SARA
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SUDBURY AREA RISK ASSESSMENT

VOLUME III - CHAPTER 6.0
CONCLUSIONS AND RECOMMENDATIONS

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6.0 INTRODUCTION

The Sudbury Ecological Risk Assessment is a scientific study that is intended to determine whether terrestrial ecological receptors are at risk due to COC in smelter emissions, and whether consideration of risk management measures is warranted.

This chapter provides a summary of the ERA results by Objective, and also integrates the findings of the separate Objectives. In addition, a method was developed to extrapolate results from the field studies for Objective 1 to a larger region of Sudbury to identify areas possibly requiring risk management. Lastly, the characteristics of impacted sites are summarized, providing some diagnostic tools to help identify areas where risk management may be appropriate. It is important to note, however, that this chapter is not intended to provide risk management strategies, or to definitively identify areas where risk management is required.

As stated in Chapter 1, the main goal for the Sudbury ERA not only recognizes the importance of evaluating ecological risks, but also identifies the need to support activities related to ecological recovery. The main goal is:

"*To characterize the current and future risks of Chemicals of Concern (COC) to terrestrial and aquatic ecosystem components from particulate emissions from Sudbury smelters. To provide information to support activities related to the recovery of regionally-representative, self-sustaining ecosystems in areas of Sudbury affected by the COC.*"

It is important to note that the term "recovery" is not meant to imply restoration to a pristine forest ecosystem that existed prior to impacts from the smelters and other human activities in the Sudbury region. Rather, the goal is to achieve a diverse self-sustaining terrestrial ecosystem, recognizing that it may differ from the original ecological landscape. The definition of a self-sustaining ecosystem was provided in Chapter 3 and is repeated later in this chapter. A self-sustaining ecosystem is a diverse landscape that does not require continued human intervention to maintain its essential functions.

The ERA recognizes three fundamental tenets of the terrestrial ecosystem around Sudbury: (1) that past activities have severely impacted the vegetation and contributed to the existing landscape; (2) that restoration and regreening activities have been, and continue to be, very successful over broad areas; and (3) that not all areas have received regreening treatments, and recovery in some areas has been inhibited.

To meet the Goal of the ERA, four specific ERA Objectives were developed in consultation with the Technical Committee:

Objective 1: *Evaluate the extent to which COC are preventing the recovery of regionally representative, self-sustaining terrestrial plant communities.*

Objective 2: *Evaluate risks to terrestrial wildlife populations and communities due to COC.*

Objective 3: *Evaluate risks to individuals of threatened or endangered terrestrial species due to COC.*

Objective 4: *Conduct a comprehensive Problem Formulation for the aquatic and wetland environments in the Sudbury area to facilitate more detailed risk assessment in the aquatic/wetland ecosystems.*

The results of the first three objectives were to be used to address a Risk Management Objective which was stated as:*"Evaluate levels of COC in various soil types to determine COC levels in soil which do not result in unacceptable risks to Valued Ecosystem Components (VECs)".* However, this was not possible, as outlined in Section 6.5.

Conclusions arising from each of the specific Objectives are summarized in Section 6.1. Uncertainties surrounding the ERA are described in Section 6.2. Section 6.3 describes the approach using satellite imagery to extrapolate the current study results to the larger Sudbury landscape. Section 6.4 summarizes the characteristics of impacted and reference sites. The Aquatic Problem Formulation was presented in Chapter 5 and is not discussed further in this chapter.

6.1   Ecological Risk Assessment Objective Conclusions

6.1.1   Objective 1

This Objective focused on the Plant Community. The conclusions are summarized below.

Objective 1 was addressed using a weight-of-evidence approach. To achieve this, detailed data for each of the four Lines of Evidence (LOE) were gathered from 22 study sites (18 test sites, one historically-limed site and three reference sites) along three transects corresponding with the three smelters at Coniston, Copper Cliff and Falconbridge.

The LOE were as follows:

- Soil physical and chemical characteristics;

- Single-species toxicity testing using several terrestrial species in the laboratory;

- A detailed plant community assessment; and

- An assessment of *in situ* decomposition using litter bags.

The test sites represented locations containing a range of soil metal concentrations and physical conditions along the three transects. Three reference sites were selected for comparative purposes at sites where the concentrations of COC were below the MOE Table F background criteria (MOEE, 1997). They were also generally representative of northeastern Ontario forest community conditions. Total metal concentrations and soil pH were the primary factors used to guide site selection. The test and reference sites for this study were selected to ensure a pH range of 4.0 to 5.0 in the 0–5 cm surface soil depth, in an attempt to minimize the potential influence of pH variability on the evaluation.

The four LOE were integrated to form an overall impact ranking (low, moderate or severe impact) for each of the test sites. The data from the LOE were ultimately used to try to identify which soil and environmental conditions were related to impacted terrestrial sites. The information could then be applied to a broader spatial area, and used as a basis for risk management.

The four LOE were not given equal weighting in the ranking process. The LOE were considered in the following order of importance:

- Plant community;

- Soil toxicity testing;

- Litter decomposition; and

- Soil chemistry

The order of weighting was based primarily on ecological relevance, with certainty of the approach and/or results given secondary consideration. The plant community assessment was given the most significance as it integrates and ultimately reflects all environmental conditions present at a site. The toxicity testing LOE was given the next weighting since several different test species were utilized, and the influence of soil pH was also evaluated. If these two LOE were both ranked severely impacted, the site was ranked severely impacted (red). Decomposition was given the second lowest weighting. Although decomposition is an ecologically important function, an experimental procedure was used, and the analysis was based on only one variable. Thus, there was more uncertainty related to this LOE than the previous two. The fourth LOE, soil characterization, was given the lowest weighting. Although there was a high degree of certainty in the results, it is only a descriptive parameter. However, the soil characterization was fundamental for interpreting the other LOE and overall site ranking.

The ranges in concentrations and mean levels of COC for each transect and the reference sites are summarized in Table 6.1.

Table 6.1   Ranges and Mean COC Concentrations (mg/kg)* at Test and Reference Sites

Metal	Copper Cliff Range	Mean	Falconbridge Range	Mean	Coniston Range	Mean	Reference Range	Mean
Arsenic	26–72	27	26–117	51	2.1–12.7	6.2	2.6–5.8	4.5
Cadmium	0.27– 1.26	0.40	0.26 – 1.1	0.44	0.12–0.44	0.18	0.17 – 0.28	0.20
Cobalt	7.8 – 41.5	17.0	4.8–48.4	16.3	5.5–11.5	9.4	5.4–11.5	6.81
Copper	97 – 1,000	339	87–655	264	76–240	96	18.7–42	33
Lead	29 – 99	34	28–162	62	4.6–28.0	9	18.6–33.0	21
Nickel	77–1100	321	78–422	167	77–255	110	39–46	33
Selenium	1.4–10.5	3.0	1.2 – 5.6	2.4	0.3–0.92	0.65	0.48–1.0	0.69

*Values are for HNO_3 extracted total metal concentrations in soil cores as described in Chapter 3

The extensive studies carried out for Objective #1 conclude that the existing soil conditions and landscape have largely been shaped by historical activities and historical deposition of metals (see also Section 6.1.4). The current levels of COC in soil are also continuing to impede the recovery of a self-sustaining plant community at some locations in the Sudbury region. However, other environmental variables and soil conditions are contributing to the inhibition of ecosystem recovery. All of these factors are intertwined to the extent that it is not practical or possible to quantify their individual roles over the broader study area. It was concluded that risk due to the COC could not be ruled out for the terrestrial vegetation community VEC.

6.1.1.1   Copper Cliff Sites

For the Copper Cliff sites there was an inverse relationship between metal concentration in soil and distance from the smelter, with higher metal levels (both total and water extracted) at sites closer to the smelter. There was a clear association between elevated metal concentrations in soil and the level of site impact. Five of the COC were present at levels in excess of the MOE Table A criteria (Table 6.2), although Se was only marginally elevated at one test site. While the SARA Group recognizes that these guidelines do not directly apply to the test or reference sites as the soil pH levels are below 5, the comparisons were made to give an overall indication of the concentrations of COC in the site soils. Soil infertility at some of the sites, along the Copper Cliff transect, was also associated with lack of recovery.

6.1.1.2   Falconbridge

The Falconbridge sites closest to the smelter in a downwind direction had the highest metal levels. There was an association between sites with high metal levels in the soil and the level of impact. Soil Ca and pH were identified as important factors affecting the bioavailability of metals. Five of the COC were present at levels exceeding the MOE Table A criteria (Table 6.2).

6.1.1.3   Coniston

Severe impact was generally associated with the highest soil metal concentrations with the Coniston sites. However, this was not the case in the instances where erosion was a confounding factor. Many sites were moderately to severely eroded. At the severely impacted sites, often close to the now inactive smelter, the metal levels were actually low compared to those on the other transects. In fact, only two COC were present along this transect at levels exceeding Table A criteria (Table 6.2). Other COC levels were comparable to reference conditions. Historically, it is likely that metal deposition and SO_2 levels were high at those sites resulting in a loss of vegetation, and subsequently a loss of soil due to erosion. In the process of soil loss, metals were removed as well, resulting in relict soil layers that are nutrient deficient and lack organic matter. The main factors contributing to impact at these sites were low pH and low nutrient levels, erosion, and lack of organic matter in the soil.

Table 6.2   List of COC with Concentrations Exceeding MOE Table A Criteria Along Test Transects

Copper Cliff	Falconbridge	Coniston
As	As	Cu
Co	Co	Ni
Cu	Cu	
Ni	Ni	
Se	Pb	

The spatial location and the overall ranking of each of the test sites is illustrated in Figure 6-1. The outline of an area referred to as the "semi-barrens" is also shown on Figure 6-1. This area is discussed later in the chapter.

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Figure 6-1 - ERA Objective 1 Overall Site Ranking
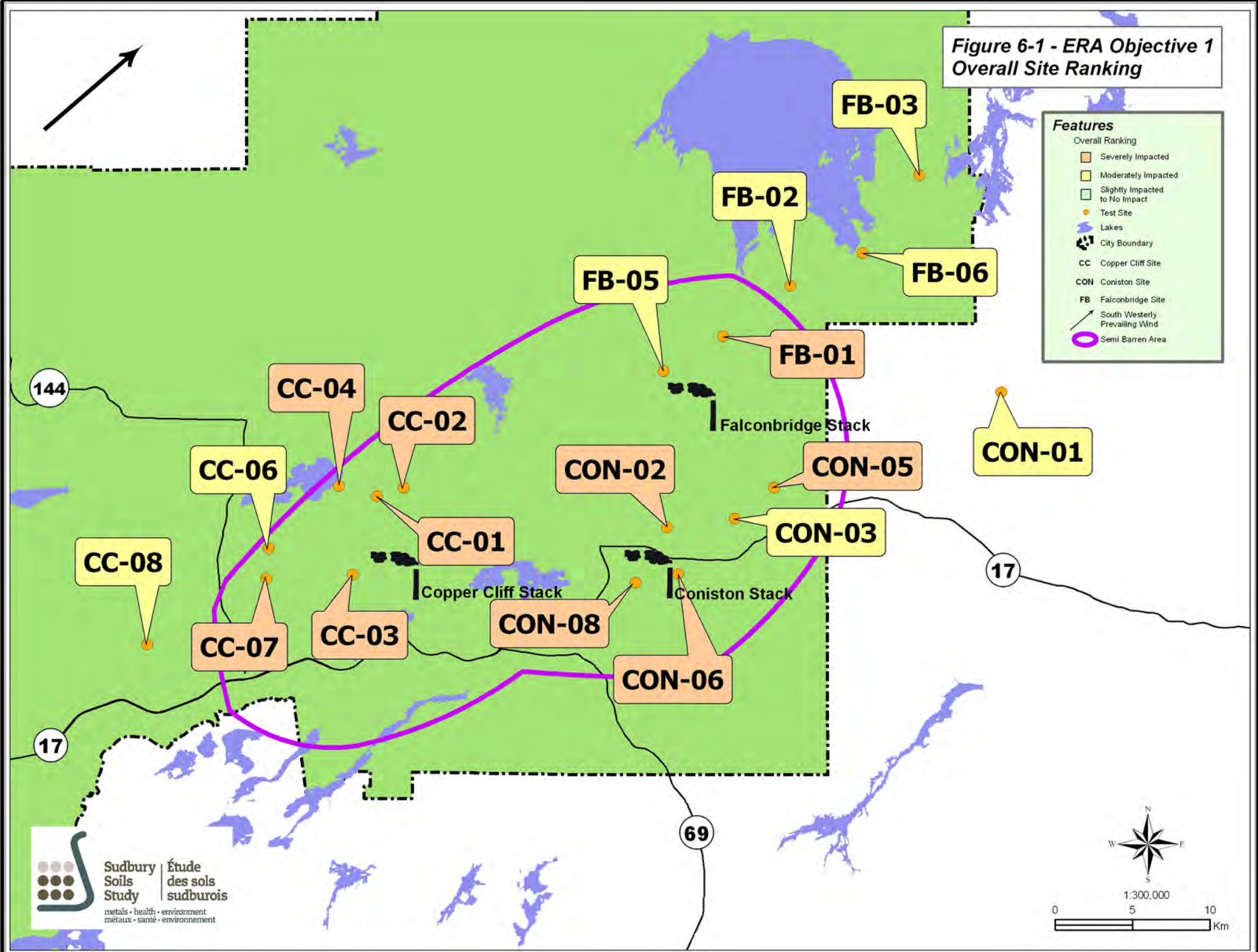
Features

Overall Ranking

- Severely Impacted
- Moderately Impacted
- Slightly Impacted to No Impact
- Test Site
- Lakes
- City Boundary
- **CC** Copper Cliff Site
- **CON** Coniston Site
- **FB** Falconbridge Site
- South Westerly Prevailing Wind
- Semi Barren Area

FB-03

FB-02

FB-05

FB-06

FB-01

CC-04

CC-02

CC-06

CON-02

CON-05

CON-01

Falconbridge Stack

CC-08

CC-01

CON-03

Copper Cliff Stack

Coniston Stack

CC-07

CC-03

CON-08

CON-06

144

17

17

69

Sudbury Soils Study | Étude des sols sudburois
metals · health · environment
métaux · santé · environment

1:300,000

0   5   10
Km

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6.1.1.4   Distance from Smelter

The field study was not designed to determine the spatial extent of impacts from the smelters, but some generalizations can be made based on the field observations. The test and reference sites were selected primarily based on soil metal content. Suitable reference sites were all greater than 25 km from the nearest smelter (see Table 6.3). None of the test sites were given a final "green" or low impact ranking, although at some test sites individual LOE did have low impact rankings. The "moderately" impacted sites (excluding CON-7, which was limed in the past) ranged from 3.5 to 25 km from the nearest smelter, although most (7/8) were over 5 km from the smelter, with 5 out of 8 sites greater than 8 km away. The "severely" impacted sites ranged from 1.8 to 8.9 km from a smelter, with 80% being within 5 km of a smelter. The relationship between site ranking and distance from the smelter is illustrated in Figure 6-2.
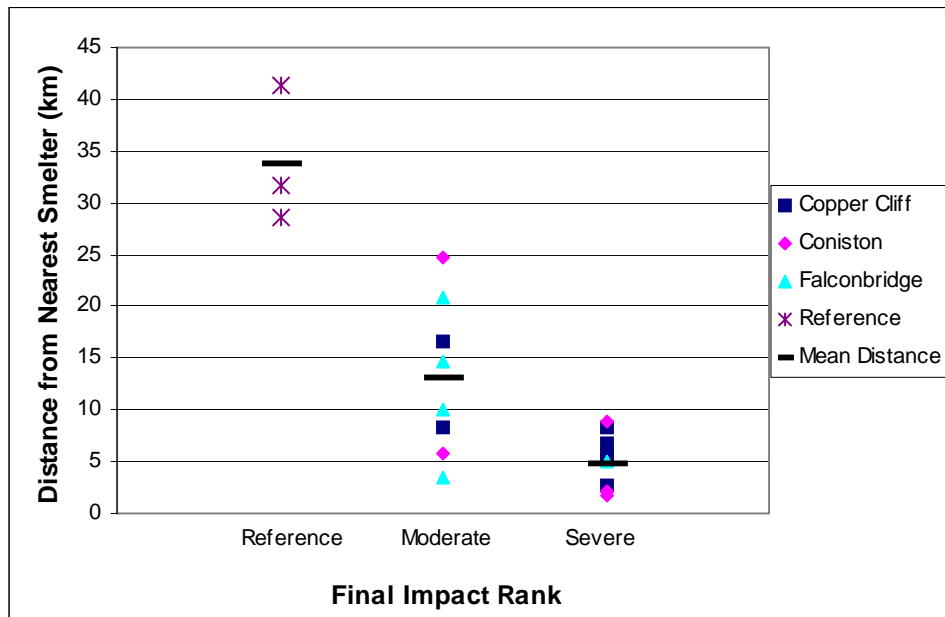

Figure 6-2   Distance from nearest smelter for individual sites at each impact level

Table 6.3   Summary of Site Distances (km) from Smelters Relative to Rankings

	Reference	Moderate Impact	Severe Impact
Copper Cliff	31.6	8.4–16.6	2.7–8.3
Coniston	41.3	5.7–24.8	1.8–8.9
Falconbridge	28.6	3.5–20.9	5.1

These distances can be used for general guidance in the future to help focus risk management, recognizing there will be exceptions and site-specific conditions that need to be taken into account. All three reference sites were located well outside of the "peanut" shaped area referred to as the semi-barrens (Figure 6-1). Some of the test sites were also located outside the semi-barren area, although this boundary was not a factor in site selection. The test sites outside the semi-barren area are listed in Table 6.4, along with the plant community ranking and final overall ranking.

Table 6.4   Test Sites Outside Semi-Barren Area with Site Ranking

Test Site	Distance from Smelter (km)	Plant Community Ranking	Final Ranking
CC08	16.6	Severe	Moderate
FB02	10.0	None-Low	Moderate
FB03	20.9	Moderate	Moderate
FB06	14.7	Moderate	Moderate
CON01	24.8	Moderate	Moderate

These results clearly demonstrate that ecological effects do extend beyond the area previously identified as the semi-barrens (see also Section 6.3).

There was an association between distance from the smelter and some plant community variables (such as species richness, reestablishment of sensitive lichen species and percentage leaf litter). Figure 6-3 shows that the number of plant species tends to increase with increasing distance away from the smelter. These trends were apparent along the Copper Cliff and Falconbridge sites although they were not clearly

observed at the Coniston sites. The lack of relationship at the Coniston sites may be a result of the low total metal levels in the soils and/or other factors such as soil erosion.
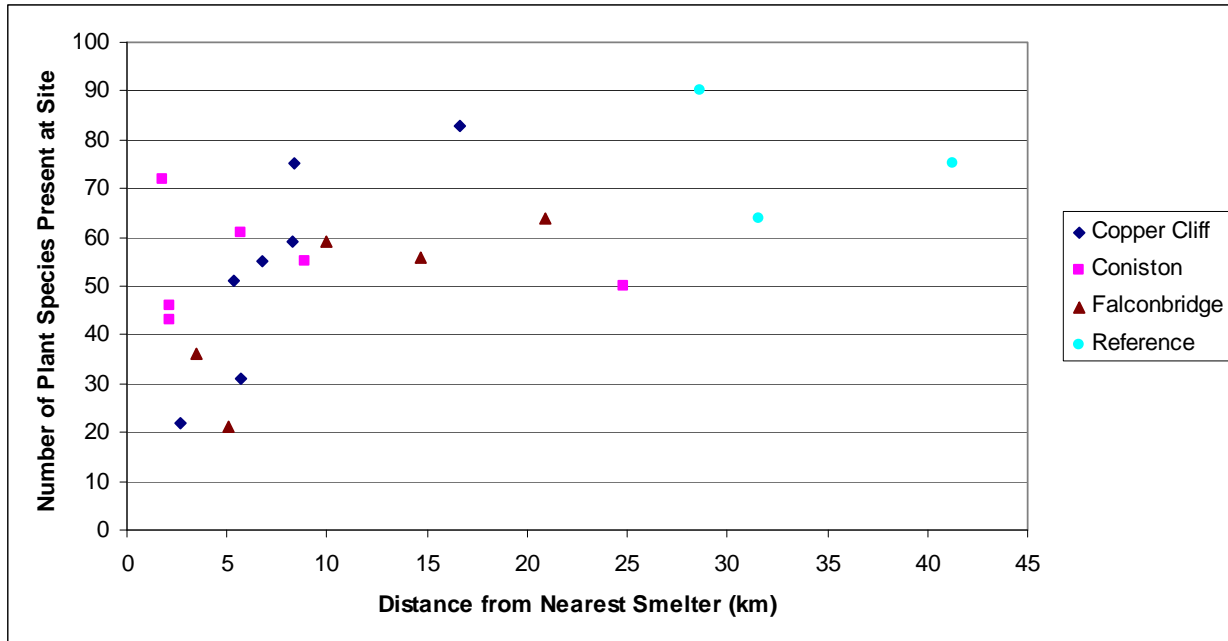

Figure 6-3   Species richness at test and reference sites plotted against distance from the nearest smelter.

6.1.1.5   The Role of pH

Soil pH was not a chemical of concern in this risk assessment, but is known to have a major influence on metal availability and suitability of soils for plant growth. During the Objective #1 studies, the role of soil pH was evaluated in two ways: a) toxicity tests were conducted in natural and pH-amended soils, and b) the characteristics of a historically limed field site (CON-07) were compared to an adjacent non-limed site (CON-08). These studies were discussed in greater detail in Chapter 3, Section 3.14.2.7.

The studies showed that:

- Low soil pH can impact plant growth directly, and
- pH influences metal bioavailability and toxicity in soil.

Raising soil pH above approximately 5.2 can remove some of the direct toxic effects of low pH and also reduces metal bioavailability such that plant growth can be promoted even in the presence of elevated total metal levels.

6.1.2 Objective 2

Objective #2 was addressed using a combination of risk modelling to VECs and field survey data on populations from the literature. This objective looked at nine different terrestrial wildlife VECs. The conclusions are presented below.

Risks could not be ruled out definitively for American robins and ruffed grouse in the direct toxicity modelling for Se (90th percentile ER>1.0 although all ER<2.0). Hundreds of species of birds are known to occur in Sudbury. The breeding success of water birds in the Sudbury area appears to be recovering from earlier declines from lake acidification. The Christmas bird count data for non-migratory species show increasing numbers of birds from 1980 to 1995. American robins are breeding in Sudbury. Grouse were extirpated from the Sudbury area, but the population has since recovered and ruffed grouse is currently a hunted species.

Small mammals were predicted to be most at risk, based on the number and magnitude of exceedances of ER=1.0. However, the predicted 90th percentile risks to individual short-tailed shrews and meadow voles were all ER $\leq$ 3). The 90th percentile ERs were less than 1.0 for individual shrews and voles when less conservative TRVs were used. Therefore, direct toxicity risks were considered low because: there was a low magnitude of exceedance of ER=1.0; exceedances only occurred when using the most conservative TRV; and naturalists and researchers note that shrews and voles are abundant in the Sudbury area and that the Sudbury area as a whole is suitable to sustain populations of small mammals.

Direct toxicity modelling does not address risks to wildlife VECs due to loss of or changes in their habitat. However, indirect effects on wildlife VECs were considered. Changes in plant communities that provide cover, nest sites and food may result in changes in the populations or communities of small mammals and other organisms that use the habitat. Plant communities in the Sudbury area have been impacted. Naturalists and researchers also note that the wildlife species present in Sudbury reflect the habitats present. Currently, researchers at Laurentian University are conducting a large-scale study of the Sudbury forests, and the response of mammalian populations to the patterns of recovery.

Based on all of the information presented in Chapter 4 and the associated appendices, it is unlikely that metals in soil are exerting a significant direct toxic effect on VEC populations in the Sudbury area.

However, previous effects of smelter emissions on habitat quality (*e.g.*, loss of particular plant species used as food or cover) may be having a continued influence on some species of birds and mammals in the study area.

6.1.3 Objective 3: Threatened and Endangered Species Conclusions

Objective 3 was addressed using risk modelling. As described under Objective 2, modelling was conducted to rule out risks to VECs. The Peregrine falcon was identified as the only vulnerable, threatened or endangered animal in the Sudbury area. Risks were ruled out for this VEC for all COC in all areas of the Study Area. Peregrine falcons were re-introduced into the Sudbury area in 1990 and 1991, and there is evidence that the population is successfully reproducing.

6.1.4 Integration of Objectives

Evaluating the status of wildlife in the Sudbury region cannot be done without consideration of the impacts to habitat. The ERA recognizes that habitat can have a large influence on wildlife populations and communities in the Sudbury region. If the plant community in the Sudbury region was not impacted, it is very unlikely that risk management would be required only for wildlife as concluded from Objective 2. However, as discussed under Objective 1, the plant community continues to be impacted, and, consequently, wildlife in the region may be affected.

Historical activities (*e.g.,* logging, previous SO_2 emissions, urban development, fire, metal deposition) have impacted the regional vegetation. These impacts were followed by soil erosion in some areas of the region. In combination, these impacts have shaped the current vegetation patterns and ecological landscape. The results from the Objective 1 studies indicate that current COC levels in the soil continue to contribute to the inhibition of recovery of the plant community, but that they do not act alone. The ERA concluded that metals, pH, erosion, nutrient deficiency and a lack of organic matter, factors which may be directly or indirectly linked to historic smelter activities, all contribute to a lack of a self-sustaining plant community. These variables are further described in Section 6.4 below. Consideration of risk management is warranted to address plant community impacts and to mitigate current and future risk.

Figure 6-4 provides a conceptual model illustrating linkages between some of the known ecological stressors to the plant community and the wildlife VECs.

There is little doubt that a combination of smelter emissions and other activities (primarily logging and forest fires) historically caused widespread loss of the original forest cover in the area. The subsequent sequence of events has resulted in a large area (barren and semi-barren lands) that has either bare exposed bedrock providing little growth medium for plants, or impacted soil conditions that prevent natural recovery to a self-sustaining ecosystem.

Up to the year 2004, almost 3,400 ha of land had been treated with lime by the City of Greater Sudbury. Most of this land was also fertilized and seeded with a grass/legume mixture. (This number does not include areas treated by the two companies, Vale Inco and Xstrata Nickel.) In addition, over 8.2 million trees have been planted. While impressive, the area treated to date represents a small fraction of the over 80,000 ha impacted by historical activities. Within the impacted areas, the loss of soil and vegetation will have a direct consequence for wildlife. As described elsewhere in this report there is both a reduction in plant species diversity at impacted sites, as well as a shift in plant species composition.

At this level of assessment, it is not possible to quantify the relative effects of the plant community impacts on each of the wildlife VECs. Therefore, future risk management that deals with impacts to the plant community may also consider wildlife habitat suitability. Restoring the plant communities will change the habitat suitability for wildlife species that make use of these forested habitats. However, populations of some wildlife species that have thrived under the disturbed conditions in the Sudbury area may decrease because of this restoration. Thus, it is recommended that plant community restoration be conducted with broader goals in mind that include wildlife habitat suitability.
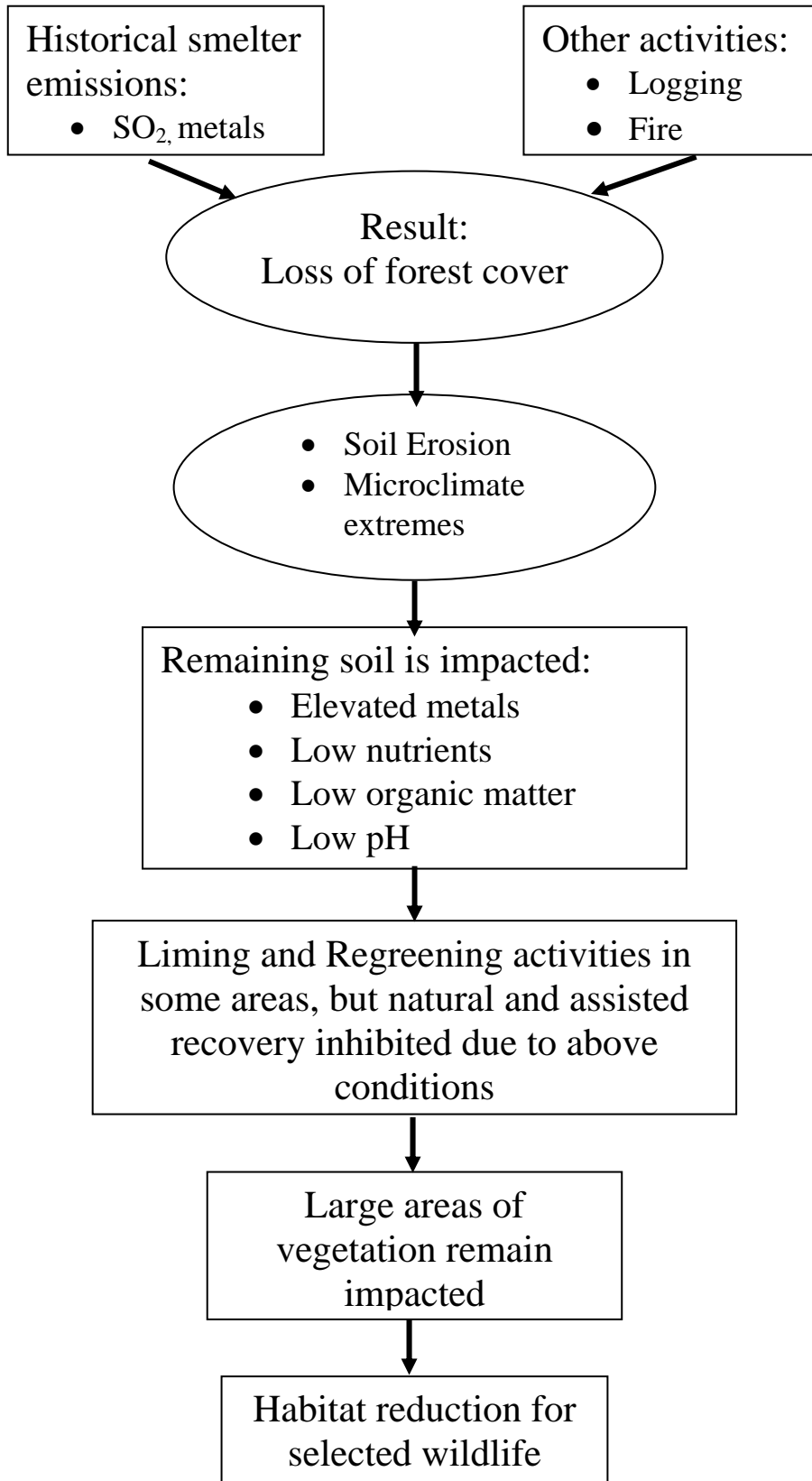
Figure 6-4   Conceptual Linkages of Ecological Stressors with Habitat and Wildlife VECs

6.2   **Summary of Uncertainties and Limitations of the ERA**

6.2.1   **Objective 1**

Each LOE from the Objective 1 study is associated with particular uncertainties. These were discussed in Chapter 3, and in detail in each of the LOE ranking reports.

The uncertainties related to each LOE and other aspects of Objective 1 are briefly reviewed here:

Plant Community

There is a high level of confidence in the study approach and metrics used for this LOE. There will be some variability in field measurements, but this was minimized in this study by using the same field biologists at all sites, and because all measurements underwent quality control procedures by two expert ecologists.

Toxicity Testing

There is a moderate level of certainty for this LOE from several sources. Although multiple test species were evaluated with standardized test protocols, these protocols were not designed for the Sudbury-specific test species, which is a source of uncertainty. Uncertainty was also associated with quantifying the interactions between pH and metal bioavailability, and with the inability of the testing procedures to separate these two factors. The invertebrate tests are also a source of uncertainty because one test did not show an adverse response (springtails), while the other did not produce reliable results (earthworms).

Litter Decomposition

There is a moderate level of uncertainty for this LOE as only one variable (% biomass loss over time) was evaluated, using methods modified from agricultural soils for use in a boreal forest ecosystem. Sampling variability was minimized by having numerous replicate samples at 20 different sites.

Soil Chemistry

There is a high level of confidence with this LOE as the methodology provides relatively precise data. There is some inherent variability in the results because natural soils tend to be very heterogeneous. There was some uncertainty in the typical ranges developed for soil chemistry values, due to a lack of information in the literature.

Selection of Reference Sites

The Sudbury region is in a transitional zone between the Great Lakes-Saint Lawrence Forest and the Boreal Forest ecological regions. It is also where four climatic zones intersect. Therefore, the reference sites did not always completely represent all of the sites in the corresponding transect, nor were all of the climatic zones entirely represented. There were also little data available to describe "representative" soil chemistry for a northern Ontario boreal forest ecosystem.

6.2.2   Objective 2

There are numerous sources of uncertainty in the risk model for wildlife. The most significant limitations and uncertainties exist for the following parameters and model components: concentrations of COC in ambient media (particularly in lake sediments and whole body fish); uptake models used to estimate concentrations in dietary items; wildlife exposure parameters (*e.g*., soil ingestion rates); and TRVs. However, parameters and methods were selected to ensure that direct toxicity from exposure to COC is not under-predicted.

6.2.3   Objective 3

Conservative methods were used to assess risks to the Peregrine falcon. Uncertainties listed under Objective 2 also pertain to this Objective. However, the SARA Group is confident that direct toxicity risks from exposure to COC in soil have not been under-predicted.

6.3   Extrapolated Ranking Map

The results of the final site ranking derived from the Objective 1 study for the 22 study sites were extrapolated to the larger study area using remote sensing techniques to produce an Extrapolated Ranking Map (Figure 6-5). The red, yellow and green areas on the map represent areas which are similar to the 22 study sites developed for the Objective 1 studies. This approach assumed that that there is an association between ground cover characteristics and the final site impact rankings. This chapter presents the results of this analysis and only a very brief description of the methodology is provided. A detailed description of the methodology can be found in Appendix I.

The satellite images used in the analysis of the Extrapolated Ranking Map covered 9,238 km^2. Areas were identified that have similar spectral signatures (i.e., similar ground cover characteristics) as the impacted (red and yellow) and reference sites (green) derived from the Objective 1 studies. Screening of these areas was achieved based upon the spectral image of the natural features as well as filtering techniques to remove questionable pixels and, therefore, reduce the uncertainty associated with the analysis. The areas identified that were similar to the 22 study sites were classified using the same red, yellow and green classifications obtained from the final site rankings in Objective 1.

The results of this analysis show that:

- 2.6% of the study area (representing 244 km^2) was classified as red or severely impacted;
- 4.4 % of the study area (representing 406 km^2) was classified as yellow or moderately impacted and
- 6.8% of the study area (representing 631 km^2) was classified as green or areas that are similar to the reference sites.

The remaining approximately 85% of the area (7956 km^2) could not be classified according to the ranking report system. The unclassified areas represent regions which were discarded in the analysis for one reason or another (see Appendix I for details) and consist of a variety of land uses including lakes, wetlands, industrial areas and urban centres as well as regions that were screened out to increase certainty in the analysis.

Within the classified areas (1281 km^2) 19% of this area was identified as red or severely impacted, 31% as yellow or moderately impacted, and 49% as green or corresponding to the reference sites. When the Extrapolated Ranking Map approach is used for areas that could be classified, up to 50% of the land was moderately or severely impacted.

On the ground, each pixel represents an area of 30 m by 30 m. One of the major limitations of using the remote sensing approach is that the level of resolution required for discrimination of subtle differences between sites could not be achieved. However, use of remote sensing techniques to identify potential areas of impact is a reasonable approach that provides a strong visual starting point for planners and scientists. The Extrapolated Ranking Map can be used as a qualitative guide to identify areas to focus remediation and monitoring efforts. Ground truthing of the site classification is required at each location before any further work can be proposed or planned. If suitable, some of these locations can be used as benchmarks to evaluate the rate of vegetation change through ongoing observation. Mapping support can

be improved over time through additional ground observations, and with the use of higher resolution imagery to refine the areas of impact. Ground based spectral analysis can also be used to improve classification of impacted areas. Future analyses could consider additional monitoring (e.g., every three to five years) to refine the time series approach.

For illustrative purposes, the "peanut" shaped, semi barren area identified through atmospheric modeling of the smelter emissions from Chapter 5 in Volume I has been added to the extrapolated ranking map (Figure 6-5). The area outlined by the "peanut" boundary in Figure 6-5 is approximately 80,690 ha (807 km^2). This compares favourably with other studies that estimated the area of the semi-barrens in 1970 as about 83,796 ha (McCall et al., 1995, Volume I, Chapter 4). The difference between the two analyses (3,106 ha) represents a difference of only 3.7%, which may be due to measurement variability and inaccuracies of the actual boundary. Within the semi barren "peanut" areas the Extrapolated Ranking analysis identified:

- 8.4% (6,850 ha) as red, denoting severe impact;
- 3.8 % (3,030 ha) as yellow, denoting moderate impact; and,
- 2.1% (1,710 ha) as green, denoting areas that are similar to the reference sites.

A compact disc (CD) version of this map is provided at the back of this report. The appropriate software is provided so the interested reader can access the map electronically and enlarge specific areas of interest. Another map with results extrapolated beyond the semi-barren area is provided in Appendix I.

This map is a useful tool to guide future risk management activities, but it is not intended to be a definitive blueprint for risk management in the Sudbury area. The map is based on extrapolation of data from 22 sites; therefore, there are uncertainties and limitations surrounding its application. The extrapolation has not been verified through "ground-truthing." Ground-truthing is the process of actually going to specific locations in the field, taking quantitative measurements of the ecosystem, classifying the ecosystem as either low, moderately or severely impacted, and comparing the field ranking with the extrapolated map classification. If the map is to be used to identify priority areas for risk management, then those areas of the map must be ground-truthed before any risk management activities are planned or implemented.

Plant community measurements and soil chemistry characteristics useful for classifying a site for ground-truthing are provided below in Section 6.4.

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Figure 6-5
Extrapolated Ranking Map
of the Semi-Barrens
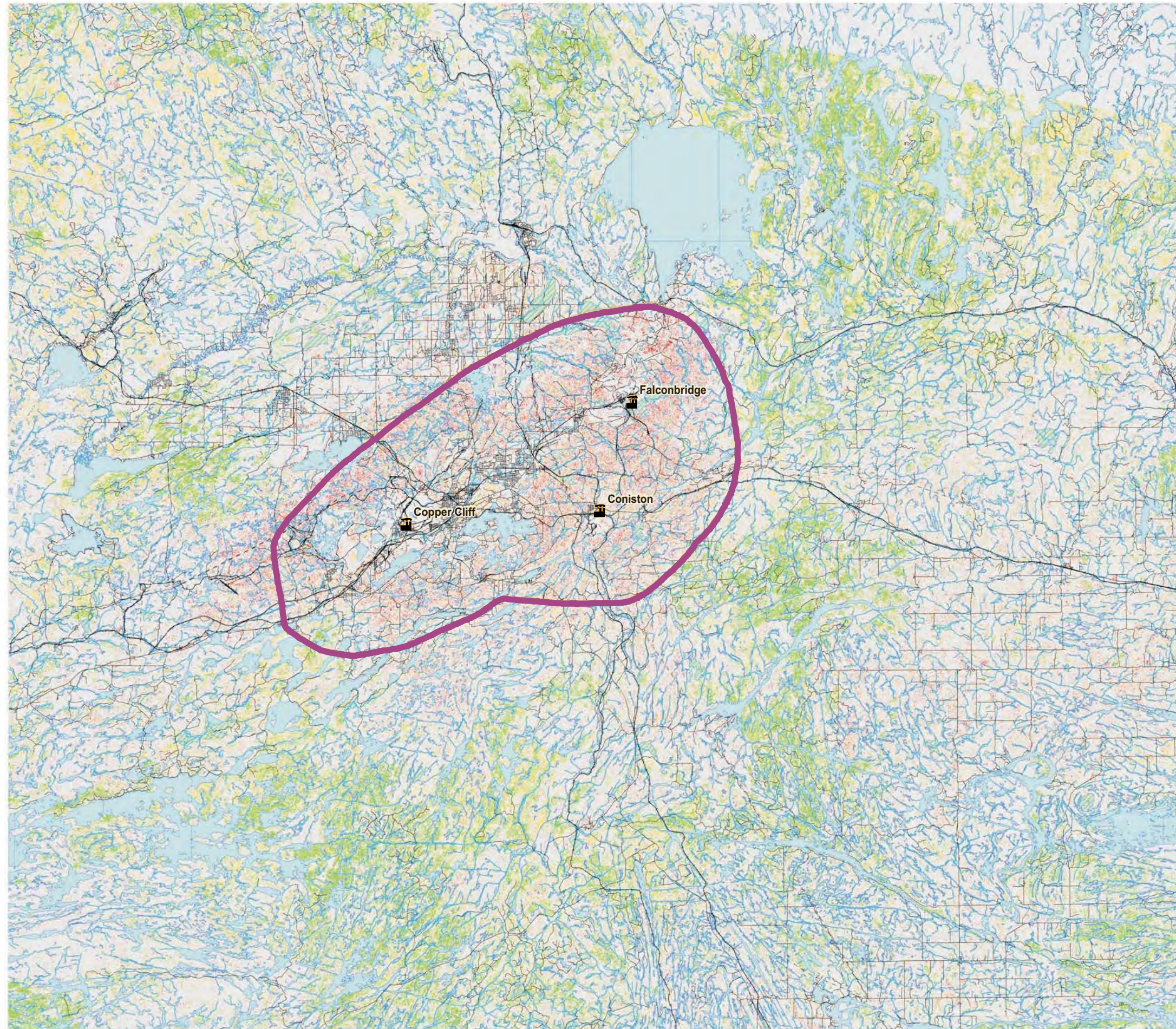
Ecological Risk Map

Red   - Most Impacted
Yellow - Moderately Impacted
Green - Least Impacted

0 2.5 5   10   15   20
Kilometers
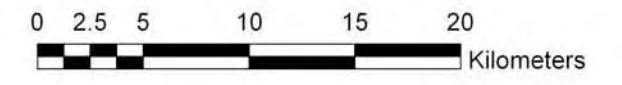
Legend

Semi Barren	Road	Waterbody Segment
Smelters	Utilities	Wetland Area, Permanent
Railway	Rivers	

NAD83 UTM Zone 17
Landsat 7 TM August 2003
Queen's Printer of Ontario - Ontario Base Mapping
4DM Inc. 2006

Falconbridge

Copper Cliff

Coniston

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6.4 Site Characterization

This section provides a definition of a self-sustaining forest ecosystem, which is the ultimate goal of restoration and recovery in the Sudbury region. This is followed by a listing of plant community and soil chemistry characteristics that are associated with impacted and reference sites.

6.4.1 Defining a Self-Sustaining Forest Ecosystem

A self-sustaining forest ecosystem is an assemblage of plants, with a treed overstory, that occurs with a degree of predictability for a given place on any given topographic position, soil type and aspect within a climatic zone.

In self-sustaining forest communities, ecosystem processes and functions such as energy flow, production, nutrient cycling, reproduction, regeneration and decomposition are not impaired. Topography, soil structure, texture and nutrients are important determinants of species composition and forest structure.

The structural and functional components of a natural regional forest ecosystem are predictable. They include the complexity of the tree, shrub and ground layers that provide habitat for mammals, birds and invertebrates. Topography, soil structure, texture, nutrients and moisture are important determinants of species composition and forest structure. A natural self-sustaining community in the Sudbury region would have established along a predictable pattern to maturity following an intermittent or natural catastrophic event, such as fire, windstorm, beaver disturbance, insect infestation or other natural events. However, the metal levels, low soil pH, organic content, fertility and erosion identified at some of the test sites represent ongoing perturbations. Recovery in these areas does not necessarily follow a predictable pattern.

6.4.2 Determining Ecosystem Impairment

The degree to which an ecosystem is considered impaired can be determined by comparing its key structural and functional components, and its processes to those of a healthy system. This section describes characteristics of the plant community, and the soil parameter values that can be used as guidance for field assessments of the level of site impact. Plant community and soil chemistry are two lines of evidence that can be directly measured in the field, and through laboratory soil analysis. The other lines of evidence used in the ERA (soil toxicity testing, litter bag decomposition) involve lengthy and costly tests, and are not readily incorporated into a field site assessment procedure.

Plant Community

Some of the important characteristics of the plant community that can be quantified for different levels of impact were extracted from the plant Line of Evidence results for the reference and ranked test sites (for additional detail, see Appendix GE4), and are summarized in Table 6.5. These characteristics can be used in the field as a guide to help identify the severity of site impact.

For example, a self-sustaining system tends to be composed of 50 plant species or more. Sites with less than 50 species may be considered impacted. Impacted sites tend to have trees shorter than 10 m, and have up to 60% bare rock or soil, which is often eroded. Non-impacted sites can have high numbers of shade-tolerant, perennial, and sensitive species, whereas impacted sites have few. Impacted sites tend to be dominated by a single species, which may be non-native and invasive. More examples of plant community characteristics that may be used in the field as a tool for preliminary identification of impact levels are provided in Table 6.5.

Table 6.5   Characteristics of Low to Not, Moderately and Severely Impacted Plant Communities [a]

Characteristic	Low to Not Impacted	Moderately Impacted	Severely Impacted
Life History (Perennial Analysis)	Sites tend to have approximately 50 or more perennial species.	Sites tend to have fewer than 50 perennial species.	
Species Dominance	Sites tend to have less than 20% cover by a single species.	Sites tend to have more than 20% cover by a single species.	
Conifer Cover	Sites tend to have near-complete canopy cover.	Sites tend to have either 0 to 50% canopy cover, with 0 to 10% understory cover.	Sites tend to have 0 to 5% combined canopy and understory cover.
Introduced and Invasive Species	Sites have negligible cover of non-native and potentially invasive species.	Sites tend to have 0 to 50% cover of non-native and potentially invasive species combined.	
Shade Tolerance	Sites tend to have 10 to 15 shade tolerant species.[b]	Sites tend to have 5 to 10 shade tolerant species.	Sites tend to have 0 to 5 shade tolerant species.
Percent Cover of Mineral Substrate	Sites tend to have no bare rock or soil.	Sites tend to have 0 to 10% of bare rock or soil.	Sites have 0 to 60% of bare rock or soil.
Reestablishment of Sensitive Species	Sites tend to have 5 to 10 good conditions indicator species.[b]	Sites tend to have 0 to 5 good conditions indicator species.	
Acid and Metal Tolerant Indicators	Sites tend to have 5 to 10 acid and metal tolerant indicator species.[b]	Sites tend to have 10 to 15 acid and metal tolerant indicator species.	

Table 6.5   Characteristics of Low to Not, Moderately and Severely Impacted Plant Communities [a]

Characteristic	Low to Not Impacted	Moderately Impacted	Severely Impacted
Maximum Tree Height	Sites tend to have a maximum tree height of 10 to 14 m.	Sites tend to have a maximum tree height of less than 10 m.	
Total Vegetation Cover	Sites tend to have a surface soil retention index of 100.	Sites tend to have a surface soil retention index of 95 to 100.	Sites tend to have a surface soil retention index of 40 to 95.
Leaf Litter Cover	Sites tend to have 85 to 90% leaf litter cover.	Sites tend to have 65 to 85% leaf litter cover.	Sites tend to have 0 to 65% leaf litter cover.

a   The characteristics of moderately and severely impacted sites were described based on the plant community data
b   Species lists for different categories of plants (for example shade tolerant species) are provided in Appendix GE-4-A of the full technical report.

Site Chemistry

The ranges of values for soil chemical parameters associated with the different site classifications are presented in Table 6.6. These characteristics may be used as a tool for the preliminary identification of impact levels. Soil samples must obviously be collected in the field and returned to the laboratory to obtain these types of data. However, the information is fundamental to classifying the relative impact or risk associated with a site, and can be useful to help identify appropriate soil treatment strategies for future risk management.

COC concentrations in soil are presented separately in Table 6.7 because various factors, including the influence of soil erosion, mean that there is considerable overlap and variability in soil metal concentrations between site rankings. Figure 6-6 shows that while the highest metal levels are always associated with severe impacts to the plant community, severe impacts can also be present at eroded sites with very low metal levels. Thus, factors other than only soil metal concentrations must be considered when describing extent of impact at a site.

Table 6.6   Soil Chemistry Characteristics of Low to Not, Moderately and Severely Impacted Sites

| Characteristic	Low to Not Impacted	Moderately Impacted	Severely Impacted
Organic Matter (g/100g)			
Total C	>3.9	3–3.9	<3
Total N	≥0.22	0.11–0.21	≤0.1
Soil Exchange Complex Chemistry (cmol(+)/kg)			
Cation Exchange Capacity	≥25	20–24	≤19
Calcium	≥0.4	0.25–0.39	≤0.24
Magnesium	>0.15	0.1–0.15	<0.1
Ca:Mg Ratio	3–5.9	1.5-2.9 or >6	≤1.4
Base saturation (%)	≥5	2–4.9	≤1.9
Fertility (mg/kg)			
N as Ammonium	≥0.4	0.2–0.39	≤0.19
Extractable P	≥8	5–7.9	<5
Extractable K	≥65	45–64	≤44
Extractable Fe	750–1800	500–749 or >1800	≤499
Extractable Mn	25–200	10–24 or >200	<10
Fe:Mn	15-50	5–14 or >50	<5
Extractable Mg	>25	15–25	<15
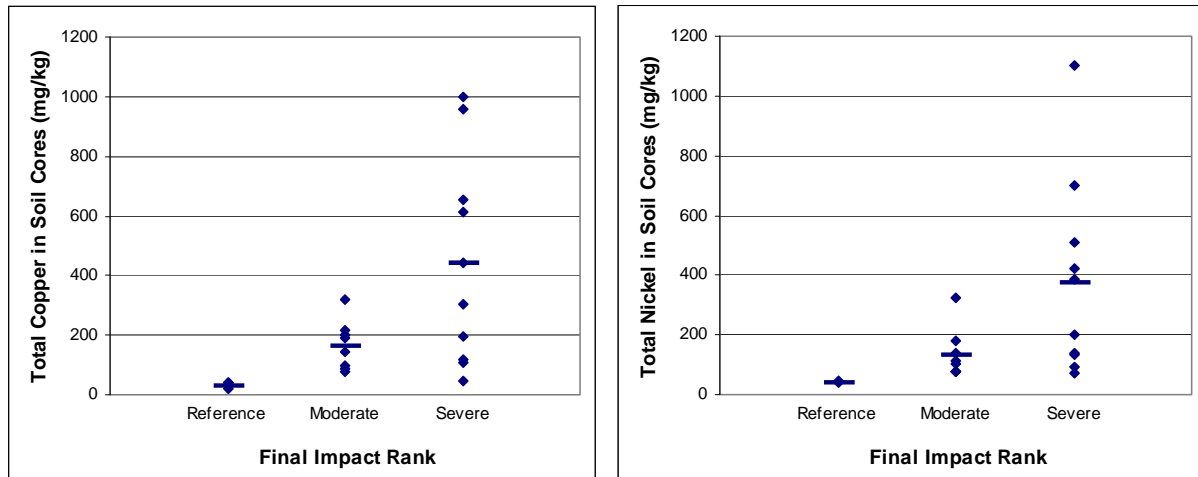
Figure 6-6   Total copper and nickel concentrations in soils from reference and test sites.

Table 6.7   Range of total COC concentrations (mg/kg) at different sites.

COC	Reference Site		Moderately Impacted		Severely Impacted	
	Mean	Range	Mean	Range	Mean	Range
Arsenic	4.37	2.7 - 5.9	23.2	9.5 – 45	36.5	2.1 – 117
Cadmium	0.23	0.17 – 0.28	0.44	0.24 – 1.17	0.59	0.12 – 1.26
Cobalt	7.24	4.9 – 11.5	13.7	4.84 – 48.4	20.3	9.01 – 41.5
Copper	33.3	18.7 – 42.0	166	76 – 320	444	48.7 – 1000
Lead	21.9	14.0 – 33.0	39.3	17.2 – 83	51.5	4.6 – 162
Nickel	41.6	38.9 – 46.0	136.4	77 – 325	376	70.2 – 1110
Selenium	0.74	0.48 – 1.0	1.5	0.85 – 3.4	3.5	0.3 – 10.5

6.5   Risk Management Objective, Conclusions and Recommendations

The Risk Management Objective, identified in Section 6.1 above, was to:

"Evaluate levels of COC in various soil types to determine COC levels in soil which do not result in unacceptable risks to Valued Ecosystem Components (VECs)".

This risk management objective assumes that metal concentrations in soil that are protective of VECs can be back-calculated using risk assessment models. However, it is apparent from the results of the ERA that individual total COC levels in soil cannot be related directly to the level of impact, or risk, for plant communities or wildlife. Other factors (soil pH, soil organic matter, nutrient levels, metal bioavailability and erosion) influence the plant community, and the plant community influences wildlife habitat to a significant degree. Therefore, an alternative approach is needed to meet the risk management objectives.

The SARA Group recommends that risk management objectives be defined spatially using ecological parameters, not concentrations of COC in soil. For the plant community, these ecological parameters could include those that were evaluated during the plant community assessment. The characteristics of plant communities (e.g., species richness and diversity, presence of shade tolerant species, abundance of metal and acid tolerant species, tree height, density/cover, etc.) at different levels of impact are described in Table 6.5. Similarly, soil chemistry characteristics at different impact levels are described in Table 6.6. These characteristics can be used as tools for the preliminary identification of plant communities to meet the risk management objective.

Previous impacts of smelter emissions on plant communities have obviously had an effect on habitat quality for wildlife (*e.g.*, loss of particular plant species used as food or cover). Therefore, the SARA Group recommends that future risk management to address impacts on the plant community be planned to also consider wildlife habitat suitability. Changing the plant communities in Sudbury will have a positive effect on some wildlife species, and may have a negative effect on others. Therefore, the SARA Group also recommends that stakeholders be consulted during the risk management process, so that human use needs and priorities (*e.g.*, recreation, hunting, etc.) can also be considered.

Although there are uncertainties and limitations inherent in the data used for this ERA, it can be concluded that ecological receptors, particularly the plant community, continue to be at risk in the study area, and consideration of risk management is warranted. Undoubtedly, additional studies could have been done, different data could have been collected, and the existing data could be viewed in other ways. As the Committee that reviewed the Coeur d'Alene ERA noted (NAS, 2005): they "found it neither

necessary nor appropriate to evaluate all of the underlying scientific studies or to identify all of the aspects of the ERA that could have been improved. The committee recognizes that at a site as large and as obviously disturbed as the Coeur d'Alene River basin, there is no limit to the number or types of data collection activities that could have been conducted. Similarly, any ERA of the scope and complexity of the Coeur d'Alene River basin ERA could be improved through better data analysis techniques and more thorough documentation. In reviewing this ERA, the committee chose to limit its review to the studies and analyses that were critical to supporting the conclusions and management recommendations." This perspective also applies to Sudbury.

The Sudbury ERA recommends that risk management be considered in the regions identified in the Extrapolated Ranking map. It is important that portions of the map be ground-truthed prior to taking any remedial actions. Other factors such as site access and stakeholder interests should also be considered. In addition, interactions (pH, lack of soil, fertility, organic matter or COC concentrations) should be assessed on a site-specific basis, to determine the primary factors that should be addressed for successful risk management.

Further understanding of the interactions of soil modifying factors and their relative influence on soil toxicity may be gained by development of a terrestrial biotic ligand model (BLM) for Sudbury soils. The BLM approach was originally developed to explain the influence of modifying factors on the aquatic toxicity of copper. It has recently been applied to terrestrial soils for Ni and Cu, but not the other COC. The potential for application of a BLM to Sudbury soils could be explored.

The SARA Group also recommends that the 22 sites established during the Objective 1 studies, or a representative portion of these, be considered either for long-term monitoring studies to determine plant community change over time, or used for remediation trials to evaluate amendment strategies.

In summary, the study team is confident that this ERA has considerably expanded the knowledge of anthropogenic impacts to the terrestrial ecosystem in the Sudbury area. More importantly, it has provided insight into the variables and conditions present in the soil that continue to impact the plant community. Given the number of variables and conditions that continue to impact the plant community, the study team recommends that risk management objectives for the Study Area be defined spatially using soil characteristics and ecological parameters, rather than by levels of COC in soil. As well as addressing indirect effects on wildlife (*e.g*., loss of particular plant species used as food or cover), the ERA has recognized, for the first time, the question of direct metal toxicity to wildlife in the region. It is recommended that any future risk management consider wildlife habitat. Like any major scientific

endeavor, the ERA provides enough information to stimulate more questions about the terrestrial ecosystems around Sudbury.

If risk management is pursued in the Sudbury area, this document provides the foundation for effective and focused strategies to be developed. The extrapolated Ranking map, in combination with ground-truthing, can be used to identify areas for risk management. To continue the knowledge gathered in this document, further studies can be undertaken in the years to come. Various stakeholders in the region are well positioned to continue with the excellent work on regreening that has taken place during the past 30 years, and to incorporate knowledge gained from this study into the regreening process.

6.6 References

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