SUDBURY AREA RISK ASSESSMENT

VOLUME III - CHAPTER 2.0
PROBLEM FORMULATION

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2.0 PROBLEM FORMULATION FOR THE TERRESTRIAL ERA

The problem formulation for the terrestrial ERA includes a compilation and review of ecological information (Section 2.1), the definition of the study area (Section 2.2), a summary of COC (Section 2.3), identification of VECs (Section 2.4; aquatic VECs such as fish, invertebrates, amphibians and wildlife with a significant dietary link to the aquatic environment [mink, loon and mallard] are discussed in Chapter 5), identification of assessment endpoints (Section 2.5), and presentation of the conceptual model (Section 2.6). A summary of the problem formulation is in Section 2.7. References are provided in Section 2.8.

2.1 Compilation and Review of Ecological Information

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

Initial literature search tasks included identifying applicable studies from existing collections of local ecological research documents. These collections are located throughout Ontario, and specifically Sudbury, including in the offices of the MOE, Vale Inco, Xstrata Nickel, City of Greater Sudbury, Sudbury Public Library, and local educational institutions such as the collections at the J.N. Desmarais Library and the Centre for Environmental Monitoring at Laurentian University. In addition, a literature search was conducted using available ecological and toxicological databases (*e.g.*, Biosis, Enviroline, Agricola). The searches of relevant peer-reviewed journals, dissertations, government publications, and databases were conducted using selected keywords to obtain key results as they relate to studies conducted in the Sudbury area, for both the aquatic and terrestrial environments. A separate search was conducted to identify toxicological literature related to the COC and effects on terrestrial biota. Those papers were used to develop toxicological profiles which were in turn used to develop Toxicity Reference Values (TRVs) for selected VECs (Section 4.2).

A summary of this review is provided in Appendix C. The review demonstrated that there were limited data available to parameterize the SARA wildlife exposure model with Sudbury-specific wildlife information. In addition, there were limited data available to assist in the interpretation of the results of the risk characterization (*e.g.*, data on wildlife population trends, reproductive success, and/or evidence of local presence/absence of wildlife species). Thus, additional information was sought from other sources to incorporate local knowledge on wildlife populations. The sources of this additional information were:

- Wildlife research community at Laurentian University;
- Data from government agencies;
- Published and anecdotal knowledge from wildlife societies;
- Published and anecdotal knowledge from hunting societies; and,
- Web-based search.

1. Ecological Research Community at Laurentian University

The SARA Group invited Laurentian University faculty members to two workshops during the initial stages of the ecological risk assessment to inform the faculty of the study and its scope, and to solicit input and information from these local researchers. The following is a brief overview of faculty members and researchers that subsequently participated in the ecological risk assessment:

- Dr. Glenn Parker: provided data on deer diet and metal concentrations in Sudbury-area deer;
- Dr. Peter Beckett: provided information on the regreening programs carried out in the Sudbury region, assisted the SARA Group to locate field study sites to evaluate ERA Objective #1, and helped develop the detailed vegetation community survey protocol as a critical Line of Evidence (LOE) used to evaluate ERA Objective #1;
- Dr. Graeme Spiers: assisted with locating field study sites to evaluate ERA Objective #1 and participated in developing the protocol for assessing soil physical and chemical parameters for this Line of Evidence used to evaluate ERA Objective #1;
- Dr. John Gunn, Mr. Bill Keller and Mr. George Morgan (Laurentian University and Ministry of Natural Resources Freshwater Co-op Unit): collected fish from eight local lakes for tissue metal analysis, and provided detailed water chemistry and zooplankton population information used in the Aquatic Problem Formulation;
- Dr. Robitaille (various emails between May 2004 and September 2005): provided data on small mammal populations in Sudbury; richness of species; prepublication data and abstract;
- Mr. Winterhalder, formerly of Laurentian University (email November 2004) and previous graduate student Andrea Sinclair (December, 2004): provided a thesis on small mammal populations;

- Mr. Chris Blomme, Laurentian University (various emails between March 2007 and September 2007): provided information on local wildlife species;
- Dr. David Lesbarrères Laurentian University (various emails between March 2007 and April 2007) provided information on local amphibian and reptile species;
- Dr. Jacqueline Litzgus, Laurentian University (various emails between March 2007 and September 2007): provided information on local amphibian and reptile species.

2. Government Agency Data

Ontario Ministry of Natural Resources:

- Jason Langis/Paul Biscaia/Mike Hall. Area Biologists, Sudbury District (various emails and phone conversations between May and September, 2005); Melanie Alkins, Acting Nipissing Area Management Biologist, North Bay District Office (various emails September, 2005): informed that moose are the only wildlife for which long-term population data exist for the Sudbury area; Sudbury area covers three OMNR wildlife management units (WMU 39, 41, 42); received data for WMU 41 and 42; requested WMU 39 data (September to October, 2005; from Christine Selinger) but did not receive reply.

Environment Canada:

- Juliana Molinari, Sudbury Area Effects Zone, LRTAP Biomonitoring Database (email February, 2005); Don McNicol, Outreach Officer, Canadian Wildlife Service (email August through September, 2005); Russ Weeber, Acid Rain Biologist, Canadian Wildlife Service - Ontario Region (email September, 2005): supplied with Sudbury waterfowl data in 2004 Canadian Acid Deposition Science Assessment and Summary of Key Results. Also searched the Canadian Wildlife Service, Hinterland's Who's Who website (www.hww.ca/hww2.asp?id=54): wildlife profiles (habitat and food preferences) for moose, ruffed grouse, beaver, red fox, peregrine falcon, mallard, white-tailed deer and common loon.

Sudbury:

- Sudbury & District Health Unit. Ido Vettoretti, Environmental Health Specialist: provided sightings data for red fox and coyote for 2001 and 2002; documentation of where foxes have been found (as part of rabies monitoring program); mentioned that there are numerous red foxes in Sudbury area.

- City of Greater Sudbury web site (http://www.city.greatersudbury.on.ca/cms/index.cfm): anecdotal information available for sightings of VECs.

3. Wildlife Societies' Published and Anecdotal Knowledge

- Sudbury Naturalists; Loon Survey for Greater Sudbury, Marlies and Deiter Schoenefeld (visit February, 2004; phone interview February, 2005): provided anecdotal data on Sudbury wildlife, in particular loons; referred SARA Group to Kathy Jones for data, Bird Survey of Canada. Also contacted local naturalists Charlie Whitelaw and John Lemon (phone interview February, 2004): provided anecdotal information on increase and decline of bird species; noted that the trends are province-wide and not Sudbury-specific;
- Bird Studies Canada, Kathy Jones, Aquatic Surveys Officer (phone interview and email February, 2005): forwarded Canadian Lakes Loon Survey 20-year report, suggested other sources of information;
- National Audubon Society Christmas Bird Count website (http://www.audubon.org/bird/cbc, September, 2005): obtained data for Sudbury area for 1980 to 2005;
- Sudbury Valley Trustees website (www.sudburyvalleytrustees.org): sightings of mink, red fox, ruffed grouse, American robin, white-tailed deer;
- Sudbury District Archived Birding Reports, 2002 Sudbury District (http://www.web-nat.com/bic/ont/Archives/arcsud2002.htm): anecdotal evidence of breeding peregrines in Sudbury; and,
- Science North, Franco Mariotti, Staff Scientist/Biologist (email January, 2004): noted that bird list for Sudbury is out of print, unavailable and outdated; provided contact information for Sudbury Naturalists.

4. Hunting Societies' Published and Anecdotal Knowledge

- Ducks Unlimited (phone November, 2004): informed that they do not collect any information on Sudbury wildlife; and,
- Ruffed Grouse Society of Canada, James Abbey, Executive Director (various phone and email correspondence, November and December, 2004): anecdotal information on the ruffed grouse in Sudbury area.

5. General Web Search

- Google search for information on each VEC (November, 2004): search terms used were the VEC common name AND Sudbury NOT motel NOT hotel NOT lodge; many websites found noting wildlife sightings, however, locations and dates were never available; and,

The relevant Sudbury-specific data from all sources listed above were incorporated into the ecological exposure model and the risk characterization, as summarized in Sections 4.2 and 4.5, respectively.

2.2 Definition of the Study Area for the Terrestrial ERA

The initial study area for the Sudbury Soils Study was defined as the area from which soil samples were collected during the 2001 Sudbury Regional Soils Project. The extensive 2001 soil survey was undertaken to address data gaps in the concentrations of metals and metalloids identified by the MOE in their review of the historical soil and vegetation quality data for the Sudbury area (MOE, 2001). The data gaps prevented detailed geochemical mapping of the Sudbury area required for the recommended risk assessment studies.

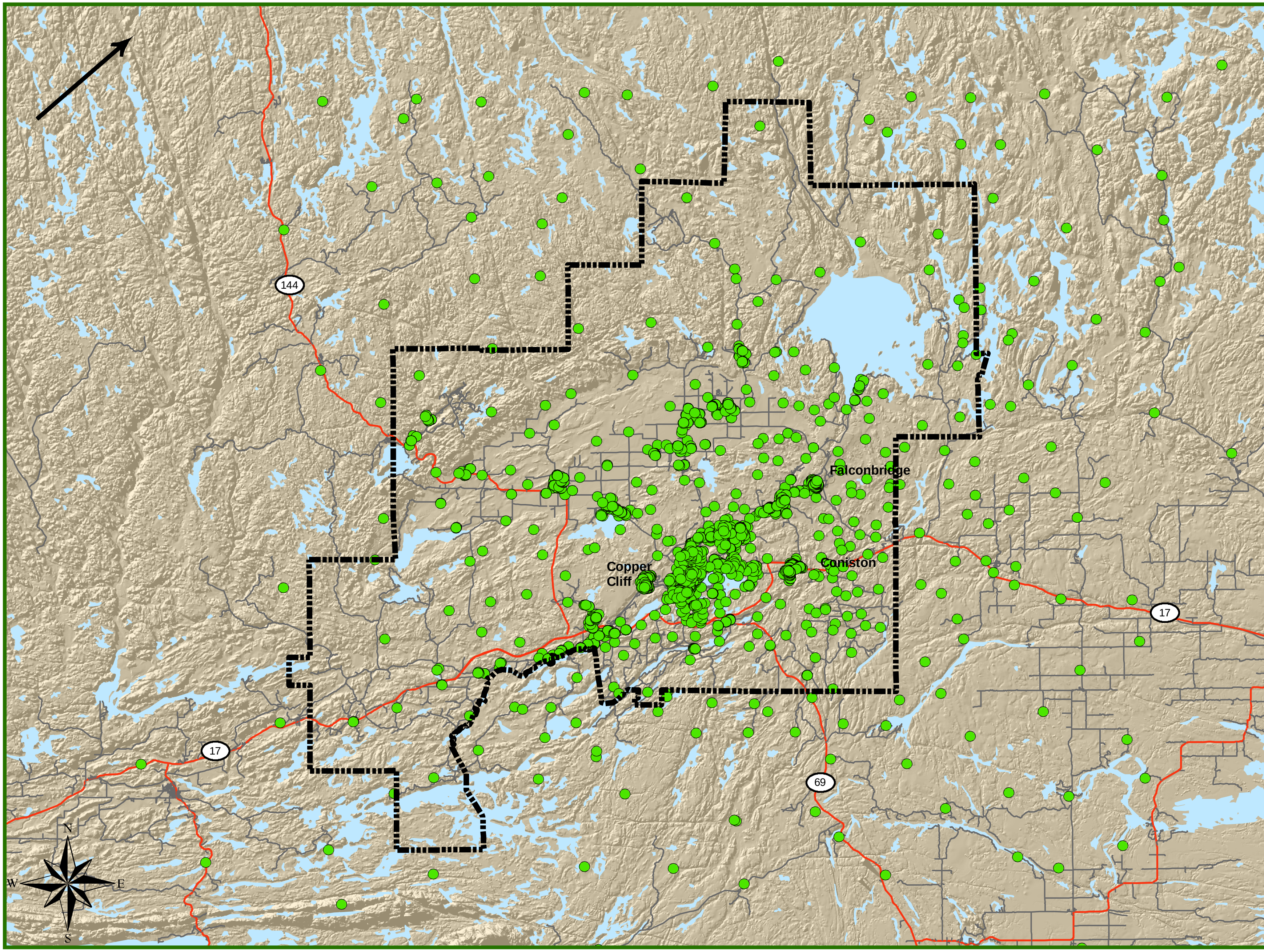
The Centre for Environmental Monitoring (CEM) at Laurentian University designed the regional soil sampling program to collect data from rural and remote areas with undisturbed soils. Details on the sampling programs, methodology and results are provided in separate reports (MOE, 2003; CEM, 2004) and described in Volume I, Chapters 7 and 9.

As the area sampled by the CEM covered the broadest geographical area, it has been used to describe the boundaries of the study area for the ERA. The regional sampling survey was developed using a randomly stratified sampling plan. The nested sampling grid was centred on the three historical smelters, Copper Cliff, Coniston and Falconbridge, with the centroid in the vicinity of the Copper Cliff smelter (CEM, 2004).

The cells of the stratified sampling plan ranged in size, with the smallest cells being closest to the smelters and in zones historically known to reflect smelter impact. The final nested sampling grid covered an area approximately 200 km x 200 km in size (40,000 km^2). The final sampling grid for the regional soil survey is shown in Figure 2-1; sample locations from the urban and residential soil survey are not shown. This initial study area (the entire area shown in Figure 2-1) represented an enormous area (roughly the size of Switzerland) to begin the ERA.

To provide a more refined and meaningful interpretation of the wildlife exposure model results, the study area was subdivided into three Zones and four Communities of Interest as identified in Figure 2-2. The boundaries of the zones were defined on the basis of metal concentrations in soil (see maps in Volume I, Chapter 9), and on the basis of terrain. Zone 1 is generally "upwind" of the smelters with low metal levels in soil. Zone 2 was delineated to include the area between the three smelters containing the highest metal levels in soil. Zone 3 is south and southeast (generally down-wind) of the smelters.

The four Communities of Interest (*i.e.*, Coniston, Copper Cliff, Falconbridge and Sudbury–central) were defined in the human health risk assessment (see Volume II, Chapter 2; SARA, 2008). These Communities of Interest are urban environments and were appropriate for the assessment of some VECs which live in urban areas.



Sudbury Soils Study | Étude des sols sudburois
metals • health • environment
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Figure 2-1: Initial Study Area for the Terrestrial ERA

Greater Sudbury Boundary
Soil Samples 0-5cm
South Westerly Prevailing Wind

Scale 1:630,000

0 5 10 Km

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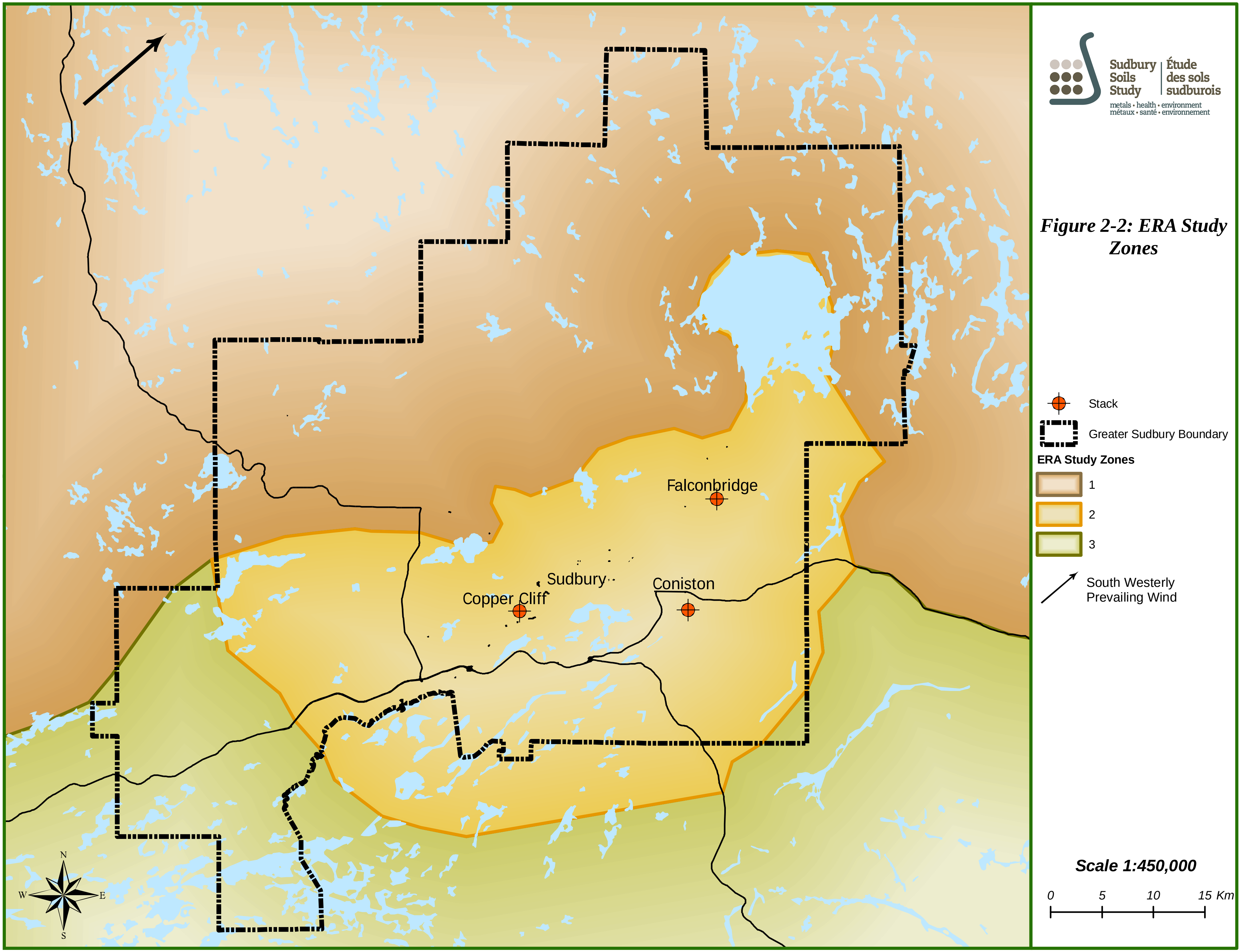

Figure 2-2: ERA Study Zones

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2.3 Identification of Chemicals of Concern for the Terrestrial ERA

The primary source of COC to the terrestrial environment included in this assessment is aerial deposition of particulate-associated metals and metalloids from smelter emissions. In addition, fugitive dust from tailings areas, old roasting beds and ongoing operations have also contributed to metal levels in soils. In this step, the chemicals present in the study area that pose the greatest potential for exposure and risk to the terrestrial ecosystem are identified.

It is common practice in ERAs to limit the number of chemicals evaluated to those chemicals that represent the greatest concern in the area under consideration. This is done because it is impractical in terms of time and cost to conduct a risk assessment for every chemical that has been found to occur in a particular area. In addition, the concentrations of many chemicals associated with a particular site may be similar to chemical concentrations found naturally in the area rather than the result of current or former activities on a site.

A complete description of the COC selection process for the Sudbury Soils Study including the ERA, is provided in Volume I, Chapter 8 and Appendices B, C and D. An overview of the COC selection process is provided in this section. The selection of COC for the risk assessment was based on metal concentrations in Sudbury soils measured during the 2001 soil survey. Approximately 8,400 soil samples were collected from the study area and analyzed for 20 inorganic parameters:

- aluminium (Al)
- antimony (Sb)
- arsenic (As)
- barium (Ba)
- beryllium (Be)
- calcium (Ca)
- cadmium (Cd)
- cobalt (Co)
- copper (Cu)
- chromium (Cr)
- iron (Fe)
- magnesium (Mg)
- manganese (Mn)
- molybdenum (Mo)
- nickel (Ni)
- lead (Pb)
- selenium (Se)
- strontium (Sr)
- vanadium (V)
- zinc (Zn)

The study Terms Of Reference provided to the SARA Group included three criteria for the selection of COC:

- Parameter must be above the Table A (potable groundwater) or Table B (non-potable groundwater) criteria published in the Ontario Ministry of the Environment's Guideline for Use at Contaminated Sites in Ontario (the "Guideline"; MOEE, 1997), depending on whether the specific area under study has surface or well water sources for potable water. In general, these criteria were developed "to protect against adverse effects to human health, ecological health and the natural environment" (MOEE, 1997);

- Parameter must be present across the study area; and,
- Parameter must scientifically show origin from the companies' operations.

The COC selection process is conceptually illustrated in Figure 2-3.

The first three criteria for COC screening were met by As, Co, Cu, Ni, Pb and Se.

Use of the Table A and B soil quality criteria in the *Guideline for Use at Contaminated Sites in Ontario*, (MOEE, 1997) (Criterion 1 for evaluating a COC) only applied to soils with a pH range of 5.0 to 9.0. For soils with a pH outside this range, Table F criteria, or background levels, should be used as alternate screening values (MOEE, 1997).

Soil pH in northern Ontario is known to be naturally low (pH < 5.0) with soil pH further reduced in the study area due to the smelter emissions.

During the original 2001 survey, soil pH was measured in only one of every 10 samples, or 10% of samples. There were 229 soil samples from the urban soil survey for which pH results existed. Of these, 224 (98%) had a pH >5.0. This higher pH range can likely be attributed to homeowners amending residential soils with lime, organic matter and fertilizers. Therefore, low soil pH relative to the MOE generic criteria was considered to be an issue primarily in samples from rural, un-amended sites, and not urban residential properties.

As part of the Sudbury Soils Study, Laurentian University was contracted to measure soil pH in all of the regional surface soil samples collected in 2001. Of 365 surface (0 to 5 cm) samples analyzed, soil pH was <5.0 for 347 (95%) of the samples. Therefore, the database was re-screened using Table F as a criterion, for those samples with soil pH <5.0. The results of this secondary screening exercise are summarized in Table 2.1.

Table 2.1 Summary of Secondary Data Screening and Evaluation

Parameter	Table A criterion	Table F criterion	Values > Table F # of samples	Values with pH < 5 and > Table F # of samples**	Max Value	95th percentile
Al	NC	NC		-	38000	20000
As	20	17	388	161	410	80
Ba	750	210	2	1	720	130
Be	1.2	1.2	0	0	1	0.25
Ca	NC	NC	-	-	24000	9500
Cd	12	1	152	29	4.1	1.7
Co	40	21	238	58	150	45
Cr	750	71	42	7	1100	67
Cu	225	85	699	241	5000	1100
Fe	NC	NC	-	-	74000	28000
Mg	NC	NC	-	-	10000	5400
Mn	NC	NC	-	-	3300	480
Mo	40	2.5	53	9	17	2.3
Ni	150	43	954	286	3649	1100
Pb*	200	120	57	3	790	120
Sb*	13	1	40	6	4.4	0.9
Se	10	1.9	468	183	27	6
Sr	NC	NC	-	-	110	52
V	200	91	0	0	74	50
Zn	600	160	10	0	310	97

Samples with pH values = 1201 (Values are from original and duplicate samples taken from 0-5, 5-10, 10-20 cm soil depths)
Samples with pH < 5 = 401
NC – No Criterion
*no value reported for some samples
** only values that have an associated pH value
All values are presented in mg/kg

This secondary screening step identified five additional elements that exceeded Table F in samples with pH <5.0 (sample size exceeding Table F in brackets): Ba (1), Cd (29), Cr (7), Mo (9) and Sb (6). Of these, four of the elements (Ba, Cr, Mo and Sb) exceeded Table F in a very small number of samples. In addition, the 95th percentile concentration of these elements was less than Table F. Therefore, these elements were excluded from further consideration as candidate COC.

Cadmium exceeded Table F in 29 soil samples with pH <5.0, and the 95th percentile concentration (1.7 mg/kg) was greater than the Table F value (1.0 mg/kg). Therefore, additional evaluation of the distribution of Cd in Sudbury soils was undertaken.

Consensus was reached within the TC that Cd not be included as a COC for the Human Health Risk Assessment (HHRA) for two main reasons:

1. Low soil pH was associated almost exclusively with samples collected from rural and remote sites; and,

2. The maximum Cd concentration was less than half of the Table A criteria which are protective of human health (*i.e.*, 12 mg/kg for residential/parkland, and 3 mg/kg for agricultural land, based on exposure to grazing animals).

However, Cd was included as a COC for the ERA at the request of the MOE. Further discussion of Cd as a COC is provided in Appendix F of Volume I.

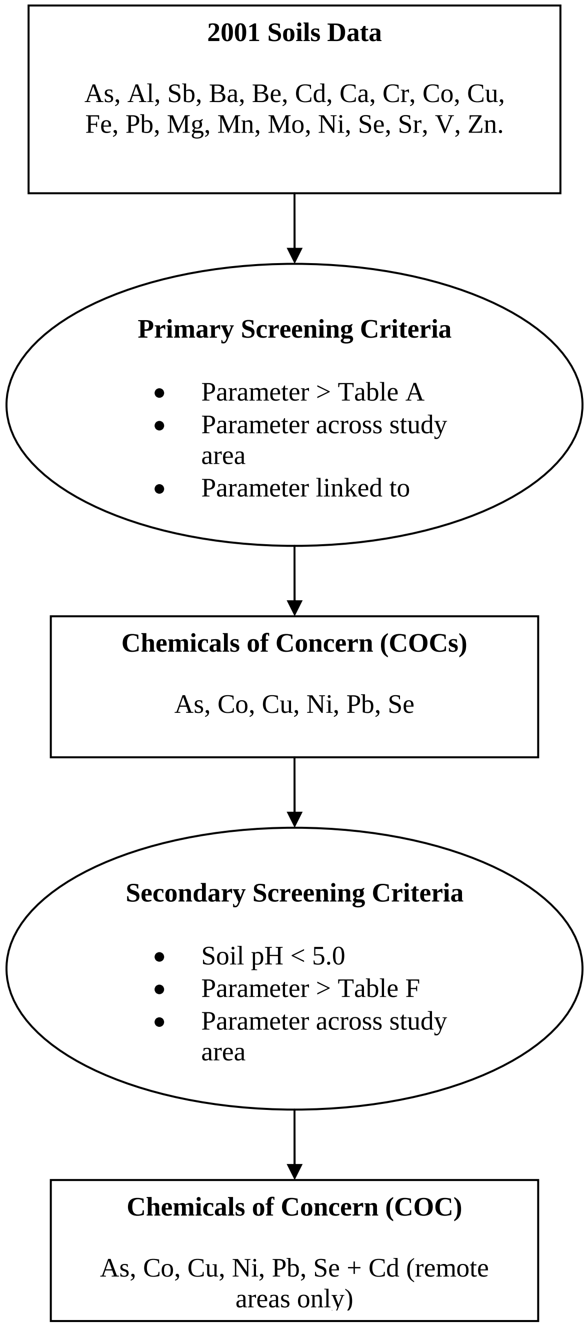

Figure 2-3 Soil Data Screening Process for selection of COC for the ERA

Higher trophic level wildlife may have increased risk when COC accumulate or biomagnify in their food sources. Of the seven COC, As, Co, Cu, Ni and Pb do not significantly bioaccumulate into wildlife dietary items and do not biomagnify to upper trophic levels (Sample *et al.*, 1998a, 1998b; BJC, 1998). However, Cd and Se may bioaccumulate into dietary items (*e.g.,* plants, invertebrates) to concentrations which exceed the levels of the COC in soil (see Chapter 4). Selenium is an essential element with a narrow concentration range (factor of ~10) between deficiency and toxicity (Chapman, 1999). Selenium can accumulate through the food web including uptake in invertebrates (Freeman *et al.,* 2006), plants (Efroymson *et al*., 2004), birds (Mora *et al*., 2006) and mammals (Mackey *et al.,* 2003). Cd also can accumulate through the food web including uptake in invertebrates (Hsu *et al.,* 2006), plants and birds (Larison, 2000; Larison, 2002) and mammals (Cabanaro *et al.*, 2006; Parker and Hamr, 2001).

2.4 Identification of Valued Ecosystem Components (VEC)

A VEC is a species, population or community that is important to people, has economic and/or social value, is ecologically significant and can be evaluated in a risk assessment. Identification and selection of VECs is a critical step in the ERA and the process began early in this study. The general process followed for VEC selection in this study is illustrated in Figure 2-4.

Background information was collected on potential species of plants, mammals, birds and reptiles that occur in the Study Area (Appendix A). Information was collected from existing literature, and discussions with key agencies (*e.g.,* Ontario Ministry of Natural Resources), researchers at Laurentian University and special interest groups *(e.g.*, Sudbury Ornithological Society).

A series of public workshops was held in the spring of 2003 to obtain input from members of the public, as well as special interest groups, to identify species of special interest or concern. This step was valuable in identifying candidate VECs.

Additional details on the VEC selection process are discussed in the following sections of this report:

- Terrestrial plants – Section 2.4.1 under Objective #1;
- Soil invertebrates – Section 2.4.1 under Objective #1;
- Wildlife (birds and mammals) – Section 2.4.2 under Objective #2;
- Vulnerable, threatened and endangered species of birds and mammals – Section 2.4.2 under Objective #3;

- Soil microbes, reptiles, agricultural species and pets – Section 2.4.3 under Species Not Recommended as VECs;
- Aquatic VECs (fish, invertebrates, plants, amphibians) are discussed in Chapter 5 and,
- Wildlife with a significant dietary link to the aquatic environment *(i.e.*, mink, loon, mallard) also are discussed in Chapter 5.

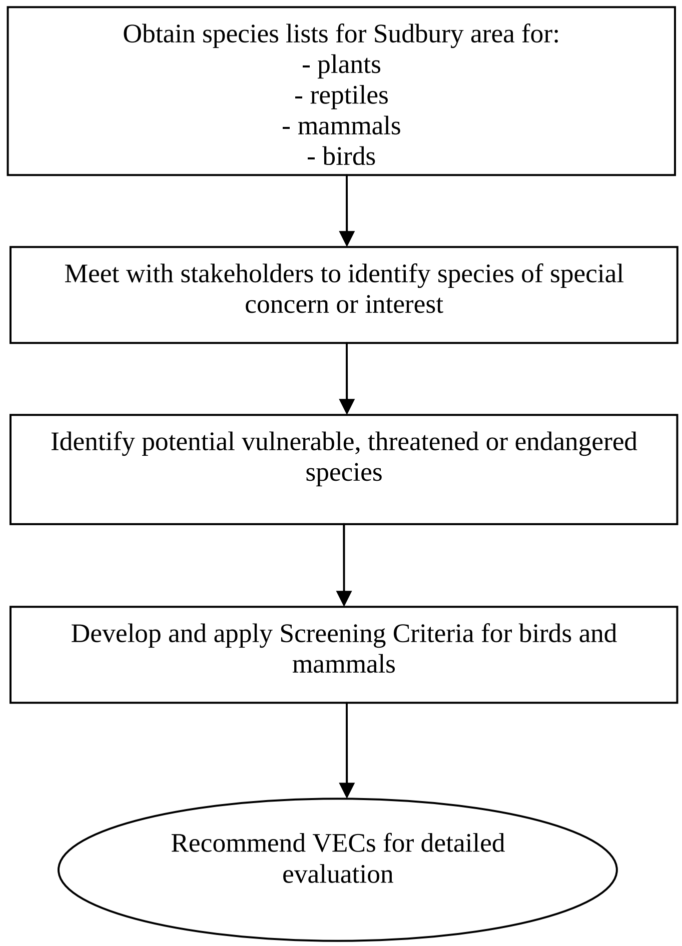

Figure 2-4 Overview of Selection Process for Terrestrial Valued Ecosystem Components

The rationale and selection process used to identify candidate VECs are provided in greater detail in subsequent sections of this report. The selection process identified 12 terrestrial VECs evaluated in the ERA:

- Terrestrial plant communities;
- Northern Short-tailed Shrew;
- Blueberry;
- Meadow Vole;
- Soil invertebrates;
- Moose;
- American Robin;
- White-tailed Deer;
- Ruffed Grouse;
- Red Fox;
- Peregrine Falcon; and
- Beaver.

2.4.1 VECs for Objective #1: Evaluate the Extent to which COC are Preventing the Recovery of Regionally Representative, Self-sustaining Terrestrial Plant Communities

Lists of plant species present in the Sudbury area, as well as species identified as being of concern to Sudbury residents, are provided in Appendices A and G. Terrestrial plants are critical components of the ecosystem because of the functions they fulfill, including: decreasing soil erosion; carbon cycling; provision of human enjoyment (*e.g.*, hiking, berry-picking, camping, *etc*.); and provision of habitat to wildlife (including food, cover from predators, nesting sites, *etc*.). These functions are not fulfilled by single species or types of plants in an area, but by the community as a whole (*e.g.*, trees may provide nesting sites, grasses may provide cover from predators, and understory plants may provide seeds and berries that are eaten by wildlife).

The selection of the community *versus* a single species as the VEC of concern is highlighted in a recent paper (Anand and Desrochers, 2004). The authors compared a single species metric (in this case, amount of cover provided by either paper birch (*Betula papyrifera*), wavy hair grass (*Deschampsia flexuosa*) or blueberry (*Vaccinium angustifolium*)) to a community metric (in this case Shannon diversity index, which uses the number of species and species dominance in a measure of diversity). The two approaches were evaluated at sites located at various distances from the Coniston smelter in Sudbury, including two sites that have undergone "regreening". Anand and Desrochers (2004) indicated that only the community metric (diversity) shows a consistent relationship (increase) with distance from the smelter. The single species cover metric showed no relationship with distance from the smelter. The authors concluded that, although the study of single species provides some information, it may be misleading to use these data for an assessment of a larger process, such as ecosystem "recovery". Therefore, because no one plant species is indicative of a community, and the concern in Sudbury is for "recovery" or protection of more than a single species, the current ERA evaluated terrestrial plants as a community (or several communities), and, therefore, it was not necessary to identify individual plant species as VECs. The blueberry was one exception and is discussed in more detail below.

Four general plant "communities" have been described for the Sudbury Area (Amiro and Courtin, 1981). The first is "barren" land, completely devoid of trees, that includes the areas immediately surrounding the smelters. In the 1970s, the barren area was estimated to cover 20,000 ha. The second area is comprised of two communities, the "transition birch" and "transition maple" (this area is also referred to as semi-barren or the transition zone). During the 1970s, the extent of the semi-barrens was estimated to be 80,000 ha. Beyond this transition zone, the Sudbury landscape returns to what is considered the natural plant community of the region, which includes red oak (*Quercus rubra*), jack pine (*Pinus banksiana*), birch, maple (*Acer* sp.), sugar maple (*A. saccharum*), largetooth aspen (*Populus grandidentata*) and poplars (*Populus* sp.) (Courtin, 1995). In 1993 (Sinclair, 1996), the following plant communities were found: birch/pine community, trembling Aspen community, big-toothed aspen community, red oak community, white birch community, and an association of sites termed the Treeless community (*i.e.*, barrens). These general plant communities serve as the starting point for addressing risks to and recovery of vegetation. The spatial extent of the barren and semi-barren areas was discussed in Volume I. Plant communities in the Sudbury area were assessed in detail for the terrestrial ERA as described in Chapter 3.0 of this volume.

Blueberries are widely distributed throughout the study area and have special economic and social value in Sudbury, which makes them an important VEC. Blueberries prefer well-drained, acidic soils (pH 4.0 to 5.5) and full exposure to sunlight (NB DAFA, 2003), which are two conditions present in the semi-barren areas. Therefore, it is possible that some remedial activities (*e.g.*, liming and fertilizing of soil) to promote shrub and tree growth could adversely affect blueberries in some areas. Blueberries were not specifically evaluated in the ERA but were included as a VEC for the ERA in recognition of their social-economic importance and to help ensure these considerations are not overlooked during future risk management.

Terrestrial plants within private property in residential areas, including grass, flowers, ornamental trees and vegetables, are not included as part of the ERA. Residents routinely amend their soil, as shown by the less acidic soil pH measurements for residential areas and gardens in Sudbury. In addition, there have been few complaints from residents regarding difficulties with growing grass, trees, flowers, *etc.*, with the exception of some past complaints directly related to SO_2 fumigation. Therefore, due to the lack of widespread concern about the growth or yield of plants on private residential property, these groups of plants are not recommended as VECs for the ERA. However, metal uptake into vegetables was evaluated as part of the human health risk assessment.

Soil communities contain diverse populations of decomposers, predators, microbial symbionts, pathogens, and parasites. This group of organisms is not considered to have any social importance by the average citizen but they perform very important ecological functions. These organisms facilitate soil formation, organic matter breakdown, nutrient cycling, and thus contribute to, overall soil fertility. They also provide food to wildlife. The quality of the soil, its fertility, and structure are essential for the maintenance of the biodiversity and dynamics of terrestrial ecosystems (Wentsel *et al.*, 2003). It has previously been suggested that plants and soil-dwelling organisms may be more at risk to atmospheric emissions from smelters than wildlife (Welbourn, 1996). Therefore, soil invertebrates *(e.g.,* earthworms) were identified as VECs under this objective. The toxicity of Sudbury soil to earthworms was evaluated directly through laboratory testing. In addition, qualitative observations on the relative abundance of earthworms in the study area were made during the field investigations. The results of these studies are provided in Chapter 3.0 of this report.

Soil fungi play important roles in soil function, particularly in decomposition and nutrient dynamics. Mycorrhizal fungi play a particularly important role as they are symbiotic with higher plants, considerably enhancing nutrient uptake into plant tissue as well as playing other roles, depending on type. Metal pollutants have been shown to have impacts on both the number of fungal fruiting bodies and in the structure of the fungal community, and this has been confirmed to be the case in previous studies at Sudbury (Gunn, 1995). However, simple enumeration of the extent of mycorrhizal infection is not necessarily a valid measure of impact. Some mychorrizae are removed by exposure to high concentrations of metals, whilst others are resistant to metals and can infer this resistance to their host plants. Soil mycorrhizal fungi were not included as a VEC for the risk assessment and not considered further in this report.

2.4.2 VECs for Objective #2: Evaluate Risks to Terrestrial Wildlife Populations and Communities due to COC and Objective #3: Evaluate Risks to Individuals of Threatened or Endangered Terrestrial Species Due to COC

Lists of avian and mammalian species present in the Sudbury area, as well as species identified as being of special interest to Sudbury residents, are provided in Appendix A. Consideration also was given to species that may have been present in the Sudbury area in the past, but which are no longer present due to their sensitivity to current conditions. The Ontario Ministry of Natural Resources and several Laurentian University biology professors and researchers were contacted to determine whether any such wildlife species could be identified. Only the Peregrine falcon and ruffed grouse were identified as species that were formerly locally-extirpated; these species are now found in Sudbury, and were considered during VEC selection.

Threatened and endangered species and other species of concern were identified by reviewing the Federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and Natural Heritage Information Centre (NHIC) databases and by contacting the local Ministry of Natural Resources (MNR, 2003a,b pers. comm.) office in Sudbury. Only vulnerable, threatened or endangered (VTE) species that are present in the Study Area were identified as VECs, because there could have been numerous reasons, unrelated to the smelters, for species to have become extinct or locally extirpated.

No species were reported as threatened or endangered within the City of Greater Sudbury (MNR, 2003a pers. comm.). One species, the Wood Turtle, was listed as vulnerable for the general area (see discussion in Section 2.4.3 regarding reptiles). The VTE species outside, but within a 100 km radius of, the City of Greater Sudbury (MNR, 2003b pers. comm.) include:

- Bald Eagle (endangered) (nest sites observed);
- Peregrine Falcon (endangered) (nest sites observed);
- Red-shouldered Hawk (vulnerable) (nest sites observed); and,
- Eastern Massasauga Rattler (threatened) (see discussion in Section 2.4.3).

Selection criteria were developed and applied to reduce the candidate lists of mammalian and avian species, presented in Appendix A, to a manageable number, while ensuring adequate representation from all relevant trophic levels and feeding guilds. The approach to developing the VEC selection criteria was a Sudbury-specific approach modified from the approach outlined by Suter (1993), Becker *et al.*, (1998) and U.S. EPA (1998). Criteria used to select avian and mammalian VECs for this study included:

- VTE species (sensitive species);
- Resident or reproduces in the Sudbury area (thereby exposed to COC during a sensitive life stage);
- Ecological significance (a VEC which is "ecologically significant" is one that helps sustain the natural structure, function and biodiversity of an ecosystem or its components [U.S. EPA, 1998]; non-native or pest species were considered to have low ecological significance);
- Identified by a stakeholder as being important;
- Has socio-economic importance (*e.g.*, moose) and therefore a direct connection to the human health risk assessment (*e.g.,* is hunted and consumed by Sudbury residents);
- Had potential for high exposure to the COC (this reflects a close association with soil for terrestrial species [*e.g.,* consumes soil invertebrates rather than flying insects], small home range, high food intake relative to body weight);
- Information existed on populations in the area;
- Toxicity data for the COC were available for closely-related species (*e.g.*, laboratory rat and mouse data were considered appropriate for small wild rodents such as shrews, voles, mice, rats, squirrels, moles); and
- Represented a major feeding guild (and trophic level).

These ranking criteria were evaluated to determine which species would be selected as the representative VEC for a particular feeding guild. The criteria that applied to each species ("yes" scores) were summed. The highest ranked species <u>for each feeding guild</u> was recommended (see Tables 2.2 and 2.3). In some cases, a herbivore (*e.g.,* vole) and insectivore (*e.g.,* shrew) were both chosen as VECs over a single omnivore (*e.g.,* mice) even though mice ranked the same as vole and shrew. A summary of the selected VECs for each region of the Study Area is provided in Table 2.4.

Table 2.2 Ranking of Mammalian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	*Selection Criteria*									
	Status			Societal importance		Exposure Evaluation				
Mammals	VTE	Resident or Breeds in Area	Ecological Significance	Identified by Stakeholder	Link to Human Health	High Exposure Potential	Feeding Guild	Information on Local Populations	Toxicity Data Available for COC	Total No. of "Y"
Shrews (5 species)	No	Yes	Yes	Yes	No	Yes	I	Yes	Yes	6
Moles (2 species)	No	Yes	Yes	No	No	Yes	I	No	Yes	4
Bats (2 species)	No	Yes	Yes	No	No	No	I	No	No	2
Snowshoe hare	No	Yes	Yes	Yes	Yes	Yes	H	No	No	5
Chipmunks (2 species)	No	Yes	Yes	No	No	Yes	H	Yes	Yes	5
Woodchuck	No	Yes	Yes	No	No	No	H	No	No	2
Squirrels (3 species)	No	Yes	Yes	No	No	No	H	Yes	Yes	4
Beaver	No	Yes	Yes	Yes	No	A, Yes	H	Yes	No	5
Voles (2 species)	No	Yes	Yes	Yes	No	Yes	H	Yes	Yes	6
Muskrat	No	Yes	Yes	No	No	A, Yes	H	No	No	3
Norway Rat	No	Yes	No	No	No	Yes	H	No	Yes	3
Mice (3 species)	No	Yes	Yes	Yes	No	Yes	H, I	Yes	Yes	6
Porcupine	No	Yes	Yes	No	No	No	H	No	No	2
Coyote	No	Yes	Yes	No	No	No	C	No	No	2
Gray Wolf	No	Yes	Yes	No	No	No	C	No	No	2
Red Fox	No	Yes	Yes	Yes	No	No	C	Yes	No	4

Table 2.2 Ranking of Mammalian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	Selection Criteria									
	Status			Societal importance		Exposure Evaluation				
Mammals	VTE	Resident or Breeds in Area	Ecological Significance	Identified by Stakeholder	Link to Human Health	High Exposure Potential	Feeding Guild	Information on Local Populations	Toxicity Data Available for COC	Total No. of "Y"
Black Bear	No	Yes	Yes	Yes	Yes	No	H, P, I	No	No	4
Raccoon	No	Yes	Yes	No	No	No	I, H	No	No	2
Mustelids (Marten, Fisher, Weasel)	No	Yes	Yes	No	No	No	C	No	No	2
Mink	No	Yes	Yes	No	No	A, Yes	P	Yes	Yes	5
Striped Skunk	No	Yes	Yes	No	No	Yes	I, C	No	No	3
River Otter	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Canada Lynx	No	Yes	Yes	No	No	No	C	No	No	2
Wapiti (Elk)	No	Yes	Yes	Yes	Yes	No	H	Yes	No	5
White-tailed Deer	No	Yes	Yes	Yes	Yes	No	H	No	No	4
Moose	No	Yes	Yes	Yes	Yes	A, No	H	No	No	4

Notes:
VTE indicates Vulnerable, Threatened or Endangered Species.
Ecological Significance reflects role in ecosystem as important predator or prey species. Non-native species or pest species are not considered to have ecological significance.
High Exposure Potential reflects close association with soil, primarily through feeding behaviour, small home range, and high food intake relative to body weight. Species which feed primarily from the aquatic environment are indicated by an "A", and are assumed to have a high potential for exposure to COC in the aquatic environment.
Feeding Guild indicated by P (piscivore), H (herbivore, includes species that eat vegetation, fruit, seeds, *etc*.), C (carnivore, includes species that consume carrion), I (insectivore, includes benthivores and vermivores).
Shading indicates highest ranking species, selected as VECs.

Table 2.3 Ranking of Avian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	Selection Criteria: Status			Societal importance		Exposure Evaluation		Effect Information		
Birds	VTE	Resident or Breeds in Area	Ecological Significance	Identified by Stakeholder	Link to Human Health	High Exposure Potential	Feeding Guild	Information on Local Populations	Toxicity Data Available for COC	Total No. of "Y"
Common Loon	No	Yes	Yes	Yes	No	A, Yes	P	Yes	No	5
Pied-billed Grebe	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Double-crested Cormorant	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Great Blue Heron	No	Yes	Yes	Yes	No	A, Yes	P	No	No	4
American Bittern	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Turkey Vulture	No	No	Yes	No	No	No	C	No	No	1
Canada Goose	No	Yes	Yes	Yes	No	No	H	No	No	3
Ducks (several species including Mallard)	No	Yes	Yes	No	No	A, Yes	IH	No	Yes	4
Osprey	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Northern Harrier	No	Yes	Yes	No	No	No	C	No	No	2
Hawks (several species)	No	Yes	Yes	No	No	No	C	No	No	2
Falcons (2 species)	Yes	Yes	Yes	Yes	No	No	C	Yes	No	5
Ruffed Grouse	No	Yes	Yes	Yes	Yes	Yes	H	Yes	Yes	7
Rails (2 species)	No	Yes	Yes	No	No	A, Yes	I	No	No	3
Sandhill Crane	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Plovers (3 species)	No	No	Yes	No	No	A, Yes	I	No	No	2
Kildeer	No	Yes	Yes	No	No	A, Yes	I	No	No	3

Table 2.3 Ranking of Avian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	*Selection Criteria*									
	Status			Societal importance		Exposure Evaluation		Effect Information		
Birds	VTE	Resident or Breeds in Area	Ecological Significance	Identified by Stakeholder	Link to Human Health	High Exposure Potential	Feeding Guild	Information on Local Populations	Toxicity Data Available for COC	Total No. of "Y"
Sandpipers (several species)	No	Yes	Yes	No	No	A, Yes	I	No	No	3
Common Snipe	No	Yes	Yes	No	No	A, Yes	I	No	No	3
American Woodcock	No	Yes	Yes	No	No	A, Yes	I	No	No	3
Gulls (3 species)	No	Yes	Yes	No	No	A, Yes	C, H, P	No	No	3
Caspian Tern	No	No	Yes	No	No	A, Yes	P	No	No	2
Doves (2 species)	No	Yes	Yes	No	No	No	H	No	No	2
Black-billed cuckoo	No	Yes	Yes	No	No	Yes	I	No	No	3
Owls (3 species)	No	Yes	Yes	No	No	No	C	No	No	2
Nighthawks (2 species)	No	Yes	Yes	No	No	No	I	No	No	2
Chimney Swift	No	Yes	Yes	No	No	No	I	No	No	2
Ruby-throated Hummingbird	No	Yes	Yes	No	No	No	H	No	No	2
Belted Kingfisher	No	Yes	Yes	No	No	A, Yes	P	No	No	3
Woodpeckers (6 species)	No	Yes	Yes	No	No	No	I	No	No	2
Flycatchers (8 species)	No	Yes	Yes	No	No	No	I	No	No	2
Northern Shrike	No	No	Yes	No	No	No	I, C	No	No	1
Vireos (4 species)	No	Yes	Yes	No	No	Yes	I	No	No	3
Jays (2 species)	No	Yes	Yes	Yes	No	No	H, I	No	No	3

Table 2.3 Ranking of Avian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	*Selection Criteria*									
	Status			Societal importance		Exposure Evaluation		Effect Information		
Birds	VTE	Resident or Breeds in Area	Ecological Significance	Identified by Stakeholder	Link to Human Health	High Exposure Potential	Feeding Guild	Information on Local Populations	Toxicity Data Available for COC	Total No. of "Y"
American Crow	No	Yes	Yes	No	No	No	H, I	No	No	2
Common Raven	No	Yes	Yes	No	No	No	H, I	No	No	2
Horned Lark	No	Yes	Yes	No	No	No	H, I	No	No	2
Swallows (5 species)	No	Yes	Yes	Yes	No	No	I	No	No	3
Chickadees (2 species)	No	Yes	Yes	No	No	No	H, I	No	No	2
Nuthatches (2 species)	No	Yes	Yes	No	No	No	H	No	No	2
Brown Creeper	No	Yes	Yes	No	No	No	I	No	No	2
Wren (2 species)	No	Yes	Yes	No	No	Yes	I	No	No	3
Kinglets (2 species)	No	Yes	Yes	No	No	No	I	No	No	2
Thrushes (5 species) + American Robin	No	Yes	Yes	Yes	No	Yes	I, H	No	No	4
Mimics (3 species)	No	Yes	Yes	No	No	Yes	I	No	No	3
European Starling	No	Yes	No	No	No	No	I, H	No	No	1
American Pipit	No	Yes	Yes	No	No	No	H, I	No	No	2
Waxwings (2 species)	No	Yes	Yes	No	No	No	H, I	No	No	2
Warblers (22 species)	No	Yes	Yes	No	No	No	I	No	No	2
Scarlet Tanager	No	Yes	Yes	No	No	No	I	No	No	2
Sparrows (11 species)	No	Yes	Yes	No	No	No	I	No	No	2

Table 2.3 Ranking of Avian Wildlife Species for Selection of Representative VECs for the ERA

Ecological receptors	*Selection Criteria*									
	Status			**Societal importance**		**Exposure Evaluation**		**Effect Information**		
<u>Birds</u>	**VTE**	**Resident or Breeds in Area**	**Ecological Significance**	**Identified by Stakeholder**	**Link to Human Health**	**High Exposure Potential**	**Feeding Guild**	**Information on Local Populations**	**Toxicity Data Available for COC**	**Total No. of "Y"**
Dark-eyed Junco	No	Yes	Yes	No	No	No	H	No	No	2
Longspurs (2 species)	No	No	Yes	No	No	No	H	No	No	1
Rose-breasted Grosbeak	No	Yes	Yes	No	No	No	H	No	No	2
Indigo Bunting	No	Yes	Yes	No	No	No	H	No	No	2
Bobolink	No	Yes	Yes	No	No	No	H	No	No	2
Blackbirds (7 species)	No	Yes	Yes	No	No	No	H	No	No	2
Baltimore Oriole	No	Yes	Yes	No	No	No	I	No	No	2
Finches (8 species)	No	Yes	Yes	No	No	No	I, H	No	No	2
House Sparrow	No	Yes	Yes	No	No	No	I, H	No	No	2

Notes:
VTE indicates Vulnerable, Threatened or Endangered Species.
Ecological Significance reflects role in ecosystem as important predator or prey species. Non-native species or pest species are not considered to have ecological significance.
High Exposure Potential reflects close association with soil, primarily through feeding behaviour, small home range, and high food intake relative to body weight. Species which feed primarily from the aquatic environment are indicated by an "A" and are assumed to have a high potential for exposure to COC in the aquatic environment.
Feeding Guild indicated by P (piscivore), H (herbivore, includes species that eat vegetation, fruit, seeds, *etc*.), C (carnivore, includes species that consume carrion), I (insectivore, includes benthivores and vermivore
Shading indicates highest ranking species, selected as VECs.

While some Stakeholders might disagree with aspects of the ranking protocol (*e.g.*, some Stakeholders may argue that raccoons, bears or crows are pests and, therefore, should be ranked lower, while others may argue that a link to human health is irrelevant for an ERA), the end result of the ranking was a list of species that are commonly evaluated in an ERA and that are representative of the species and foodwebs in Sudbury. In addition, two species were added at the request of the Technical Committee (White-tailed Deer, Red Fox). Therefore, the final list of wildlife VECs for Objectives 2 and 3 of the Sudbury ERA is:

Mammals

- Northern Short-tailed Shrew;
- Meadow Vole;
- Moose;
- White-tailed Deer;
- Red Fox;
- Beaver, and
- Mink (evaluated as part of the aquatic problem formulation in Chapter 5).

Birds

- American Robin;
- Ruffed Grouse;
- Peregrine Falcon;
- Common Loon (evaluated as part of the aquatic problem formulation in Chapter 5); and
- Mallard (evaluated as part of the aquatic problem formulation in Chapter 5).

Many of the species identified above could be exposed to COC throughout the study area, including wildland areas and within or close to the urban area. However, wide-ranging species (moose, deer) would forage minimally within the urban areas (Coniston, Falconbridge, Copper Cliff and Sudbury Core). Wildlife with an aquatic-based diet (mink, loon and mallard) would not forage within the urban areas of Coniston, Falconbridge or Copper Cliff due to the lack of lakes; these three VECs were considered in the aquatic problem formulation (Chapter 5). Therefore, VECs were evaluated in particular regions of the study area, as summarized in Table 2.4.

Table 2.4 Wildlife Valued Ecosystem Components Assessed in Various Regions of the Study Area

VEC	Falconbridge	Copper Cliff	Coniston	Sudbury Core	Zone 1	Zone 2	Zone 3
Northern Short-tailed Shrew	✓	✓	✓	✓	✓	✓	✓
Meadow Vole	✓	✓	✓	✓	✓	✓	✓
Moose					✓	✓	✓
White-tailed Deer					✓	✓	✓
Red Fox	✓	✓	✓	✓	✓	✓	✓
Beaver				✓	✓	✓	✓
American Robin	✓	✓	✓	✓	✓	✓	✓
Ruffed Grouse	✓	✓	✓	✓	✓	✓	✓
Peregrine Falcon	✓	✓	✓	✓	✓	✓	✓

2.4.3 Species Not Recommended as VECs

Soil microbes, reptiles, agricultural species, pets and a few particular species identified by Stakeholders were not recommended for evaluation in the ERA. The rationale for excluding these species groups is provided below.

<u>Soil Microbial Community</u>

The soil microbial community *per se* was not evaluated as a VEC. However, the functions it provides (*e.g*., litter decomposition) are considered measures that influence plant community success. Various soil parameters were included as measures for the plant community VEC (*e.g.*, soil nutrient levels, litter decomposition rates) rather than assessing the soil microbial community as an independent VEC. Litter decomposition by the soil microbial community was assessed by undertaking field trials using litter bags (see Chapter 3).

Consideration of the function of the soil microbial community rather than the diversity of the community is supported by recent work by U.S. EPA (2003) and a recent study in Sudbury (Anand *et al*., 2003). The Anand *et al.* (2003) study evaluated soil (excluding litter) microorganism diversity and dynamics and found few correlations between the microbial community and soil metal levels along a transect south from Coniston. Although lead concentrations were significantly correlated to microbial diversity, water-soluble manganese to microbial assemblage, and water-soluble zinc to microbial diversity, the authors concluded that the impact of metals on soil microbes was "not remarkable". In fact, microbial communities were most strongly influenced by soil moisture and phosphorus levels (Anand *et al*., 2003). In addition, although changes in soil microbial community and function can be measured (Maxwell, 1995), the importance of these changes to the plant community is not clear, at least in a quantitative way. For example, it is recognized that plants need nitrogen. There are many organisms and processes that provide nitrogen, including free-living microorganisms (such as cyanobacteria that are limited by low soil pH) and symbiotic microorganisms (such as *Rhizobium* associated with legumes, and the angiosperms-actinomycete symbiosis, which has the advantage of being able to function in a more acidic pH range) (Maxwell, 1995). The composition and function of microbes performing this function may vary on small spatial and time scales, and are influenced strongly by environmental factors (*e.g*., temperature, moisture). Therefore, it is the influence of the combination of soil characteristics, including nitrogen, on the plant community that is the concern, not the composition of the microbial community. Therefore, the terrestrial plant community is recommended as the VEC of concern, not the soil microbial community.

<u>Reptiles</u>

Reptiles were not selected as VECs for a number of reasons. First, the lack of metal toxicity data for reptiles prevents their evaluation *via* exposure and risk modelling. Toxicity tests cannot be conducted because there are no standardized tests for reptiles (Meyers-Schone, 2000). In many cases, an ERA will focus on a reptilian species only when there is a threatened or endangered reptile at a site (Meyers-Schone, 2000). The only vulnerable, threatened or endangered reptile found within the City of Great Sudbury is the Wood Turtle (vulnerable), which is found in the Vermillion River system. Sudbury is on the edge of the Wood Turtle's Canadian range (see Appendix A), and one of the main threats to its survival is habitat degradation (Litzgus, 1996). Although one of the most terrestrial members of this turtle family, it frequents streams, creeks and rivers, preferring clear streams with moderate currents (Litzgus, 1996). Because of these factors, and the fact that the Vermillion River, where this species is found, is primarily upwind of emissions from the smelters, the Wood Turtle was not selected as a VEC.

The Eastern Massasauga Rattler (threatened) has been sighted within a 100 km radius of Sudbury, southwest of the City of Greater Sudbury (refer to range map in Appendix A) but is not common. This snake is carnivorous, preying primarily on small rodents and birds and, therefore, is expected to receive a relatively low exposure to metals in soils. Therefore, the Eastern Massasauga Rattler was not selected as a VEC.

<u>Agricultural Species</u>

Agricultural species, including a variety of livestock and crops, are present within the Sudbury area (Appendix A of this Volume). The main farming area is located in the northwestern portion of the City of

Greater Sudbury, in the area known as Blezard Valley. This area is predominantly upwind of the smelters. The local office of the Ontario Ministry of Agriculture and Food (OMAF), and the local offices of the MOE, Vale Inco and Xstrata Nickel were contacted for information pertaining to agricultural species and possible concerns related to smelter emissions. They informed the SARA Group that no one has come forward with an official complaint regarding impacts to agricultural crops or livestock from smelter emissions within approximately the past decade, and previous concerns were related to SO_2 (OMAF, 2004 pers. comm.; MOE, 2004 pers. comm.; Val Inco, 2004 pers. comm.; Xstrata Nickel, 2004 pers. comm.). This was confirmed in 2006 by Vale Inco (Vale Inco, 2006 pers. comm.), Xstrata Nickel (Xstrata Nickel, 2006 pers. comm.) and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2006 pers. comm.). MOE was not able to confirm this, as it is not possible to check the records for complaints (MOE, 2006 pers. comm.). It is assumed that if agricultural producers were concerned or had detectable impacts from the smelters, one of Vale Inco, Xstrata Nickel, the MOE or OMAF would have been contacted. No such concerns or complaints have been expressed, as far as the SARA Group has been able to determine. Therefore, due to the low exposure potential, lack of evidence of an impact and relationship with human health rather than ecological integrity, agricultural species were not selected as VECs for the ERA.

<u>Pets</u>

Pets, such as cats and dogs, were identified as being of concern for some residents. Similar to livestock, pets are expected to receive lower exposure than wildlife species, because they typically live independent of the natural environment in man-made structures and consume food that is not obtained from the local ecosystem. Pets are not routinely assessed by ERA or HHRA (human health risk assessment) and no standard methods exist to assess risks to pets. The ERA is assessing risks to some wildlife that are similar to some pets (*e.g.*, fox are related to dogs). Therefore, pets were not selected as VECs for the ERA.

<u>Particular Species Identified by Stakeholders</u>

An important criterion when selecting VECs was whether or not the species had been identified by Stakeholders as being important or of concern (see Tables 2.2 and 2.3). However, not every species identified by a Stakeholder was selected as a VEC for the ERA. There are two main reasons for this. First, some species recommended by a Stakeholder, such as black bear and luna moth, were identified because they are plentiful (see Table 2.6). In the case of the bear, Stakeholders identified them as a problem because they are too plentiful. Second, the VECs selected for evaluation in the ERA could be considered surrogates for many species because they have a similar diet (*e.g.*, Ruffed Grouse was selected to represent herbivorous birds, such as the Blue Jay). Additional rationale for excluding species as VECs is provided in Table 2.6.

2.4.4 Summary of Terrestrial VECs Recommended for the ERA

The terrestrial VECs recommended for evaluation in the ERA include:

- Terrestrial plant communities;
- Blueberry;
- Soil invertebrates;
- Northern Short-tailed Shrew;
- Meadow Vole;
- Moose;
- White-tailed Deer;
- Red Fox;
- Beaver;
- American Robin;
- Ruffed Grouse; and
- Peregrine Falcon.

A summary of the rationale for the recommendation of each of the terrestrial avian and mammalian VECs is provided in Table 2.5. A summary of the rationale for excluding particular species or groups of species as VECs is provided in Table 2.6.

Table 2.5 Summary of Rationale for Recommendation of Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Recommendation
Terrestrial Plant Communities	Primary producers	- plants provide various functions, including: decreasing soil erosion, carbon cycling; provision of human enjoyment (*e.g.*, hiking, camping); provision of habitat to wildlife - the plant community is more relevant than selecting a particular species - have been studied by Laurentian University and others - toxicity data are available for individual species - site-specific data collected in 2004 can be used to supplement data in the literature

Table 2.5 Summary of Rationale for Recommendation of Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Recommendation
Blueberries	Primary producers	- plentiful in the Sudbury area, have economic and social value - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - have been studied by Laurentian University - habitat may be affected by restoration activities
Soil Invertebrate Communities	Primary consumers, decomposers	- invertebrates provide various important ecosystem functions, including: soil aeration and breakdown of organic matter; provision of food to wildlife - have been studied by Laurentian University - toxicity data in the literature are available - site-specific data collected in 2004 can be used to supplement data in the literature
Northern Short-tailed Shrew (*Blarina brevicauda*)	Invertebrate-eating small mammal populations; secondary consumer	- close contact with soil, small home range, and high food intake rate relative to body weight results in high exposure potential to COC - reported as plentiful in the Sudbury area (Dobbyn *et al*., 1994) - small mammals with small range identified by Stakeholders as requiring special attention at the Have Your Say Workshops - have been studied by Laurentian University - toxicity data are abundant for small mammals (primarily rats and mice) - shrews breed in the area and serve ecological functions (*e.g.*, as food to wildlife) - shrews were the highest ranking invertebrate-eating small mammals (see Table 2.1) and can represent other small mammals that consume soil and litter invertebrates (*e.g*., worms, insects, larvae, *etc*.) as well as omnivores such as mice.
Meadow Vole (*Microtus pennsylvanicus*)	Herbivorous small mammal populations; primary consumer	- close contact with soil, small home range, and high food intake rate relative to body weight results in high exposure potential to COC - reported as common in the Sudbury area (Dobbyn *et al*., 1994) - small mammals with small range identified by Stakeholders as requiring special attention at the Have Your Say Workshops - have been studied by Laurentian University - toxicity data are abundant for small mammals (primarily rats and mice) which are closely related to this species - voles breed in the area and serve ecological functions (*e.g.*, as food to wildlife) - voles were the highest ranking herbivores (see Table 2.1) and can represent other small mammals which consume plants (*e.g*., grass, seeds, roots, fungi, *etc*.) as well as omnivores such as mice.

Table 2.5 Summary of Rationale for Recommendation of Terrestrial VECs

VEC	**Feeding Guild and/or Trophic Level**	**Rationale for Recommendation**
Moose (*Alces alces*) and White-tailed Deer (*Odocoileus virginianus*)	Herbivorous large mammal populations; primary consumers	- elk, deer and moose are all ruminants, common in the area, and identified by Stakeholders as important. Moose and deer were recommended as VECs because they are hunted (social and economic value, link to human health), although deer are hunted more than moose. - moose forage in wetland areas on plants including aquatic species, whereas deer forage in farmland and suburban areas on various terrestrial plants. - there are few toxicity data for wild ruminants, and therefore the ERA will likely have to rely on toxicity data from studies with cattle. - however, due to Stakeholder concern and the link to human health, these species were recommended as VECs. Deer were added as a VEC specifically at the request of the Technical Committee. - elk were not added as VECs because they would be exposed to similar levels of COC as deer. - also, a recent study by Parker and Hamr (2001) concluded that the elk herd was not severely impacted or threatened by metal contamination. In addition, the fetuses evaluated were all exhibiting normal, healthy development (no impairment of ovulation, conception or gestational developmental processes) (Parker and Hamr, 2001). - finally, the elk population has been re-introduced and occurs only in one portion of the study area.
Red Fox (*Vulpes vulpes*)	Omnivorous mammal populations; primary consumer through top predator	- fox are omnivorous, feeding on whatever is available, including fruit and other vegetation in summer, birds and mammals in winter, invertebrates such as grasshoppers and beetles, and even crayfish. - fox were identified by Stakeholders as requiring special attention. - sightings are recorded for the Sudbury area, although no population studies have been conducted by local researchers - the ERA will have to rely on toxicity data from studies with dogs or rodents. - fox were specifically requested by the Technical Committee for inclusion in the ERA, although they have an opportunistic feeding strategy; the request was that they be considered as a representative predator.
American Beaver *(Castor canadensis)*	Herbivorous mammal populations with link to aquatic environment; primary consumer	- live and breed in urban lakes, and throughout the study area, which may result in high exposure to COC in the aquatic environment - reported as plentiful in the Sudbury area (Dobbyn *et al*., 1994) - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - have been studied by Laurentian University - there are no toxicity data for this species; however, data for small rodents (primarily rats and mice) can be used.

Table 2.5 Summary of Rationale for Recommendation of Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Recommendation
Mink *(Mustela vison)*	Piscivorous mammal populations; tertiary consumer (Evaluated in the Aquatic Problem Formulation; Appendix H)	- live and breed near lakes, and consume fish, amphibians, muskrat and other small mammals and marsh birds, which may result in exposure to COC in the aquatic environment - however, no piscivorous mammal was identified by Stakeholders as requiring special attention at the Have Your Say Workshops - reported as common in the Sudbury area (Dobbyn *et al*., 1994) - one local toxicity study is available - toxicity data are available for this species as it has been recognized as being sensitive to chemicals
American Robin (*Turdus migratorius*)	Invertebrate-eating bird populations; secondary consumer	- is common and breeds in Sudbury - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - feeds on worms and other soil and litter invertebrates which are in close contact with soils and therefore has potential for high exposure to COC in soil and diet - although toxicity data are not available for this species, robins are routinely evaluated in ERAs by using data from other bird species - robins and thrushes were the highest ranking invertebrate-eating birds (see Table 2.2) and may be representative of other invertebrate-eating or omnivorous birds, such as American woodcock
Ruffed Grouse (*Bonasa umbellus*)	Herbivorous bird populations; primary consumer	- non-migratory, therefore occur year-round and breed within the study area - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - hunted by local residents for food - have been studied by Laurentian University - ground-dwelling bird that feeds on seeds, buds, berries, insects and therefore has high potential for exposure to COC in soil and diet - toxicity data are available for closely-related species such as chickens and quail - ruffed grouse was the highest ranking herbivorous bird (see Table 2.2), and may be representative of other herbivorous birds
Peregrine Falcon (*Falco peregrinus*)	Endangered species; carnivorous bird populations; top predator	- re-introduced to the Sudbury area - breed in the Sudbury area, and there is some local information on these birds - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - due to Stakeholder concern and the fact that this species is endangered, Peregrine Falcon was recommended as a VEC. - falcons were the highest ranking carnivorous birds (see Table 2.2) and can represent other carnivorous birds such as owls, hawks and harriers.

Table 2.5 Summary of Rationale for Recommendation of Terrestrial VECs

VEC	**Feeding Guild and/or Trophic Level**	**Rationale for Recommendation**
Common Loon (*Gavia immer*)	Piscivorous bird populations; tertiary consumer (Evaluated in the Aquatic Problem Formulation; Appendix H)	- live and breed in urban lakes, and throughout the study area, and consume fish, which may result in high exposure to COC in the aquatic environment - common in the Sudbury area, and have been monitored by local naturalists for decades - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - loons were the highest ranking piscivorous bird (see Table 2.2) and may represent other fish-eating birds, such as great blue heron, which also was identified by Stakeholders as requiring special attention.
Mallard (*Anas platyrhynchos*)	Omnivorous bird populations; secondary consumer (Evaluated in the Aquatic Problem Formulation; Appendix H)	- live and breed in urban lakes, and throughout the study area, and consume benthic invertebrates and aquatic vegetation, which may result in high exposure to COC in the aquatic environment - no benthivorous bird or duck was identified by Stakeholders as requiring special attention at the Have Your Say Workshops; loons do eat some crayfish, and have been identified as a VEC - common in the Sudbury area - toxicity data are available for this species - may represent other benthivorous birds, including various duck species, as well as other invertebrate-eating shorebirds (*e.g.*, plover), which were ranked lower than ducks/mallard (see Table 2.2).

Table 2.6 Summary of Rationale for Excluding Potential Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Exclusion
Soil Microbial Communities	Decomposers	- soil microbes provide various functions that influence the plant community, including: soil development, litter decomposition, nitrogen fixation - have been studied by Laurentian University - strongly influenced by soil moisture, temperature and nutrients - not identified by Stakeholders as requiring special attention - functions that affect the plant community will be measured to help address impacts to the plant community VEC
Luna Moth	Primary consumer	- identified by Stakeholders because of their abundance in the Sudbury area - the significant number of birch trees, upon which the luna moth caterpillar depends (adult moths do not feed), has likely resulted in increased numbers of these moths being observed in the Sudbury area - the ERA will not evaluate risks to these moths, because of the observations that they are abundant in the area.
Pets	multiple	- identified by Stakeholders as requiring special attention - not routinely assessed by ERA or HHRA (human health risk assessment) - no standard methods available to assess impacts to pets - pets typically live independent of the natural environment in man-made structures and consume food that is not obtained from the local ecosystem - pets also are exposed to other chemicals such as those in veterinary products (*e.g.*, flea treatments) - the ERA is assessing risk to wildlife that are similar to some pets (*e.g.*, fox are related to dogs) - incorporated into HHRA through consideration of pets as possible mechanism for exposing people to chemicals (*e.g.*, soil on fur)
Livestock	Primary consumers	- not identified by Stakeholders as requiring special attention - no concerns or issues were brought to the SARA Group's attention during the course of the project - not routinely assessed by ERA or HHRA - no standard methods available to assess impacts to livestock - incorporated into HHRA through consideration of livestock as food for people
Home Garden Plants/Produce	Primary producers	- not broadly identified by Stakeholders as requiring special attention - not routinely assessed by ERA - people generally apply amendments to the soil to optimize plant growth (*e.g.*, lime, fertilizer, top soil) - incorporated into HHRA through inclusion of home garden produce into the exposure assessment (*e.g.*, vegetable garden survey conducted in Sudbury)

Table 2.6 Summary of Rationale for Excluding Potential Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Exclusion
Flying Insects	Variable, depending on species; primary consumers, secondary consumers	- not identified by Stakeholders as requiring special attention (with exception of luna moth discussed above) - toxicity data are available for the larval stage of many flying insects (*e.g.*, those that live as larvae in water or sediment) and therefore an aquatic ERA can evaluate this life stage of these organisms - no toxicity data are available for these species once they have emerged - no standard methods for estimating risk to grazing insects (those that feed on plant material) because invertebrates are assessed by estimating exposure to soil, water or sediment, not by estimating a dose from feeding
Reptiles	Variable, depending on species; secondary consumers, tertiary consumers	- turtle identified by Stakeholders as requiring special attention - not routinely assessed in ERA unless threatened or endangered species; the vulnerable Wood Turtle is found in the Vermillion River system - major cause for decreasing numbers of wood turtles is habitat loss; Sudbury is on the edge of its range in Canada - no toxicity data available to estimate risks to reptiles using standard modelling techniques
Black Bear (*Ursus americanus*)	Omnivorous large mammal populations; variable, depending on diet - primary, secondary and tertiary consumers	- black bear were identified by Stakeholders as being of concern - however, Stakeholders have commented that Black Bears are common in the area, to the point where they need to be trapped and moved away from the city. - bear have a varied diet, and a large home range; therefore, their exposure will be lower than that experienced by smaller mammals - there are no toxicity data for large mammals such as bears, and therefore the ERA would have to rely on toxicity data from studies with smaller mammals. - a link to the human health food chain may be present; however, this becomes an issue for the HHRA, not the ecological risk assessment
Snowshoe Hare *(Lepus anerucabys)*	Herbivorous mammal populations; primary consumer	- forages on grasses and other green vegetation, and berries when available, conifer buds and bark in the winter. - identified by Stakeholders as requiring special attention - no studies have been conducted by local researchers - there are few toxicity data for this species; toxicity data for small rodents (primarily rats and mice) would have to be used for some COC. - meadow vole was selected as the representative herbivorous VEC, although the habitat preferences of these two species are different (hare prefers forest, vole prefers meadows) - the Technical Committee has expressed concerns about the link to human health through people's consumption of hare. Therefore, this is an issue for the HHRA, and will not be considered in the ERA.
Canada Goose *(Branta canadensis)*	Omnivorous bird populations; primary and secondary consumers	- Canada Goose lives and breeds near lakes, consuming grass on shore and aquatic invertebrates - identified by Stakeholders at the Have Your Say Workshops - Canada goose is a large, migratory bird - no local toxicity study available - ruffed grouse were selected as VEC to represent herbivorous birds,

Table 2.6 Summary of Rationale for Excluding Potential Terrestrial VECs

VEC	Feeding Guild and/or Trophic Level	Rationale for Exclusion
		and robins for insectivorous (although more omnivorous during parts of the year) birds. Therefore this species was not recommended as a VEC, as other recommended VECs may act as surrogates for this species.
Blue Jay *(Cyanocitta cristata)*	Omnivorous bird populations; primary and secondary consumers	- blue jays consume mostly fruit and seeds, and some insects - identified by Stakeholders at the Have Your Say Workshops - no local toxicity study available - ruffed grouse were selected as VEC to represent herbivorous birds, and robins for insectivorous (although more omnivorous during parts of the year) birds. The robin may consume more invertebrates than the jay. Therefore this species was not recommended as a VEC, as other recommended VECs may act as surrogates for this species.
Swallows (various species)	Insectivorous bird populations; secondary consumers	- primarily consume flying insects (some species consume emergent aquatic insects) - identified by Stakeholders as requiring special attention at the Have Your Say Workshops - no local toxicity study available for these species - American robin was recommended as VEC to represent terrestrial invertebrate-eating birds and mallard as the VEC to represent benthivorous bird.
American Woodcock (*Scolopax minor*)	Insectivorous bird populations; secondary consumers	- primarily consume earthworms, which are not common in Sudbury (outside of urban areas) - not identified by Stakeholders as requiring special attention at the Have Your Say Workshops - no local toxicity study available for these species - prefers moist habitats - American robin was recommended as VEC to represent terrestrial invertebrate-eating birds, due to its smaller home range, the wide-spread habitat and more diverse diet as compared to woodcock.

2.5 Assessment Endpoints and Measures

Assessment endpoints for the ERA were selected for the different VECs identified in Section 2.4. An Assessment Endpoint is defined as an explicit expression of what is to be protected, defined by an ecological species (*e.g.*, the endangered Peregrine Falcon), population (*e.g.*, American robin) or community (*e.g.*, terrestrial plants) and a characteristic. A characteristic is an attribute that is important to protect and which is potentially at risk (*e.g.*, persistence). Assessment endpoints are neutral (U.S. EPA, 1998) and, therefore, they should not contain words like "protect", "maintain", or "restore" or indicate a direction for change, such as "loss" or "increase".

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

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

Population persistence could be affected directly (*i.e.*, as a result of direct toxicity of the COC on survival, growth or reproduction), or indirectly (*e.g.*, as a result of decreased habitat suitability, or COC effects on food resources). Both direct and indirect toxicity to wildlife are addressed in Chapter 4.

Assessment endpoints must be measurable directly or be assessable using surrogate measures (U.S. EPA, 1998). For example, presence of loons may be assessed directly because loon surveys have been undertaken for approximately 30 years in the Sudbury area. However, such surveys have not been completed/published for small mammals such as shrews and voles in Sudbury. Therefore, if the assessment endpoints are not directly measurable, then other "measures" may be used to evaluate the risk to the assessment endpoints. There are three categories of measures (U.S. EPA, 1998):

1. Measure of Exposure: a measure of chemical presence and movement in the environment and its contact with the VEC.

   Examples:

   - Concentrations of COC in soil; and
   - Concentrations of COC in wildlife dietary items.

2. Measure of Effect: a measure that describes a change in a characteristic of a VEC in response to a chemical to which it is exposed.

   Examples:

   - Number of shrews in an area (density); and
   - Laboratory mammalian toxicity test data from the literature.

3. Measure of Ecosystem and VEC Characteristics: measures that influence the behaviour and location of VECs, the distribution of a chemical, and life-history characteristics of the VECs that may affect exposure or response to the chemical.

   Examples:

   - Home range; and
   - Habitat requirements and preferences for the VEC.

Different measures were used to assess each VEC, depending upon the availability of data and the level of uncertainty in these data. Several measures were used to evaluate the lines of evidence for the plant and invertebrate communities in Chapter 3. Measures for wildlife VECs are described in Chapter 4. A summary of the VECs, assessment endpoints and measures is provided in Table 2.7

Table 2.7 Summary of VECs, Assessment Endpoints and Measures

VEC	Assessment Endpoint	Measurement Endpoints
Terrestrial Plant Communities	Presence of a self-sustaining forest ecosystem	- Concentration of COC in soil - Soil characterization parameters (e.g., organic matter, CEC, fertility) - Site-specific laboratory toxicity test results (northern wheatgrass, red clover, goldenrod and white spruce) - Site-specific plant community survey data (various measures of site biodiversity, ecological integrity, long-term site productivity, and soil and water conservation) - Site-specific measurement of decomposition and nutrient cycling (leaf litter bags)
Blueberries	Survival, growth and yield	- Concentration of COC in soil
Soil Invertebrate Communities	Survival and reproduction	- Concentration of COC in soil - Site-specific laboratory toxicity test results (earthworm, litter bags)
Avian and Mammalian Wildlife (excluding threatened and endangered wildlife)	Population persistence	- Concentration of COC in soil - Concentration of COC in diet - Wildlife toxicity data from the literature - Population information from the Sudbury area
Peregrine Falcon (Threatened and endangered Wildlife)	Survival and reproduction of individuals	- Concentration of COC in soil - Concentration of COC in diet - Wildlife toxicity data from the literature - Population information from the Sudbury area

2.6 Conceptual Model

A conceptual model is a written description and a visual representation of the relationships between VECs and the COC to which they may be exposed. Conceptual models can serve three purposes: 1) clarification of assumptions concerning the situation being assessed; 2) as a communication tool for conveying those assumptions; and, 3) providing a basis for organization and completion of the risk assessment (Suter, 1999). Conceptual models are powerful learning and communication tools when initiating an ERA, and they are easily modified as the ERA progresses and data gaps are filled. Conceptual models include identification and discussion of contaminated media, chemical migration pathways, exposure pathways and VECs. The conceptual model diagram for plants, terrestrial invertebrates and wildlife is provided in Figure 2-5.

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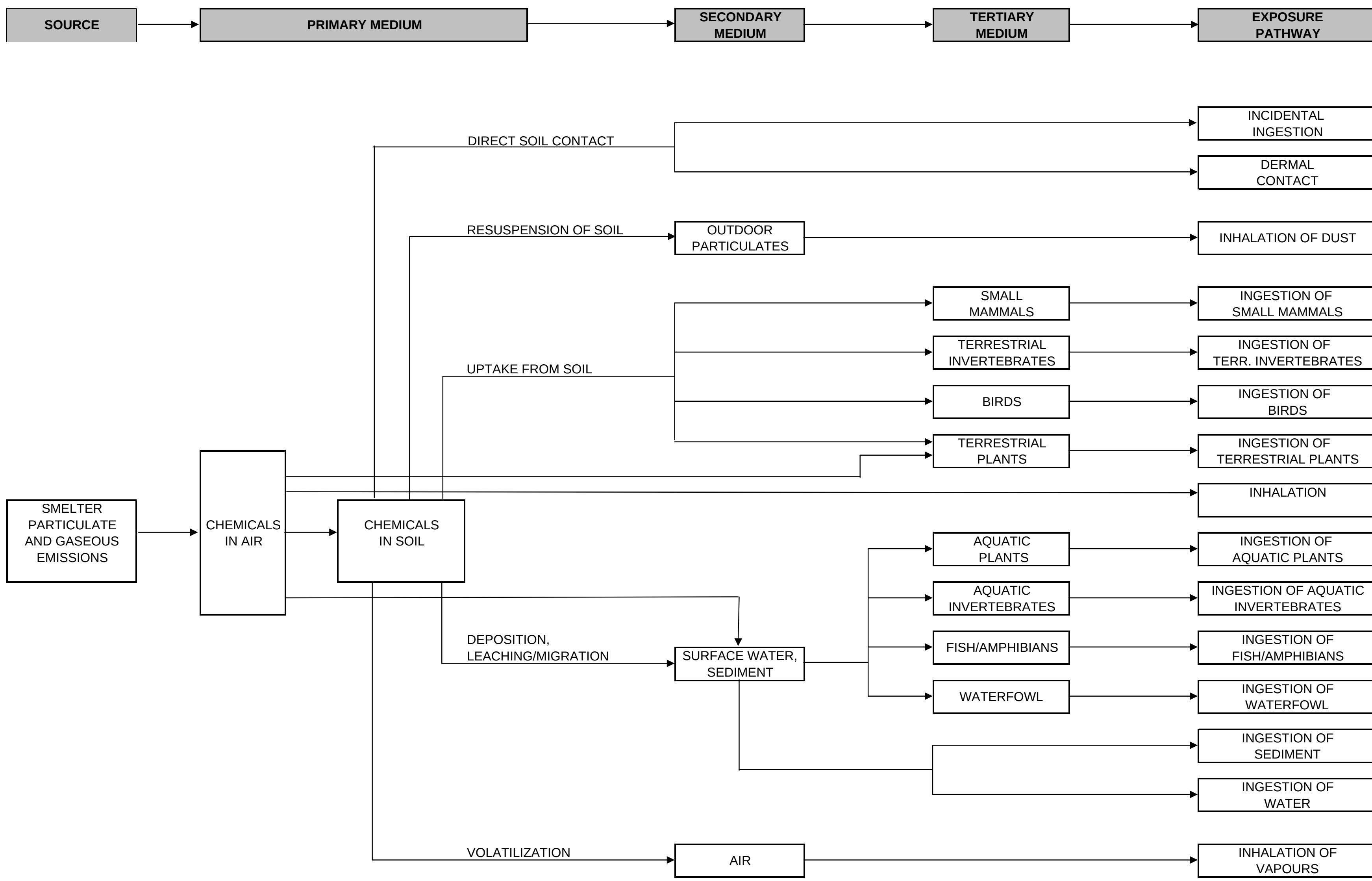

VALUED ECOSYSTEM COMPONENTS AND EXPOSURE PATHWAYS

EXPOSURE PATHWAY	Short-tailed Shrew	Meadow Vole	American Beaver	Moose	White-tailed Deer	Red Fox	Mink	American Robin	Common Loon	Mallard	Peregrine Falcon	Ruffed Grouse
INCIDENTAL INGESTION	√	√	√	√	√	√		√				√
DERMAL CONTACT												
INHALATION OF DUST												
INGESTION OF SMALL MAMMALS	√					√*	√*				√*	
INGESTION OF TERR. INVERTEBRATES	√							√				√
INGESTION OF BIRDS						√*					√*	
INGESTION OF TERRESTRIAL PLANTS	√	√	√	√	√	√		√		√		√
INHALATION												
INGESTION OF AQUATIC PLANTS			√	√						√		
INGESTION OF AQUATIC INVERTEBRATES							√		√	√		
INGESTION OF FISH/AMPHIBIANS							√		√			
INGESTION OF WATERFOWL							√*					
INGESTION OF SEDIMENT							√			√		
INGESTION OF WATER	√	√	√	√	√	√	√	√	√	√	√	√
INHALATION OF VAPOURS												

* Although red fox, mink and peregrine falcons consume birds (waterfowl, in the case of mink) in addition to small mammals, the model conservatively assumed that this part of the diet consisted of small mammals only, due to the availability of models to predict body burden in small mammals.
Check marks indicate pathway was assessed in the ERA; blank cells indicate pathway was not assessed.
Mink, loon and mallard are assessed as part of the Aquatic Problem Formulation in Chapter 5.

Figure 2-5: Conceptual Model for Terrestrial ERA

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Wildlife VECs may be exposed to chemicals via several potential exposure pathways, such as ingestion, inhalation and dermal contact. Chemicals may be ingested by consumption of food and water, and by incidental ingestion of soil or sediment. Chemicals may be inhaled if they are volatile, or if they are components of fine particulate matter. Dermal exposure occurs when chemicals are absorbed through the skin from soil, water or sediment.

Dermal exposure is assumed to be negligible for birds and mammals. Feathers on birds and fur on mammals reduce dermal exposure by limiting the contact of skin with chemicals in environmental media (Sample *et al*., 1997). In addition, metals do not cross the dermis, and are unlikely to be absorbed through skin (Watters *et al*., 1980). Inhalation exposure is also assumed to be negligible for birds and mammals, because the COC (*i.e.*, metals and metalloids) generally have low volatility, and resuspension of fine soil particles is minimized when there is adequate vegetative cover. Relevant inhalation toxicity data also are lacking for wildlife, which makes it difficult to assess ecological risks from this exposure route, especially for birds, but also for mammals where the toxicity endpoint often is not related to our ecological assessment endpoints of concern (*e.g*., lung irritation as opposed to reproduction). Therefore, only exposure *via* ingestion was evaluated in the ERA. This agrees with Environment Canada (EC, 1994) and British Columbia (BC MELP, 1998) guidance which acknowledges ingestion as the major pathway of concern for wildlife at contaminated sites.

2.7 Summary of the Problem Formulation

This step of the ERA collected and synthesized background information, identified the study area, and selected the COC for detailed evaluation. VECs were identified based on stakeholder input, availability of information on local populations, sensitivity to COC, ecological significance, socio-economic importance, and potential for exposure, to represent major feeding guilds and trophic levels. The conceptual model linking the COC released from the smelters to the VECs in the study area was developed in this chapter. Assessment endpoints were selected which are evaluated in Chapter 3 for plants and invertebrates, and in Chapter 4 for avian and mammalian wildlife. Aquatic VECs are discussed in Chapter 5. Reviews of available information were conducted for both the terrestrial and aquatic environments, and these are provided in Appendices C and H, respectively.

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