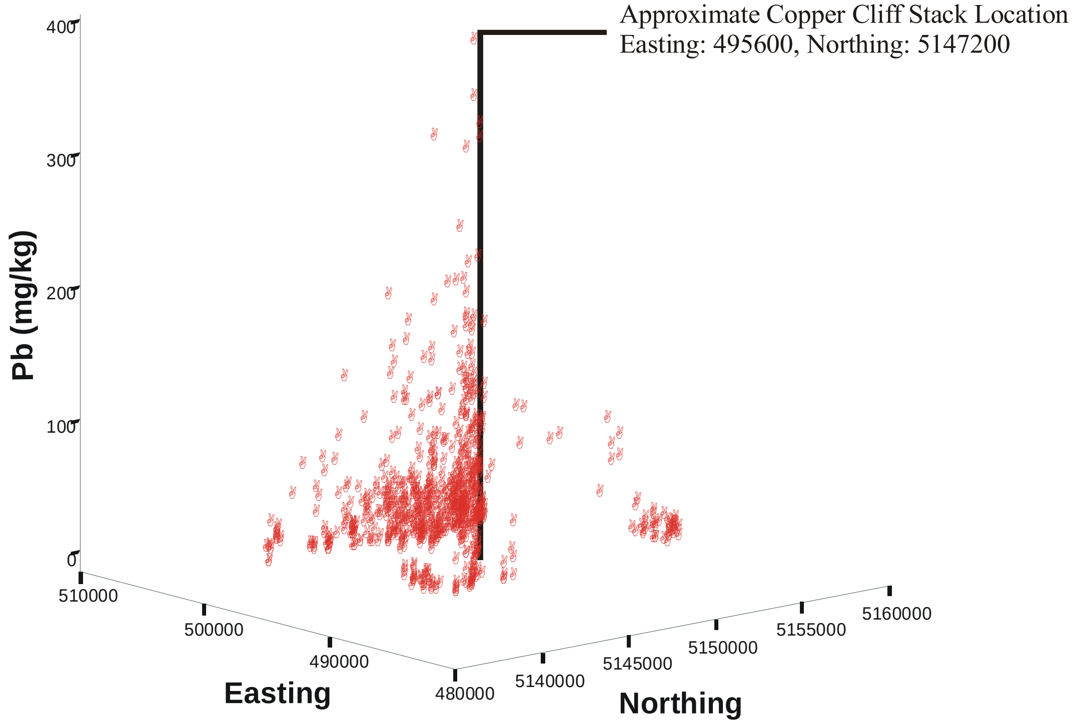

Figure 3-5 Lead Concentration vs. Location within a 10 km Radius from the Copper Cliff Smelter

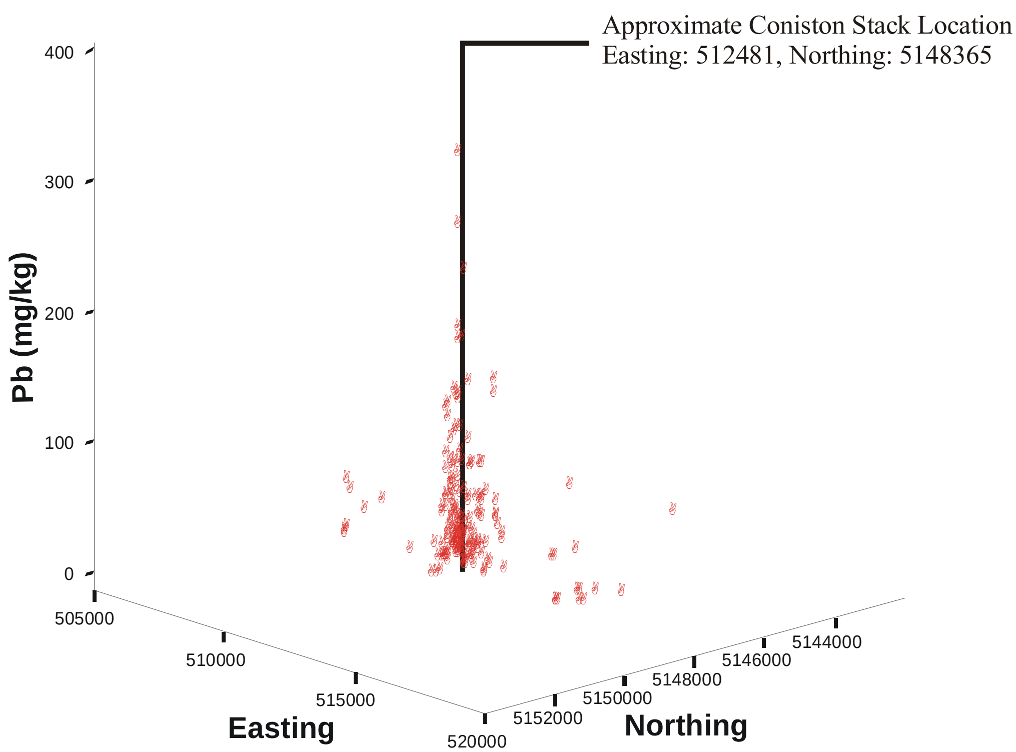

Figure 3-6 Lead Concentration vs. Location within a 5 km Radius from the Coniston Smelter

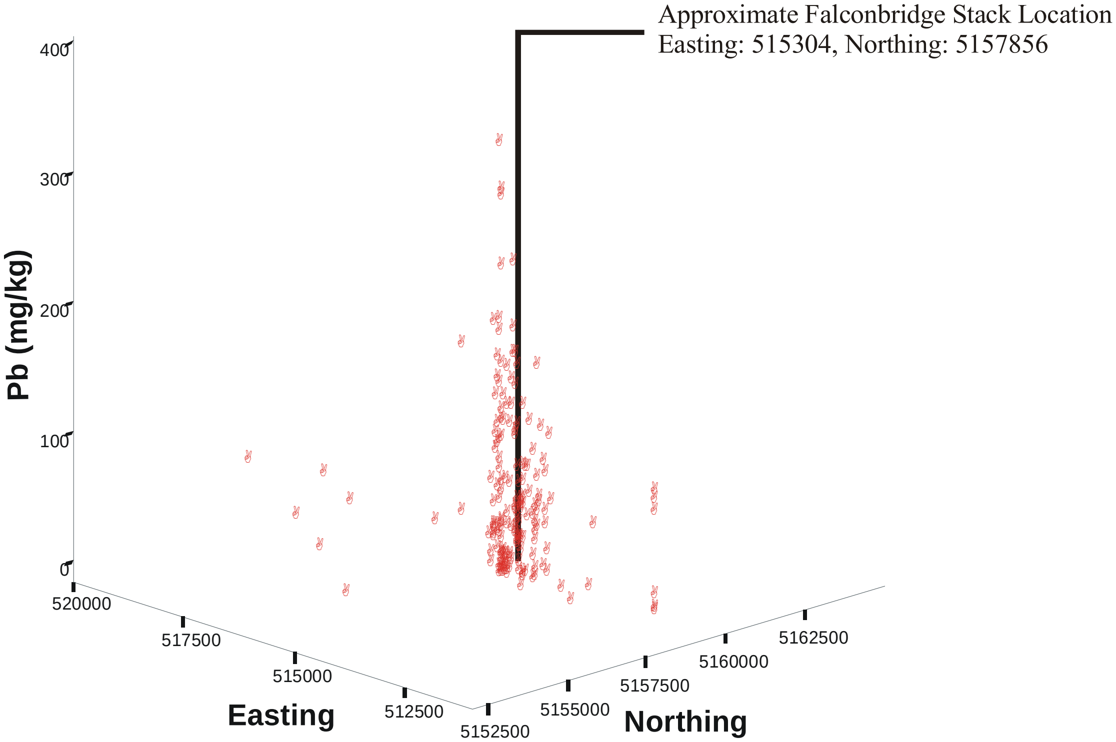

Figure 3-7 Lead Concentration vs. Location within a 5 km Radius from the Falconbridge Smelter

Statistical Analysis

Two regression and correlation analyses were performed. The first analysis included lead concentration greater than or equal to 200 mg/kg, in relation to distance from the smelter. The second analysis evaluated lead concentration in relation to other metals. Samples considered in the analysis were contained within a defined radius from the smelters (10 km for Copper Cliff, 5 km for Coniston and Falconbridge due to the close proximity of these two smelters). The correlation analysis was performed using SPSS v.12.

Determining the spatial link between elevated levels of lead and the smelter source:

Spearman's rank correlation was used to correlate lead concentration and distance from the smelter. For details on the selection of correlation tests, see Appendix B.1 at the end of this report. The test value for a Spearman's rank correlation can range anywhere from -1 to +1. A value of -1 indicates a perfect negative correlation (as one variable increases, the other decreases); a value of +1 indicates a perfect positive correlation (as one variable increases, the other increases); a value of 0 indicates that no correlation exists between the two variables in question. The closer the test value is to -1 or +1 is also an indication of the strength of the correlation between the two variables being tested. A general scale for determining the strength of the correlation is as follows:

Table 3.2 A General Scale* for Classifying the Strength of a Spearman's Rank Correlation

Test statistic (r value)	Strength of correlation
0.9 – 1.0	very high correlation, very dependable relationship
0.7 – 0.9	high correlation, marked relationship
0.4 – 0.7	moderate correlation, substantial relationship
0.2 – 0.4	low correlation, relationship definite but small
< 0.2	slight, almost negligible correlation

* From Senter (1969).

The level of confidence is the probability by which the results are not due to random chance alone. For this analysis, a confidence level of 99% was used. This statistical significance is also reflected in the α value ($\alpha = 0.01$) which is the probability of the results occurring due to random chance alone.

A one-tailed test was used in this analysis (*i.e.* it was assumed that concentrations of lead would not decrease closer to the smelters or as levels of the other COCs increased). Therefore the parameters for this test were $n = 1536$, $\alpha = 0.01$ (99% level of confidence), using a one-tailed test.

The results of the analysis are summarized in Table 3.3. The full details of the statistical analysis are provided at the end of this report.

Table 3.3 Pb Levels (mg/kg) in Surface Soil (0 – 5 cm) Correlated to Distance from the Smelters

Smelter source	Correlation coefficient (r)*	p value
Copper Cliff (n = 1536)	-0.475	0.000
Coniston (n = 370)	-0.159	0.000
Falconbridge (n = 367)	-0.292	0.000

* Test type = one-tailed, $\alpha = 0.01$

The correlation coefficient for lead versus distance from the Copper Cliff smelter was $r = -0.475$ with $p<0.01$ which implies a significant, correlation between lead and distance from the smelter. The negative sign in the test value signifies that the correlation is negative in nature (*i.e.* as the distance to the smelter decreases, lead levels increase).

Determining the correlation between levels of lead and levels of other established COCs associated with the smelter:

An additional comparison between lead and other COCs associated with smelter operations was performed based on the premise that if lead follows a similar distribution pattern as the established COCs already associated with smelter operations, then the results would suggest that the source of lead was also due to smelter operations.

Spearman's coefficient was used to correlate the levels of lead and other established COCs associated with the smelter, namely nickel and copper. The same parameters used in the first correlation also apply here (*i.e.* n = 1536, α = 0.01, and one-tailed test). Although a one-tailed test was also used in this correlation, it should be noted that a positive correlation was anticipated here, as lead levels were not expected to decrease as levels of the other COCs increase. The results of the analysis are summarized in Table 3.4. Full details of this statistical analysis are provided in Appendix B.1 at the end of this report.

For comparison purposes, the correlation between soil lead concentrations and vanadium (V) concentrations were examined, as V is an element not related to the smelting process.

Table 3.4 Correlation between Pb, Cu, Ni and V in Soil (0 - 5 cm)

Smelter source	Correlation coefficient test values (r)*		
	Cu	Ni	V**
Copper Cliff (n=1,536)	0.923	0.929	0.179
Coniston (n=370)	0.847	0.853	-0.183
Falconbridge (n=367)	0.930	0.887	0.301

* Test type = one-tailed, α = 0.01
** Not a COC

There was a significant, positive correlation between levels of lead and the two other COCs (r values >0.8). The correlation between lead and vanadium was almost negligible (r=0.179, p<0.01). These results indicate little or no association between lead levels and elements not associated with smelter operations.

The results of these statistical analyses, including the spatial distribution mapping, scatterplots, and correlation analysis all strongly indicate that lead is related to smelting operations in Copper Cliff, and to a lesser extent the other two smelters.

4.0 SCANNING ELECTRON MICROSCOPE ANALYSIS

A more detailed characterization of the mineralogy of lead in soil samples from the Sudbury area was undertaken under contract by the Geosciences Laboratories, Ministry of Northern Development and Mines (MNDM), Sudbury. A copy of the full report provided by the Geosciences Laboratory is available upon request to the SARA Group. An overview of the study is provided in the following text.

The objectives of the Geosciences evaluation were to a) characterize the deportation of lead in Sudbury soil samples to aid in determination of the source of lead, and b) compare those results with particles on air filter samples collected from inside the Inco and Falconbridge smelter stacks.

Characterization was completed on 22 soil samples collected from several areas in the Sudbury region, but especially from properties in the vicinity of the three smelter sources; Copper Cliff, Coniston and Falconbridge. Lead concentrations in the soil samples ranged from 66 to 640 mg/kg. In addition, two filter stack samples were obtained from the Inco smelter, and one filter stack sample from the Falconbridge smelter for detailed examination.

4.1 Methods

The methodology employed for all soil samples is outlined in Figure 4-1. Epoxy mounts of the filter material were prepared without any separation. Energy dispersive (ED) analyses were completed using the scanning electron microscope (SEM). Wavelength dispersive (WD) analyses were completed using the electron microprobe (EMP). All electron micrographs and element x-ray maps were collected using the SEM. ED analyses were performed using an accelerating voltage of 20 kV, beam current of 2 nA, count time of 100 s at a working distance of 38 mm. Pure metal standards and natural oxides were used as standards, using in-house characterization values of the oxide standards for quality control. Backscatter electron (BSE) micrographs were collected using the same analytical conditions.

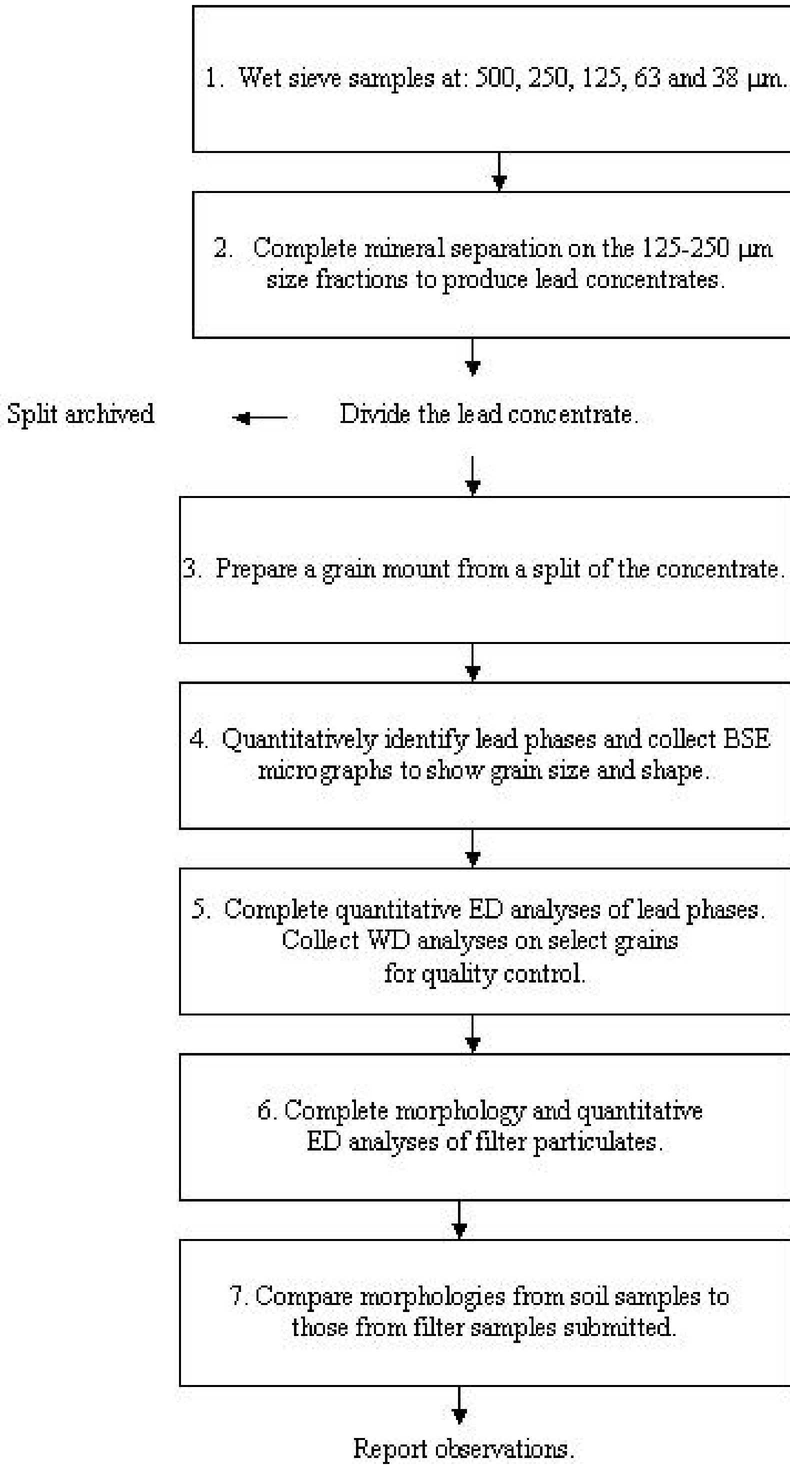

Figure 4-1 Flowchart of SEM Analysis Methodology

4.2 Results

Soil samples from Copper Cliff contained spherical and sub-spherical lead-bearing morphologies. Silica and iron-rich “stack spheres” were common in all soil samples, indicating deposition of particles from high temperature emissions sources. Lead-bearing spheres were not observed in soils from locations other than Copper Cliff.

Lead occurred in the soil samples in both oxide and metallic form. No other elements were detected in the metallic phase of lead. Of the lead-bearing particles analyzed, 56% had detectable levels of Ni and Cu. There was a positive correlation between Pb-Cu, and Pb-Ni.

Particles from the stack filter samples were generally less than 10 µm in diameter, which is the minimum particle size for ED analysis. Particles from both Inco and Falconbridge contained almost perfectly spherical “stack spheres” which are formed as a result of high temperatures encountered during the smelting process. However, the chemistry of the particles was different between samples from Inco and Falconbridge.

Lead phases were common in the filter samples from the Inco stack. The lead phases occurred both within the spheres and along the sphere rim. No lead phases were detected in the filter sample from the Falconbridge stack. Sulphur, Fe, Cu and Ni were the primary elements detected in particles from the Falconbridge filter samples.

4.3 Summary

The findings of the SEM work indicate that Pb in the Sudbury soils is present in both oxide and metallic form. The presence of “stack spheres” in all the soil samples is consistent with deposition from a high temperature source. Air filters from the Inco (Copper Cliff) smelter included spherical particles that contained significant levels of Pb, in conjunction with Ni and Cu. The one stack filter sample from Falconbridge did not contain detectable concentrations of Pb.

These filter observations are consistent with the spatial distribution of Pb in the Sudbury area, where elevated soil Pb levels occurred primarily in the vicinity of the Copper Cliff smelter.

5.0 SUMMARY AND RECOMMENDATIONS

This data review demonstrates the following:

1. Soil samples in the Sudbury area (n = 129) contain lead concentrations greater than or equal to the MOE Table A criteria. Overall, the proportion of soil containing elevated lead is relatively small (1.6 % of 8148 samples);

2. Samples with elevated lead are present across the study area, although primarily in the Copper Cliff area;

3. The distribution of soil samples with elevated lead concentrations is statistically correlated with distance to the smelters, indicating the source is linked to the smelter operations; and,

4. Scanning electron microscope analysis revealed characteristics of lead particles in soil consistent with lead particles emitted from the Copper Cliff smelter.

The data suggest that elevated lead concentrations present in Sudbury soil samples can be linked to smelter operations.

Therefore, it is recommended that lead be designated as a COC in the Sudbury Soils Study and that it be carried forth for detailed evaluation in both the human health and ecological risk assessments.

6.0 REFERENCES

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

Ministry of the Environment (MOE). 2001. Metals in Soil and Vegetation in the Sudbury Area (Survey 2000 and Additional Historic Data).

Ministry of the Environment (MOE). 1997. Guideline for Use at Contaminated Sites in Ontario.

Senter, R.J., 1969. Analysis of Data. Scott, Foresman and Company, Glenview, Illinois.

APPENDIX B.1:

STATISTICAL ANALYSIS

Correlation analysis

A common statistical method for establishing relationships such as those in this study is through correlation analysis. Correlation analysis involves comparing a test value, determined from an equation based on the number of samples, and the two variables whose relationship is in question (in this case lead concentration and distance) to critical values in published statistical tables. This comparison is often made by a statistical program. If the test value is greater than the critical value for a certain sample size, then it can be concluded that a correlation exists between the two variables in question. The test value is then compared to the scale provided below in Table A-1.

Table A.1 A general scale* for classifying the strength of a Spearman's rank correlation.

Test statistic (r value)	Strength of correlation
0.9 – 1.0	very high correlation, very dependable relationship
0.7 – 0.9	high correlation, marked relationship
0.4 – 0.7	moderate correlation, substantial relationship
0.2 – 0.4	low correlation, relationship definite but small
< 0.2	slight, almost negligible correlation

* From Senter (1969)

The significance of the correlation is determined by the p value or probability (as calculated by SPSS v.12), indicating the chance of the correlation results being due to random chance alone.

Correlation method selection

Two common methods of correlation analysis are Pearson's correlation and Spearman's rank correlation. The benefit of using Spearman's correlation analysis is that the data need not follow a linear relationship (producing a straight line when lead concentration versus distance to smelter is graphed), nor does the data have to be normally distributed (data symmetrically distributed about their average), two assumptions which must be made when using Pearson's correlation analysis. Spearman's rank correlation (as the name implies) must have the data presented by rank, where as Pearson's correlation analysis allows one to use the raw data. The ability of Spearman's rank correlation to determine the relationship between two variables without the assumption of linearity or normalized distributions made it more desirable for the analysis.

Correlations performed

Spearman's rank correlation was calculated to determine:

1. If there is a spatial link between the concentration level of lead and the distance from the smelter (*i.e.* the closer one gets to the smelter, the higher the concentration level of lead).

2. If there is a similar distribution pattern in elevated levels of lead as that of other established COCs associated with smelter operation, indicating that elevated lead levels originate from smelter operations.

To perform Spearman's rank correlation test, the data for lead, distance from the smelter, and data for the COCs corresponding to the same sites as the lead data was ranked using SPSS and then the correlation coefficient determined. The tests were one-tailed and used a significance value of $\alpha = 0.01$. Vanadium was used in the second analysis as a control, as this metal is not associated with smelter operations and should therefore have no significant relationship with lead.

Correlation analysis 1: Lead levels and distance from the Copper Cliff smelter.

The total number of samples (n) was 1536, consisting of all samples at the 0-5 cm depth out to a radius of 10 000 m from the Copper Cliff smelter. Samples with Pb <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o1}: There is no correlation between lead and distance from the Copper Cliff smelter.

Alternate Hypothesis H_{a1}: There is a correlation between lead levels and distance from the Copper Cliff smelter.

Results

The correlation coefficient associated with distance and lead was -0.475 with a $p<0.01$ (indicated by the "Sig. (1-tailed)" value) which implies a significant negative correlation between lead and distance from the Copper Cliff smelter.

Complete results of the statistical analysis are found in Table A.2.

Correlation analysis 2: Lead levels and other established COC levels.

The total number of samples (n) was 1536, consisting of all samples at the 0-5 cm depth out to a radius of 10 000 m from the Copper Cliff smelter. Samples with Pb <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o2}: There is no correlation between the concentration level of lead in the soil and the concentration level of other established COCs associated with smelter operation.

Alternate Hypothesis H_{a2}: There is a correlation between the concentration level of lead in the soil and the level of other established COCs associated with smelter operation.

Results

The correlation coefficients associated with lead and copper, nickel were both > 0.9 with $p<0.01$ which implies a significant, high correlation between lead and copper, nickel. The correlation coefficient for V was 0.179 with $p=0.011$ indicating that there was negligible correlation between Pb and V.

Complete results of the statistical analysis are found in Table A.2.

Table A.2 Spearman's Correlation Coefficients for Pb, Distance, and other COCs out to a Radius of 10 000 m from Copper Cliff Smelter

		Pb	Cu	Ni	V*	Distance
Pb	Correlation Coefficient	1.000	0.923	0.929	0.179	-0.475
	Sig. (1-tailed)	-	0.000	0.000	0.000	0.000
	n	1536	1536	1536	1536	1536
Cu	Correlation Coefficient	0.923	1.000	0.982	0.202	-0.624
	Sig. (1-tailed)	0.000	-	0.000	0.000	0.000
	n	1536	1536	1536	1536	1536
Ni	Correlation Coefficient	0.929	0.982	1.000	0.194	-0.576
	Sig. (1-tailed)	0.000	0.000	-	0.000	0.000
	n	1536	1536	1536	1536	1536
V	Correlation Coefficient	0.179	0.202	0.194	1.000	-0.058
	Sig. (1-tailed)	0.000	0.000	0.000	-	0.011
	n	1536	1536	1536	1536	1536
Distance	Correlation Coefficient	-0.475	-0.624	-0.576	-0.058	1.000
	Sig. (1-tailed)	0.000	0.000	0.000	0.011	-
	n	1536	1536	1536	1536	1536

* not a COC, for reference only

Correlation analysis 1: Lead levels and distance from the Coniston smelter.

The total number of samples (n) was 370, consisting of all samples at the 0-5 cm depth out to a radius of 5000 m from the Coniston smelter. Samples with lead <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o1}: There is no correlation between lead and distance from the Coniston smelter.

Alternate Hypothesis H_{a1}: There is a correlation between lead levels and distance from the Coniston smelter.

Results

The correlation coefficient associated with distance and lead was -0.159 with $p<0.01$ which implies a significant, negative correlation between lead and distance from the Coniston smelter. Complete results of the statistical analysis are found in Table A.3.

Correlation analysis 2: Lead levels and other established COC levels.
The total number of samples (n) was 370, consisting of all samples at the 0-5 cm depth out to a radius of 5000 m from the Coniston smelter. Samples with Pb <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o2}: There is no correlation between the concentration level of lead in the soil and the concentration level of other established COCs associated with smelter operation.

Alternate Hypothesis H_{a2}: There is a correlation between the concentration level of lead in the soil and the level of other established COCs associated with smelter operation.

Results

The correlation coefficients associated with Pb and Cu, Ni were both > 0.8 with $p<0.01$ which implies a significant, high correlation between lead and copper or nickel (other metals associated with smelter operation). The correlation coefficient for V was -0.183 with $p<0.01$ indicating that there was negligible correlation between Pb and V.

Complete results of the statistical analysis are found in Table A.3.

Table A.3 Spearman's Correlation Coefficients for Pb, Distance, and other COCs out to a radius of 5000 m from Coniston smelter

		Pb	Cu	Ni	V*	Distance
Pb	Correlation Coefficient	1.000	0.847	0.853	-0.183	-0.159
	Sig. (1-tailed)	-	0.000	0.000	0.000	0.001
	n	370	370	370	370	370
Cu	Correlation Coefficient	0.847	1.000	0.981	-0.118	-0.008
	Sig. (1-tailed)	0.000	-	0.000	0.012	0.440
	n	370	370	370	370	370
Ni	Correlation Coefficient	0.853	0.981	1.000	-0.135	-0.039
	Sig. (1-tailed)	0.000	0.000	-	0.005	0.227
	n	370	370	370	370	370
V	Correlation Coefficient	-0.183	-0.118	-0.135	1.000	0.268
	Sig. (1-tailed)	0.000	0.012	0.005	-	0.000
	n	370	370	370	370	370
Distance	Correlation Coefficient	-0.159	-0.008	-0.039	0.268	1.000
	Sig. (1-tailed)	0.001	0.440	0.227	0.000	-
	n	370	370	370	370	370

* not a COC, for reference only

Correlation analysis 1: Lead levels and distance from the Falconbridge smelter.

The total number of samples (n) was 367, consisting of all samples at the 0-5 cm depth out to a radius of 5000 m from the Falconbridge smelter. Samples with lead <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o1}: There is no correlation between lead and distance from the Falconbridge smelter.

Alternate Hypothesis H_{a1}: There is a correlation between lead levels and distance from the Falconbridge smelter.

Results

The correlation coefficient associated with distance and lead was -0.292 with $p<0.01$, which implies a significant, negative correlation between lead concentration and distance from the smelter.

Complete results of the statistical analysis are found in Table A.4.

Correlation analysis 2: Lead levels and other established COC levels.

The total number of samples (n) was 367, consisting of all samples at the 0-5 cm depth out to a radius of 5000 m from the Falconbridge smelter. Samples with Pb <200 mg/kg were included to produce a better correlation coefficient.

Hypotheses

Null Hypothesis H_{o2}: There is no correlation between the concentration level of lead in the soil and the concentration level of other established COCs associated with smelter operation.

Alternate Hypothesis H_{a2}: There is a correlation between the concentration level of lead in the soil and the level of other established COCs associated with smelter operation.

Results

The correlation coefficients associated with lead and copper, Ni were both > 0.8 with $p<0.01$ which implies a significant, positive correlation between lead and copper or nickel.

The correlation coefficient for V was 0.301 with $p<0.01$indicating that the correlation between lead and vanadium was significant but negligible.

Complete results of the statistical analysis are found in Table A.4.

Table A.4 Spearman's Correlation Coefficients for Pb, Distance, and other COCs out to a radius of 5000 m from Falconbridge smelter

		Pb	Cu	Ni	V*	Distance
Pb	Correlation Coefficient	1.000	0.930	0.887	0.301	-0.292
	Sig. (1-tailed)	.	0.000	0.000	0.000	0.000
	n	367	367	367	367	367
Cu	Correlation Coefficient	0.930	1.000	0.972	0.287	-0.283
	Sig. (1-tailed)	0.000	.	0.000	0.000	0.000
	n	367	367	367	367	367
Ni	Correlation Coefficient	0.887	0.972	1.000	0.267	-0.328
	Sig. (1-tailed)	0.000	0.000	.	0.000	0.000
	n	367	367	367	367	367
V	Correlation Coefficient	0.301	0.287	0.267	1.000	-0.255
	Sig. (1-tailed)	0.000	0.000	0.000	.	0.000
	n	367	367	367	367	367
Distance	Correlation Coefficient	-0.292	-0.283	-0.328	-0.255	1.000
	Sig. (1-tailed)	0.000	0.000	0.000	0.000	.
	n	367	367	367	367	367

* not a COC, for reference only

Summary

The test for correlation using Spearman's correlation analysis suggests two things:

1. That there is a relationship between lead and distance from the smelters- the closer one gets to the smelter, the higher the levels of Pb found in the soil.

2. That lead follows the same trend as the other already established COCs, which increase in concentration level as the distance to the smelter decreases, therefore indicating a link between the presence of elevated levels of lead and smelter operation.