Sudbury Soils Study | Étude des sols sudburois

metals • health • environment
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Summary of Volume III: Ecological Risk Assessment

March 2009

Prepared by:

SARA GROUP

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Preface

The Sudbury Soils Study was conducted over a seven-year period from 2001 to 2008 and encompassed a 40,000 square kilometre study area. The purpose of this comprehensive scientific study was to determine whether the levels of metals in the study area environment pose a risk to humans, plants, or animals. The first two years of the study were devoted to developing and carrying out an extensive soil sampling and analysis program. The next stage involved three years of intensive field and laboratory studies and report writing, followed by two years of technical review.

The complete *Sudbury Soils Study* will be comprised of three volumes:

Volume I: ....*Background, Study Organization and 2001 Soils Survey;*
Volume II: ....*Human Health Risk Assessment (HHRA);* and
Volume III: ....*Ecological Risk Assessment (ERA)*.

This document provides a summary of the information in *Volume III: Ecological Risk Assessment* (ERA). The Sudbury area ERA was conducted by the Sudbury Area Risk Assessment (SARA) Group. The purpose of the ERA was two-fold: To evaluate the risks to terrestrial plants and animals from exposure to metals originating from air emissions from local smelting operations; and to provide information to support the recovery of local ecosystems in areas known to have been affected by historic local mining, smelting and refining operations. The intent of this document is to provide a summary report of the study process and conclusions of the ERA. A list of acronyms and a glossary of terms can be found at the end of this report.

This document does not deal with risk management or remediation. These issues are addressed in a *Risk Management Framework* prepared by Vale Inco, Xstrata Nickel and the City of Greater Sudbury, which is available to the public at local libraries, at the Ontario Ministry of the Environment (MOE) office and online at www.sudburysoilsstudy.com.

The complete technical report (ERA) including scientific approaches, technical information and detailed results is available for viewing at the offices of the MOE at 199 Larch Street in Sudbury, and at the public libraries in Greater Sudbury. Volumes I and II were released concurrently in May 2008. Volume III (ERA) was released in February 2009. Electronic copies of the entire technical ERA report and additional information are available online at www.sudburysoilsstudy.com.

1. Executive Summary

The driving force for the Sudbury Soils Study was elevated metal concentrations in soil. Therefore, the focus of the Sudbury Area Ecological Risk Assessment (ERA) was the terrestrial environment.

The main goal of the ERA was:

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

The study covered an area of 40,000 square kilometres, making it one of the largest and most comprehensive studies of its kind in North America

Four specific objectives were developed to help achieve the primary ERA goal:

1. Evaluate the extent to which COC are preventing the recovery of regionally representative, self-sustaining terrestrial plant communities;
2. Evaluate risks to terrestrial wildlife populations and communities due to COC;
3. Evaluate risks to threatened or endangered terrestrial species due to COC; and,
4. Conduct a comprehensive problem formulation for the aquatic and wetland environments in the Sudbury area.

The study covered an area of 40,000 square kilometres, making it one of the largest and most comprehensive studies of its kind in North America.

Upon the recommendation of the Ontario Ministry of the Environment (MOE), the ERA was voluntarily commissioned by Vale Inco and Xstrata Nickel, and was administered by a multi-stakeholder Technical Committee. The Technical Committee was comprised of members from the MOE, the Sudbury & District Health Unit, the City of Greater Sudbury, Vale Inco, Xstrata Nickel, and the First Nations & Inuit Health Branch of Health Canada. 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.

A large quantity of data from the study area were collected for the ERA. Samples of soil, water, sediment, plants, terrestrial invertebrates, and fish tissue were collected, and scientific studies were conducted in both the field and in the laboratory. All of the data collected were analyzed by a group of scientists and independent consultants who joined together to form the Sudbury Area Risk Assessment (SARA) Group. The SARA Group used the data collected from the study area to evaluate potential impacts to terrestrial plants and animals for seven chemicals of concern (COC): arsenic, cadmium, cobalt, copper, lead, nickel, and selenium.

The second draft of the ERA report prepared by the SARA Group was thoroughly reviewed by an Independent Expert Review Panel (IERP) comprised of six leading North American scientists who specialize in plant and wildlife ecology, ecotoxicology, and ERA. The methods used to evaluate risks in ERA are conservative, which means that the assumptions used to calculate risk predictions tend to over-estimate risk in the interest of protecting plants and animals. The IERP agreed with the approach and assumptions used in the Sudbury area ERA.

Conclusions

The main conclusions from the ERA for the Greater Sudbury study area are as follows:

1. Terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the Chemicals of Concern (COC) in soil.
2. Terrestrial plant communities in the Greater Sudbury area are also impacted by other factors such as soil erosion, low nutrient levels, lack of soil organic matter, and/or low soil pH.
3. The assessment suggests that COC originating from smelter emissions are not currently exerting a direct effect on wildlife populations 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.
4. 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.
5. An aquatic problem formulation was developed as an information gathering and interpretation stage to focus the approach for a possible future detailed aquatic ecological risk assessment. However, given the extensive aquatic research and monitoring studies that have been conducted in this area over the past two decades no detailed aquatic ecological risk assessment is planned at this time.

Results from the ERA field studies were applied to the larger Sudbury region using satellite imagery. This approach was used to classify areas of vegetation that were potentially impacted from historical activities and smelter emissions, and where natural recovery continues to be at risk. Within the areas that could be classified using this approach, approximately one half of the vegetation was identified as moderately to severely impacted. Further field studies and ground-truthing are required to validate these findings and to confirm areas for restoration and regreening activities.

The SARA Group is confident that the ERA did not underestimate risks to plants and animals in the Greater Sudbury area. The results and conclusions from this risk assessment will be used as the basis for future risk management decisions in the Greater Sudbury area and to support activities related to the re-greening of the Greater Sudbury area landscape.

2. Background

2.1 Why Was the Sudbury Soils Study Conducted?

Nickel and copper production in the Greater Sudbury area have provided tremendous social and economic benefits to the region and to all of Canada

The rich mineral deposits in and around the City of Greater Sudbury in northern Ontario (Figure 2.1) have drawn people to the area for well over a century. The Greater Sudbury area encompasses one of the largest known nickel ore bodies on Earth. This, along with a mining history of more than 125 years, earned Sudbury international recognition as "The Nickel Capital of the World." Nickel and copper production in the Greater Sudbury area have provided tremendous social and economic benefits to the region and to all of Canada.

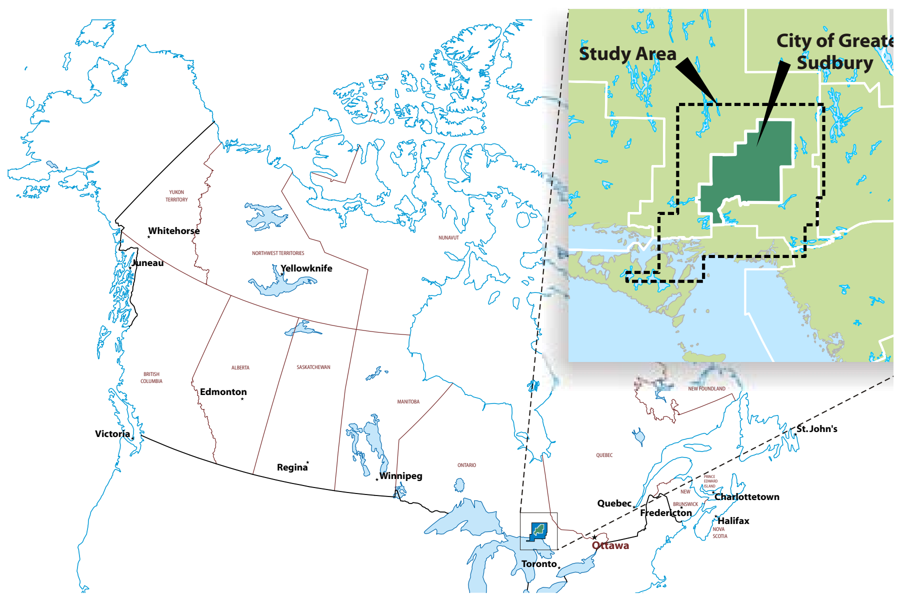


Figure 2-1: The City of Greater Sudbury in Northern Ontario, Canada

In addition to the benefits of mining, there have been environmental consequences associated with smelting and refining operations over the past century. The Ontario Ministry of the Environment (MOE) and the two major mining companies in the Greater Sudbury area-Vale Inco (formerly Inco Ltd.) and Xstrata Nickel (formerly Falconbridge Ltd.) have conducted soil sampling programs across the region for more than 35 years.

In 2001, the MOE published a report that reviewed and summarized the results of soil sampling programs conducted in the study area from 1971 to 2000. The MOE reported that in some areas of the region, levels of cobalt, copper, nickel, and arsenic did not meet provincial soil quality guidelines. These areas were generally near the historic metal production centres of Copper Cliff, Coniston, and Falconbridge. As a result of these findings, the MOE report recommended that:

1. A more detailed soil study be undertaken to fill information gaps from previous sampling programs; and
2. Detailed human health and ecological risk assessments (HHRA and ERA) be conducted.

Both Vale Inco and Xstrata Nickel accepted these recommendations and, in 2001, the two companies voluntarily commissioned the Sudbury Soils Study (see Figure 2-2 Chronology of Events).

The first phase of the Sudbury Soils Study was a comprehensive soil sampling and analysis program that was undertaken in 2001 by the MOE and the mining companies. The data from this program provided up-to-date information on metal concentrations in study area soils and formed the basis of the risk assessment work to follow. The 2001 Soil Survey is summarized in Section 3.1.2.1.

The second phase of the study began in 2003 when comprehensive human health and ecological risk assessments were initiated. The main goal of the ERA was to:

Evaluate the current and future risks from metal particulate emissions from Sudbury smelters to terrestrial and aquatic ecosystem components; and to provide information to support the recovery of self-sustaining ecosystems in areas of Sudbury affected by airborne metal emissions.

Since the impetus force for the Sudbury Soils Study was elevated metal concentrations in soil, the focus of the Ecological Risk Assessment (ERA) was the terrestrial environment. A risk assessment for aquatic ecosystems was not within the scope of this ERA. An aquatic problem formulation, which represents the first step of a risk assessment, was conducted as part of this study. The aquatic problem formulation is outlined in the full ERA technical report but is not discussed further in this summary report.

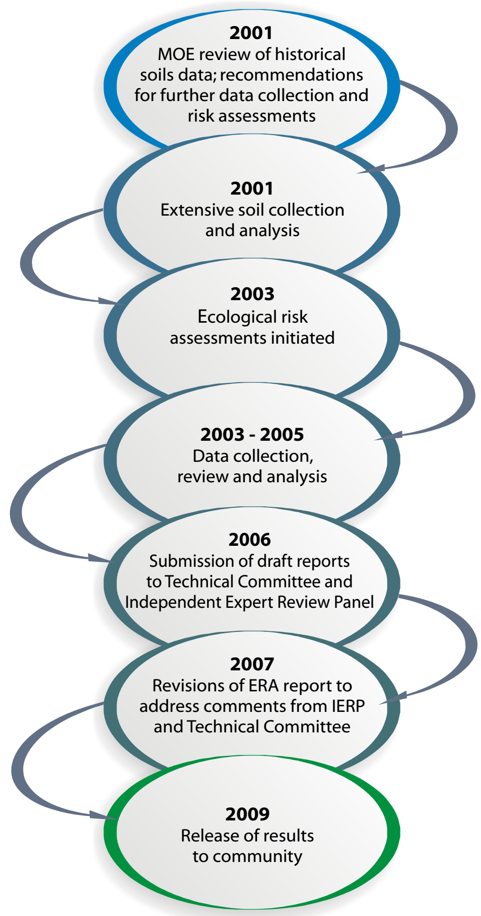


Figure 2-2: Chronology of Events for the Sudbury Soils Study

2.2 Who Was Involved in the Sudbury Soils Study?

The Sudbury Soils Study was initiated in the summer of 2001 following meetings between the MOE, the City of Greater Sudbury, the Sudbury & District Health Unit, and the two mining companies. It was important to the success of the study to involve a range of stakeholders, including local, regional, and provincial regulators, scientists, plant and wildlife experts, and members of the local community.

A **Technical Committee (TC)** was formed in 2001 to develop, guide, and implement all technical aspects of the Sudbury Soils Study. The TC included members from the Ontario Ministry of the Environment, the Sudbury & District Health Unit, the City of Greater Sudbury, the First Nations & Inuit Health Branch of Health Canada, Vale Inco, and Xstrata Nickel.

The overall vision of the TC for the Sudbury Soils Study was to develop *"a transparent process that provides a thorough, scientifically sound assessment of environmental and health risks to the Sudbury community and effectively communicates results so that future decisions are informed and valued."*

A number of measures and procedures were implemented to ensure that a transparent and scientifically rigorous study was conducted. These included the establishment of a Public Advisory Committee (PAC) and a Communications Sub-committee, involvement of an Independent Process Observer, consultation with an independent Scientific Advisor, and review of a draft of the ERA by an Independent Expert Review Panel (IERP). Each of these is discussed briefly below.

Members of the PAC, the Canadian Auto Workers Union (representing Xstrata Nickel workers), and the United Steelworkers (representing Vale Inco workers) were also invited to attend and observe the TC meetings.

A Public Advisory Committee (PAC) was established in 2002 to facilitate community involvement and promote the flow of information between the TC and the public. The PAC was comprised of 10 to 15 volunteer citizens drawn from the study area communities.

A **Communications Sub-committee (CSC)** was formed in 2002 to help oversee communications and consultation initiatives for the Sudbury Soils Study. The CSC worked with the TC, the PAC, and the Independent Process Observer (see next section) to ensure timely and effective public consultation. The mandate of the CSC was to foster community awareness and participation throughout the study process.

The Independennt Process Observer, Mr. Mariotti, was given full autonomy to ensure that all TC members were given equal access and input to the process, and to represent the interests of the community

The **Independent Process Observer (IPO)** was retained to attend all TC and PAC meetings , and had access to all scientific discussions. The IPO was Mr. Franco Mariotti, a biologist and staff scientist at Science North and a respected member of the community. In this role, Mr. Mariotti was given full autonomy to ensure that all TC members were given equal access and input to the process, and to represent the interests of the community. Mr. Mariotti observed all TC and sub-committee decisions. He published his observations in quarterly reports that were distributed to interested stakeholders and community members, and posted on the Sudbury Soils Study website.

The ERA was conducted by several professional environmental consulting firms, which joined together to form the **Sudbury Area Risk Assessment (SARA) Group**. The SARA Group is an affiliation of several Ontario-based consulting firms specializing in the various scientific disciplines required to carry out a study of this broad scope. The main partners of the SARA Group are AECOM (formerly Gartner Lee Limited and C.Wren and Associates), Intrinsik Environmental Sciences Inc. (formerly Cantox Environmental Inc.), Rowan Williams Davies and Irwin Inc., SGS Lakefield, Goss Gilroy Inc., and Dr. Lesbia Smith, M.D.

The TC also appointed a **Scientific Advisor** Dr. Stella Swanson, formerly Golder and Associates, to independently review the development of the ERA and to provide support and guidance to the TC and PAC during the ERA.

Given the TC's commitment to transparency and sound science in conducting the risk assessment, the draft ERA report underwent a comprehensive peer review by an **Independent Expert Review Panel (IERP)**. The IERP was comprised of six leading North American scientists specializing in plant and wildlife ecology, ecotoxicology, and ecological risk assessment. The panel was formed and administered by *Toxicology Excellence for Risk Assessment (TERA)* an international not-for-profit organization located in Cincinnati, Ohio.

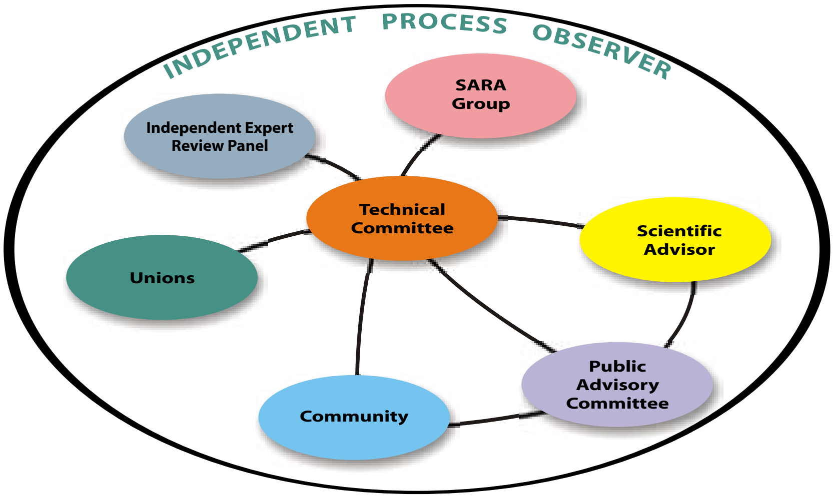


Figure 2-3: Organization Linkages for the Sudbury Soils Study

2.3 Public Consultation

Timely and effective public consultation was a priority for the Sudbury Soils Study partners. This was accomplished via several communication initiatives, including:

- Email and direct mail updates to interested groups and individuals;
- The *Update* community newsletter, distributed in local newspapers;
- Sudbury Soils Study website (*www.sudburysoilsstudy.com*);
- Toll-free phone line and email for interaction with the SARA Group;
- Quarterly IPO Reports from Franco Mariotti;
- Public Question and Answer (*Q&A*) forum on the Sudbury Soils Study website;
- Participation of the SARA Group in meetings of the TC, CSC, PAC, local interest groups, and local First Nations Communities, namely Whitefish Lake First Nations and Wahnapitae First Nations;
- Media relations, including television, radio, and newspaper interviews with members of the SARA Group;
- *Have Your Say Workshops* in Copper Cliff, Coniston, and Falconbridge to obtain community input on the study and selection of valued ecosystem components;
- *Public Open Houses* to facilitate community updates and direct interaction of community members with the study partners; and
- Telephone survey of a representative number of Greater Sudbury area residents to evaluate the effectiveness of the communications initiatives and to assess public opinion of the Study.

The Sudbury community made meaningful and significant contributions to the Sudbury Soils Study. Input provided by the community was valuable in helping the SARA Group and the TC shape the study and the manner in which results were communicated to the public.

2.4 What is Ecological Risk Assessment?

The term risk refers to the chance or likelihood that a particular event will occur

The term *risk* refers to the chance or likelihood that a particular event will occur. Ecological risk assessment (ERA) is a formal analytical process that evaluates the likelihood that a given group of plants or animals may experience adverse effects from exposure to particular chemicals in the environment. The plants and animals studied in an ERA are referred to as *valued ecosystem components (VECs*). It is important to note that risks to populations or communities of plants and animals, rather than individuals, are generally evaluated in an ERA. However, in cases where vulnerable, threatened, or endangered species are present in the study area, risks to individual members of those species are also assessed.

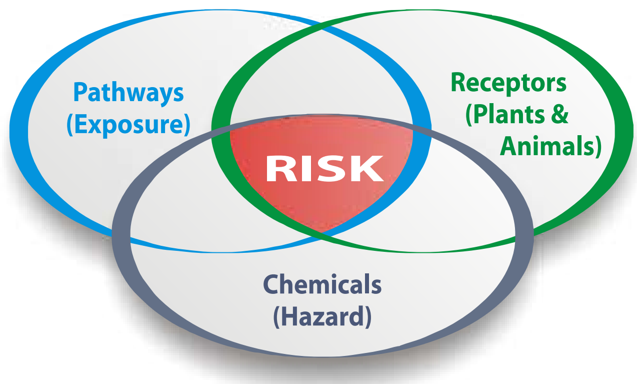


Figure 2-4: Combination of Factors Contributing to Ecological Risk

The plants and animals studied in an ERA are referred to as Valued Ecosystem Components (VECs)

As shown in Figure 2-4, three factors contribute to ecological risk:

1. The toxicity of the identified chemical(s);
2. The sensitivity of the exposed VECs; and
3. The existence of a complete exposure pathway for plants (root or shoot uptake) or animals (through swallowing, breathing, or skin contact) to come in contact with the chemical, and the frequency and duration of the exposure.

Ecological risks are generally evaluated using one (or a combination) of two approaches: the standard ERA framework approach, and the weight-of-evidence approach. Each of these is described in more detail in the following sections.

2.4.1 The Standard ERA Framework Approach

The standard ERA framework combines knowledge of specific chemicals, exposure pathways, and VECs to calculate numeric risk predictions for plants and animals in a particular area. The relevance and accuracy of any risk prediction depends on the quality and quantity of available information for all three factors (chemicals, exposure pathways, and VECs). The more comprehensive and site-specific the information used in the ERA, the more confident scientists can be that their predictions reflect actual risks to plants and animals.

The standard ERA approach was used to address Objectives 2 and 3 in this study.

Several federal, provincial, and state regulators provide guidance on conducting risk assessments, including the Canadian Council of Ministers of the Environment (CCME), the United States Environmental Protection Agency (U.S. EPA), and the MOE. The Sudbury area ERA is geographically the largest study of its kind in Canada. The study area covered approximately 40,000 square kilometres (an area the size of Switzerland) and involved multiple stakeholders and property owners. Although there was no guidance available at the time for conducting area-wide studies of this size, the Sudbury area ERA followed the risk assessment framework recognized by the CCME, MOE, and the U.S. EPA.

The risk assessment framework includes the following four components:

1. *Problem formulation*

   This is an information gathering and interpretation stage that focuses the scope of the risk assessment and characterizes the study area in detail. This component also identifies Chemicals of Concern (COC); populations of plants and animals (or *VECs*) that may be exposed to the COC; the pathways by which VECs may come into contact with the COC, and any information gaps that may exist.

2. *Exposure assessment*

   This component involves using a precautionary and conservative approach to calculate the amount of COC to which VECs have been exposed. All potential exposure pathways are considered. Site-specific data (samples of soil, plants, water, and fish) were collected as part of this study, providing measured metal concentrations in the study area environment that were used to calculate exposures for each VEC to each COC.

3. *Hazard assessment*

   This stage involves an evaluation of the COC and the adverse effects that might occur under the exposure conditions that may be experienced by study area VECs. This is also the stage when Toxicity Reference Values (TRVs) are determined. These are levels of exposure that are not expected to result in significant adverse effects, and are, therefore, protective of the plant and animal populations being studied.

4. *Risk Characterization*

   At this stage of the ERA, numerical risks are calculated based on a comparison of exposure estimates (from the exposure assessment) with exposure limits (from the hazard assessment) for each VEC and each COC.

The Sudbury area ERA followed the risk assessment framework recognised by the CCME, MOE and the U.S. EPA.

Although based on real environmental data, the risk predictions are theoretical because they are usually calculated using mathematical models and general assumptions about the VECs. The predicted risks using this ERA process do not necessarily equate to actual risks to plants or animals. By design, a standard ERA is a *conservative* process, meaning that the methods, models, and assumptions used generally overestimate actual risks to ensure that plants and animals are protected. Therefore, when calculated risks are insignificant, actual risks can confidently be ruled out. However, in cases where calculated risks are significant, further investigation is required to determine whether there is a need for action to reduce exposure. The standard ERA framework approach provides a tool for ruling out risks that are insignificant and for focusing attention on areas of greatest concern.

Two approaches (standard framework and weight-of-evidence) are often used together to characterize ecological risk

2.4.2 Weight-of-Evidence Approach for Ecological Risks

This approach was used to address Objective 1 of the study due to the complexity of the Sudbury landscape and presence of many confounding factors in addition to the COC. Depending on the VECs being assessed, a variety of types of data and information can be collected to aid in the evaluation of risk. Examples of these various types of information or *lines of evidence* include:

- *Field studies* – to physically examine and/or conduct experiments in the study area to assess the condition of VECs;
- *Population/community surveys* – to take actual counts and make observations of plants and animals living in the study area;
- *Toxicity studies* – to test whether plants and animals (earthworms, for example) can survive, grow, and reproduce in soil collected from the study area;
- *Soil characterization studies* – to determine whether the physical and chemical nature of the soil may be having an effect on plants and animals in the study area;
- *Published scientific literature* – documented studies and information on the VECs, COC, and/or the study area; and
- *Numeric risk calculations* from a standard ERA framework approach.

Both the quality and the quantity of evidence that is used to evaluate risk are taken into consideration. This process of scientifically evaluating and incorporating various lines of evidence to assess ecological risk is known as a *weight-of-evidence* approach. Note that the numeric risk results from a standard ERA framework approach may be considered as one line of evidence in a weight-of-evidence approach. In fact, it is important to consider other lines of evidence in cases where numeric risk estimates predict the potential for significant risk. Therefore, the two approaches (standard framework and weight-of-evidence) are often used together to characterize ecological risk.

Regardless of the approach (standard framework or weight-of-evidence), ERA is a tool used to focus risk management efforts on the most important areas and issues of concern. Where the ERA process indicates unacceptable risk, risk managers must determine what can be done to reduce risks to acceptable levels. The ERA provided useful information to allow risk managers to make informed decisions.

3. The Sudbury Area ERA

The Sudbury area ERA was unique in many ways. First, it was assumed that wide-scale impacts to the area landscape had occurred as a result of over 100 years of human activities including smelter emissions. Also, smelter emissions of metals were recognized as just one source of stress to the local vegetation. Historically, widespread logging, sulphur dioxide emissions from roast yards and early smelters, soil erosion and forest fires have also contributed to the present environmental conditions. In addition, the surrounding ecosystem is in a state of change, for the better, as a result of over 30 years of re-greening and restoration activities, as well as significant emissions reductions. These factors posed unique challenges to the Sudbury area ERA.

The SARA Group used both the standard risk assessment framework and a weight-of-evidence approach in assessing risks of metals

The study was broadly divided between examining potential impacts to the terrestrial plant community and wildlife.

1. To evaluate the extent to which the Chemicals of Concern (COC) (metals from emissions) are preventing the recovery of regionally representative, self-sustaining terrestrial plant communities,

2. To evaluate risks to terrestrial wildlife populations and communities due to COC, and to evaluate risks to individuals of threatened or endangered species due to COC.

The SARA Group used both the standard risk assessment framework and a weight-of-evidence approach in assessing risks of metals to the ecosystem. It is understood that vegetation in the Greater Sudbury area has been adversely affected and that it continues to struggle to recover from these historic impacts. Therefore, the goal of the risk assessment for plant communities was to evaluate the extent to which COC are responsible for impeding the recovery of those communities.

Potential risks to wildlife in the study area are much less obvious than those to plants. In this case, the standard framework approach was the primary tool used to evaluate risks. The resulting numeric risk estimates were then used to identify cases where risks could be ruled out. A weight-of-evidence approach was then used to further investigate instances where risks could not be ruled out.

The ERA was carried out in three phases, as shown in Figure 3-1.

The initial stages of gathering information, defining the study area, identifying important species and communities (or Valued Ecosystem Components), and identifying exposure pathways were the same for both plants and wildlife. Together, these activities constitute the *problem formulation* stage of the standard ERA framework. Therefore, the problem formulation presented in Section 3.1 sets the stage for both the wildlife and plant community portions of the ERA. Section 3.2 summarizes Phase 2, which is the sampling stage to fill data gaps in Phase 1. The remainder of the ERA is divided, with the approach and results of the plant community assessment in Section 3.3.1, and presentation of the wildlife assessment in Section 3.3.2.

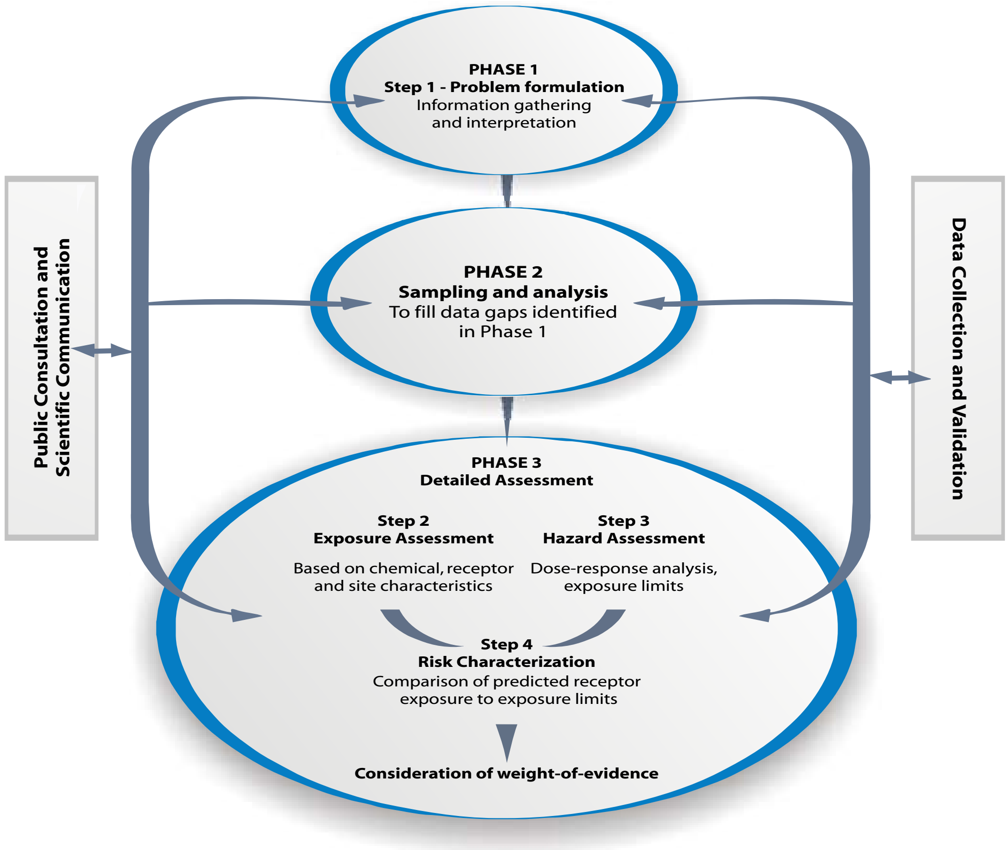


Figure 3-1: Three Phases of the Sudbury Area ERA

3.1 Phase One: Problem Formulation

In this phase the SARA Group reviewed all available background information, which helped to focus the approach of the study and lay the foundation for the ERA. The following sections describe each of the problem formulation tasks (background data compilation, study area description, identification of chemicals of concern, selection of VECs, identification of exposure pathways, and identification of information gaps) as completed for the Sudbury area ERA.

3.1.1 Background Data Compilation

The ecological data review involved collecting relevant information from local experts, published scientific documents, web-based sources, and industry and government publications. A comprehensive literature search was conducted to determine the current state of knowledge of ecological effects of metals in the Greater Sudbury area. Specific sources of background data for the ERA consisted of the following:

Ecological research community at Laurentian University, Sudbury, Ontario

The SARA Group recognized that a great amount of local expertise exists in Sudbury. Scientists from Laurentian University were contacted and many became actively involved in the ERA. Some Laurentian faculty members (and their areas of local expertise) who participated in the ERA included:

- Dr. Graeme Spiers (soil science and geology);
- Dr. Peter Becket (vegetation communities and ecology);
- Dr. John Gunn, Mr. Bill Keller and Mr. George Morgan (Freshwater Co-op Unit, fisheries, water quality and zooplankton);
- Dr. Glenn Parker (deer diets and metal concentrations);
- Dr. Jean-Francois Robitaille, and Ms. Andrea Sinclair (small mammal populations);
- Mr. Keith Winterhalder (formerly Laurentian University; provided many photographs related to re-greening activities);
- Mr. Chris Blomme (wildlife species); and
- Dr. David Lesbarrères and Dr. Jacqueline Litzgus (amphibian and reptile species).

Scientists from Laurentian University were contacted and many became actively involved in the ERA

Government Agencies

The staff and resources of several government agencies were consulted for information on wildlife populations in the study area. Sources of information included:

- Ontario Ministry of Natural Resources;
- Environment Canada;
- Sudbury & District Health Unit; and
- City of Greater Sudbury.

Wildlife and Hunting Societies

Various wildlife and hunting societies provided information on wildlife populations in the study area. Sources of information included:

- Sudbury Naturalists; Bird Studies Canada;
- National Audubon Society;
- Sudbury Valley Trustees;
- Sudbury District Birding Archives;
- Science North (Mr. Franco Mariotti, Staff Scientist/Biologist);
- Ducks Unlimited; and
- Ruffed Grouse Society of Canada.

3.1.2 Study Area History and Description

The ERA study area is defined by the bounds of the 2001 Soil Survey. It encompasses a large geographic region of approximately 40,000 square kilometres (Figure 2-1). The study area includes the City of Greater Sudbury and captures a diverse natural environment. The Sudbury region is in the transitional zone between the Great Lakes–St. Lawrence Forest, and the Boreal Forest ecological regions.

Naturally occurring copper and nickel deposits were discovered in the Sudbury basin in 1883 as the railway was being built through the Murray area near Sudbury. The Canadian Copper Company started mining at Copper Cliff in 1886 and began operating the region's first smelter in 1888. Since that time, mining activities continued to expand in the area and significantly influenced the local economy.

Initially, open roast yards were constructed for recovering nickel and copper from the mined ores. In the early 1900s, nearly all woody vegetation had been removed from the vicinity of the roast yards to provide fuel for the roasting process. It is estimated that more than 3.3 million cubic metres of wood were burned in the roast yards (equivalent to 17 football fields stacked 100 feet high). Over the 40-year history of the roast yards, researchers estimate that 10 million tonnes of sulphur dioxide were released from the ores.

See Volume 1 of the Sudbury Soils Study report for a more complete description of the history, environmental impacts of mining in the areas, and details of the re-greening efforts

Extensive logging and ore roasting activities dramatically changed the Sudbury landscape. The loss of vegetation resulted in extensive soil erosion that, combined with ongoing metal production facility emissions, prevented the natural regeneration of the forests that once covered the Sudbury bedrock. Early facility emissions consisted of larger and heavier particles that settled more rapidly and closer to the emission sources, compared with later emissions containing smaller and lighter particles that settled more slowly, drifting further from the production sites. The impact of historic facility emissions is therefore greater closer to the production sites. Areas immediately surrounding the smelter sites are known as the 'barrens' and continue to be devoid of self-sustaining plant communities. Inco Ltd. closed the smelter operation at Coniston in 1972. Vale Inco and Xstrata Nickel still operate smelting facilities in the towns of Copper Cliff and Falconbridge, respectively.

Ecosystems in the Greater Sudbury area have been recovering from historical impacts since the mid-1970s. Major reductions in mining and smelting emissions, wide-scale treatment of damaged lands (with lime and fertilizer), and vegetation planting initiatives aimed at 're-greening' the Sudbury landscape have all contributed to ecosystem recovery and transformation. See Volume I of the Sudbury Soils Study report for a more complete description of the history, environmental impacts of mining in the area, and details of the re-greening efforts.

3.1.2.1 The 2001 Soil Survey and Initial Study Area.

The three studies that comprised the 2001 Soil Survey are briefly described below.

The *regional soil survey* completed by Laurentian University focused on collecting soil samples to determine the extent of the area, or the *footprint*, that may have been affected by facility emissions. Remote and undisturbed areas were also sampled to help determine background levels of metals naturally occurring in the local soils. The results of this sampling program defined the boundaries of the study area. The sampling locations and initial study area are shown in Figure 3-2. The shaded area represents the boundaries of the City of Greater Sudbury.

The *urban soil survey* was conducted by the MOE and focused on sampling soils from schools, daycare centres, parks and beaches throughout the study area, as well as from 439 residential properties.

The *Falconbridge soil survey*, completed by Golder Associates Ltd., focused on collecting soil samples from the Town of Falconbridge and some surrounding municipal and crown lands.

Over 8,400 soil samples from 1,190 locations were collected throughout the study area during the 2001 Soil Survey. Each sample was analyzed for 20 different metals/chemicals. Further details of the 2001 Soil Survey are available in separate reports (SARA Group, 2008 - Volume I, Chapters 7, 9, and 10; CEM, 2004; MOE, 2001). A summary of the results of the combined data from the three soil studies that comprise the 2001 Soil Survey is provided in Table 3-1.

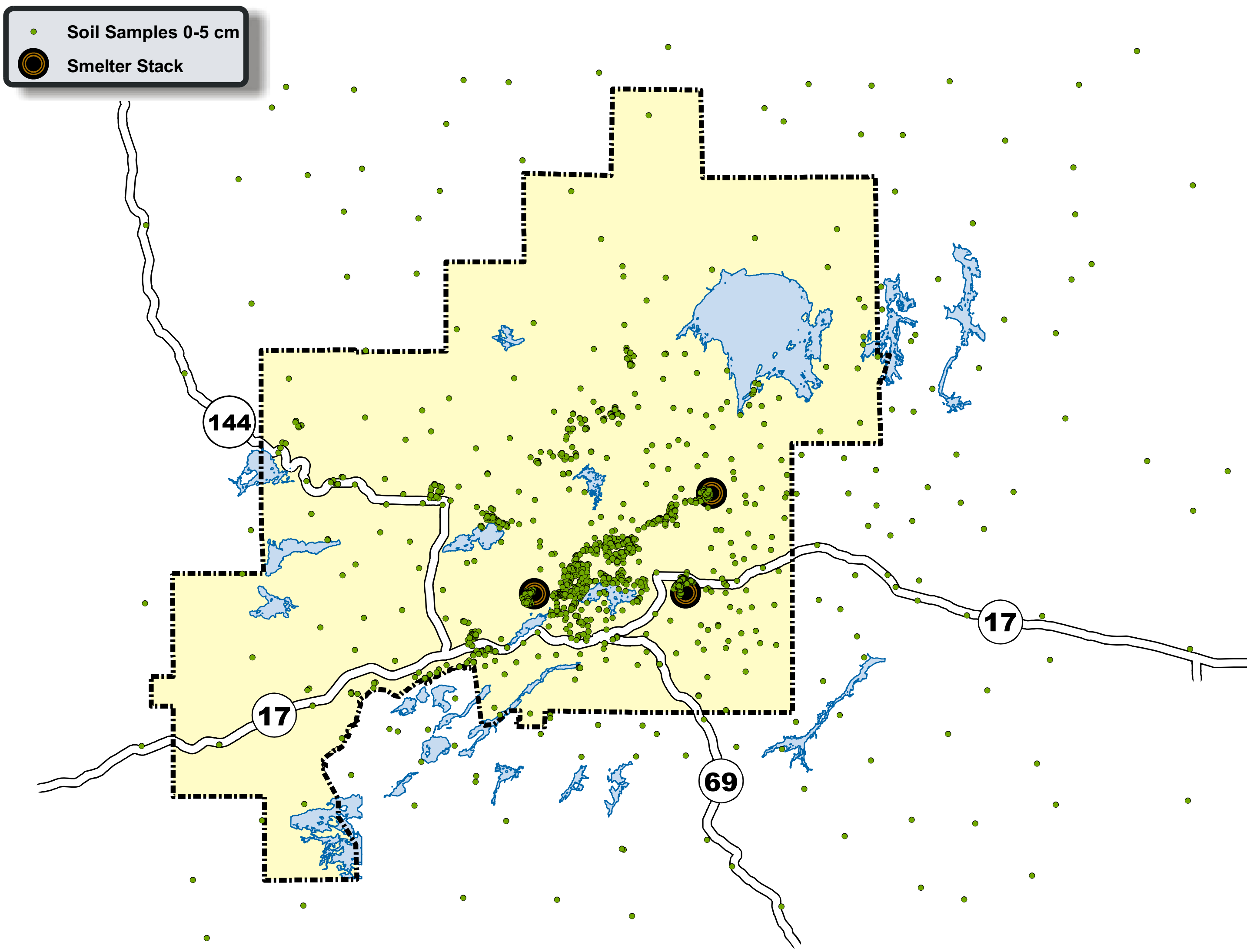


Figure 3-2: Soil sampling locations and initial study area for the ERA

Table 3-1: Summary of 2001 Soil Survey Results for 20 Elements[1]

Element	Concentration in Soil (mg/kg) [2]			
	Minimum	Average	Maximum	MOE Guideline [3]
Aluminum	2,100	9,366	32,000	NC [4]
Antimony	0.4	0.5	4.4	13
Arsenic	2.5	13.3	400	20
Barium	9.8	54	270	750
Beryllium	0.25	0.3	2	1.2
Cadmium	0.4	0.7	6.7	12
Calcium	470	5,783	250,000	NC
Chromium	9	34	150	750
Cobalt	2	15.4	190	40
Copper	5.2	299	5,600	150
Iron	4,400	16,087	49,000	NC
Lead	1	37	410	200
Magnesium	350	3,217	26,000	NC
Manganese	36	220	3,300	NC
Molybdenum	0.75	1.0	17	40
Nickel	11	286	3,700	150
Selenium	0.5	1.8	49	10
Strontium	5	35	340	NC
Vanadium	8	30	78	200
Zinc	1.25	45	250	600

[1] Soil samples taken from the 0-5 cm depth.
[2] mg/kg = milligrams per kilogram or parts per million
[3] MOEE (1997) Table A criteria for coarse textured soils in a residential/parkland landuse. Guidelines are set "to protect against adverse effects to human health, ecological health and the natural environment".
[4] NC = no criterion

The data show localized areas containing elevated levels of some metals in soil. These areas are generally centered on the City of Greater Sudbury in the vicinity of the three metal production centres of Copper Cliff, Coniston, and Falconbridge. Concentrations of the elements are generally higher in surface soils (0 to 5 cm) than deeper soil layers, indicating that atmospheric deposition from the production facilities is a source of metals to the soils. The detailed metal concentration data collected for the Soil Survey provided the basis for the risk assessment studies that followed.

3.1.3 Identifying Chemicals of Concern (COC)

Since not all of the chemicals detected in a given area will pose a risk to plants, animals, or the environment in general, it is not necessary to conduct a detailed risk assessment for each one. The process of selecting the chemicals that have the greatest potential risk is known as *screening*.

To identify the COC for the study area, metal concentrations in the soil were compared with soil quality guidelines published by the MOE in their *Guideline for Use at Contaminated Sites in Ontario* (MOEE, 1997). Soil quality guidelines are set by the MOE "to protect against adverse effects to human health, ecological health and the natural environment" (MOEE 1997). These risk-based soil quality guidelines apply to soils that are within a specific range of acidity, as measured by pH.

Specifically, the MOE guidelines only apply to soils that have a measured pH in the range of 5 to 9 (a lower pH value is associated with greater acidity). In cases where soil pH is outside of this range, the MOE's typical Ontario background soil concentrations are used for screening purposes. The soils in the Greater Sudbury area tend to be naturally acidic and, in many rural areas, have a pH that is below 5. In these cases, metal concentrations in soil were compared with typical Ontario background concentrations, rather than the risk-based guidelines.

Exceedance of the guidelines does not necessarily mean there is an actual risk to people, plants, or animals, and does not imply the need for remediation or risk management. Rather, exceedance of the soil quality guidelines identifies the need for further study in the form of a risk assessment.

Exceedance of the soil quality guidelines identifies the need for further study in the form of a risk assessment

Three criteria were established by the Technical Committee for COC screening:

1. The chemical must be present at levels higher than the MOE soil quality guideline (for soils with pH of 5-9) or typical Ontario background levels (for soils with pH <5);
2. The chemical must be present across the study area; and
3. The chemical must be associated with the mining companies' operations.

Screening of the data collected in the 2001 Soil Survey identified seven COC for the ERA: arsenic, cadmium, cobalt, copper, lead, nickel and selenium. The COC screening process is illustrated in Figure 3-3.

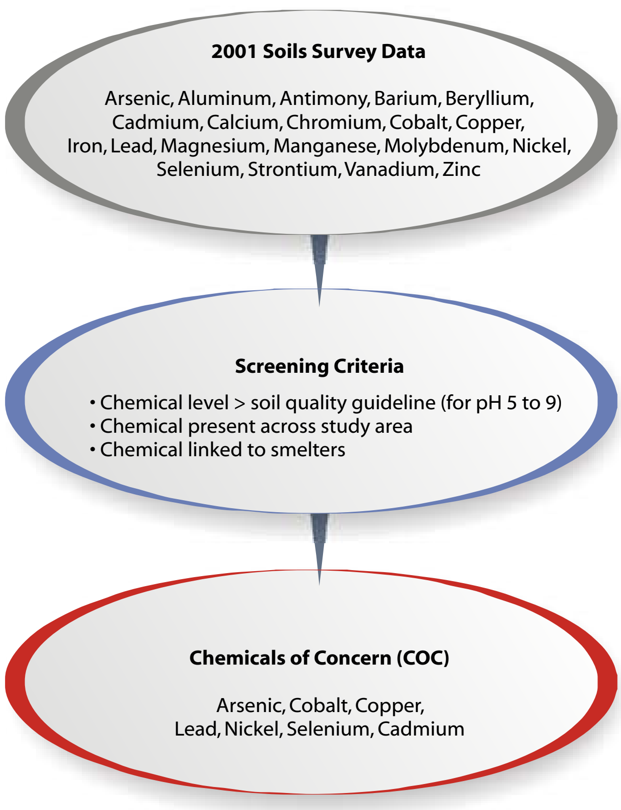


Figure 3-3: COC Selection Process

3.1.4 Selecting Valued Ecosystem Components (VECs)

It is not possible or necessary to assess risks to each and every plant and animal species present in a given study area. Therefore, a representative subset of plants and animals is usually selected for evaluation. These representative groups are known as *valued ecosystem components* (VECs). A VEC is an ecological species, population, or community that has social or economic importance to humans, is ecologically significant, and can be evaluated in an ERA. Selection of VECs is a critical step in the ERA process, as all relevant ecological groups in the study area should be represented by the VECs selected. The following criteria were used in selecting VECs for the Sudbury study area:

- Species is vulnerable, threatened, endangered, or of concern;
- Species is resident or reproduces in the Greater Sudbury area (thereby exposed to COC during a sensitive life stage);
- Species is ecologically significant (e.g., important producer, predator, or prey species);
- Species was identified by stakeholders as being important;
- Species has potential for high exposure to COC; and
- Species has socio-economic importance (such as moose), and therefore, a connection to human health (for example, is hunted and eaten by area residents).

VEC selection involved the identification of the species of plants, mammals, birds, reptiles, and amphibians present in the study area. Species lists were completed during the compilation of background information described in Section 3.1.1. Input from the community and special interest groups was obtained through a series of *Have Your Say* public workshops held in the spring of 2003.

After the initial selection, criteria were applied to the species lists and a total of 12 VECs were identified for the terrestrial ERA. The VECs, their feeding group/trophic levels, and the main reasons they were identified are briefly described in the following section:

1. **Plant communities (primary producers)**

   Plant communities are critical ecological components because of their role as primary producers (converting energy from sunlight into food) and in carbon cycling. They also decrease soil erosion, provide habitat to wildlife, and provide human enjoyment. These functions are served not by a single plant species, but by the community as a whole.

2. **Blueberry (primary producers)**

   Blueberry has social and economic value, is linked to human health in the Greater Sudbury area, and was identified by stakeholders at *Have Your Say Workshops* as a species of special interest. In addition, blueberry prefers well-drained acidic soils and full sunlight. Therefore, the re-greening efforts (increasing soil pH and planting trees and shrubs) taking place in the region could adversely affect blueberry habitat.

3. **Soil invertebrate communities (primary consumers and decomposers)**

   Although they are not considered by average citizens to have any social value, soil invertebrates such as earthworms serve important ecological functions such as soil formation, organic matter breakdown, nutrient cycling, and provision of food for wildlife.

4. Northern short-tailed shrew (invertebrate-eating small mammals; secondary consumers)

Northern short-tailed shrews eat soil invertebrates and are exposed to COC because of their close association with the soil, their small home range, and high food intake rate relative to their body weight. Shrews are also food for wildlife predators.


Photo credit: John White

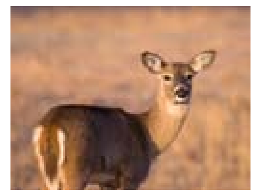
5. Meadow vole (herbivorous small mammals; primary consumers)

Meadow voles are herbivorous, which means that they eat plant material. They are exposured to COC because of their close association with the soil, their small home range, and high food intake rate relative to their body weight. Voles also provide food for wildlife.


Photo credit: John White

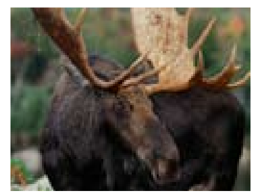
6. White-tailed deer (herbivorous large mammals, primary consumers)

Deer forage on plants in and around farmland and suburban environments. Deer are hunted in the study area and therefore have social and economic value and a link to human health. Stakeholders identified white-tailed deer as an important species.



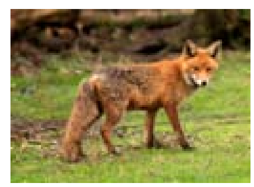
7. Moose (herbivorous large mammals, primary consumers)

Moose forage on plants in wetland areas. Like deer, moose are hunted in the study area, have social and economic value, are linked to human health, and were identified by stakeholders as an important species.



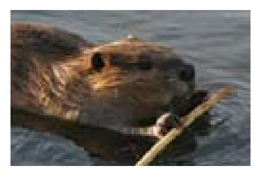
8. Red fox (omnivorous mammals, primary consumers through top predators)

Foxes are omnivorous, meaning that they will eat both plant and animal material. Fox will generally eat whatever is available, including fruit and vegetation in the summer, and birds and mammals in winter. They will also eat invertebrates such as grasshoppers, beetles, and crayfish.



9. American beaver (herbivorous mammals linked to the aquatic environment, primary consumers)

Beavers feed on plant material and live and breed in lakes throughout the study area. Therefore, beavers may be exposed to the COC in the aquatic environment.

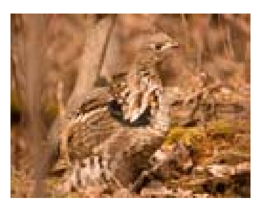


10. American robin (invertebrate-eating birds, secondary consumers)

Robins are exposed to COC because they feed on worms and other soil and litter invertebrates that are closely associated with the soil. Stakeholders identified the American robin as an important species.

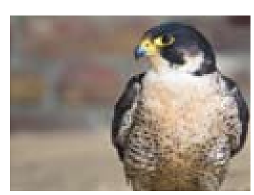
11. Ruffed grouse (herbivorous birds, primary consumers)

Ruffed grouse are ground-dwelling birds that feed on seeds, buds, berries, and some insects and, therefore, have the potential for high exposures to the COC. Ruffed grouse are hunted in the study area and, therefore, have social and economic value and are a link to human health.



12. Peregrine falcon (carnivorous birds, top predators)

The peregrine falcon is a threatened species that has been re-introduced to the study area. They are carnivorous, meaning that they eat the meat of other animals. Stakeholders identified the peregrine falcon as a species of concern.



3.1.5 Exposure Pathways

There are three primary routes by which wildlife may come in contact with COC: ingestion (swallowing), inhalation (breathing), and dermal (skin) contact. For the purposes of risk assessment, dermal exposure is not considered to be significant for birds and mammals. This is because the feathers on birds and fur on mammals limit the contact of chemicals with skin. In addition, metals are not likely to be absorbed through the skin, even with direct contact. Inhalation of metals is also considered to be an insignificant pathway for mammals and birds. This is because metals do not evaporate in air and fine dust particles do not tend to be re-suspended in air in the preferred habitats (where vegetation cover is present) of most wildlife. Therefore, the only exposure route considered for wildlife VECs in the ERA was ingestion. This approach is consistent with federal and provincial guidance for ERA, both of which acknowledge ingestion as the major pathway of exposure for wildlife.

COC can be taken up by plants via either their roots or shoots. Roots may be directly exposed to COC in soil and in soil water. Shoots may be directly exposed to COC in airborne particles or dust deposited on leaves and/or stems. The exposure pathways assessed in the ERA are shown in Figure 3-4.

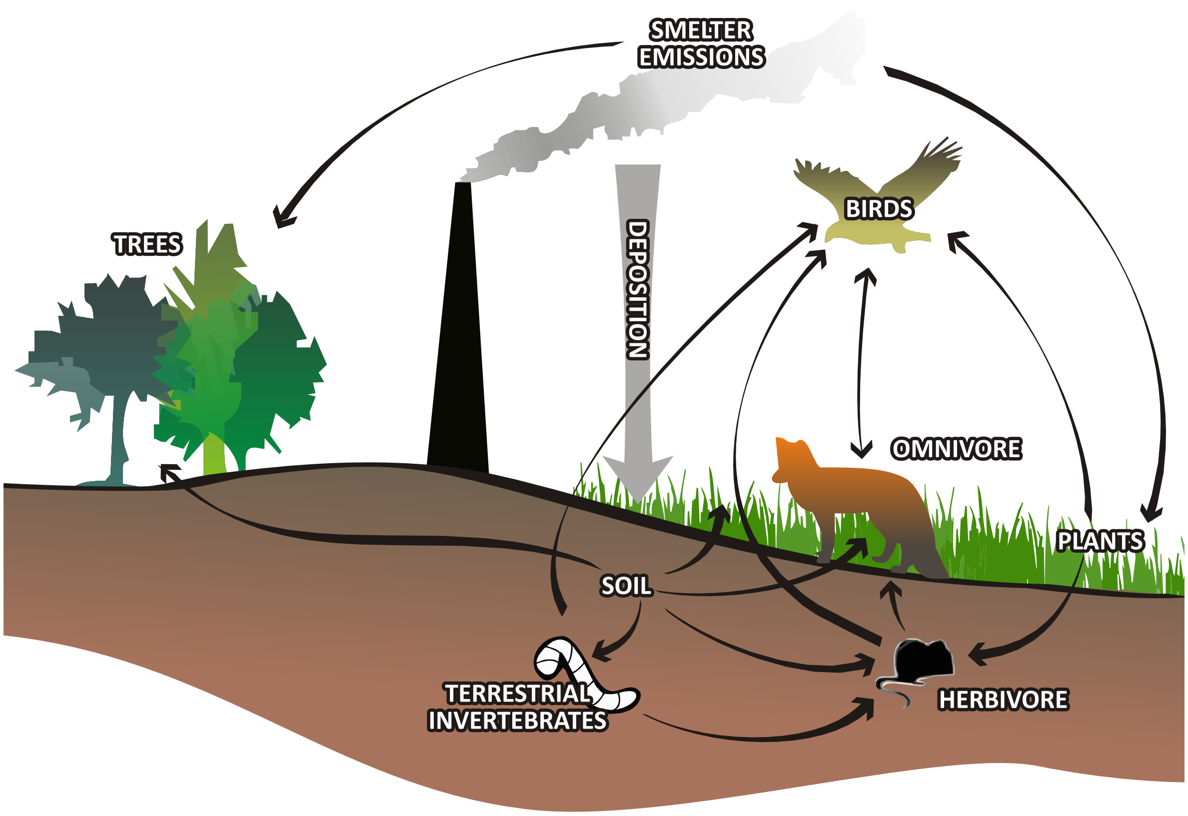


Figure 3-4: Exposure Pathways Assessed in the ERA

3.1.6 Information Gaps

As a result of the 2001 Soil Survey, the SARA Group had access to extensive data for COC in soil within the study area. The review of background data (see Section 3.1.1) identified additional information on the ecological effects of metals in the Sudbury area. However, for the wildlife assessment, information was lacking for COC levels in wildlife food items. In addition, the information required for the weight-of-evidence approach for the plant community assessment was not available. These were identified as information gaps that needed to be filled in order to make the most accurate risk predictions possible. For the wildlife assessment, the SARA Group recommended that more information be collected on levels of COC in:

- Soil invertebrates;
- Plants; and
- Local fish.

For the plant community assessment, the SARA group required detailed information for study sites on:

- Soil physical and chemical characteristics;
- Soil toxicity;
- Detailed ecological plant community structure and condition; and
- The general functioning of the soil invertebrate and microbial communities.

The process of filling these information gaps is described in the next section.

3.2 Phase Two: Sudbury-specific Sampling Methods

Several sampling programs were undertaken from 2003 through 2005 to gather the Sudbury-specific information needed to complete the ERA. The collection of this information was necessary to ensure that the final risk predictions were as accurate as possible. The following sections briefly describe the sampling and survey programs that were carried out for the ERA.

Sampling programs were undertaken from 2003 to 2005 to gather the Sudbury-specific information needed to complete the ERA

3.2.1 Vegetation Assessment

3.2.1.1 Vegetation Study Sites

Study sites were chosen at increasing distances from each of the Copper Cliff, Coniston, and Falconbridge smelters (See Figure 3-5). Eighteen test or exposure sites were selected which had elevated copper and nickel concentrations and a soil pH between 4 and 5.

In addition to the 18 test sites, three *reference sites* were chosen to represent areas that had not been impacted by COC emissions from the smelters. Metal concentrations in soils at the reference sites are representative of natural local background levels. Reference sites were chosen to have similar conditions to the test sites, except for soil metal concentrations, and could therefore be used for comparison purposes.

One additional site near Coniston was chosen as an example of a historically limed site for comparison. The site (CON-07) had been limed and seeded in the early 1980's. The vegetation community was visibly much more developed than the adjacent site (CON-08) which had never been treated or limed. Thus, a total of 22 study sites – 18 test sites, three reference sites, and one historically limed site – were selected for the Greater Sudbury area plant community assessment.

3.2.1.2 Physical and Chemical Soil Characterization

During the summer and fall of 2004, the SARA Group collected soil from each of the 22 field sites to evaluate physical and chemical characteristics. The information was used to characterize the soils with respect to soil type, amount of organic matter, fertility, and soil chemistry (including pH, metals, etc.). These factors all determine the suitability of the soil for supporting plant growth. This information was used in the weight-of-evidence approach for evaluating impacts to plant communities in the study area.

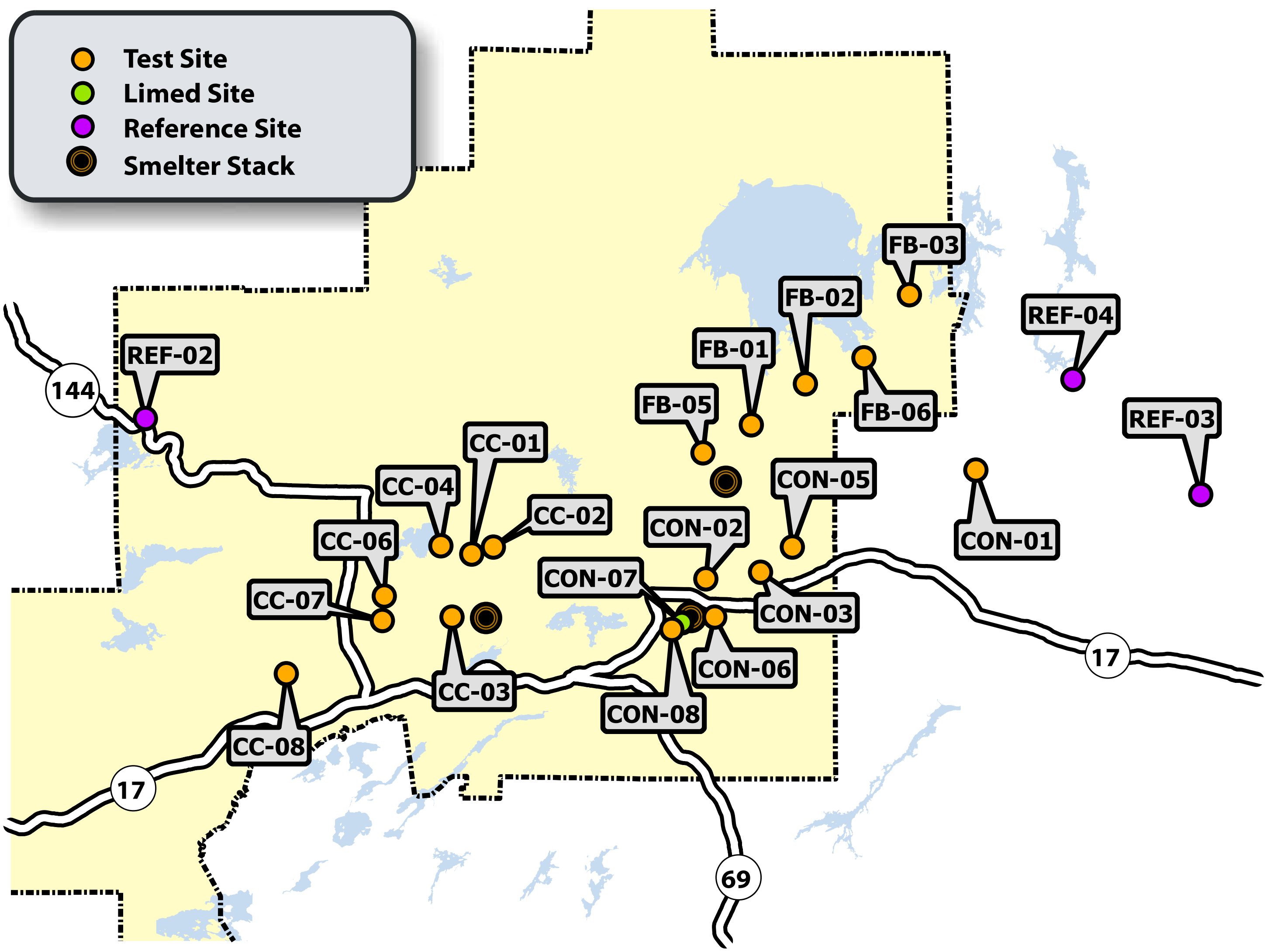


Figure 3-5: ERA Study Site Locations

3.2.1.3 Soil Toxicity Testing

Additional bulk soil samples collected from the 22 sites were used to perform laboratory toxicity tests with plants and soil invertebrates. The plants and invertebrates tested were white spruce, northern wheatgrass, red clover, goldenrod, and earthworms. Information from the toxicity studies was used in the weight-of-evidence approach for evaluating impacts to plant communities and soil invertebrates in the study area.

3.2.1.4 Plant Community Survey

During the summer of 2004, the SARA Group conducted a detailed plant community survey to characterize the vegetation and physical conditions at each of the 22 field sites. The information collected at each site included a thorough inventory of plant species present, percentage of ground covered by vegetation, the condition of trees and shrubs, the amount of woody debris on the site, and the ecological site classification (which is based on terrain, soil type, and dominant plant species). This information was used in the weight-of-evidence approach for evaluating impacts to plant communities in the study area.

3.2.1.5 Litter Decomposition Study

An important function performed by soil invertebrate and microbial communities is the breakdown, or *decomposition*, of organic matter such as fallen leaves. Litter decomposition is similar to composting and is critical for maintaining soil fertility and productivity. At each of the 22 plant assessment sites, the SARA Group evaluated the rate of litter decomposition and compared decomposition rates between test and reference sites.

3.2.2 Terrestrial Wildlife Assessment

3.2.2.1 Wildlife Study Area Zones

Seven discrete areas were considered for the wildlife portion of the ERA. First, the study area was subdivided into three broad zones: Zones 1, 2, and 3, as shown in Figure 3-6. The boundaries of the zones were defined on the basis of COC concentrations in soil, and terrain. Zone 1 is located generally upwind of the smelters and has low soil metal concentrations. Zone 2 includes the area between the three smelters and contains the highest soil metal concentrations. Zone 3 is located to the south and southeast, of the smelters and has lower metal levels.

In addition to the three wildlife zones, four of the communities of interest (Coniston, Copper Cliff, Falconbridge, and Sudbury Centre) identified in the human health risk assessment (HHRA) were included in the ERA. These four communities were included to account for wildlife VECs that live or spend portions of their time in urban environments (ie. Robins).

3.2.2.2 Wildlife Dietary Field Survey

In 2003 soil, vegetation, and terrestrial invertebrates were collected to obtain information on metal concentrations in wildlife food sources and to evaluate the relationship between metal concentrations in soil and dietary items. This was accomplished through simultaneous sampling of soil, grasses (roots and shoots), and grasshoppers from 17 locations in the study area. The relationship between soil metal concentrations and metal concentrations in plants and invertebrates was used to estimate metal concentrations in plants and invertebrates for the whole study area over various soil metal concentrations. These results were used in calculating wildlife exposures to the COC.

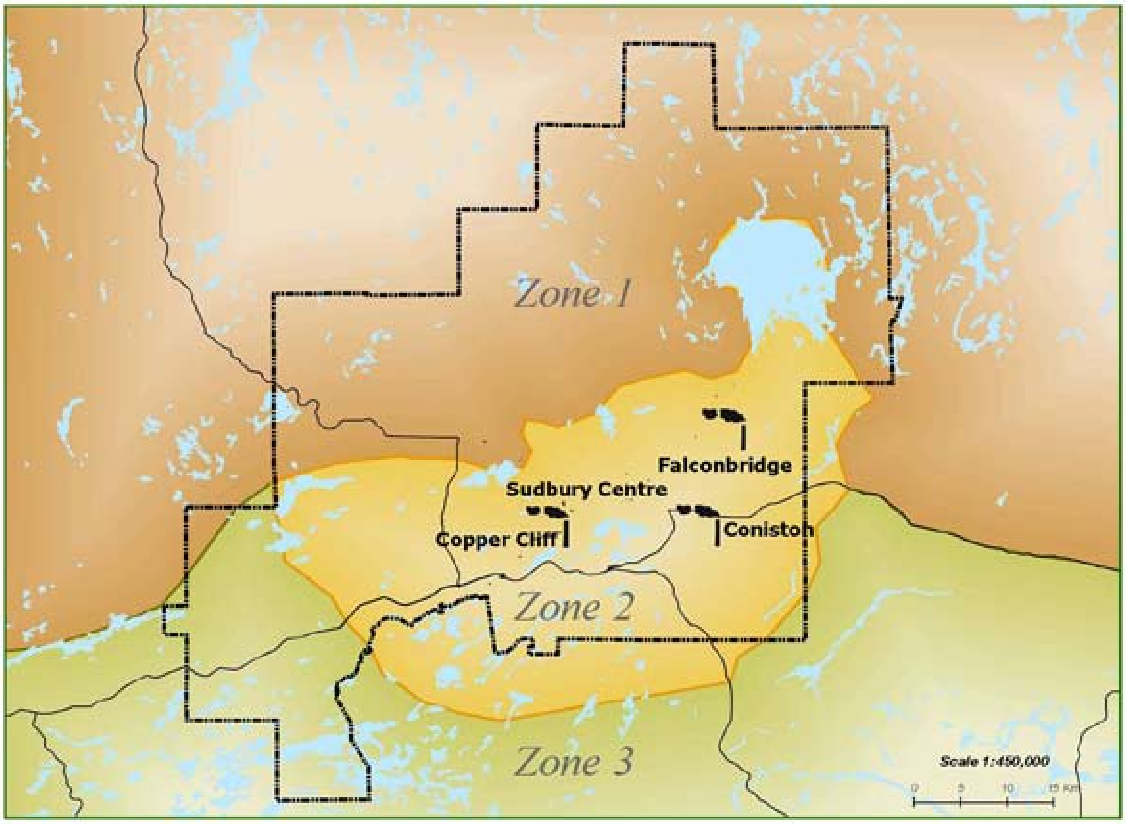


Figure 3-6: Wildlife Study Area Zones

3.2.2.3 Local Fish Survey

Through the summer and fall of 2003, the Co-operative Freshwater Ecology Unit of Laurentian University was contracted to collect fish from lakes in the Greater Sudbury area. Fish were collected from eight lakes – Ashigami, Crooked, Long, Massey, McFarlane, Ramsey, Vermillion, and Whitson. Fish tissues were analyzed for metals and the data used in calculating COC exposure to wildlife VECs that consume fish.

Tissues of walleye and large (> 15 cm) yellow perch were analyzed for the concentration of COC and those data were used in the HHRA. Tissues from smaller perch (< 15 cm), lake herring and spottail shiner were also collected and analyzed for COC levels. These data were used in the ERA to help determine exposure of fish-eating mammals and birds to metal concentrations in forage fish species. The information also provided baseline data on metal uptake in fish between lakes and insight into the factors affecting metal uptake and bioavailabililty.

3.3 Phase Three: Detailed Assessment Results

The third and final phase of the ERA involved combining all of the information collected in the previous two phases to predict risks to study area plants and animals from COC exposure. The following sections detail the process and results for plant communities (Section 3.3.1) and for wildlife (Section 3.3.2) in the study area.

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

The plant community was assessed using a weight-of-evidence approach involving four lines of evidence (LOE). Each LOE was evaluated separately, and then the quality and quantity of the data from each line was taken into consideration as the LOE were integrated to produce a final result.

The four lines of evidence that were used in the plant community assessment are:

- Soil characterization;
- Toxicity testing;
- Plant community survey; and,
- Decomposition assessment.

The results of the vegetation assessment are site rankings that describe the level of impact observed at the site. Sites were given one of three possible ranks: green (low to not impacted), yellow (moderately impacted) or red (severely impacted) which denoted the level of impact relative to the reference sites. Figure 3-7 summarizes the approach used to obtain the ranks.

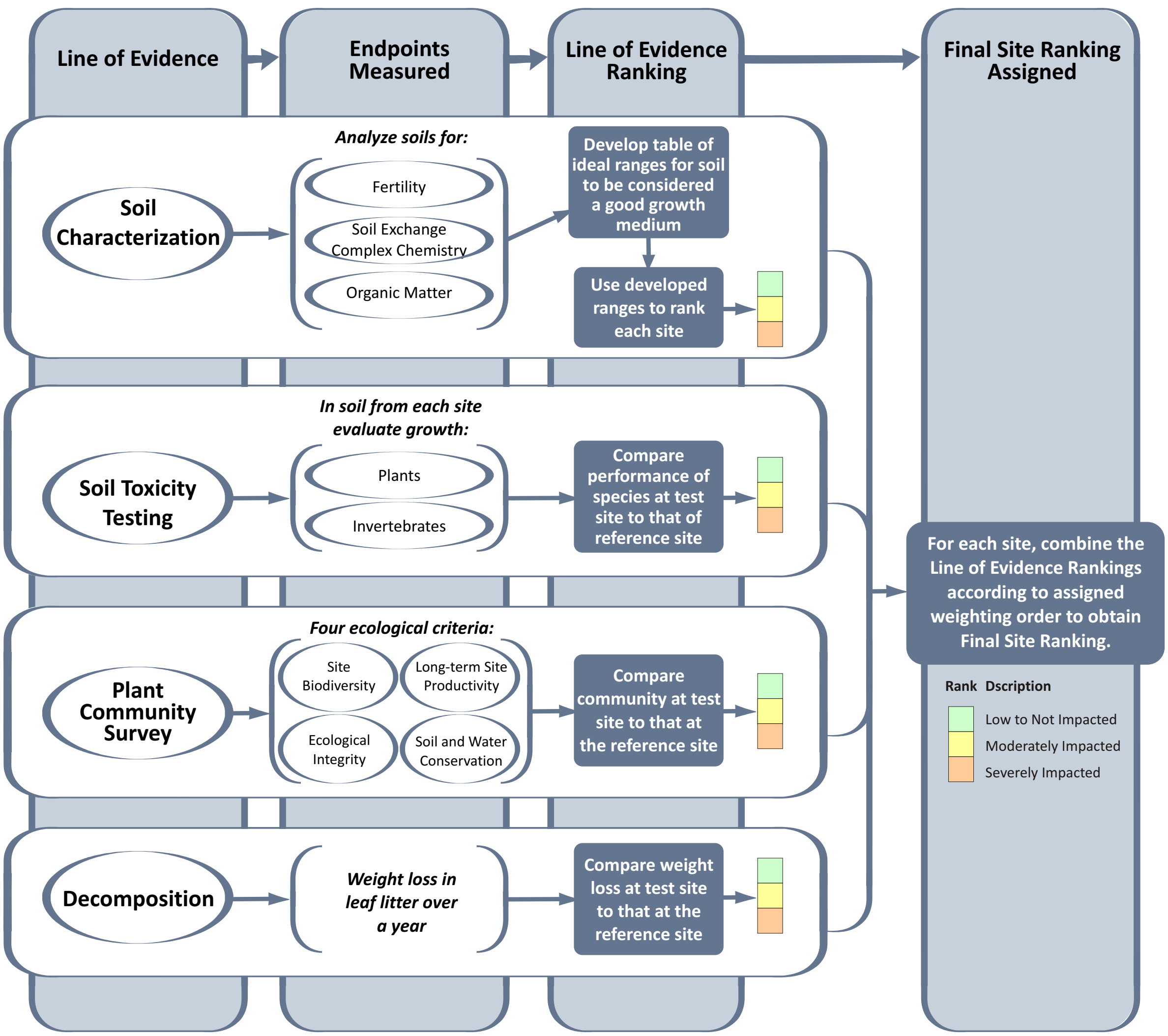


Figure 3-7: Summary of the Approach Used to Determine the Ranking of Sites during the Objective 1 Studies

3.3.1.1 Soil Characterization

The numerous surveys, sampling programs, and studies conducted for this ERA provided a wealth of detailed Sudbury-specific information. Incorporation of these data into the ERA significantly increased the accuracy of, and confidence in, risk predictions for study area plants and animals.

For the soil characterization LOE, the soil quality data collected for each of the test sites were compared to the equivalent data for the reference sites. Based on this comparison, each test site was assigned an impact rank (green, yellow or red). Concentrations of COC were not evaluated in the soil characterization LOE.

Soils at two test sites (FB-02 and FB-06) were considered to be a good medium for plant growth, and these sites were assigned a green soil LOE rank. Four sites had soils that were unlikely to support healthy plant growth, and were considered severely impacted. Soils at the remaining 12 sites had at least some characteristics that were limiting to plant growth, and these sites were assigned a yellow soil LOE rank. Specific issues noted in impacted soils included eroded top soil layers, poor soil fertility, poor nutrient balance, limited capacity to retain water and burnt soil layers (due to historical forest fires).

Figure 3-8 illustrates the soil profile at two different sites. The soil profile on the left (FB-02) was considered to have low or no impact. In contrast, the soil profile on the right (CON-08) is considered severely impacted with little to no organic layer that is necessary to support plant growth.

a)  b) 

Figure 3-8: Soil profiles at low to not impacted (a), and severely impacted sites (b).

3.3.1.2 Soil Toxicity Testing

The results of toxicity tests conducted with plant and earthworm species in soil from the test sites were compared to the equivalent data for the reference sites. Various parameters were measured to evaluate the impact of the soil on the test organisms. In plants, shoot length, root length, shoot weight and root weight were measured. In earthworms, the body weight per individual and number of offspring were measured.

Figure 3-9 is a photograph showing that root and shoot growth of Northern wheat grass grown in soil from one of the test sites (plant on the right) are severely impaired compared to grass grown in soil from a reference site (plants on left). This example illustrates that root length of northern wheatgrass was strongly impacted in soil from the test site (CON-03) compared with wheatgrass grown in soils from a reference site (REF-02).

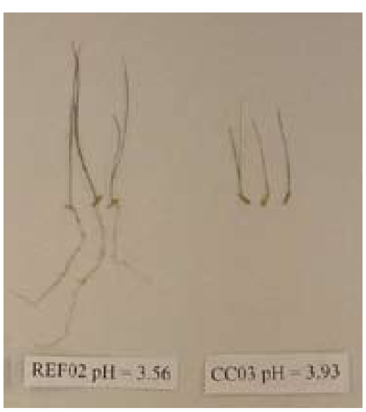


Figure 3-9: Results of toxicity test conducted in reference and test site soils

A series of toxicity tests were also conducted to examine the effect of adding lime to the test soils on response of the test organisms. The addition of lime raised soil pH and reduced metal bioavailability, which enhanced growth of red clover and northern wheatgrass. The effect of pH amendment seemed to be more pronounced in soils collected closer to the smelters.

Soils from the different sites affected plant growth differently. Adverse effects were not clearly related to metal concentrations in the soil, although higher metal levels tended to show a greater impact. When soil pH was raised in the laboratory with the addition of lime, the effect of metals was reduced but not eliminated altogether.

3.3.1.3 Plant Community Survey

The plant community surveys collected data that were grouped according to four major ecological criteria: site biodiversity, ecological integrity, long-term site productivity, and soil and water conservation. The indicator results for the test sites were compared to those from the reference sites. Based on this comparison, each test site was assigned an impact rank (green, yellow or red) for the plant community LOE.

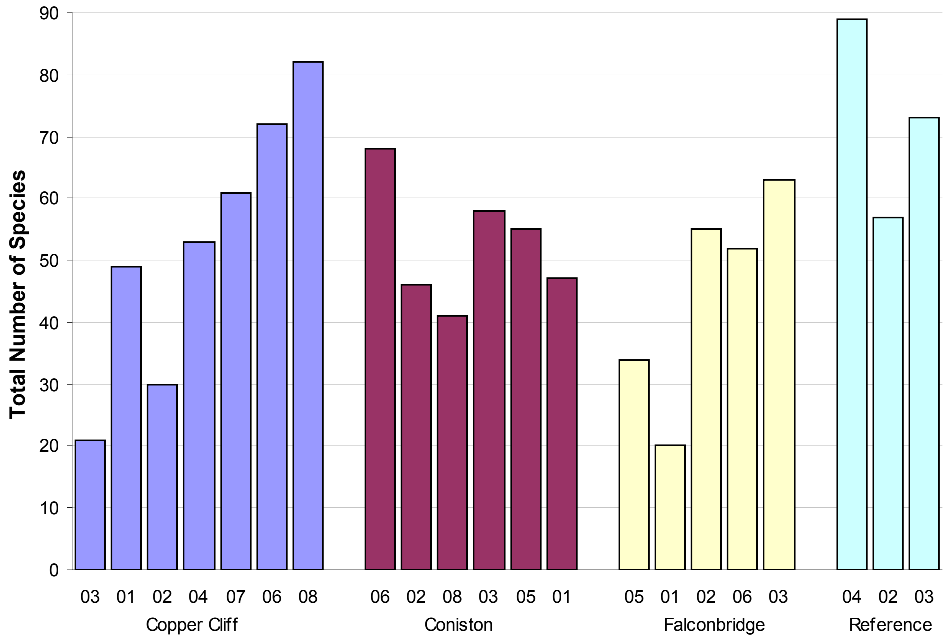
Figure 3-10 compares plant communities at a healthy site (left photo) with that of an impacted site (right photo). The plant community at the healthy site has 75 different species present compared with only 21 species at the impacted site.

a)  b) 

Figure 3-10: Plant communities with healthy (a) and impacted (b) species richness.

Species richness is a count of the number of plant species present at the site and is one of the biodiversity indicators. In general, a greater number of plant species means a healthier ecosystem. Species richness was highly variable across the test sites, ranging from 21 to 86 species per site. Species richness tended to be lower closer to the smelters, and increase with distance away from the smelter particularly for the Copper Cliff and Falconbridge transects (Figure 3-11). The field sites are presented in Figure 3-11 by site number in order of increasing distance from the smelter (left to right).

Figure 3-11: Summary of the Total Number of Plant Species found at each of the Field Sites. (Numbers are site locations)



3.3.1.4 Litter Decomposition Study

Litter decomposition tests were conducted over the course of a full year. Decomposition was measured as the weight loss from birch leaves placed in net bags on the ground. (Figure 3-12).

Figure 3-12: Litter bags for decomposition assessment: a) birch leaves in nylon mesh litter bags; and b) litter bags on forest surface.

Litter decomposition is an important ecological function of forest ecosystems that returns nutrients back into the soil, where they become available for plant health and growth. The results of the litter decomposition tests show that litter decomposition was highly variable, even at the reference sites. In general, leaf decomposition was somewhat slower (impacted) at the test sites relative to the reference sites.

3.3.1.5 COC Levels in Soil

The concentrations of COC were measured at each of the 18 test sites, 1 limed site and 3 reference areas. The data are provided in Table 3-2 below. Metal concentrations at the reference sites were notably lower than at the test sites.

Metal concentrations were generally higher closer to the smelters unless the site was eroded. The concentrations decreased with increasing distance away from the smelters. This trend is illustrated

Table 3-2: Total COC Concentrations (mg/kg) and pH in Soil Cores

Site	pH ($CaCl_2$)	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Selenium
CC-01	3.8	46	1.3	26.7	960	70	700	6.2
CC-02	4	44	0.7	35.8	611	53	511	4.7
CC-03	3.8	72	0.6	41.5	1,000	99.5	1,100	10.5
CC-04	3.8	29	0.9	21.8	441	49	386	2.7
CC-06	3.9	15.5	0.4	9.9	144	17.2	103	1.5
CC-07	3.6	26	0.5	14	303	38	200	2.4
CC-08	3.6	9.6	0.3	7.8	97	29	77.5	1.4
CON-01	3.4	9.5	0.3	5.5	76	28	77	0.9
CON-02	3.8	12.7	0.2	9.0	195	15	138	1.0
CON-03	3.6	28	0.2	11.5	191	35	112	0.9
CON-05	3.6	11.4	0.4	11	118	15.1	92.9	0.7
CON-06	4	2.1	0.1	9.4	48.7	4.6	70.2	0.3
CON-07[a]	6.5	7.2	0.2	10.2	240	11	255	1.1
CON-08	4	5.2	0.2	10.9	107	9.1	132	0.9
FB-01	3.2	117	1	23.3	655	162	422	5.6
FB-02	4.1	45	1.2	48.4	320	83	325	3.4
FB-03	3.6	10.9	0.3	4.8	87	28	78	1.1
FB-05	3.9	41	0.3	10.3	215	33	140	1.2
FB-06	3.5	26	0.6	11.7	200	61	179	1.7
REF-02	3.6	4.6	0.3	4.9	42	33	46	1
REF-03	4.1	2.7	0.2	11.5	18.7	14	40	0.48
REF-04	3.6	5.9	0.2	5.4	39.3	18.6	38.9	0.75

[a] CON-07 is the historically limed and re-greened site. The pH is consequently much higher at CON-07 than at the other test sites.

for copper and nickel at the field sites as shown in Figure 3-13. Metal levels were generally lower at the Coniston sites, likely as a result of considerable soil erosion in this area.

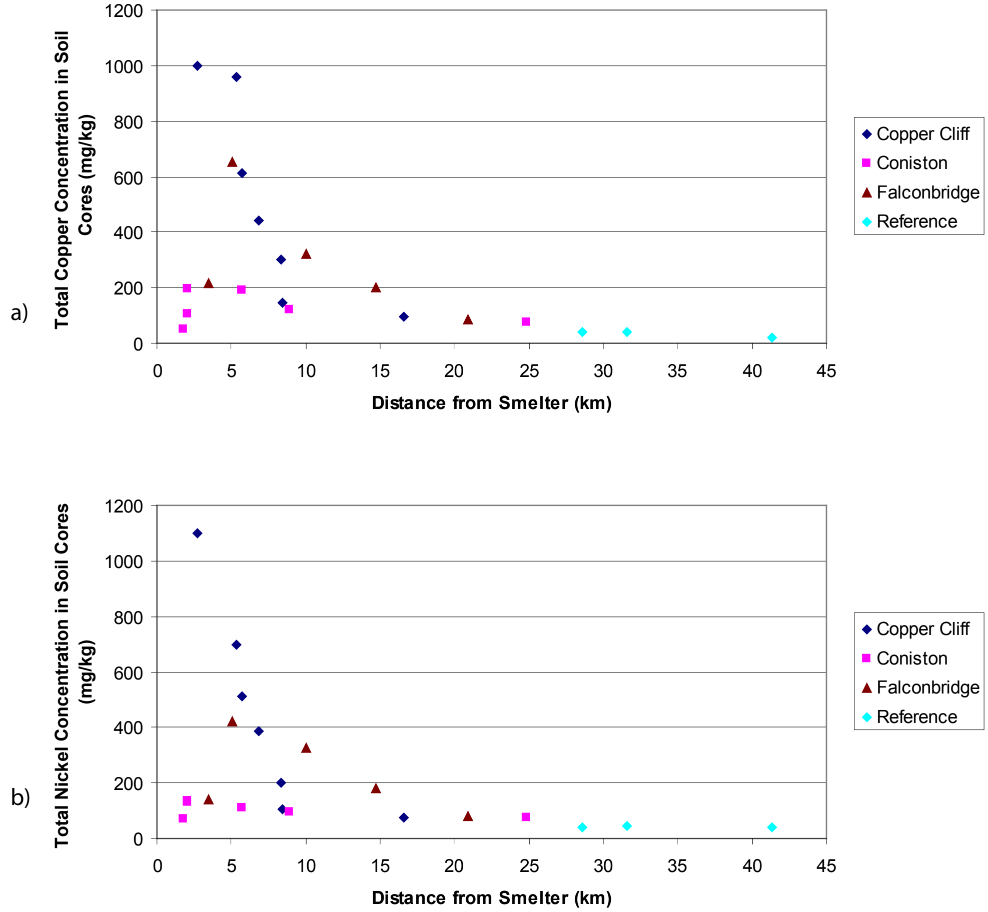


Figure 3-13: Relationship between a) Total Copper and b) Total Nickel Concentrations in Soil and Distance from the Nearest Smelter.

3.3.1.6 Plant Community Results (Objective #1)

Test sites located closer to the smelter stacks tended to be more highly impacted

The interim site rankings from each of the four lines of evidence were integrated to arrive at a final site ranking. Each final site ranking was achieved by giving more weight, or importance, to the most ecologically relevant lines of evidence. The lines of evidence were considered in the following order of importance:

- Plant community;
- Toxicity testing;
- Soil characterization; and
- Decomposition.

The final ranks for the 18 test sites are summarized in Table 3-3. All of the test sites were considered to be moderately to severely impacted compared to reference sites. The test sites located closer to the smelter stacks tended to be more highly impacted.

Table 3-3: Impact Ranking for Test Sites for Each LOE and Final Site Rank

	Interim				Final Rank
	Plant Community Assessment	Toxicity Testing	Soil Characterization	Decomposition Assessment	
CC-01	Red	Red	Yellow	Red	Red
CC-02	Red	Red	Red	Red	Red
CC-03[a]	Red	Red	Red	N/A	Red
CC-04	Red	Red	Yellow	Green	Red
CC-06	Yellow	Yellow / Red	Yellow	Red	Yellow
CC-07	Red	Red	Yellow	Red	Red
CC-08	Red	Yellow	Yellow	Yellow	Yellow
CON-01	Yellow	Yellow	Yellow	Red	Yellow
CON-02	Red	Red	Red	Red	Red
CON-03	Yellow	Yellow / Red	Yellow	Red	Yellow
CON-05[a]	Red	Yellow / Red	Yellow	N/A	Red
CON-06	Red	Red	Yellow	Red	Red
CON-07[b]	Yellow	Yellow	Yellow	Red	N/A
CON-08	Red	Red	Red	Red	Red
FB-01	Red	Red	Yellow	Red	Red
FB-02	Green	Yellow / Red	Green	Red	Yellow
FB-03	Yellow	Yellow / Red	Yellow	Yellow	Yellow
FB-05	Yellow	Green / Yellow	Yellow	Green	Yellow
FB-06	Yellow	Green	Green	Red	Yellow

[a] Decomposition could not be assessed at CC-03 and CON-05 because access to these sites was restricted. The final rankings for these sites were assigned based on the other three lines of evidence.
[b] CON-07 is the historically limed and re-greened site. A final rank was not assigned to this site.

Statistical analyses of the data from the four lines of evidence were used to try to determine which of the factors present in the Greater Sudbury area are contributing to the observed impacts on the plant community. These analyses found that the levels of COC in site soil were related to the toxicity of the soils to plants and also to the plant community at the test sites.

Thus, COC levels in the soil are continuing to impact local vegetation and inhibit the recovery of natural self-sustaining plant communities. However, other factors were also identified as contributing to the toxicity of the test site soils and to the observed effects on plant communities. These factors are:

- Soil fertility;
- Low soil pH, or soil acidity;
- Forest fires;
- Soil erosion; and
- Low organic matter content in soil.

Since these factors are often correlated to one another, it is not possible to completely separate their relative influence on the plant community.

3.3.1.7 Comparison of Limed (CON-07) vs. Not Limed (CON-08) sites

The natural re-establishment of vegetation in the Sudbury area has been hindered by metals and acidic soil conditions as well as numerous other factors. The term "re-greening" describes the reclamation activities that have re-established forest and vegetation cover on industrially damaged land in the Sudbury region. Studies in the 1970s indicated that liming of the soil raised pH sufficiently to reduce soil toxicity, facilitating growth and survival of grasses on many test sites throughout the city. Between 1978 and 1983 lime, fertilizer and seed were applied on sites selected along the major arteries into Sudbury.

Figure 3-14: Photograph of the Historically Limed Site (CON-07 on right) compared to the non-treated area (CON-08 on left)

Data collected from the four LOE indicate that re-greening activities employed within the Sudbury region are working

During the ERA, two sites were chosen in close proximity to each other. One had been limed and re-planted as part of the regreening efforts (CON-07) and the other (CON-08 100 metres away) had not been treated. Identical information was collected at both sites while the limed site (CON-07) is quite different from the 18 test sites, its existence and proximity to CON-08 provide a unique opportunity to evaluate the efficacy of historic liming and replanting. CON-07 was included in the assessment reports but was not considered in the final ranking of the sites.

The plant community at CON-07 and CON-08, (Figure 3-14) although in close proximity to each other, were in fact significantly different. The limed site (CON-07) showed evidence of being a site in transition, while 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, providing a viable seed source, and increasing the soil pH thereby decreasing metal availability. 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 working.

By comparison without the addition of lime, seeding or strategic planting, CON-08 has retained its barren appearance and its status as a severely impacted site. Soil erosion, lack of organic matter 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 bioavailability of metals in the soil.

3.3.2 Terrestrial Wildlife Assessment (Objectives #2 & 3)

The three components of the detailed assessment for wildlife – exposure assessment, hazard assessment, and risk characterization - are described in the following sections. Results of the wildlife assessment of the ERA are presented in Section 3.3.2.4.

3.3.2.1 Exposure Assessment

The wildlife exposure assessment uses mathematical equations, or *models*, to estimate the total exposure of each VEC to each COC. The exposure models combine all of the available information about VECs and COC levels. The use of Sudbury-specific information is critical at this stage to make the most accurate exposure estimates possible.

The physical and behavioural characteristics (such as body weight, dietary habits, food and water consumption rates, home range area, habitat preferences, *etc.*) of the different wildlife VECs directly affect their exposures to the COC. The range of values for most characteristics of each VEC is available in the wildlife literature and in material published by government agencies, such as the U.S. EPA (United States Environmental Protection Agency)

Exposure models were used to combine this information with the Sudbury-specific data on COC levels in soil, water, sediment and dietary items, to estimate exposures for each VEC in each study zone and/or Community of Interest. Since ingestion is the primary exposure route of concern for wildlife (see Section 3.1.5), this was the only exposure route considered in the ERA.

There are two general approaches to modelling exposure. The first and most widely used is *deterministic* exposure modelling. Deterministic modelling uses single values to represent VEC characteristics (for example, body weight of moose = 325 kilograms) and COC levels (for example, 10 milligrams of arsenic per kilogram of soil) when estimating exposures. The result is a single numerical estimate of exposure.

The second approach, known as *probabilistic* exposure modelling, makes use of the full range of data available for each VEC characteristic and COC level in a particular exposure source (soil, water, sediment, and food items). This approach allows for the calculation of a range of exposures that may be experienced by a given population and accounts for the natural variation in wildlife populations and in COC levels. The probabilistic method allows scientists to use all of the data and information collected (rather than single point estimates) to fully characterize exposure for a VEC population in a given area. Exposure estimates generated by the probabilistic approach are more informative, as scientists can determine the probability that members of a population will experience a particular level of exposure to a COC in a given area. This also allows them to determine the probability that a population is likely to be at risk from specific levels of exposure (see Section 3.3.2.3 for further details).

The toxicity of a chemical depends on many factors, including the properties of the chemical, the amount of the chemical taken in, and the duration of the exposure

3.3.2.2 Hazard Assessment

The term 'toxicity' refers to the ability of a chemical to cause temporary or permanent adverse effects to any part of the body. The toxicity of a chemical depends on many factors, including the properties of the chemical, the amount of the chemical taken in, and the duration of the exposure. For many chemicals, there is an upper exposure limit, at or below which adverse effects are not expected to occur. These limits in ERA are usually reported as the *amount of chemical per unit body weight per unit time* that an animal may be exposed to every day of its life, that is not expected to cause adverse effects. These limits are called Toxicity Reference Values (TRVs) and are based on animal toxicity studies published in the scientific literature.

During the hazard assessment, detailed toxicological profiles were prepared for each COC and VEC combination using detailed toxicological reviews completed by regulatory agencies (such as the U.S. EPA), toxicological databases, and the most up-to-date scientific literature. The SARA Group selected Toxicity Reference Values from high quality, long-term toxicity studies where animals were exposed to COC via ingestion (the same route assessed in the ERA) and in which effects on individual survival, growth, and reproduction were measured. These individual-level effects can have direct impacts on wildlife populations and are, therefore, relevant in assessing risks to VECs.

3.3.2.3 *Risk Characterization*

The risk characterization component of the wildlife ERA combines the exposure assessment (exposure estimates) and the hazard assessment (TRVs) to estimate risk for each COC and VEC combination. This comparison provides an *Exposure Ratio*, as follows:

$$\textit{Exposure Ratio} = \frac{\textit{Estimated Exposure}}{\textit{Toxicity Reference Value}}$$

When estimated exposures from all sources are less than or equal to the TRV (exposure ratio $\leq$ 1), adverse effects are not expected. Risks may be considered insignificant and no further study is warranted. When the estimated exposure exceeds the exposure limit (exposure ratio > 1), the risk of adverse effects cannot be ruled out and should be investigated further.

For the probabilistic wildlife exposure assessment in this ERA, the full range of estimated exposures was compared to the exposure limit to determine the probability that exposure ratios would exceed a value of one (exposure ratio > 1). For COC and VEC combinations where 90% or more of the calculated exposure ratios fall below a value of one, adverse effects can be confidently ruled out. That is, the estimated exposures for 90% or more of the population are below the TRV. Where more than 10% of the calculated exposure ratios are greater than a value of one, the potential adverse effects cannot be ruled out and further investigation is required. These cases do not imply risk, but rather a need for additional time and effort to evaluate the uncertainty and degree of conservatism incorporated into the risk assessment and to consider additional site-specific information, or *lines of evidence*.

3.3.2.4 *Wildlife Assessment Results*

As described previously, the results of the standard ERA framework approach are conservative because the models and assumptions used tend to over-estimate risks in the interest of protecting plants and animals. Therefore, in cases where risks are predicted, it is important to revisit the assumptions and data used in the exposure models and to consider any additional information in a weight-of-evidence approach (see Section 2.4.2) to validate the calculations.

Although no field studies on wildlife populations were conducted as part of the Sudbury area ERA, there is considerable information available from area naturalists and researchers. In addition, there is a wealth of published data on area bird populations, from the *Breeding Bird Atlas* and *Christmas Bird Counts* from the National Audubon Society, and other sources.

Table 3-4 provides a summary of calculated risks to wildlife VECs in each of the study zones. The values in the table represent the 90th percentile exposure ratio, meaning that 90% of the population would experience risks less than this value. For example, the exposure ratio of 90% for the population of robins in Falconbridge to selenium is less than 1.4. The exposure ratios shown in Table 3-4 were calculated using the lowest and, therefore, most conservative of all of the TRVs considered for the ERA. Only exposure ratiosn >1 are shown in Table 3-4.

Table 3-4: Summary of Calculated Risks (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**

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

Risk to study area birds and mammals from direct toxicity to COC is unlikely

Risks, principally due to selenium, could not be definitively ruled out for robins, grouse, fox or falcons. However, the 90th percentile exposure ratios were only marginally greater than one in all cases. Furthermore, data show that hundreds of species of birds are found in Sudbury. The Christmas Bird Count data for non-migratory birds show increasing numbers from 1980 to 1995. American robins are breeding in Sudbury and although grouse were at one time eliminated from portions of the Greater Sudbury area, the population has since recovered and ruffed grouse currently is a hunted species. Peregrine falcons were re-introduced into the Greater Sudbury area in 1990 and 1991 and there is evidence that they are breeding in the region. Consideration of this information, along with the use of conservative exposure limits and exposure ratios marginally exceeding 1.0 indicates that risk to study area birds and foxes from direct toxicity to COC is unlikely.

Of all of the VECs considered, small mammals were predicted to be most at risk, based on the number and magnitude of exposure ratios that were greater than one for selenium and, to a lesser extent, nickel. However, the predicted exposure ratios for most (90%) of short-tailed shrews and meadow voles were all in the order of three or less. Naturalists and researchers report that shrews and voles are abundant in the Greater Sudbury area and that the region as a whole is suitable to sustain populations of small mammals.

It is unlikely that COC in soil are exerting a significant direct toxic effect on terrestrial wildlife populations in the Greater Sudbury area

However, ERA modelling does not address risks to small mammals or other VECs from loss of or changes in their habitat or changes in the habitat of their predators. Habitat for small mammals such as voles and shrews must provide suitable cover from predators, food sources, and nest sites. Changes in plant communities as a result of smelter emissions may result in changes in the populations or communities of small mammals and other animals that use the habitat.

Based on all of the information considered in the ERA and the conservative nature of the risk models and assumptions, it is unlikely that COC in soil are currently exerting a significant direct toxic effect on terrestrial wildlife populations in the Greater Sudbury area, nor are they predicted to in the future. However, historic impacts of smelter emissions on habitat quality (such as loss of particular plant species used as food or cover) may be having a continued effect on some birds and mammals in the study area.

4. Defining the Sudbury Landscape

The test sites include five locations outside of the area known as the semi-barrens (see Figure 4-1). All five of these locations were ranked Yellow, or moderately impacted. These results show that impacts on the plant community do extend beyond the semi-barrens area. Clearly, impacts to the Sudbury-area plant community are widespread.

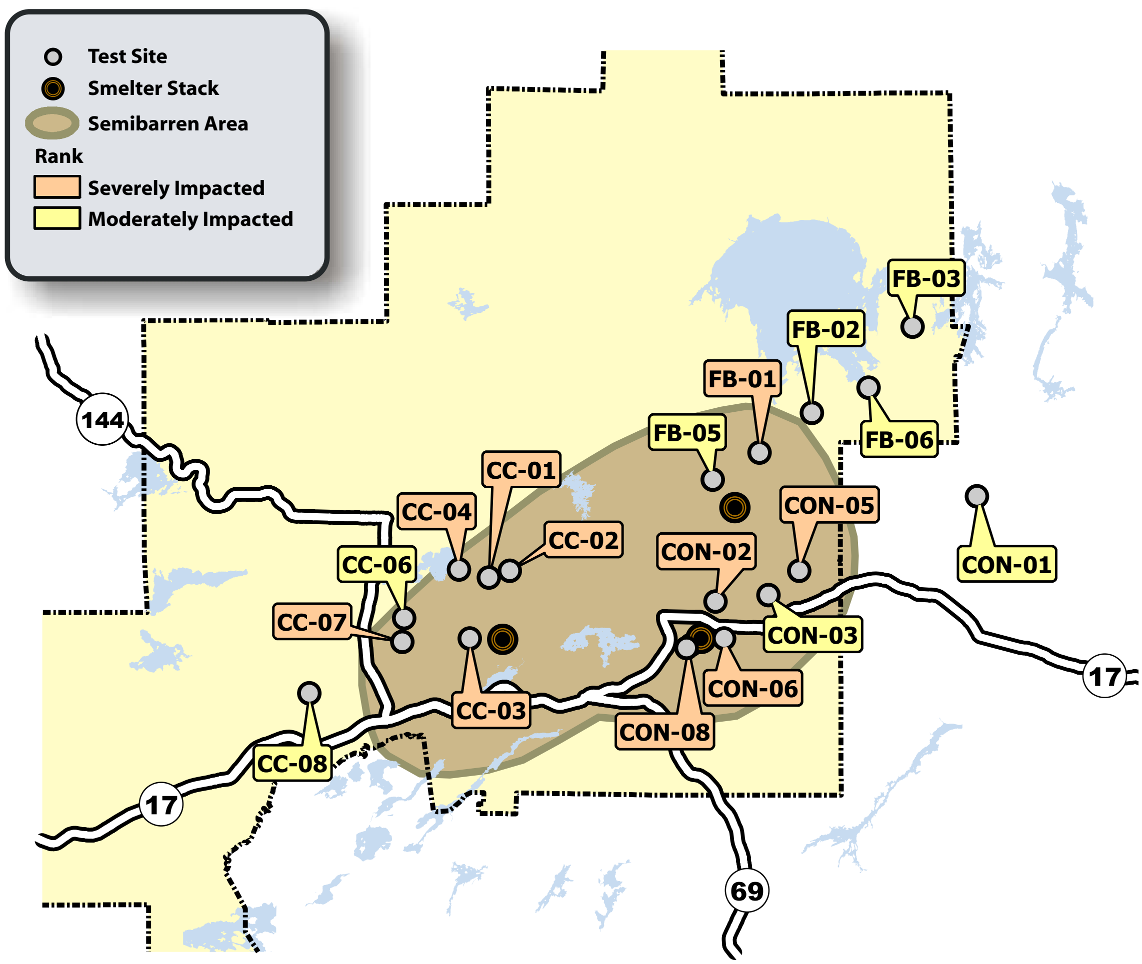


Figure 4-1: Final Test Site Rankings for the Plant Community Assessment

An important outcome of the ERA was being able to review the data to identify and describe characteristics of healthy and impacted vegetation communities in the Greater Sudbury area. Prior to this study such numerical descriptors did not exist.

The range of COC concentrations found at the reference sites, and at moderately and severely impacted sites is illustrated in Figure 4-2. Metal levels are clearly lower in the reference sites than in the impacted sites for all COC.

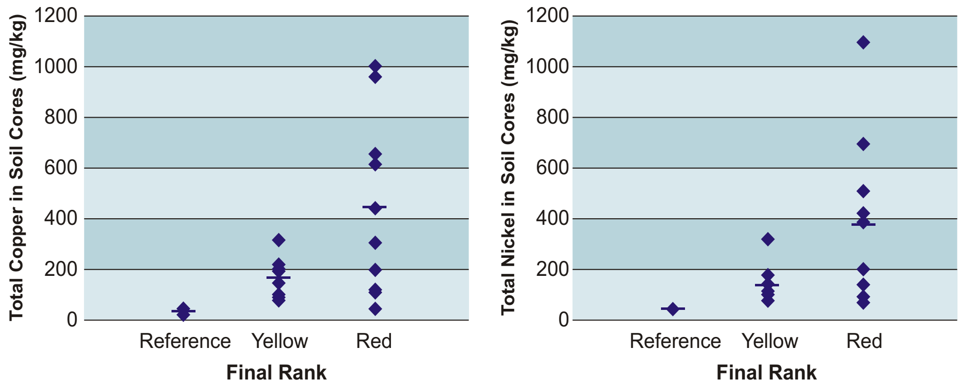


Figure 4-2: Total copper and nickel concentrations in soils from sites of different final ranks.

The actual COC data for the different types of sites are summarized in Table 4-1. Although there is considerable overlap in the range of metal levels, the average metal concentration was greatest at the severely impacted sites.

Table 4-1: Range of 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

Table 4-2 summarizes the ranges of several parameters that were measured at the test and reference sites for the soil quality line of evidence. These parameters do not include the COC but do include chemical variables related to soil fertility and nutrient status. The soil chemistry characteristics of sites at different impact levels were described using a combination of data from the literature, and the soil chemistry data collected at the study sites. This information can be used in future surveys to help define and classify sites where re-greening efforts may be directed.

Table 4-2: Soil Chemistry Characteristics of Low, 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

This information can be used in future surveys to help define and classify sites where re-greening efforts may be directed

From the detailed data collected during the ERA the SARA Group was also able to identify characteristics of the plant community common to the degree or severity of impact. For example, Low or Not Impacted sites tended to have more than 60 different plant species present, while impacted sites had fewer than 60 species that were arranged differently in plant groupings. This information is summarized in Table 4.3.

Table 4-3: Characteristics of Low, Moderately and Severely Impacted Plant Communities

Criterion	Low to Not Impacted	Moderately Impacted	Severely Impacted
Species Richness	Sites tend to have 60 species or more, with at least three species in each plant grouping[a].	Sites tend to have less than 60 species, with at least three species in each plant grouping[a].	Sites tend to have less than 60 species. Generally, at least one plant grouping[a] has less than three species.
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	Have less than 20% cover by a single species.	Often have more than 20% cover by a single species.	
Conifer Cover	Have near-complete canopy cover.	Have either 0 or 50% canopy cover, with 0 to 10% understory cover.	Have 0 to 5% combined canopy and understory cover.
Introduced and Invasive Species	Have negligible cover of non-native and potentially invasive species.	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.	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.	Have 0 to 10% of bare rock or soil.	Have 0 to 60% of bare rock or soil.
Reestablishment of Sensitive Species	Sites tend to have 5 to 10 good conditions indicator species.	Have 0 to 5 good conditions indicator species.	
Acid and Metal Tolerant Indicators	Have 5 to 10 acid and metal tolerant indicator species.	Have 10 to 15 acid and metal tolerant indicator species.	
Maximum Tree Height	Have a maximum tree height of 10 to 14 m.	Generally have a maximum tree height of less than 10 m.	

[a] Plant groupings: ferns, grasses and sedges, herbs, lichens and mosses, shrubs, and trees.

4.1 Landscape Ranking Map

The final site rankings for the 22 study sites were extrapolated to the larger study area using remote sensing techniques to produce a Landscape Ranking Map (Figure 4-3). The red, yellow and green areas on the map represent areas which have similar characteristics to the 22 study sites. This approach assumed that there is an association between ground-cover characteristics of a site as determined by satellite imagery and the final site impact rankings. The "peanut" shaped area on the map represents the area identified in Volume I and is approximately the same as the area referred to as the "semi-barren" area. The total area represented in this map is 9,238 km^2

Using this approach only about 15% (1281 km^2) of the area could be classified (i.e. green, yellow, red). The remaining areas (7956 km^2) cannot be classified as similar to any of the study sites. The unclassified areas consist of a variety of land uses including lakes, wetlands, industrial areas and urban centres. Within the classified areas, 19% (243 km^2) was identified as Red or severely impacted, 31% (397 km^2) as Yellow or moderately impacted, and 49% (628 km^2) as Green or corresponding to the reference sites. Using this approach within the areas that could be classified, up to 50% of the land may be considered moderately or severely impacted.

The landscape map using a combination of satellite imagery and data collected in this risk assessment, was an attempt to identify candidate areas for future regreening or restoration activities. The results are considered preliminary at this time and all candidate areas will need to be confirmed by additional surveys on the ground.

An electronic copy of this map is available in CD format within the full ERA Technical Report.

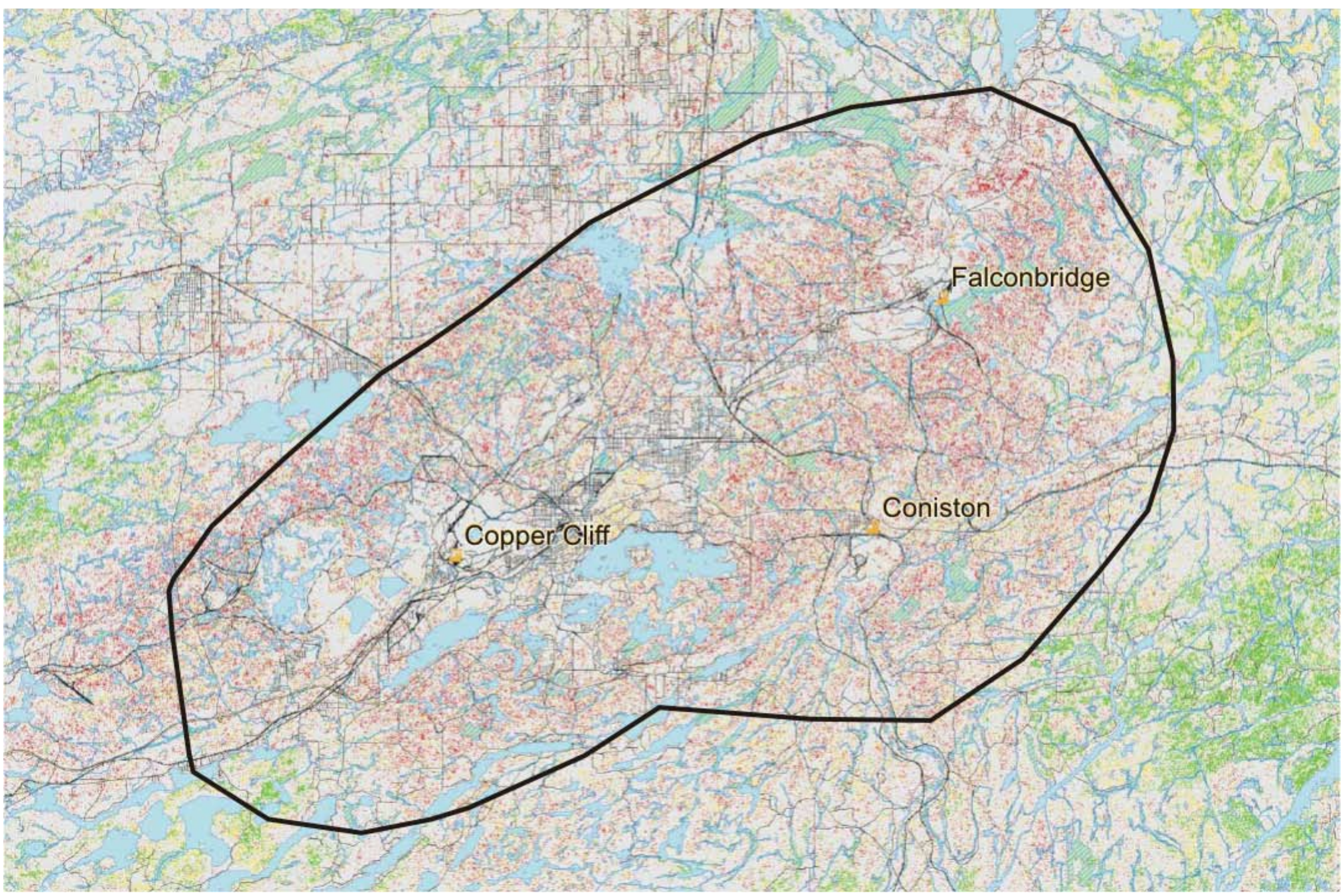


Figure 4-3: Landscape Ranking Map

5. Summary and Conclusions

The main goals of the Sudbury area ERA were to evaluate the current and future risks from metal particulate emissions from Sudbury smelters to terrestrial ecosystem components; and to provide information to support the recovery of self-sustaining ecosystems in areas of Sudbury affected by airborne metal emissions.

The main conclusions from the ERA for the Greater Sudbury study area are as follows:

1. Terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the Chemicals of Concern (COC) in soil.

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

2. The assessment suggests that COC originating from smelter emissions are not currently exerting a direct effect on wildlife populations 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.

3. 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.

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

The results and conclusions from this risk assessment will be used as the basis for future risk management decisions in the Greater Sudbury area.

6. Next Steps

In response to the results of the ERA, Vale Inco and Xstrata Nickel are working in conjunction with the City of Greater Sudbury and the Ontario Ministry of the Environment to continue to promote re-greening and restoration activities within the area affected by smelter emissions.

After the release of the ERA results, there will be a review period for public comments. Comments will be accepted in writing by mail, fax, email, or online at www.sudburysoilsstudy.com. Further information on the public review period and comments will be provided in the local media and the Sudbury Soils Study website.

Copies of the full technical report (*Sudbury Area Ecological Risk Assessment)* are available for viewing at the offices of the Ontario Ministry of the Environment at 199 Larch Street, Sudbury and at the public libraries in Sudbury. Electronic copies of the entire technical report and all other information regarding the Sudbury Soils Study are available on the Sudbury Soils Study website at www.sudburysoilsstudy.com.

7. References

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8. List of Acronyms

CCME	Canadian Council of Ministers of the Environment
CEM	Centre for Environmental Monitoring at Laurentian University, Sudbury, Ontario
COC	Chemical(s) of Concern
CSC	Communications Sub-committee
ERA	Ecological Risk Assessment
HHRA	Human Health Risk Assessment
ER	Exposure Ratio
IERP	Independent Expert Review Panel
IPO	Independent Process Observer
LOE	Lines of Evidence
MOE/MOEE	Ontario Ministry of the Environment (and Energy)
PAC	Public Advisory Committee
Q&A	Question and Answer
SARA	Sudbury Area Risk Assessment
TC	Technical Committee
TERA	Toxicology Excellence for Risk Assessment
TRV	Toxicity Reference Value
U.S. EPA	United States Environmental Protection Agency
VEC	Valued Ecosystem Component

9. Glossary of Terms

Background Concentration
The typical level of a chemical present in the environment. The term often refers to naturally occurring or uncontaminated conditions, which vary from one location to another. For example, background concentrations of metals are generally greater in northern Ontario due to the geology of the area, which is rich in mineral deposits.

Bioavailability
The portion (or fraction) of the total amount of a chemical in a particular medium (such as soil or dust) to which one is exposed that is absorbed into the bloodstream.

Centre for Environmental Monitoring (CEM)
A group formed by scientists in 2000 at Laurentian University in Sudbury, Ontario that uses the "natural laboratories" of the region to study the effects of metal production emissions and abatement technologies on the environment and human health.

Chemical(s) of Concern (COC)
In the case of the Sudbury area ERA, a chemical or chemicals that is/are present in soil at levels greater than Ontario Ministry of the Environment guidelines. Chemicals of concern may pose a risk to human health and/or the environment and are therefore evaluated further in a risk assessment.

Communications Sub-committee (CSC)
Group formed in 2002 to help oversee communications and consultation initiatives for the Sudbury Soils Study and to ensure timely and effective public consultation. The Communications Sub-committee was comprised of communications professionals from the organizations represented on the Technical Committee, as well as members of the SARA Group. The mandate of the Communications Sub-committee was to foster community awareness and participation throughout the study process.

Community of Interest
A geographical community identified at the beginning of a risk assessment that may be exposed to the chemicals of concern. Receptors in the communities of interest are therefore subjects in the ecological risk assessment process.

Concentration
The proportion of one substance contained in a given amount of another. The concentration unit has two components: the numerator (quantity of substance contained) and the denominator (quantity of the material in which the first substance is contained). For example, a lead soil concentration of 4 mg/kg represents 4 milligrams of lead present within one kilogram of soil, or 4 parts of lead within every million parts of soil.

Contaminant
A substance that is either present in an environment where it does not naturally occur or is present at levels that are greater than background levels.

Dermal
Referring to the skin.

Information Gap
Information that is either unavailable or limited, and that would likely reduce uncertainty in the risk assessment if it were available or if the data set was more complete.

Dose
The amount of a chemical to which a receptor is exposed over a given period of time. Dose is a measure or estimate of exposure and is often expressed as an amount of chemical per unit of body weight per unit of time (such as milligrams of chemical per kilogram of body weight per day). See also Exposure.

Ecological Risk Assessment (ERA)
A process that evaluated the likelihood that adverse ecological effects may occur to receptors (such as plants and animals exposure to a particular chemical or chemicals. [See also Risk Assessment].

Effect
Change in the state or dynamics of an organism, system, or population caused by exposure to some agent or chemical.

Emissions
Materials that are released to the environment from a particular source or activity.

Environmental Quality Guidelines
Regulatory science-based limits for a variety of substances and environmental quality parameters that are set to protect human health and/or the environment.

Exposure
Refers to contact of a chemical with the outer boundaries of the body (skin, lungs, digestive tract). See also Dose.

Exposure Assessment
The part of the risk assessment process where chemical doses received by receptors are either calculated or measured directly. The exposure assessment also takes into consideration the length of time and the nature of a population exposed to a chemical.

Exposure Pathway
The means by which a chemical moves from its source (such as soil, food, water, or air) into the body of a receptor. Pathways link the source of a chemical to receptors.

Exposure Ratio (ER)
Ratio of an estimated exposure to a exposure limit for a particular chemical of concern and valued ecosystem component combination. An exposure ratio less than or equal to 1.0 indicates that the estimated exposure is lower than the exposure limit and that no adverse population-level effects are expected. An exposure ratio greater than one indicates that the estimated exposure is higher than the exposure limit and that the risk of adverse effects on individuals and populations should be investigated further.

Exposure Route
Refers to one of the three specific ways in which a chemical enters into the body of a wildlife receptor (ingestion (swallowing), inhalation (breathing in), or dermal absorption (through the skin); or to one of the three specific ways in which a chemical enters into plant tissue (root uptake, absorption from the air, or dustfall onto leaf surfaces).

Greater Sudbury Area
The study area for the human health risk assessment, centred on the City of Greater Sudbury and radiating to the surrounding regions (approximately 40,000 square kilometres), in the core of the Canadian Shield in Northern Ontario. The study area includes the five communities of interest: Coniston, Copper Cliff, Falconbridge, Hanmer, and Sudbury Centre.

Guidelines
General recommended limits on the level of a particular substance in a specific medium or environment that are set to protect against adverse effects to humans and/or the natural environment. Exceedances of guidelines trigger the need for further study. An example is the Ontario Ministry of the Environment soil quality guidelines.

Hazard
Refers to the inherent properties of a chemical that enable it to cause adverse effects when an organism, system or population is exposed to it.

Hazard Assessment
Phase of the risk assessment that describes the relationship between levels of chemicals of concern and ecological effects.

Human Health Risk Assessment (HHRA)
A risk assessment that evaluates potential health risks to hypothetical human populations from exposure to a particular chemical or chemicals. See also Risk Assessment.

Independent Expert Review Panel (IERP)
An international group of scientists chosen by the Toxicology Excellence for Risk Assessment (TERA) group (who were retained by the Technical Committee) to peer review the Ecological Risk Assessment.

Independent Process Observer
Position established to ensure that all stakeholders were given equal access and input into the Sudbury Soils Study and to represent the interests of the community. This position was filled by Mr. Franco Mariotti, a biologist and staff scientist at Science North in Sudbury and a resident of the community.

Ingestion
The consumption of a substance by an organism.

Inhalation
Breathing air and the substances it contains into the respiratory tract.

Litter
In the context of this study litter refers to organic material such as leaves, twigs, seed and fruit that falls from trees, or dieback of perennial plants, that accumulates on the ground and is subject to natural decay processes.

Ontario Ministry of the Environment (and Energy) (MOE / MOEE)
Provincial agency responsible for developing, implementing, and enforcing regulations and various programs that address environmental issues. Formerly known as the Ontario Ministry of the Environment and Energy. The Ontario Ministry of the Environment is a member of the Sudbury Soils Study Technical Committee.

Percent Difference
A qualitative indicator of quality assurance and quality control. The result is a numerical interpretation is comparing two values with one another. The lower the percent difference the more similar the values are.

Population
A group of organisms living within a given location in space and time, or sharing similar characteristics.

Problem Formulation
Initial stage of risk assessment where information is gathered and interpreted to plan and focus the assessment.

Public Advisory Committee
A group of Greater Sudbury area residents established in 2002 to facilitate community involvement in the Sudbury Soils Study and to promote the flow of information between the Technical Committee and the public.

Receptor
A specific group of animals or people that could come into contact with chemicals of concern.

Remediation/Remedial
Correction or improvement of a problem, such as work that is done to clean up or stop the release of chemicals from a contaminated site.

Risk
In ecological risk assessment, risk refers to the likelihood of experiencing adverse health effects caused by exposure to chemicals of concern.

Risk Assessment
A process that estimates the likelihood that receptors (plants, animals or people) may experience adverse effects from a particular series of events or circumstances, such as exposure to chemicals. The four components of a risk assessment are:

1. Problem formulation;
2. Exposure assessment;
3. Hazard assessment; and
4. Risk characterization.

Risk Characterization
Final phase of the risk assessment, where the exposure and effects information are combined to evaluate potential impacts of exposures to chemicals of concern.

Risk Management
The process of deciding whether, how, and how much to reduce or eliminate possible adverse effects on people and the environment. Risk management takes into consideration the results of the risk assessment, engineering capabilities (what can physically be done and how effective it will be), and social, economic, and political concerns.

Route of Exposure
See Exposure Route.

Safe
In the context of risk assessment, safe implies very low or negligible or acceptable risk.

SARA Group
The affiliation of several Ontario-based consulting firms specializing in the various scientific disciplines responsible for conducting the Human Health and Ecological Sudbury Area Risk Assessments. The main partners of the SARA Group are AECOM (formerly Gartner Lee Limited and C.Wren and Associates), Intrinsik Environmental Sciences Inc. (formerly Cantox Environmental Inc.), Rowan Williams Davies and Irwin Inc., SGS Lakefield, Goss Gilroy Inc. and Dr. Lesbia Smith, MD.

Screening
The process of comparing chemical concentrations found in the environment with environmental quality guidelines in order to identify chemicals of concern for a risk assessment (See also Chemicals of Concern).

Stakeholder
Any person or organization with an interest or "stake" in the outcome of a particular process.

Study Area
The particular geographical area(s) being examined in a risk assessment. In this case, the study area is the Greater Sudbury Area as defined below.

Sudbury & District Health Unit (SDHU)
A public health agency that delivers provincially legislated public health programs and services to the residents of the Sudbury and Manitoulin districts. The health unit works with individuals, families, and the community to promote and protect health and prevent disease. The health unit is a member of the Sudbury Soils Study Technical Committee.

Sudbury Soils Study
The name given to the group of comprehensive studies initiated in 2001 that identified elevated levels of metals in Greater Sudbury area soils and then evaluated whether these metals pose a risk to people, plants, or animals in the region. The three main studies completed under the umbrella of the Sudbury Soils Study are the 2001 Soil Survey, the Sudbury Area Human Health Risk Assessment, and the Sudbury Area Ecological Risk Assessment.

Technical Committee (TC)
The six organizations with the responsibility of overseeing the Sudbury Soils Study: Ontario Ministry of the Environment, Sudbury & District Health Unit, City of Greater Sudbury, Vale Inco, Xstrata Nickel (formerly Falconbridge Limited) and the First Nations Inuit Health Branch of Health Canada. All of these organizations are identified as major stakeholders in maintaining a healthy environment in and around Sudbury.

Toxicity
Refers to the nature and severity of adverse effect(s) caused by a chemical on the biological system of an exposed organism over a given period of time.

Toxicity Reference Value
An upper exposure limit, at which adverse effects are not expected to occur. Exposures less than or equal to the toxicity reference value are therefore considered 'safe' levels of exposure. Toxicity reference values are usually reported as the amount of chemical per unit body weight per unit time that an animal may be exposed to every day of its entire life that is not expected to cause adverse effects. Toxicity reference values are determined based on animal toxicity studies published in the scientific literature.

United States Environmental Protection Agency (U.S. EPA)
Federal agency in the United States responsible for developing and enforcing environmental regulations. U.S. EPA is responsible for researching and setting national guidelines and standards for a variety of environmental programs.

Valued Ecosystem Component
A receptor, or specific group of plants or animals that could come into contact with chemicals of concern are that is identified as being of value to the community, and are selected for evaluation in the risk assessment.

Weight-of-Evidence
The result of an evaluation of multiple lines of evidence in an ecological risk assessment. Rather than simply modeling risks all available data such as chemical analysis, toxicity tests and biological surveys are examined to estimate the likelihood that effects are occurring (or will occur) to a given system or assessment endpoint. The lines of evidence are first examined independently so that the implications of each are clearly presented and then are integrated together to obtain an overall evaluation. This approach reduces the biases and uncertainties associated with using only on approach to estimate.

Notes:

Notes:

Sudbury Soils Study

Summary of Volume III:
Ecological Risk Assessment

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