SARA GROUP

SUDBURY AREA RISK ASSESSMENT

VOLUME III
EXECUTIVE SUMMARY

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ES-1.0 INTRODUCTION

The numbering system of this Executive Summary follows the chapter numbers used throughout the report.

In 2001, the Ontario Ministry of the Environment (MOE) reported that concentrations of nickel, cobalt, copper and arsenic in the Sudbury area exceeded the generic MOE soil quality criteria (MOEE, 1997). As a result of these findings the MOE (2001) made two major recommendations:

- That a more detailed soil survey be undertaken to fill data gaps; and,
- That human health and ecological risk assessments be undertaken.

Both Vale Inco (formerly Inco Limited), and Xstrata Nickel (formerly Falconbridge Limited) voluntarily accepted the MOE recommendations and began working together to establish what is commonly referred to as “The Sudbury Soils Study”. A Technical Committee was organized to oversee the Sudbury Soils Study that included representation from the following stakeholders: Ontario Ministry of the Environment, City of Greater Sudbury, Sudbury and District Health Unit, Health Canada First Nations and Inuit Health Branch, Vale Inco and Xstrata Nickel. An Independent Process Observer ensured that all stakeholders were given equal access and input to the process, and that public interests were addressed. A Public Advisory Committee facilitated community involvement and promoted the flow of information between the Technical Committee and the public. An Independent Scientific Advisor provided input to the Technical Committee to ensure that reliable scientific principles and current methodologies were used to conduct the study.

The assessment was conducted by the Sudbury Area Risk Assessment (SARA) Group, a consortium of professional environmental consulting firms and individuals. In addition, faculty and staff from the University of Guelph and Laurentian University in Sudbury were involved in carrying out particular aspects of the ERA.

Volume I of the Sudbury Soils Study (SARA 2008a) provides the background to the study including a more detailed description of the history of the Sudbury region, metal levels in soil and study organization and process. Volume II of the study is the Human Health Risk Assessment that was released in May, 2008 (SARA 2008b). This report is Volume III (Ecological Risk Assessment or ERA) of the Sudbury Soils Study

Volume I should be read in conjunction with this report because it provides background information on the Sudbury Soils Study as well as the process for selecting the Chemicals of Concern (COC) for the ERA. In particular, reviewers of the ERA should read chapters 1, 4, 5, and chapters 7 – 10 of Volume I.

The Sudbury ecosystem has been impacted by almost a century of human activities including emissions from mining and smelting operations as well as logging. It is unique, however, in that ecosystem recovery and transformation have been occurring since the mid 1970s due to major efforts at emission reductions, wide-scale treatment of damaged lands (liming and fertilizing) and vegetation planting initiatives aimed at the "re-greening" of the Sudbury landscape.

The **main goal** of the ERA was: *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.*

This goal not only recognizes the importance of evaluating ecological risks, but also the significance of contributing to ecological recovery.

Four specific objectives were identified to assist in meeting the main ERA goal:

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; and

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 current study is considered an area-wide risk assessment because it is evaluates a very large geographical area. While many elements of an area-wide risk assessment are based on the requirements for a site-specific risk assessment (SSRA), it is important to note there is no specific regulatory guidance available governing the application of risk assessment on this scale in Canada.

ES-2.0 PROBLEM FORMULATION

The problem formulation for the terrestrial ERA includes a compilation and review of ecological information (Section 2.1), the definition of the study area (Section 2.2), a selection of COC (Section 2.3), identification of valued ecosystem components (VECs) (Section 2.4) and assessment endpoints (Section 2.5), and presentation of the conceptual model (Section 2.6). A summary of the problem formulation is provided in Section 2.7.

ES-2.1 Background Data Compilation

The ecological data review involved the collection of information from relevant published scientific documents, web-based sources, and industry and government publications. A literature search was performed to determine the current state of knowledge relating to ecological effects of metals in the greater Sudbury area. Results were reviewed to ascertain which studies best fit the scope of the ERA. A list of data sources, and of faculty at Laurentian University, Sudbury, that participated in the ERA is included in this section of the report.

ES-2.2 Definition of the Study Area for the Terrestrial ERA

The initial study area for the Sudbury Soils Study was defined as the area from which soil samples were collected during the 2001 Sudbury Regional Soils Project.

The study area encompasses approximately 40,000 km^2 (200 km x 200 km) of the Sudbury basin. For the wildlife ERA, the study area was subdivided into three zones (1, 2 and 3). The boundaries of the zones were defined on the basis of metal concentrations in soil, receptor foraging areas and terrain. In addition, four Communities of Interest (COI) identified in the HHRA were evaluated for some VECs in the ERA (Consiton, Copper Cliff, Falconbridge and Sudbury Centre).

A total of 22 field study sites associated with each of the three smelters were established for the assessment of plant communities (Objective #1). The field sites ranged in distance from 1.8 to 41.3 km from the nearest smelter.

ES-2.3 Identification of Chemicals of Concern for the Terrestrial ERA

The primary source of COC to the terrestrial environment included in this assessment is aerial deposition of particulate-associated metals and metalloids from smelter emissions. The selection of COC for the risk assessment was based on metal concentrations in Sudbury soils measured during the 2001 soil survey. Approximately 8,400 soil samples were collected from the study area and analyzed for 20 inorganic parameters.

The screening process identified seven candidates COC for the ERA: arsenic, cadmium, cobalt, copper, nickel, lead and selenium.

ES-2.4 Identification of VECs

A VEC is an ecological species, population or community that is ecologically significant, is important to people, has economic and/or social value, and can be evaluated in a risk assessment. Several criteria were used to select candidate VECs for the ERA from a long list of plant and animal species in the Sudbury region.

A list of the VECs and their trophic designations for ERA Objectives 1 through 3 is provided below.

Objective 1: Plant and Invertebrate VECs:

- Terrestrial plant communities (primary producers)
- Blueberry (primary producers)
- Soil invertebrate communities (primary consumers, decomposers)

Objectives 2 and 3: Wildlife VECs:

- American Robin (secondary consumer)
- Ruffed Grouse (primary consumer)
- Peregrine Falcon (top predator)
- Northern Short-tailed Shrew (secondary consumer)
- Meadow Vole (primary consumer)
- Moose (primary consumer)
- White-tailed Deer (primary consumer)
- Red Fox (primary consumer through top predator)
- American Beaver (primary consumer)

ES-2.5 Assessment Endpoints and Measures

Assessment endpoints for the ERA were selected for each of the different VECs. An Assessment Endpoint is defined as an explicit expression of what is to be protected, defined by an ecological species (e.g., the endangered Peregrine Falcon), population (e.g., American robin) or community (e.g., terrestrial plants) and a characteristic. A characteristic is an attribute that is important to protect and which is potentially at risk (e.g., persistence). Assessment endpoints are neutral (U.S. EPA, 1998) and, therefore, they should not contain words like “protect”, “maintain”, or “restore” or indicate a direction for change, such as “loss” or “increase”.

The assessment endpoint for the plant communities is presence of a self-sustaining forest ecosystem. For soil invertebrate communities, the assessment endpoints are survival and reproduction of soil and litter biota, including earthworms.

The assessment endpoints for threatened and endangered wildlife (*i.e.,* Peregrine falcon) are survival and reproduction of individual peregrine falcons in the City of Greater Sudbury and surrounding area. The assessment endpoint for the remaining terrestrial wildlife VECs is population persistence in the City of Greater Sudbury and surrounding area.

ES-2.6 Conceptual Model

A conceptual model is a written description and a visual representation of the relationships between VECs and the COC to which they may be exposed. Conceptual models can serve three purposes: 1) clarification of assumptions concerning the situation being assessed; 2) as a communication tool for conveying those assumptions; and, 3) providing a basis for organization and completion of the risk assessment (Suter, 1999). The conceptual model diagram for plants, terrestrial invertebrates and wildlife is provided in Chapter 2, Figure 2-5.

Wildlife VECs may be exposed to chemicals via several potential exposure pathways, such as ingestion, inhalation and dermal contact. However, only exposure *via* ingestion was evaluated in the ERA.

ES-3.0 OBJECTIVE #1 EVALUATE THE EXTENT TO WHICH COC ARE PREVENTING THE RECOVERY OF REGIONALLY REPRESENTATIVE, SELF-SUSTAINING TERRESTRIAL PLANT COMMUNITIES.

This is a key objective of the ERA and one that is very specific to Sudbury. While considerable progress has been made toward the "re-greening" of the Sudbury landscape in the last three decades, significant portions of the region have not been treated, have not recovered to their full ecological potential, or biodiversity in the reclaimed areas remains low.

In risk assessment, literature-derived values are often used to predict the toxic effect of metals on VECs. However, there are three primary environmental conditions in the Sudbury area that rendered the use of literature values insufficient to address this Objective:

1. Metal mixtures are present in Sudbury soils;
2. Sudbury soils have a low soil pH (which affects the toxicity of metals); and
3. The effects of conditions 1 and 2 to plant communities relevant to Sudbury are not fully documented.

Therefore, Objective #1 was addressed using a weight-of-evidence approach. Detailed chemical, physical and biological data were gathered from 18 test sites, one historically-limed and regreened site, and 3 reference sites for a total of 22 field sites. Sites were selected on transects extending out from one of the three smelter locations: Coniston (CON), Falconbridge (FB) or Copper Cliff (CC).

The mean and ranges of COC levels in soil for each transect and the reference sites are summarized in Table ES-3.1. Metal concentrations were lowest at the Reference sites which were also farthest from the smelters. Soil metal concentrations tended to be higher closer to the smelters and decreased with increasing distance away from the smelters. Among the three smelter groupings, soil metal levels tended to be lower at the Coniston site. This is likely attributed to the fact that significant soil erosion has taken place in this area along with leeching of the metals from soils. The relationship between soil metal concentrations and distance from the smelter are discussed in Chapter 6.

Table ES 3.1 Range and Mean COC Concentrations (mg/kg)* at Test and Reference Sites

	Copper Cliff		Falconbridge		Coniston		Reference	
Metal	Range	Mean	Range	Mean	Range	Mean	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 total metal concentrations in soil cores as described in Chapter 3

Data gathered for each site were based along four Lines of Evidence (LOE):

i) Soil physical and chemical characterization (Chapter 3.3, 3.4);

ii) A detailed plant ecological community assessment (Chapter 3.5, 3.6); and

iii) Toxicity testing with four individual test species in the laboratory (Chapter 3.7, 3.8);

iv) An assessment of organic matter decomposition using *in situ* litter bags (Chapter 3.9).

Each LOE was evaluated independently to determine the relative level of impact at each site (Step 1).

The site ranking system consisted of three possible categories:

Rank	Description
Green	Low to Not Impacted
Yellow	Moderately Impacted
Red	Severely Impacted

An overview of each of the LOE is provided here with details in Chapter 3 and Appendix G.

i) The soil physical and chemical characteristics are critical to the landscape as they provide the growing foundation for vegetation. Multiple soil samples were collected at each field site and analyzed for over 50 parameters in the following groups: total and water leach metals (an indicator of plant bioavailable metal levels), pH, Cation Exchange Capacity (CEC), organic matter, fertility, bulk density as well as an *in*-situ pedon profile. Data from each of the test sties were compared to Reference site conditions to establish relative degree of impact (low, moderate, severe). Numerical criteria were developed to assist with the site rankings.

During the initial site evaluation step, the COC concentrations in soil were not known to the evaluators. COC concentrations in soil were subsequently considered in Steps 2 and 3.

Of the 18 field sites, two sites were ranked low to not impacted (both at Falconbridge), 12 sites were ranked moderately impacted and 4 sites were considered severely impacted.

Soils that were considered moderately to severely impacted tended to have higher metal concentrations, low organic matter and low fertility, and were often severely eroded. There was significant inter-site variability, and many variables were co-related, so it is not possible to clearly identify one or two specific soil parameters that reflect the degree of soil impact.

ii) The detailed plant community assessment involved a comprehensive survey at each site that consisted of measuring numerous ecological variables at each site. The living vegetation that exists at a particular site is the ultimate integrator of all environmental conditions (i.e. climate, soil quality, physical and chemical characteristics). Therefore, when considering all the LOE to assign a final site ranking, this LOE was given the greatest weight.

There were five major components evaluated in this LOE including: broad plant inventory (trees, shrubs, herbs, ferns etc.), percent cover assessment, detailed tree and tall shrub assessment, coarse woody material assessment and ecosite classification. Over 75 individual metrics were measured within these categories. The data were evaluated in terms of four ecologically significant criteria: site biodiversity, ecological integrity, long-term productivity and soil and water conservation.

The final site evaluation using this LOE indicated that one site was considered to be not impacted, six were considered to be moderately impacted, and 11 were classified as severely impacted.

iii) Bulk samples of soil were collected at each field site, homogenized, and submitted for toxicity testing with different individual test species. After a number of trials, four plant species were selected and used to rank soils based on toxicity to the test species: Northern wheatgrass, Red clover, Goldenrod and White spruce. A number of endpoints were measured such as % seed germination, shoot and root growth (length, weight). Two invertebrates were used for preliminary trials, but the springtail (*Folsomi candida*) proved to be insensitive to the test conditions (elevated metals, low pH), while earthworms (*Eisenia Andrei*) were very sensitive to test conditions but produced inconsistent results that could not be used in a ranking system.

Two approaches were developed to rank the toxicity test results: a) a comparison of test site results with the respective individual Reference soil results, and b) a comparison of test site results with a mean of all three Reference site results. The two approaches sometimes yielded a different ranking, but most site soils were ranked as either moderately or severely impacted for this LOE. The only exception was one site along the Falconbridge transect that was considered low to no impact with respect to toxicological endpoints.

iv) The rate of organic matter decomposition was assessed using *in situ* litter bags at each of the field sites. The process of litter decomposition is critical for maintaining site fertility and productivity within a forest ecosystem. The litter material was composed of white birch foliage encased in 25 nylon mesh bags at each site (two sites were not included due to site access restrictions). The proportion of biomass lost at regular intervals over a one year period was measured as the indicator of decomposition. Based on this approach two sites were not considered impacted, two sites were ranked as moderately impacted and decomposition was considered severely impacted at the remaining sites. Since this LOE only included one actual metric (i.e. biomass loss), and was based on a modified protocol, this LOE was given the lowest weight when integrating all the LOE for a final site ranking.

The site rankings for each LOE as described above, were then integrated using a weight of evidence approach to assign a final rank to each site. The process is described in Chapter 3.11. The end results of the integration are summarized in Table ES-3.2 where a final single rank is assigned to each site. The sites are arranged in increasing distance from the smelter along each transect.

Table ES-3.2 Summary of LOEs and Final Rank for Test Sites

Site	LOE					Final Rank	Distance from Associated Smelter
	Plant Community Assessment	Toxicity Testing Approach 1	Toxicity Testing Approach 2	Soil Characterization	Decomposition Assessment		
CC-03	Red	Red	Red	Red	N/A	Red	Copper Cliff 2.7 km
CC-01	Red	Red	Red	Yellow	Red	Red	Copper Cliff 5.3 km
CC-02	Red	Red	Red	Red	Red	Red	Copper Cliff 5.7 km
CC-04	Red	Red	Red	Yellow	Green	Red	Copper Cliff 6.8 km
CC-07	Red	Red	Red	Yellow	Red	Red	Copper Cliff 8.3 km
CC-06	Yellow	Yellow	Red	Yellow	Red	Yellow	Copper Cliff 8.4 km
CC-08	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Copper Cliff 16.6 km
CON-06	Red	Red	Red	Yellow	Red	Red	Coniston 1.8 km
CON-02	Red	Red	Red	Red	Red	Red	Coniston 2.1 km
CON-08	Red	Red	Red	Red	Red	Red	Coniston 2.1 km
CON-03	Yellow	Yellow	Red	Yellow	Red	Yellow	Coniston 5.7 km
CON-05	Red	Yellow	Red	Yellow	N/A	Red	Coniston 8.9 km
CON-01	Yellow	Yellow	Yellow	Yellow	Red	Yellow	Coniston 24.8 km
FB-05	Yellow	Green	Yellow	Yellow	Green	Yellow	Falconbridge 3.5 km
FB-01	Red	Red	Red	Yellow	Red	Red	Falconbridge 5.1 km
FB-02	Green	Yellow	Red	Green	Red	Yellow	Falconbridge 10 km
FB-06	Yellow	Green	Green	Green	Red	Yellow	Falconbridge 14.7 km
FB-03	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Falconbridge 20.9 km

Based on the integration of all the measured variables, all test sites evaluated were considered to be either moderately (8 sites) or severely (10 sites) impacted relative to the reference sites.

The interactions between the LOEs, and between the LOEs and COC concentrations in soil were evaluated using statistical techniques (Step 2, Chapter 3.12). Finally, the LOEs were examined using a weight–of-evidence approach to determine whether the concentrations of metals in the soil could be inhibiting the recovery of a self-sustaining forest ecosystem (Step 3, Chapter 3.13).

There is no doubt that previous activities and stresses in the study area resulted in widespread loss of the forest vegetation. Around the turn of the 20th century the landscape was cleared to provide timber to the forest industry and fuel for the early smelters and roast yards. The early smelting operations released large quantities of low-level sulphur dioxide and metals emissions which prevented recovery of the natural vegetation. These conditions persisted until the mid 1960s. The lack of vegetation subsequently caused soil erosion. In combination, these stresses have produced the existing landscape.

The extensive studies carried out to evaluate Objective #1 of the ERA suggest, with a high degree of certainty, that the concentrations of COC in soil are continuing to impact terrestrial vegetation, and impede the recovery of a self-sustaining plant community in the Sudbury region. Other factors that were also identified as important are soil fertility, low soil pH, incidence of forest fires in the past, the concentrations of calcium and organic matter in the soil.

Soil pH

The role of soil pH as a confounding factor in this study was also examined. Although pH was not considered a COC in this risk assessment, soil pH can impact plant growth directly, as well as interact with metals to modify soil toxicity. Within the Sudbury region, the range of soil pH is generally below 5.0 which is typically considered suitable for plant growth. The role of soil pH was evaluated using two approaches; a) toxicity tests were conducted in the laboratory using “natural” soils and pH-amended soils from the same sites, and b) the current characteristics of a historically-limed field site (CON-07) were compared to an adjacent but not limed site (CON-08).

The results of toxicity testing in natural and pH-amended soils for Northern Wheatgrass and Red Clover are presented in Chapter 3.14.1.Raising the pH of the soil often reduced the toxicity of the soil, but did not alleviate it altogether. With few exceptions, pH amendment resulted in an increase in emergence and biomass for both northern wheatgrass and red clover.

In general, the improvement in plant performance (emergence and biomass in both species) following pH amendment was greater in soils from sites closer to the smelters than in soils further away from the smelters, or from the reference sites. Plant response was most pronounced in soil from the site (FB-01) that had the lowest soil pH as well as the highest total metal levels (Cu = 909 mg/kg and Ni = 535 mg/kg).

A detailed comparison of site characteristics for each LOE at CON-07 and CON-08 is presented in Chapter 3.14.2. The plant community at CON-07 and CON-08, although in close proximity to each other, were in fact remarkably different. The limed site (CON-07) showed evidence of being a site in transition, while the vegetation at CON-08 was ranked as severely impacted. The past liming and re-greening activities have helped to establish a diverse plant community, with the introduction of essential minerals (Ca, Mg) providing a viable seed source, and increasing the soil pH thereby decreasing metal bioavailability. Although CON-07 is not as productive as the established reference sites, the data collected from the four LOE indicate that it is on its way to re-establishing itself, as compared to CON-08, and that the re-greening activities employed within the Sudbury region are having an effect.

On the other hand, without the addition of lime, seed source or strategic planting, CON-08 has retained its barren appearance and its status as a severely impacted site. Soil erosion, lack of organic matter, high metal concentrations, and poor community structure all indicate that the site is still impacted. These results indicate that a variety of factors are contributing to the lack of recovery at CON-08 including: low soil fertility, low pH, lack of a growth medium and the increased bioavailability of metals in the soil.

Soil samples from the field sites were subject to four different extraction techniques to assess different fractions of metal bioavailability. These results are discussed in Chapter 3.15. The different approaches yielded very different levels of metal fractions. When these COC levels were compared to the results of the plant toxicity tests no one extraction method clearly described the relationship between soil metal concentrations and the toxicity endpoints.

The results of the extensive studies carried out to evaluate Objective #1 indicate that the concentrations of COC in soil have in the past impacted plant communities, and are likely continuing to impede the recovery of a self-sustaining forest community in the Sudbury region. However, other environmental variables and soil conditions are also contributing to inhibiting ecosystem recovery and all these factors are intertwined to the extent that it is not possible or practical to isolate their individual roles over a large landscape. This is described further in Chapter 6.

ES-4.0 OBJECTIVES #2 AND #3: EVALUATE RISKS TO TERRESTRIAL WILDLIFE POPULATIONS AND COMMUNITIES (#2), AND TO INDIVIDUALS OF THREATENED AND ENDANGERED SPECIES (#3)

This chapter includes the exposure assessment, effects assessment and risk characterization for Objectives #2 and #3 that evaluate risks to terrestrial wildlife, including threatened or endangered species.

ES-4.1 Exposure Assessment

The purpose of the exposure assessment is to estimate the amount of each COC received by each VEC on a daily basis. Exposures to COC from ingestion of prey, soil, sediment and water were estimated using a total daily intake (TDI) model. Model parameters include body weight, sediment/soil intake rate, water intake rate, food intake rate, proportions of individual dietary items consumed, and concentration of each COC in each item ingested, and the relative absorption factor for each COC.

The exposure assessment was conducted using a *probabilistic* approach. This approach assumes that model parameters vary or are uncertain. Input parameters are probability distributions incorporating a range of possible values. The resulting exposure estimate can therefore be characterized as a probability distribution, with associated variability and uncertainty described.

Estimates of COC concentrations for the wildlife exposure model were derived in most cases from actual measured values in a variety of abiotic and biotic media from the Sudbury area, including surface water, sediment, soil, fish, plants and invertebrates. COC concentrations in algae, aquatic plants and benthic invertebrates had to be estimated using uptake factors and equations from the literature because Sudbury-specific data were not available.

ES-4.2 Effects Assessment

The purpose of the effects assessment is to determine levels of exposure to each COC that are not expected to result in adverse effects in each VEC. Toxicity Reference Values (TRVs) are chemical doses equivalent to acceptable exposure levels for VECs. The selection of chemical- and species-specific TRVs for the ERA began with a comprehensive search and review of toxicological literature related to the COC and VECs. Several criteria were developed to guide the identification of TRVs from the literature.

TRVs were then selected or derived according to the following order of preference:

- If available, an IC20 (concentration [or dose] resulting in a 20% inhibition of a measured endpoint in treated *versus* control test organisms) was selected;
- A Lowest-observed-adverse-effect level (LOAEL) was selected if no IC20 was available; and,
- A No-observed-adverse-effect level (NOAEL) was selected if neither an IC20 nor a LOAEL was available.

The one exception to the above ranking of effects levels occurred in the case of the peregrine falcon, the endangered species evaluated in the ERA. In this case, NOAELs were preferentially selected in establishing suitable TRVs, as is the general practice in ERA for vulnerable, threatened, or endangered species.

Where available and appropriate, the SARA Group adopted TRVs from one of two U.S. EPA sources: 1. The Coeur d'Alene ERA (2001), which evaluated risks to wildlife exposed to metals from mining and smelting emissions; and, 2. Ecological Soil Screening Level (Eco-SSL) documents (2005), which represent the most comprehensive review of toxicity data available. TRVs were available from the latter for both avian and mammalian species for cadmium and cobalt.

In addition to the establishment of COC- and VEC-specific TRVs, the effects assessment included a review of available field survey data for each VEC. The purpose of the review was to investigate breeding success and population trends for VECs in the study area. Actual field data are important in the final phase of ERA in which risks to wildlife are characterized.

ES-4.3 Risk Characterization

The purpose of risk characterization is to determine the likelihood of adverse effects to terrestrial wildlife populations occurring as a result of exposure to COC in the study area. Risk characterization combines the results of the exposure assessment with those of the effects assessment in order to provide a weight-of-evidence analysis of wildlife risks. The probabilistic exposure estimates predicted from the wildlife exposure model are compared to the TRV point estimates for individual chemicals and VECs. The resulting risk is expressed as an *exposure ratio* (ER):

$$Exposure\ Ratio\ (ER) = \frac{\text{Exposure Estimate}}{\text{Toxicity Reference Value}}$$

Predicted ERs represent the potential risks to individuals within a population, or the probability of an individual animal receiving a particular exposure.

The risk assessment results are first reviewed to determine the probability of the ER exceeding an ER=1.0, as follows:

90% or greater probability of an ER less than or equal to 1.0: signifies that most estimated exposures are less than the TRV, indicating that adverse effects can be ruled out;

Greater than 10% probability of an ER greater than 1.0: signifies that the potential for adverse effects is not ruled out; however, the significance of this potential must be judged according to the uncertainty and degree of conservatism incorporated into the risk assessment, as well as site-specific information.

Presenting the probabilities of exceeding an ER of 1.0 does not include information regarding the magnitude of the exceedance. Therefore, where risks could not be ruled out (that is, where there was a greater than 10% probability of an ER>1.0), the 90th percentile ER also is presented.

The 90th percentile ERs for all portions of the study area where there was a greater than 10% probability of an ER>1.0 are summarized in Table ES-4.1.

Table ES-4.1 Summary of Calculated Exposure Ratios to Wildlife

Valued Ecosystem Component (VEC)	Wildlife Study Zone or Community of Interest						
	Zone 1	Zone 2	Zone 3	Coniston	Copper Cliff	Falconbridge	Sudbury Centre
American robin	●	1.4 selenium	●	●	1.9 selenium	1.4 selenium	●
Ruffed grouse	●	●	●	●	1.6 selenium 1.1 copper	●	●
Peregrine falcon	●	1.1 selenium	●	●	1.5 selenium	1.2 selenium	●
Short-tailed shrew	●	1.3 selenium	●	●	1.8 selenium	1.2 selenium	●
Meadow vole	1.1 selenium	1.7 selenium	1.2 selenium	1.2 selenium 1.3 nickel	3.3 selenium 2.7 nickel	1.9 selenium 2.5 nickel	●
American beaver	●	●	●	●	●	●	●
White-tailed deer	●	●	●	●	●	●	●
Moose	●	●	●	●	●	●	●
Red fox	●	●	●	●	1.2 selenium	●	●

● **Negligible risk – no further investigation required**
Value **Exposure ratio for 90% of the population will be less than the value indicated**

Based on the calculated exposure ratios, risks from COC could be confidently ruled out for beaver, deer and moose in the study area.

Although no field studies on wildlife populations were conducted as part of the ERA, there is considerable anecdotal information from area naturalists and researchers, as well as compendia of information on abundance of birds from various sources of information.

Naturalists and researchers noted that short-tailed shrews and meadow voles are abundant in the Sudbury area even though voles and shrews were predicted to be most at risk in the direct toxicity modelling,. Although data are fragmentary, local researchers suggest that the Sudbury area as a whole is suitable to sustain populations of small and predatory mammals.

Risks were not ruled out definitively for robins, grouse and falcons in the direct toxicity modelling. However, the Christmas bird count data for non-migratory species show increasing numbers of birds from 1980 to 1995. American robins are breeding in Sudbury. Ruffed grouse were extirpated from the Sudbury area but the population has since recovered and it currently is a hunted species. Peregrine falcons were re-introduced into the Sudbury area in 1990 and 1991. There is evidence that peregrines are breeding in the Sudbury area.

The predicted risks for these VECs are primarily related to selenium. It should be noted that the TRV for selenium is very conservative, and when the next higher TRV was used, no risk to these VECs was predicted.

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 the animal VEC populations in the Sudbury area. However, as discussed in Chapter 3, previous effects of smelter emissions, logging and fires on habitat quality (*e.g.*, loss of particular plant species used as food or cover) may be having a continued influence on birds and mammals in the study area due to the long lag period from impact to recovery.

ES-4.4 Uncertainty Analysis

The acknowledgement and characterization of uncertainty and variability in risk modeling is crucial to the success of the risk-based decision-making process. Uncertainty results from a lack of knowledge while variability reflects the inherent heterogeneity of parameter values.

Model parameter variability in the ERA may be: *well, moderately* or *poorly characterized*. Similarly, uncertainty may be: *low*, *medium* or *high*. Table ES-4.2 summarizes the characterization of the variability and uncertainty in the data used to estimate exposures, including metal concentrations in surface water, sediment, fish tissue and soil, and medium-to-biota uptake models.

Table ES-4.2 Summary of variability and uncertainty for exposure model parameters

Data Type	Variability Characterization			Uncertainty		
	Well	Moderately	Poorly	Low	Medium	High
Surface water			●			●
Sediment			●			●
Fish tissue			●			●
Soil	●			●		
Sediment-benthic uptake models			●			●
Soil-plant uptake models		●			●	
Soil-invertebrate uptake models			●			●
Soil-animal uptake models			●			●

One of the largest sources of uncertainty in the ERA is the use of conservative and deterministic TRVs. Toxicological information directly related to the VEC of concern is often unavailable or limited in nature. Therefore, many of the TRVs are derived from similar or related species exposed under controlled laboratory conditions designed to maximize adverse effect. In addition, TRVs are based on effects in individual organisms, and not population-level endpoints. However, it is not practical to derive site-specific TRVs for wildlife populations. Therefore, the TRVs used in the wildlife risk modeling are selected from the literature to be as appropriate as possible (*e.g.*, form of metal, closely-related animal species), while ensuring that risks are not underestimated. The method of derivation of the TRV values for the purpose of this ERA was deemed sufficiently protective.

In risk assessment, variability and uncertainty are addressed by selecting parameter values and making assumptions that are conservative in nature, *i.e.*, standard risk assessment practice assumes that COC are more toxic, and that exposure is greater. Consequently, although it is not certain that the model is correct, the SARA Group is quite certain that the model does not underpredict risk.

ES-5.0 AQUATIC PROBLEM FORMULATION

The political boundaries of Sudbury encompass over 300 lakes and numerous wetland ecosystems. However, since the impetus and focus of the Sudbury Soils Study was related to soils, a full detailed risk assessment of the aquatic environment was considered outside the scope of this study. Therefore, a problem formulation was developed for the aquatic environment as an information gathering and interpretation stage to plan and focus the approach for a possible detailed aquatic ecological risk assessment. This information is presented in Chapter 5.

The aquatic problem formulation identifies the following:

- candidate Chemicals of Concern in water and sediments,
- potential Valued Ecosystem Components,
- lakes for possible future detailed evaluation, and
- data gaps and uncertainties in the existing information

Given the extensive monitoring and research activities related to lakes and rivers in the study area that have taken place over the past two decades, no detailed aquatic risk assessment is planned at this time. However, the information provided in the aquatic problem formulation may be useful to scientists and researchers in the Sudbury area that will continue to study and monitor the surrounding aquatic ecosystems.

ES-6.0 CONCLUSIONS AND RECOMMENDATIONS

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 that may require 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 may be appropriate.

It should be recognized 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 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. A self-sustaining ecosystem is a diverse landscape that does not require continued human intervention to maintain its essential functions.

The impact ranking for each site as determined in Chapter 3 are illustrated on Figure ES 6.1 which shows the spatial distribution of the sites in relation to the smelter locations and the area known as the semi barrens. Of the 18 test sites, 8 were considered to be moderately impacted, and 10 were considered severely impacted. All the severely impacted sites lie within the semi barrens, while sites outside this zone were considered moderately impacted.

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 results. 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 ES-6.1). The “moderately” impacted sites ranged from 3.5 to 25 km from the nearest smelter, although most (7/8) were over 5 km from the smelter. The “severely” impacted sites ranged from 1.8 to 8.9 km from a smelter, with 80% being within 5 km of a smelter.

Table ES-6.1 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

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. 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 60 or more plant species.

The ranges of values for soil COC levels associated with the different site classifications are presented in Table ES-6.2.

Table ES-6.2 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

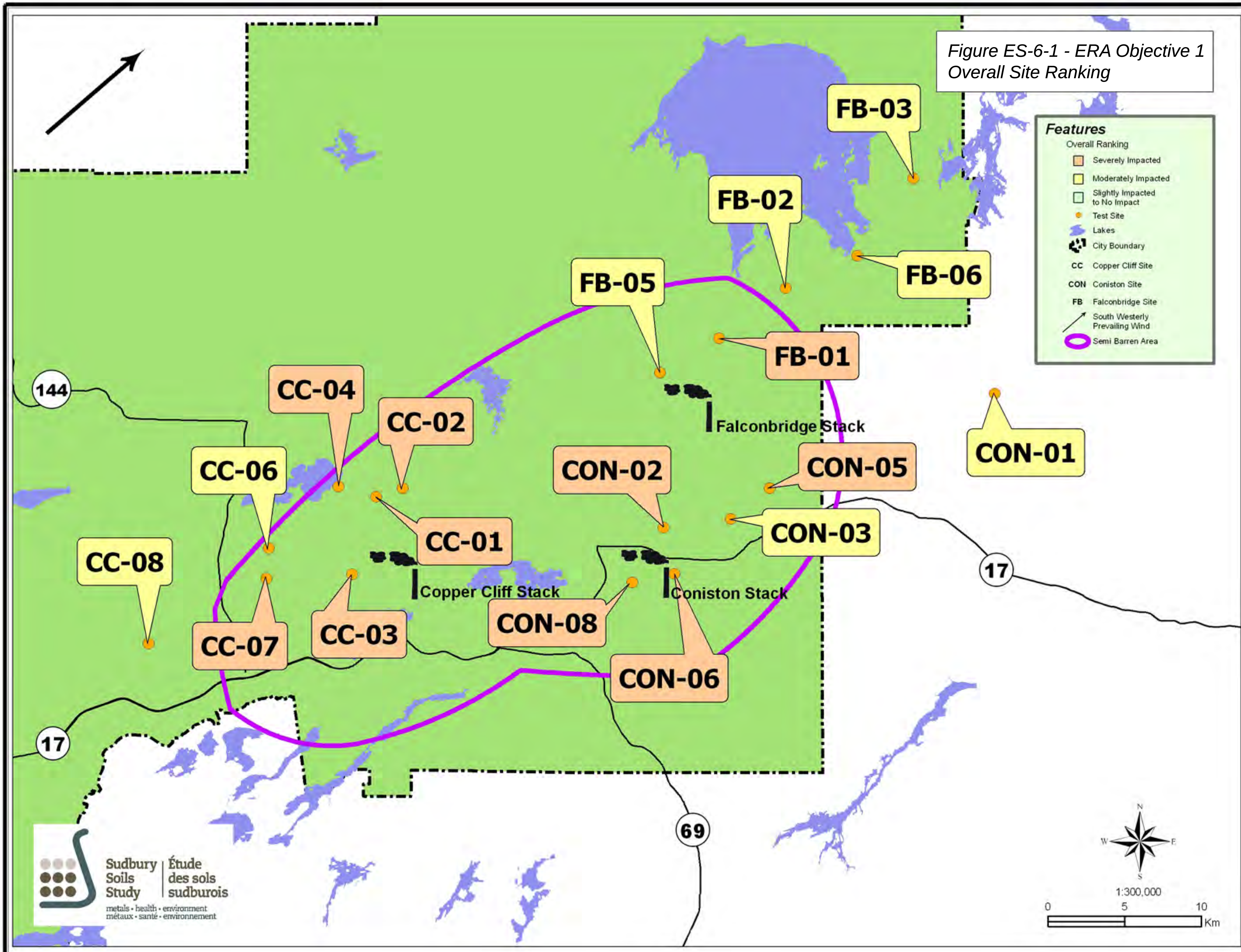
Figure ES-6-1 - ERA Objective 1
Overall Site Ranking
Features
Overall Ranking
Severely Impacted
Moderately Impacted
Slightly Impacted to No Impact
Test Site
Lakes
City Boundary
CC Copper Cliff Site
CON Coniston Site
FB Falconbridge Site
South Westerly Prevailing Wind
Semi Barren Area
FB-03
FB-02
FB-06
FB-05
FB-01
CC-04
CC-02
CC-06
CC-01
CC-08
CC-07
CC-03
CON-01
CON-02
CON-05
CON-03
CON-08
CON-06
Falconbridge Stack
Copper Cliff Stack
Coniston Stack
144
17
69
1:300,000
0
5
10
Km
N
S
E
W
Sudbury Soils Study
Étude des sols sudburois
metals • health • environment
métaux • santé • environnement

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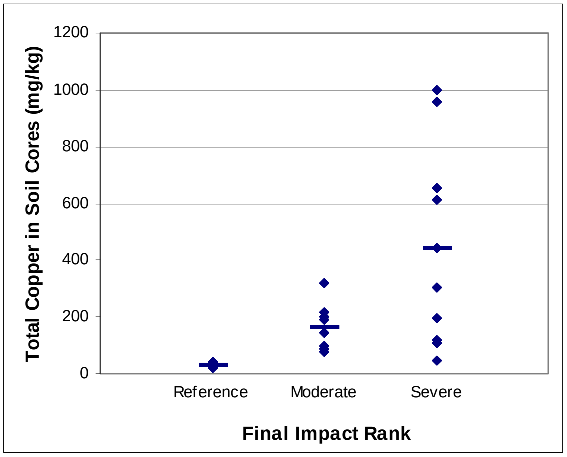
Figure ES 6.2 shows there was a wide range in COC levels (Ni and Cu illustrated for example) between the sites but COC levels were clearly lowest at the reference sites while elevated levels were observed at the most impacted sites.



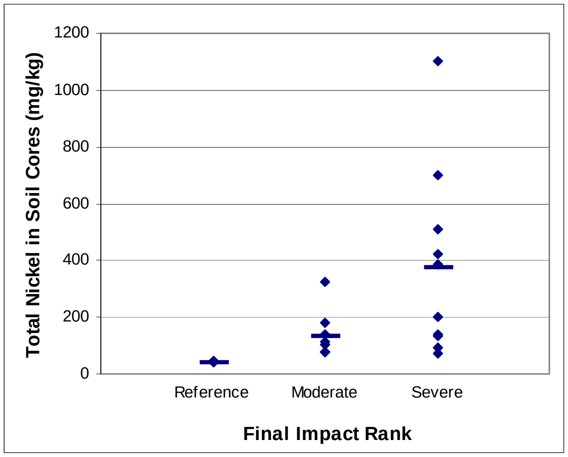


Figure ES-6.2 Total copper and nickel concentrations in soils from reference sites and test sites.

The results of the final site ranking derived from the Objective 1 study for the 22 study sites were extrapolated to the entire study area using remote sensing techniques to produce an Extrapolated Ranking Map. Areas with similar spectral signatures were classified as either impacted (red, yellow for severe or moderate) or green (reference). The area examined using this approach covered an area of 9,238 km$^{2.}$ However, 85% of the area could not be classified for a variety of reasons.

Within the areas that could be classified by this technique (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. This result shows that, using the Extrapolated Ranking Map approach within the areas that could be classified, up to 50% of the land was moderately or severely impacted.

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.

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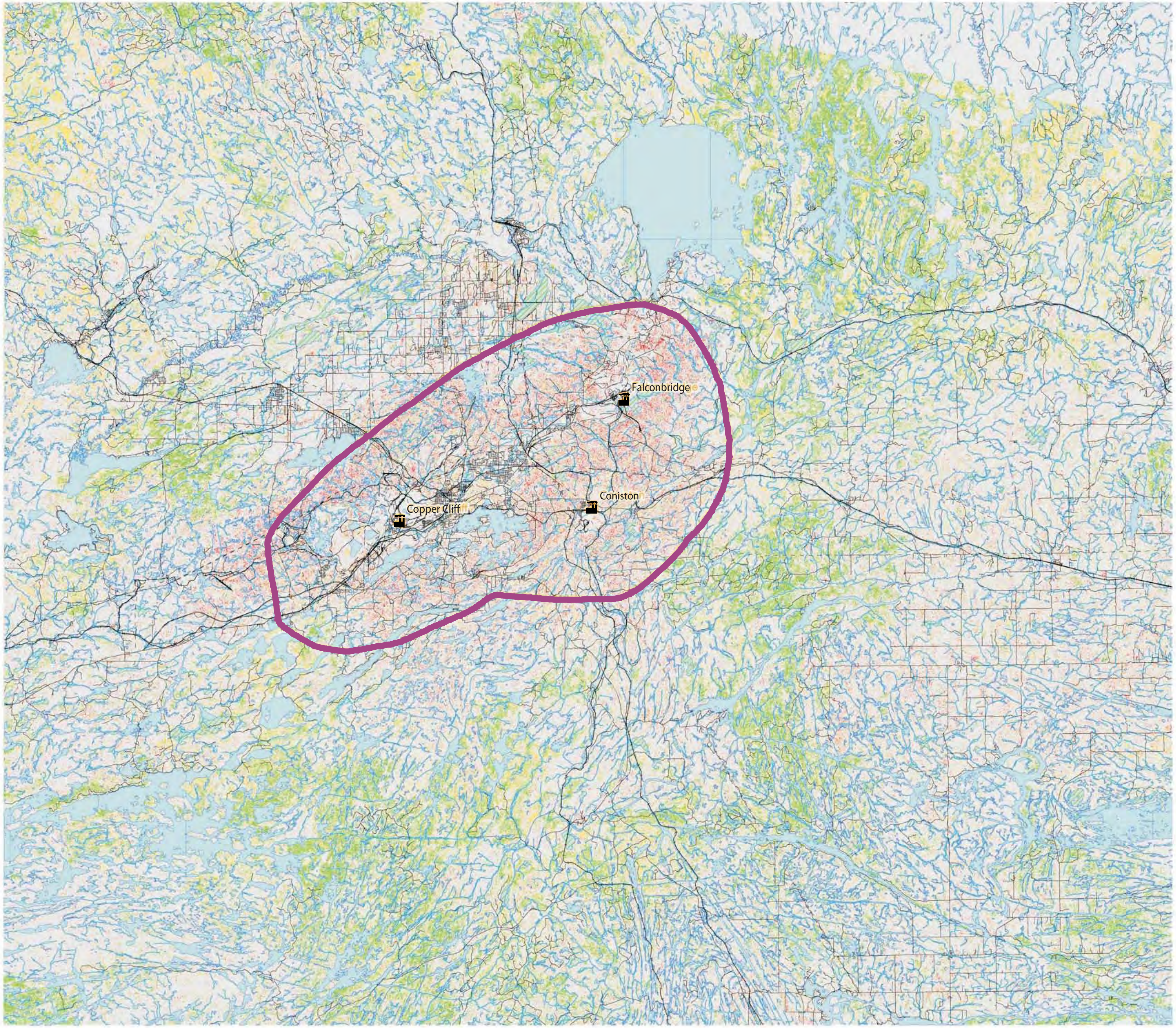
Figure ES-6-3
Extrapolated Ranking Map of the Semi-Barrens



Ecological Risk Map

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

N
W E
S

0 2.5 5 10 15 20 Kilometers

Legend

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

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

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The conclusions associated with each of the four specific ERA Objectives are as follows:

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

Terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the Chemicals of Concern in soil. Terrestrial plant communities are also impacted by other factors such as soil erosion, low nutrient levels, lack of soil organic matter, and/or low soil pH.

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

The assessment suggests that COC originating from smelter emissions are not currently exerting a direct toxic effect on wildlife in the Greater Sudbury area, nor are they predicted to in the future. However, historic impacts of smelter emissions on plant communities have affected habitat quality and, therefore, may be having a continued indirect influence on birds and mammals in the study area.

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

There are very few recognized threatened or endangered species in the study area. It is unlikely that COC from the smelters are having a direct effect on these species.

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.*

An aquatic problem formulation was developed as an information gathering and interpretation stage to focus the approach for a possible future detailed aquatic risk assessment. However, given the extensive aquatic research and monitoring studies that have been conducted in the study area during past two decades, no detailed aquatic ecological risk assessment is planned at this time.

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 vegetation community. The ERA has addressed, for the first time, the question of direct metal toxicity to wildlife in the region. Like any major scientific endeavor, the ERA provides enough information to stimulate more questions about the terrestrial ecosystems around Sudbury. If ecological risk management is pursued in the Sudbury area, this document provides the foundation for effective and focused strategies to be developed. 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 process.