Nanisivik Mine

Human Health and Ecological Risk Assessment

CanZinco Ltd.

January 2003

PROJECT NO. NBF14333

REPORT TO

CANZINCO LTD.

ON

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT
NANISIVIK MINE, NUNAVUT

Jacques Whitford Environment Limited
711 Woodstock Road
P.O. Box 1116
Fredericton, NB
E3B 5C2
Tel: (506) 457-3200
Fax: (506) 452-7652
www.jacqueswhitford.com

January 30, 2003

EXECUTIVE SUMMARY

Jacques Whitford Environment Limited (JWEL) has performed a human health and ecological risk assessment (HHERA) of the Nanisivik Mine site on Baffin Island, Nunavut. The primary objective of this study was to evaluate whether known concentrations of elements in surface soil at the site would present a significant risk to human or ecological health based on future use of the property after mine closing. Future site re-development plans have not been finalized and the risk assessment considers three alternate scenarios for future land use: commercial, residential, and recreational/hunting.

Study background

Nanisivik Mine is an underground zinc-lead mine that is owned and operated by CanZinco Ltd. (CanZinco), a division of Breakwater Resources Ltd. The mine is located on the Borden Peninsula on northern Baffin Island in the Canadian Arctic at 73^{o} 02' N, 84^{o} 31' W. The mine site is located on the south shore of Strathcona Sound approximately 30 km from Admiralty Inlet. The nearest community is Arctic Bay, located approximately 25 km west of Nanisivik and linked by a 33 km all-weather road. The airport is located approximately 9 km south of Nanisivik and accommodates flights to and from Ottawa, Iqaluit and Resolute. Mining and milling at the site has been ongoing since 1976. Due to depleted levels of economically recoverable reserves, the mine stopped producing zinc and lead concentrates in September 2002.

This report was prepared in partial fulfillment of the requirements of the Site Closure and Reclamation Plan, which was developed in accordance with the "Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories" (NWTWB 1990). This HHERA was based on accepted risk assessment standards including those published by Health Canada, the Canadian Council of Ministers of the Environment (CCME), and the United States Environmental Protection Agency (US EPA).

Data Compilation

The soil data selected for use in the risk assessment were compiled from three sources: a Phase II Environmental Site Assessment conducted by Gartner Lee Limited (GLL), on behalf of CanZinco in July 2002; a surface soil sampling program conducted by EBA Engineering Consultants Ltd. (EBA), on behalf of the Government of Nunavut in June 2002; and an extensive survey of metal (copper, lead, and zinc) concentrations in surficial soils throughout the mine area conducted by Nanisivik Mines Limited in 1985 as part of their mineral exploration activities in 1985. At the time of this 1985 survey, tailings were deposited underwater in West Twin Lake such that the dispersion of wind blown tailings (that commenced around 1991) did not affect the results.

Statistical analyses were run on both the current and background (1985) data sets to determine 95% upper confidence limits (UCLs) for each element in each study area. The primary purpose of these analyses was to determine representative exposure point concentrations (EPCs) and background soil concentrations (BSCs) for each area, for deriving potential risks associated with the identified soil concentrations. The EPC is considered to be a reasonable estimate of area-wide exposure of receptors to metals in surface soil.

Screening of Potential Chemicals of Concern

Elements included for consideration were all elements identified in the review of the GLL and EBA data at concentrations exceeding the generic CCME soil quality guidelines (CCME 1999). Generic CCME guidelines may be based on either ecological or human health protection and provide a protective initial screening of the site data. For the human health risk assessment, these elements were screened specifically against human health based generic guidelines and for the ecological risk assessment, they were screened specifically against ecologically based generic guidelines. In order of preference, these guidelines are taken from CCME (CCME 1999), Ontario Ministry of the Environment (OMOE 1996a), or the United States Environmental Protection Agency (US EPA).

Based on this screening, the elements carried forward to the quantitative risk assessments were the metals cadmium, copper, lead, silver, and zinc. Copper and silver were carried forward for the ecological risk assessment only as maximum soil concentrations for these metals were less than human health based generic guidelines.

Exposure Scenarios

The area of interest for the risk assessment was governed by the Nanisivik Mines Limited inferred lease and claim boundaries. This large area was subdivided into three smaller study areas based on probable future land use. This was done to allow for separate receptor, exposure, and land use scenarios. The area encompassing the town of Nanisivik covered approximately 29 hectares (ha) and was referred to as the 'town area'. The area encompassing the dock covered approximately 24 ha and was referred to as the 'dock area'. The remaining land (not including the town area and dock area) covered an area of approximately 4400 ha and was referred to as the 'general mine area'. Separate EPCs, BSCs, and exposure estimates were calculated for each area independently.

The town area was assumed to continue as residential land use, the dock area as commercial/light industrial land use, and the general mine area as recreational/hunting land use. Based on these land uses, the following conceptual models were developed:

Human Health

The conceptual model that forms the basis for the derivation of the human health soil quality site-specific threshold limits is as follows:

- A toddler aged 6 months to 4 years ingests and comes into dermal contact with surface soil contaminated with cadmium, lead, and zinc;

- A toddler aged 6 months to 4 years ingests wild game from hunting in the area. The wild game may have ingested or come into contact with surface soil contaminated with cadmium, lead, and zinc; and

- A person lives in Nanisivik from birth to 70 years of age and is exposed to cadmium by inhalation of soil-derived dust throughout their lifetime.

Ecological Health

Although risks of exposure to contaminated soils are the focus of this ERA, wildlife on the site may also take in metals when they drink surface water from the site. The main sources of drinking water to wildlife were assumed to include the Twin Lakes, Twin Creek and Chris Creek.

The potential exposure media for intake of metals include direct ingestion of surface water and soils, as well as metal uptake from eating plant material and animal (bird/mammal) prey at the Mine site. The major exposure pathway considered was ingestion. Inhalation and dermal absorption are also possible exposure pathways, but these are considered to be relatively minor by comparison to ingestion, and are not included as direct pathways in this ERA. Soil that adheres to fur or feathers is, for the most part, ingested by preening/licking activity and is included in the estimate of direct soil ingestion.

The selected receptors in the model are Gyrfalcon, Arctic fox, Ptarmigan and lemming. These receptors are considered to be representative of indigenous wildlife for the Nanisivik Mine area.

Risk Characterization

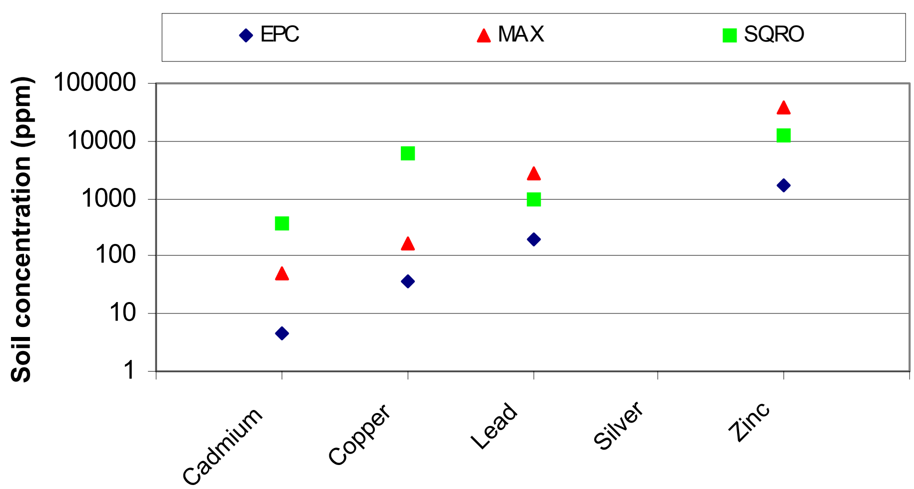
The above noted exposure scenarios were evaluated to identify the potential for adverse effects to human or ecological receptors, with the following outcomes:

- Surface soil EPCs of the identified elements are not anticipated to produce any adverse effects in the ecological receptors and exposure scenarios included in this risk assessment.

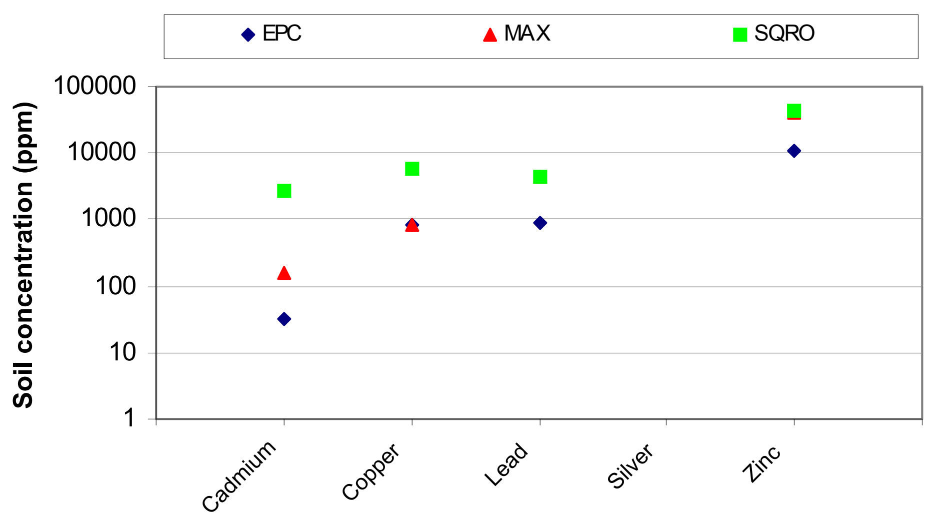
- Surface soil EPCs of the identified elements are not anticipated to produce any adverse effects in the human receptors and exposure scenarios included in this risk assessment.

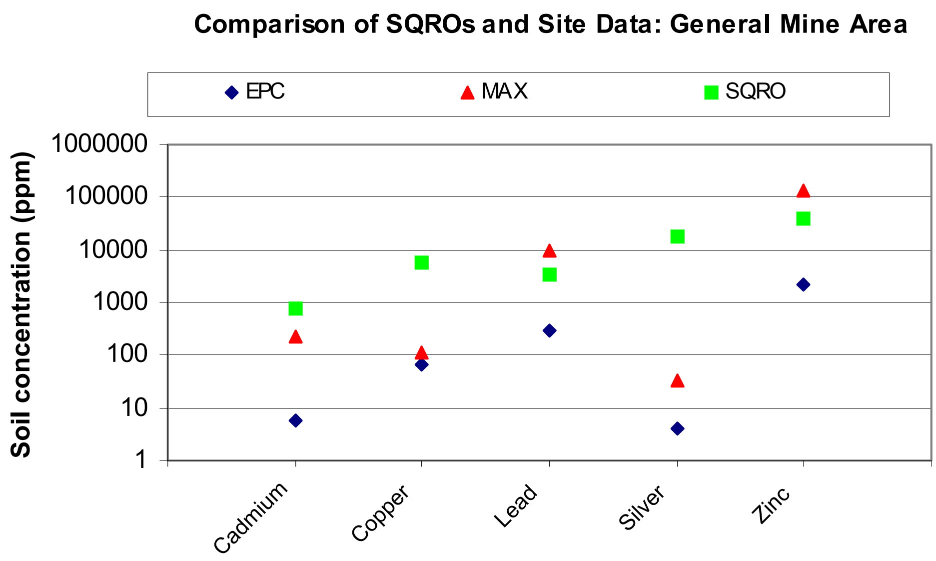
Soil Quality Remedial Objectives (SQROs) were then developed for each metal in each exposure area as the lowest of the ecological or human health site-specific threshold limits developed in this risk assessment. The SQROs were compared to current site conditions (EPCs, BSCs, and maximum concentrations). Results are summarized in graphs below for the town area, the dock area, and the general mine area.

Comparison of SQROs and Site Data: Town Area



Comparison of SQROs and Site Data: Dock Area





Maximum cadmium, copper, and silver surface soil concentrations were less than their SQROs, indicating that no remedial action is required for these metals.

Lead and zinc SQROs in the town area and general mine area are greater than their EPCs, indicating that there is no unacceptable area-wide impact. However, a limited number of sample concentrations exceeded the SQROs, indicating that localized hot spots may require risk management. No remedial action is required for the dock area.

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS (CONTINUED)

Page No.

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES, TABLES AND APPENDICES

FIGURES After Page No.

TABLES

Page No.

APPENDICES

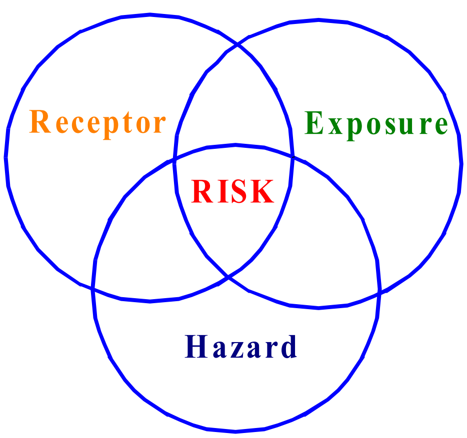
1.0 INTRODUCTION

Jacques Whitford Environment Limited (JWEL) was commissioned by CanZinco Limited (CanZinco) to complete a Human Health and Ecological Risk Assessment (HHERA) to develop surface Soil Quality Remedial Objectives (SQROs) for the Nanisivik Mine site on Baffin Island (Figure 1). The study addresses concerns regarding exposure to potentially hazardous metals in surface soil.

This report was prepared in partial fulfillment of the requirements of the Site Closure and Reclamation Plan, which was developed in accordance with the "Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories" (NWTWB 1990). This HHERA was based on accepted risk assessment standards including those published by Health Canada, the Canadian Council of Ministers of the Environment (CCME), and the United States Environmental Protection Agency (US EPA).

1.1 Scope and Objectives

The basic purpose of this study was to determine concentrations of potential contaminants of concern (COCs) in surface soil below which no adverse health effects would be expected. These site-specific SQROs are to be used in preparation for reclamation work at the Nanisivik Mine site. To meet this objective, a widely accepted risk assessment framework was adopted in which potential hazards, exposure pathways, and receptors are evaluated to determine if a risk is present, as illustrated in the diagram below:



The human health and ecological risk assessment framework comprises the following major components:

Hazard Identification: Identification of the environmental hazards that may pose a health risk (*e.g.* chemicals).

Receptor Identification: Identification of the human receptors and biota that may be exposed to the above hazard(s).

Toxicity Assessment: Identification of published, scientifically reviewed toxicity values against which exposures can be compared.

Figure 1 Site Location Map

Exposure Assessment: Qualitative or quantitative evaluation of the likelihood or degree to which the receptors will be exposed to the hazard.

Risk Characterization: Qualitative or quantitative assessment of the actual health risk of each hazard to each receptor, based on the degree of exposure.

Uncertainty Assessment: Review of the uncertainty associated with the risk estimation.

SQRO Determination: The determination of concentrations at the site below which no adverse effects would be expected.

The derivation of SQROs presented in this report follows the general methodology as outlined above. Specific tasks included:

- Review and compilation of existing data and a summary of past results;
- Qualitative risk screening to identify scenarios which are likely to present the greatest risk; and
- Quantitative risk analysis to develop SQROs for those scenarios which are most likely to present risk.

It is important to note that this report does not evaluate potential health issues that may have occurred in the past, rather it is designed only to evaluate current and potential future exposures to chemicals in soil, based on present day conditions.

1.2 Rationale

Generic or Tier I surface soil guidelines have been developed by the Canadian Council of Ministers of the Environment (CCME 1999). These guidelines are conservative benchmarks for screening purposes because if soil concentrations are less than these guidelines then the potential for human health effects is negligible. However, if soil concentrations exceed these guidelines it does not necessarily mean that unacceptable risks exist. The generic guidelines are internationally conservative, do not take into account regional or site-specific information (*e.g.,* background soil conditions) and may not be appropriate for every site or region of the country.

In fact, the protocol for CCME guideline development acknowledges that these guidelines are not set in stone but may be modified in some instances if supported by sound reasoning and/or by the provision of site-specific data. To do otherwise could result in disruptive remedial action that brings little or no health benefit. Deriving SQROs specifically for the Nanisivik Mine site is a more accurate way of assessing the human health significance of soil concentrations in the area.

Soil element concentrations were initially evaluated using the Canadian Environmental Quality Guidelines published by the CCME in 1999. SQROs were derived in accordance with the methods presented in the *Guidance Manual for Developing Site-Specific Soil Quality Objectives for Contaminated Sites in Canada* (CCME, 1996a) and *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996b).

The specific methods employed to develop the surface soil quality remedial objectives are consistent with CCME and Health Canada protocols as referenced above, and with standard human health risk assessment methodologies.

1.3 Organization of This Report

This report is presented in eleven sections. Section 1 describes the scope, objectives, and rationale of the risk assessment. Section 2 provides background information and summarizes previous reports. Section 3 describes the compilation and analysis of existing data for the risk assessment. Section 4 outlines the process by which the communities of Arctic Bay and Nanisivik were consulted to gather site-specific information relevant to the risk assessment process. Section 5 presents the general framework for the risk assessment. Section 6 presents the derivation of human health based site-specific threshold levels (SSTLs) for the COCs identified. Section 7 presents the derivation of the ecologically based SSTLs for the COCs identified. Section 8 provides the conclusions and recommendations of the report. Limitations of the work are discussed in Section 9. Section 10 provides closure. A list of references are provided in Section 11. Supporting information is provided in appendices at the back of the report.

2.0 STUDY BACKGROUND

2.1 Site Description

The Nanisivik Mine is located on the Borden Peninsula on northern Baffin Island in the Canadian Arctic at 73^{o} 02' N, 84^{o} 31' W (Figure 2). The Mine site is located on the south shore of Strathcona Sound approximately 30 km from Admiralty Inlet. The nearest community is Arctic Bay, located approximately 25 km west of Nanisivik and linked by a 33 km all-weather road. The airport is located approximately 9 km south of Nanisivik and accommodates flights to/from Ottawa, Iqaluit and Resolute. Nanisivik Mine is an underground zinc-lead mine that is owned and operated by CanZinco Ltd., a division of Breakwater Resources Ltd.. Mining and milling at the site has been ongoing since 1976. Due to depleted levels of economically recoverable reserves, the mine stopped producing zinc and lead concentrates in September 2002.

The climate at the site is typical of Canadian Arctic locations with cold temperatures and relatively low precipitation. There is snow cover approximately eight months of the year (October through May). The Mine site has a steep topography, rising to a height of 650 metres. Vegetation is sparse with virtually no soil except for thin soils that have developed in areas where wind blown material has collected. Twin Lakes Creek is the primary drainage in the area, draining East and West Twin Lakes, the town area, west adit area sub-watersheds and emptying into Strathcona Sound. Chris Creek drains surface water on the northeast side of the mine area into Strathcona Sound. Baseline studies prior to mine development indicated that neither creek supports fish populations and fish populations were also not present in East and West Twin Lakes.

Naturally occurring sulphide mineralization at surface is well documented throughout the mine area. Sands in the area, including the bottom of West Twin Lake, can be stained red due to oxidation. Natural exposures of mineralized, oxidized, weathered or gossan rock have been mapped in the area immediately north and northeast of the town, along the Area 14 road (to the southeast of the town), in Twin Lakes Creek and in other areas. These natural outcrops of mineralized rock contain high concentrations of heavy metals, including lead, zinc, copper and cadmium.

Figure 2 Site Plan of Nanisivik Mine

2.1.1 Mine Ownership

The Nanisivik Mine and related facilities are wholly owned by CanZinco Ltd., which is a division of Breakwater. CanZinco Ltd. is the sole operator of the Nanisivik Mine.

The property was optioned by Mineral Resources International Limited in 1972 who subsequently hired Strathcona Mineral Services Limited to manage the property. Development of the mine facilities took place from 1974 to 1976. Mining and milling commenced in 1976 and continued to September 2002, when the mine was closed permanently. The property was sold to CanZinco Ltd., a division of Breakwater Resources Ltd., in July of 1996.

The mine occupies land leased from the Government of Canada. Mine facilities on this land include:

- dock/concentrate storage shed area;
- mill/industrial complex including the diesel generating facility;
- administration offices;
- warehouse and storage yards;
- the town of Nanisivik;
- West Twin Lake Tailings Disposal Area;
- East Twin Lake fresh water supply;
- East Adit water treatment facility;
- open pits,
- rock dumps,
- landfill; and
- roadways.

2.1.2 Water License and Closure and Reclamation Plan

Operations at the Nanisivik Mine are governed by a Water License. The original Water License was granted by the Northwest Territories Water Board under the Northwest Territories Waters Act. The Nunavut Water Board assumed the responsibility for current Water Licenses in 1996 under the mandate of the Nunavut Land Claims Agreement Act.

Mining activities at the Nanisivik Mine were undertaken without interruption from 1976 to mine closure in September 2002. An evaluation of Nanisivik's mine operating in late 2001 indicated that the mine was no longer economic due to depressed metal prices, which were not anticipated to improve significantly to 2004. As a result of this evaluation, in September 2001 closure of the lead-zinc mine was announced for September 2002.

This HHERA has been conducted in accordance with the current Nanisivik Water Licence (Water Licence NWB1NAN0208), which came into effect on October 1, 2002. The Licence (Section G, Item 14) requires that a Human Health and Ecological Risk Assessment be conducted and submitted to the Nunavut Water Board for approval (Section G, Item 14). The HHERA was to be conducted in conjunction with a Phase II Environmental Site Assessment (Phase II ESA), which was completed by GLL (2002c). The purpose of the ESA was to identify and delineate areas of environmental concern as a prerequisite to finalization of environmental remediation measures. The purpose of the HHERA was to identify the most sensitive human and ecological receptors and use this information to develop site specific soil quality remedial objectives (SQROs). The work was to be conducted prior to the preparation of a Final Closure and Reclamation Plan.

2.2 Study Areas

The area of interest for the risk assessment was governed by the Nanisivik Mines Limited inferred lease and claim boundaries. This area encompassed all mine related facilities, including the town, all mining areas, the tailings disposal area, the industrial complex, the dock area, the landfill, and the Short Take Off and Landing (STOL) airstrip. This area generally included all land-based property from 14000E (approximately 2 km west of the town area) to 22000E (the western edge of Kuhulu Lake) and 13000N (just below East and West Twin Lakes) to Strathcona Sound, as outlined on Figure 2.

The large area incorporated by this study was subdivided into three smaller study areas based on probable future land use. This was done to allow for separate receptor, exposure, and land use scenarios. Future uses of the Mine site and facilities are currently being considered, and may include one or more of the following options:

- ongoing use of the dock storage area by Department of Fisheries and Oceans and Canadian Coast Guard as a storage facility for marine environmental response equipment and refueling;
- regional training centre for equipment operation, trades and other jobs; and
- military training base.

There are currently two closure concepts for the town facilities:

- demolition of all facilities, including demolition and reclamation of government owned facilities within the town; and,
- transfer ownership of some or all of the town facilities to other organizations for ongoing use.

The area encompassing the town of Nanisivik covered approximately 29 hectares (ha) and was referred to as the 'town area'. The area encompassing the dock covered approximately 24 ha and was referred to as the 'dock area'. The remaining land (not including the town area and dock area) covered an area of approximately 4400 ha and was referred to as the 'general mine area'. These areas are outlined on Figure 3.

2.3 Previous Reports

Since the mine opened, a number of studies have characterized the mine area in terms of contaminants that may be related to mining activities or to local conditions. Most recently, Phase 1 and 2 Environmental Site Assessments (ESAs) have been conducted as part of the Closure and Reclamation process.

Studies reviewed as part of this risk assessment included:

- Gartner Lee Ltd. 2002a. CanZinco Ltd. Nanisivik Mine Closure and Reclamation Plan. February 2002. Prepared for CanZinco Ltd.
- Gartner Lee Ltd. 2002b. Nanisivik Mine 2001 Environmental Site Assessment and Proposal for Phase 2 ESA. (Appendix to the Closure and Reclamation Plan). Prepared by Gartner Lee Ltd. for CanZinco Ltd.
- Gartner Lee Ltd. 2002c. 2002 Phase 2 Environmental Site Assessment. Nanisivik Mine, Nunavut, Site Characterization, prepared for CanZinco Ltd.
- B.C. Research Inc. 1975. Terrestrial Environmental Studies at Strathcona Sound, N.W.T., Progress Report No. 2 prepared for Strathcona Mineral Services, Project 1552.
- EBA Engineering Consultants Ltd. 2002. Soil Sampling Program. Nanisivik Town Site. Nanisivik, Nunavut. Final Report. Prepared by EBA Engineering Consultants Ltd. for Department of Sustainable Development, Nunavut.
- EBA Engineering Consultants Ltd. 2002. Letter to Paul Smith (Manager), Water Management, Government of Nunavut. Subject: July-02 Water Board Hearings, Nanisivik Mine Closure.
- Government of Nunavut. 2002. Follow-up Submission to the Nunavut Water Board on the Application by CanZinco Ltd. for a Water License, and for Approval of their Closure and Reclamation Plan.

Figure 3 Risk Assessment Study Areas

3.0 DATA COMPILATION

3.1 Sources

The soil data selected for use in the risk assessment were compiled from three sources. As part of their Phase II Environmental Site Assessment, Gartner Lee Limited (GLL), on behalf of CanZinco Limited (CanZinco), conducted a Phase II field investigation in July 2002 (GLL 2002c). Soil samples were taken from within the study area as defined in Section 2.2. Soil sample locations can be found on Figure 3. In parallel with this work, EBA Engineering Consultants Limited (EBA), on behalf of the Government of Nunavut (GN), conducted a surface soil sampling program in June 2002 (EBA 2002a). Soil samples for this investigation were limited to the vicinity of the town area.

The water data used in the Ecological Risk Assessment were taken from the Surveillance Network Program (SNP) portion of the existing Water Licence with the Nunavut Water Board. The data were collected over six years (1996 to 2001) from several sampling locations along Twin Lakes Creek and Chris Creek, and within East and West Twin Lakes. These data are part of a larger water quality data set collected since 1976 under the SNP.

The background data used as baseline information were extracted from an extensive survey of metal (copper, lead, and zinc) concentrations in surficial soils throughout the mine area conducted by Nanisivik Mines Limited in 1985 as part of their mineral exploration activities. The surface soil samples extended over a wide area, from the South Boundary Fault to Strathcona Sound and from Footprint Hill to Foreshore Flats. This data documented the range of metal concentrations that were present in surface soils in areas peripheral to mining actives as well as across some of the mineralized zones. At the time of this 1985 survey, tailings were deposited underwater in West Twin Lake such that the dispersion of wind blown tailings (that commenced around 1991) did not affect the results.

3.2 Selection of Data

3.2.1 Current Data

The soil sample data from the GLL and EBA soil sampling programs were screened for use in this risk assessment. For the purposes of the risk assessment for both human and ecological receptors, only soil samples that accurately reflect concentrations in the upper 10 to 15 cm from ground surface are relevant to potential exposures. The GLL and EBA were screened on the basis of depth and any sample that did not intersect the surface and/or extended to a depth of greater than 0.3 m below ground surface (mbgs) was excluded. This was done to ensure that the data used were representative of surface soil and not too heavily influenced by subsurface soil characteristics.

To verify that this screening was protective, an alternate data set was created that included all soil samples with any portion of the sample interval within the top 0.3 m of the soil profile. Exposure Point Concentrations (EPCs) calculated using this second data set were lower than the EPCs based on only the surface soil samples, confirming that the screened data set was protective of possible exposures.

All surface water samples were considered to be valid inputs for the risk assessment, therefore, all SNP water data from 1996 through 2001 were used.

3.2.2 Background Data

The soil geochemistry survey completed in 1985 included a large area beyond the Mine site as the purpose of the survey was to try to identify other potential mineral resources. For the purposes of defining background soil concentrations for the town area, dock area, and general mine area, only the portion of the available background data relevant to (*i.e.*, that fell within) the study area as defined in Section 2.2 were used in this risk assessment.

3.3 Data Validation

Because the data came from external sources and were manually transcribed, a Level 2 Validation check was completed for quality control. This consisted of a random 20 percent check of the original data versus the transcribed data, and was performed by a staff member external to the project.

3.4 Division of Data

As discussed in Section 2.2, the Mine site has been sub-divided into three areas for the risk assessment based on current and likely future land uses:

- The town area – assumed to continue as residential land use;
- The dock area – assumed to continue as commercial/light industrial land use; and
- The general mine area – assumed to be used for recreational and hunting purposes.

In order to provide area-specific estimates of risk and SQROs, both the current and background data sets were subdivided into these three areas for the calculation of EPCs and background soil concentrations.

3.5 Description of Data

3.5.1 Surface Soils

The EBA data were collected between June 9-12, 2002 and analysed for eighteen inorganics, including: Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Molybdenum, Nickel, Selenium, Silver, Strontium, Thallium, Tin, Vanadium, and Zinc. A total of 132 soil samples were collected, of which 109 samples were representative of surface soils within the town area and 23 were soil profile samples from within and outside of the town area. The GLL data were analysed for nineteen inorganics, including: Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Total Chromium, Hexavalent Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, Silver, Thallium, Vanadium, and Zinc. The 1985 background geochemistry data were analysed only for Copper, Lead, and Zinc.

3.5.2 Water

The water data were analysed for three inorganics: cadmium, lead, and zinc.

3.6 Statistical Analysis of Data

Statistical analyses were run on both the current and background data sets to determine distribution, median, mean, geometric mean, and 95% upper confidence limits (UCLs) for each element in each study area. The primary purpose of these analyses was to determine representative exposure point concentrations (EPCs) and background soil concentrations (BSCs) for each area, for deriving potential risks associated with the identified soil concentrations. All data were found to be log-normally distributed, hence the EPC and BSC were calculated as the 95% UCL on the geometric mean of the log-transformed data. The EPC is considered to be a reasonable estimate of the area-wide exposure to receptors of metals in surface soil.

In addition, a student t-test was run between the copper, lead, and zinc current and background data sets to determine if the data sets were statistically different.

4.0 COMMUNITY CONSULTATION

A limited consultation was conducted with local residents of Nanisivik and nearby Arctic to accurately depict the traditional historical and current use of lands, as well as to obtain information on possible ecological receptors in the area. The information received from this consultation was used to assess possible exposure scenarios and to select appropriate ecological receptors.

Interviews with local residents were conducted by Mr. Rob McCullough of JWEL and Mishak Allurut, a member of the local Inuktituk community who also served as translator. The interviews took place over two days (September 23-24, 2002) and were conducted in both English and Inuktituk. Copies of the High Arctic Community Questionnaire in both English and Inuktituk are presented in **Appendix A**. The interview candidates were solicited by placing advertisements on the local radio station and personally contacting the elders in the community. The limited consultation focussed on residents who identified themselves as hunters and/or fishermen and would therefore be most likely to make use of the land in the vicinity of the mine site after the closure and reclamation period. Persons not interviewed can be assumed to be on the land for hunting to a significantly lesser extent than those interviewed.

In total 16 people were surveyed; 14 male and 2 female, aged 40-73. Fourteen of the respondents lived in Arctic Bay and two were employees of Nanisivik Mines Limited and lived in the town area. One of the respondents did not complete the questionnaire and therefore was not included in compiling the responses. Although the majority of the respondents indicated that they did hunt and/or fish for food, very few indicated that hunting or fishing took place in or around the general Nanisivik mine area. The majority of the residents of Arctic Bay identified Admiralty and Moffet Inlets as well as locations across Strathcona Sound from Nanisivik (see Figures A-1 to A-15 in **Appendix A**) as the locations where they most often traveled to hunt and/or fish for food. The majority of respondents also indicated that they would be unlikely to hunt more often in the Nanisivik area after the mine is closed.

The most commonly identified prey items were Ptarmigan, landlocked char, seal (bearded, ringed, and harp), and rabbit. Fox, goose, caribou, Arctic char, and narwhal were also identified.

A list of survey respondents as well as a compilation of the responses to the interview questionnaire are presented in **Appendix A**.

5.0 RISK ASSESSMENT FRAMEWORK

To guide the conduct of the human health and ecological risk assessments, a common framework was developed as illustrated in Figure 4. The steps in this flowchart are described briefly below:

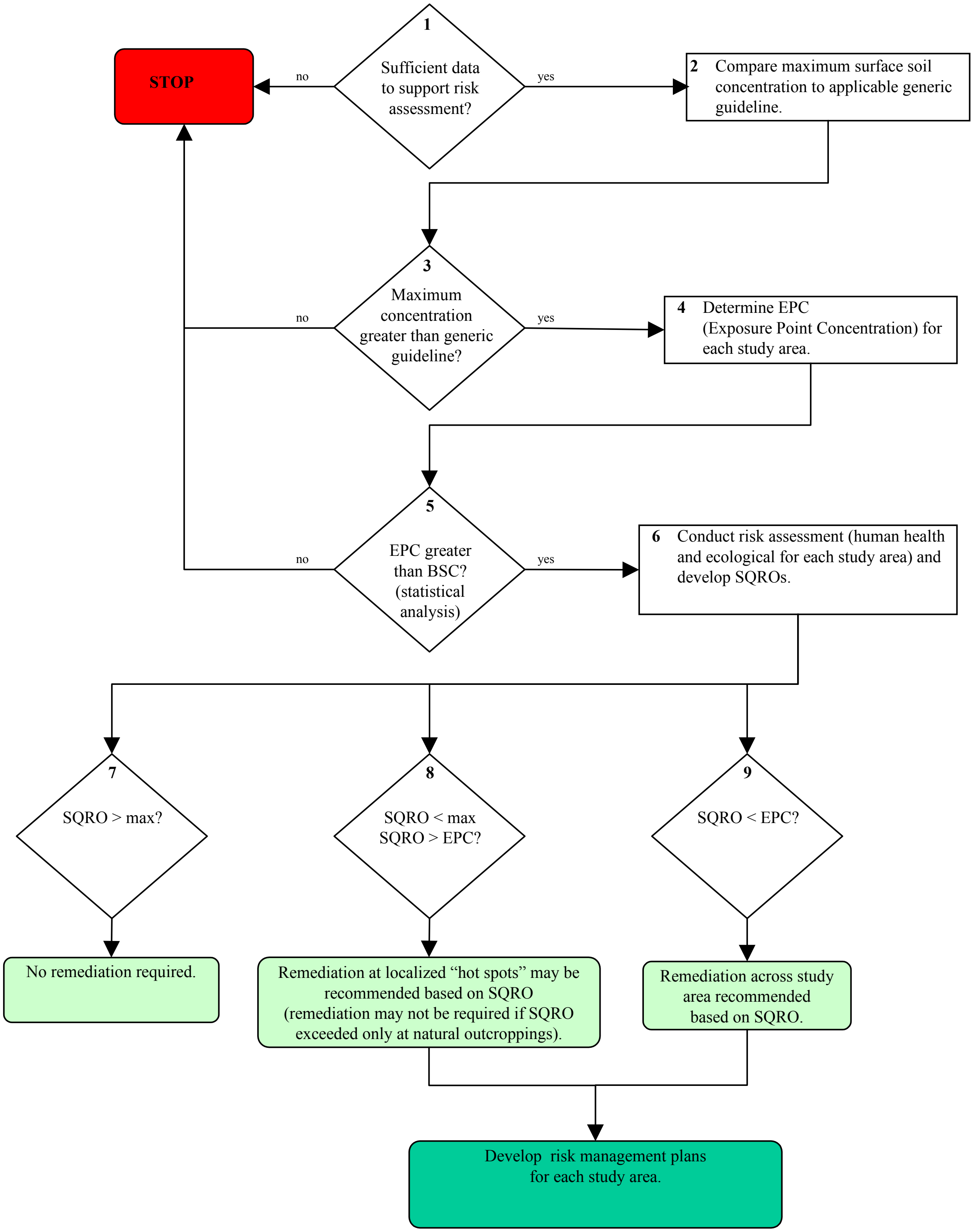
Box 1 *Sufficient data to conduct risk assessment?*
All of the GLL and EBA surface soil data supplied to JWEL was reviewed, however, in certain instances (*e.g.*, boron) only a very limited number of samples (<5) had been analyzed. A decision was made not to include such limited sampling in the risk assessment process.

Box 2 *Compare maximum concentrations to generic guidelines*
A distinction was made in this process between ecologically based and human health based guidelines. For the HHRA, results were screened against only human health based guidelines primarily taken from CCME and where these were not available from the Ontario Minstry of the Environment (OMOE). For the ERA, CCME ecologically based guidelines were used. Use of the maximum soil concentration as opposed to the EPC ensured a protective screening process.

Box 3 *Maximum concentration greater than generic guideline?*
If the maximum sample concentration from all of the GLL and EBA sampling reviewed was less than the appropriate generic guideline, then that metal was not carried forward into the quantitative risk assessment.

Box 4 *Determine the EPC*
A statistical analysis was completed on the combined data sets from GLL and EBA to compute the 95% UCLs on the log-transformed distribution. These values were adopted as the EPCs for each area and were used in the quantitative risk assessments to calculate potential risks and area-wide SQROs.

Figure 4 Risk Assessment Framework



Box 5 *EPC > BSC?*

It is important that current soil conditions are compared to natural background conditions to prevent remediation being recommended for naturally occurring conditions in the area. The 95% UCLs on the log-transformed distribution of the 1985 geochemistry survey were used as the BSCs for copper, lead, and zinc. For all other elements, the Ontario Typical Range (OTR_{98}) (MOEE, 1993) values were employed as an estimate of background conditions.

Box 6 *Conduct quantitative risk assessment*

Elements that exceeded generic guidelines and background concentrations were carried forward into the risk assessment process. This process was conducted independently for each element in each area (town area, dock area, general mine area) and for the HHRA and the ERA separately. In this way, the elements subject to ecological risk assessment were not necessarily included in the human health risk assessment and elements included in the town area were not necessarily included in the other areas. Site-specific threshold limits (SSTLs) were established for each element and each receptor. The lowest SSTL across all receptors for each element was chosen as the SQRO to be protective of all receptors at the mine site.

Box 7 *SQRO > Max?*

If the SQRO exceeds the maximum recorded soil concentration, then no further action is required.

Box 8 *SQRO < Max but >EPC?*

In this case, no unacceptable risks are predicted based on area-wide EPCs but there are localized hot spots of high metal concentrations that may require remedial action or risk management unless these samples represent naturally mineralized outcrops.

Box 9 *SQRO < EPC?*

In instance where the EPC exceeds the SQRO, there are potential risks from soil exposure over a wider area and more significant remediation or risk management would be required.

The above screening and risk assessment process is described in more detail for the human health and ecological risk assessments in Sections 6 and 7, respectively.

6.0 HUMAN HEALTH RISK ASSESSMENT

6.1 Risk Screening

6.1.1 Hazard Identification

Table 6.1 illustrates the screening of contaminants of potential concern (COPCs) in accordance with the flowchart outlined in Section 2. Metals included for consideration were all metals identified in the review of the GLL and EBA data at concentrations exceeding the generic CCME soil quality guidelines (CCME 1991, 1999). Generic CCME guidelines may be based on either ecological or human health protection and provide a protective initial screening of the site data. For the human health risk assessment, these metals are then screened specifically against human health based generic guidelines. In order of preference, these guidelines are taken from CCME (1999), Ontario Ministry of the Environment (1996a), or the United States Environmental Protection Agency (2002).

As indicated in Table 6.1, maximum silver, cobalt, copper, and nickel concentrations are less than their corresponding human health based soil quality guidelines. Boron was not analysed in samples collected from the town area. Therefore, these metals are not considered further in the town area. Concentrations of arsenic, cadmium, lead, thallium, and zinc exceed their human health based generic guidelines. Based on these results, these metals are carried forward for statistical analysis of the data and screening against natural background concentrations.

The exposure point concentrations (EPC) for arsenic and thallium are less than their background values (OTR_{98} data for rural parkland) and are not considered further in the town area. EPCs for cadmium and zinc exceed 1985 site-specific background data and/or OTR_{98} data for rural parkland. Therefore, these metals are carried forward to the quantitative risk assessment. The EPC for lead is not statistically different from the natural background data for the town area (1985 geochemistry survey of the mine area) however it is higher than background data for the general area and the OTR_{98} data for rural parkland. As it cannot be conclusively shown that the town area in 1985 was free of any influence from the mine operation, lead is also carried forward for quantitative risk assessment.

6.1.1.1 Dock Area

As indicated in Table 6.1, maximum concentrations of all metals considered are less than their corresponding human health based soil quality guidelines for industrial land use. Therefore, the dock area is not considered further in this report for human health risk assessment. It is assumed that the dock will remain as a light industrial/commercial facility and will not be residentially developed.

Table 6.1 Hazard Screening Procedure for Human Health Risk Assessment

Soil Concentrations			Generic Human Health Guidelines for Soil Ingestion						Background Soil Concentrations (BSC)					
Metal	**Minimum Observed Soil Concentration**	**Maximum Observed Soil Concentration**	**Appicable Guideline**	**Exceeds Y/N**	**Number of Samples**	**Number Exceeding Guideline**	**% Exceeding Guideline**	**Carried Forward**	**Exposure Point Concentration (EPC)**	**1985 Site Specific Background (SSB) 95% UCL**	**EPC/SSB Statistically Different? Y/N**	**OTR [1] Rural Parkland**	**EPC > BSC Y/N**	**Carried Forward Y/N**
TOWN AREA (Residential/Parkland)														
Ag	nd	8	98 [b]	N	109	0	0.00%	N	-	-	-	-	-	N
As	nd	50	12 [a]	Y	109	17	15.60%	Y	7.69	na	na	11	N	N
B	-	-	7000 [c]	N	0	0	0.00%	N [IN]	-	-	-	-	-	N [IN]
Cd	nd	50.2	14 [a]	Y	116	11	9.48%	Y	4.74	na	na	0.71	Y	Y
Co	1	112	2700 [b]	N	109	0	0.00%	N	-	-	-	-	-	N
Cu	8	166	1100 [a]	N	109	0	0.00%	N	-	-	-	-	-	N
Ni	2	87	310 [b]	N	109	0	0.00%	N	-	-	-	-	-	N
Pb	15	2720	140 [a]	Y	116	76	65.52%	Y	192.3	204.2	N	45	Y	Y [2]
Tl	nd	2	1 [a, p]	Y	109	10	9.17%	Y	0.57	na	na	0.81	N	N
Zn	90	38500	16000 [b]	Y	116	5	4.31%	Y	1706	322.8	Y	120	Y	Y
DOCK AREA (Industrial)														
Ag	1	11	240 [b]	N	3	0	0.00%	N	-	-	-	-	-	N
As	3.7	5.4	12 [a]	N	13	0	0.00%	N	-	-	-	-	-	N
B	2.2	2.2	180000 [c]	N	1	0	0.00%	N	-	-	-	-	-	N
Cd	5.1	156	2090 [a]	N	0	0	0.00%	N	-	-	-	-	-	N
Co	6	11	7200 [b]	N	3	0	0.00%	N	-	-	-	-	-	N
Cu	56	835	20000 [a]	N	3	0	0.00%	N	-	-	-	-	-	N
Ni	14	24	710 [b]	N	3	0	0.00%	N	-	-	-	-	-	N
Pb	67	4330	8200 [a]	N	0	0	0.00%	N	-	-	-	-	-	N
Tl	nd	1	32 [b]	N	3	0	0.00%	N	-	-	-	-	-	N
Zn	2020	41000	100000 [b]	N	29	0	0.00%	N	-	-	-	-	-	N
GENERAL MINE AREA (Residential/Parkland)														
Ag	nd	32	98 [b]	N	11	0	0.00%	N	-	-	-	-	-	N
As	nd	9.7	12 [a]	N	11	0	0.00%	N	-	-	-	-	-	N
B	nd	2.3	7000 [c]	N	5	0	0.00%	N	-	-	-	-	-	N
Cd	nd	230	14 [a]	Y	51	10	19.61%	Y	5.75	na	na	0.71	Y	Y
Co	6	35	2700 [b]	N	11	0	0.00%	N	-	-	-	-	-	N
Cu	10	108	1100 [a]	N	11	0	0.00%	N	-	-	-	-	-	N
Ni	10	29	310 [b]	N	11	0	0.00%	N	-	-	-	-	-	N
Pb	8	9350	140 [a]	Y	51	26	50.98%	Y	297.2	67.9	Y	45	Y	Y
Tl	nd	nd	1 [a, p]	N	11	0	0.00%	N	-	-	-	-	-	N
Zn	51	131000	16000 [b]	Y	51	6	11.76%	Y	2138	89.7	Y	120	Y	Y

[a] = CCME
[b] = MOEE
[c] = USEPA Region III
[p] = provisional guideline
[1] = Ontario Typical Range
[2] = Carried forward even though could have been screened out
"-" = Analysis not conducted
[IN] = insufficient data

6.1.1.2 General Area

As indicated in Table 6.1, maximum arsenic, boron, silver, cobalt, copper, nickel, and thallium concentrations are less than their corresponding human health based soil quality guidelines. Therefore, these elements are not considered further for the general mine area. Concentrations of cadmium, lead, and zinc exceed their human health based generic guidelines. Based on these results, these metals are carried forward for statistical analysis of the data and screening against natural background concentrations.

EPCs for cadmium, lead, and zinc exceed 1985 site-specific background data and/or OTR_{98} data for rural parkland. Therefore, these metals are carried forward to the quantitative risk assessment.

6.1.2 Receptor Identification

Existing and intended land use is an important factor in evaluating the potential exposures and estimating risk. This risk assessment is directed toward two potential end uses of the land:

- Continued residential use of the town area; and
- Intermittent use of the general area for recreational and hunting purposes.

Therefore the potential human "receptors", or people who may be most affected by the potential hazards are residents of the town or people hunting on the land. For the purposes of this assessment, the human receptor is characterized as an adult or child with no extreme sensitivities. Carcinogenic and non-carcinogenic chemicals are evaluated differently as illustrated below:

	RESIDENTIAL EXPOSURE	**HUNTING/RECREATIONAL EXPOSURE**
NON-CARCINOGENIC CHEMICAL cadmium (oral/dermal), lead, and zinc	Most sensitive receptor modelled as a toddler aged 6 months to 4 years old.	Most sensitive receptor modelled as a toddler aged 6 months to 4 years old.
CARCINOGENIC CHEMICAL cadmium (inhalation)	Receptor assumed to grow up in Nanisivik from birth to 70 years lifetime. Exposures averaged over five age groups: (0-6 months) + (6 months – 4 yrs) + (5-11 yrs) + (12-19 yrs) + (20-70 yrs).	Receptor assumed to grow up in the Nanisivik area from birth to 70 years lifetime. Exposures averaged over five age groups: (0-6 months) + (6 months – 4 yrs) + (5-11 yrs) + (12-19 yrs) + (20-70 yrs).

The above assumptions regarding receptors are the most protective approaches for the intended land uses. Important characteristics of the receptors (including body weight, soil ingestion rate, *etc.*) considered in the analysis are presented Section 6.2.

6.1.3 Exposure Pathway Assessment

The exposure assessment evaluates the likelihood that the potential hazards can come into contact with the potential receptors. The likelihood of exposure is determined through consideration of the properties of individual hazards that control chemical mobility, and the various pathways through which the hazard could move to contact the receptor, or through which the receptor could move to contact with the hazard. The exposure analysis also considers the possible mechanisms through which a hazard can be introduced to a human receptor (*i.e.*, ingestion, dermal contact, inhalation).

6.1.3.1 Potential Transport Pathways

The principal pathways through which environmental hazards can typically contact a receptor include:

- direct contact (with soil, dust, liquid product phase hazards, or water);
- transport of liquid product phase contaminants;
- transport in groundwater;
- transport in surface water;
- air borne transport (as dust); and
- transport as a vapour.

6.1.3.2 Potential Exposure Mechanisms

The mechanisms by which receptors typically become exposed to hazards include:

- inhalation;
- ingestion;
- dermal contact; and
- uptake by plants.

6.1.3.3 Human Receptor Exposure Scenarios

The exposure scenarios which have been considered for human receptors include:

- ingestion/dermal contact with soil;
- inhalation/ingestion/dermal contact with dust;
- ingestion of vegetation or garden produce grown in contaminated soil or irrigated with contaminated groundwater;
- ingestion of wild game (*e.g.*, Ptarmigan, hares) caught by hunting on the land in the mine area;

- ingestion/dermal contact with surface water;
- ingestion/dermal contact with groundwater; or
- inhalation of vapours.

JWEL has evaluated the likelihood that the identified human receptors can be exposed to the identified hazards through the various exposure scenarios using a qualitative method. The likelihood of exposure is considered and evaluated in terms of the following series of definitions, presented in Table 6.2.

Table 6.2 Exposure Definitions

Likelihood Of Exposure	Definition
Very Unlikely	Level of exposure that could result in adverse effects is not expected
Unlikely	Level of exposure that could result in adverse effects would probably not occur
Possible	Level of exposure that could result in adverse effects might be expected
Likely	Level of exposure that could result in adverse effects is expected. Exceedance of this exposure level might be expected.

The relevant exposure pathways are summarized in Table 6.3. Table 6.3 includes the qualitative evaluation of each pathway and a justification for the likelihood of exposure assigned. The likelihood of exposure includes consideration of the duration and frequency of exposure to each potential hazard and to the relative concentrations to which the receptor is likely to be exposed. Those hazard-exposure-receptor combinations considered to have the highest likelihood to contribute a health risk are carried forward for further quantitative analysis.

Table 6.3 Potential Exposure Scenarios - Human Receptors

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Ingestion of soil	Possible	Yes	Surface soil samples collected during the soil sampling programs in 2001 and 2002 were impacted by cadmium, lead, and zinc at concentrations exceeding screening guidelines for direct contact, as described in Section 3.1.1.
Dermal contact with soil	Possible	Yes	
Ingestion of dust	Possible	Yes	
Dermal contact with dust	Possible	Yes	
Ingestion of surface water	Unlikely	No	Nanisivik receives its water supply from East Twin Lake. No problems have been reported with the town water supply throughout the operation of the mine. No issues are expected with the water supply after the mine closing.
Dermal contact with surface water	Unlikely	No	
Ingestion of groundwater	Very Unlikely	No	Groundwater is not used as a drinking water source in Nanisivik.
Dermal contact with groundwater	Very Unlikely	No	As above.
Ingestion of garden produce	Very Unlikely	No	Due to the climate, home vegetable gardens are not present in Nanisivik.
Ingestion of wild game from hunting	Possible	Yes	Interviews with local residents indicates that limited hunting has occurred in the general mine area and may be expected to continue after the mine closure. Therefore, there is the potential for local game to be exposed to metal contaminated surface soil.
Inhalation of vapours	Very Unlikely	No	Cadmium, lead, and zinc are not volatile and would not produce vapours.
Explosion Hazard (via utilities)	Very Unlikely	No	As above.

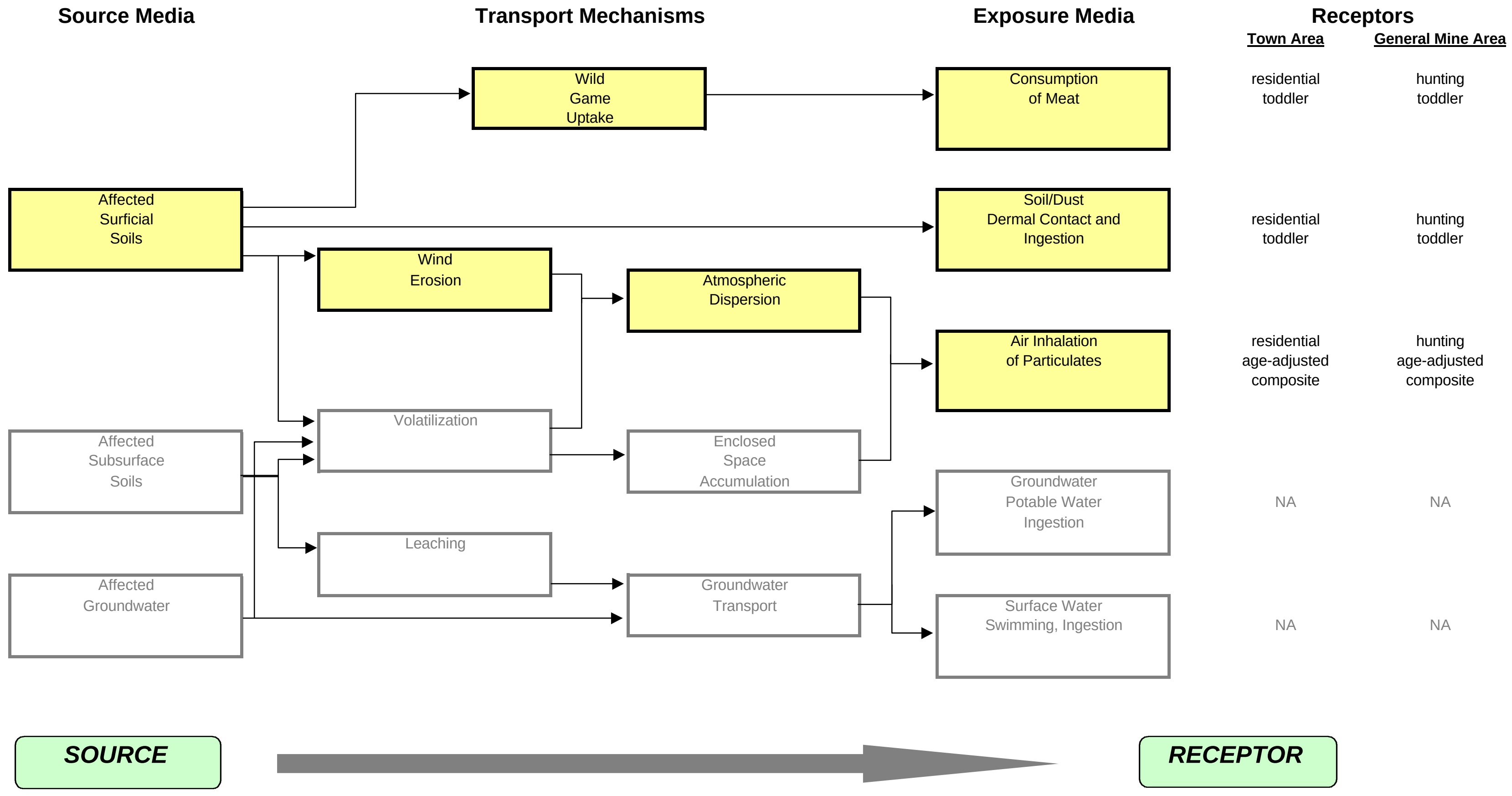
6.1.4 Qualitative Risk Characterization

Based on the qualitative risk screening presented above, the conceptual model that forms the basis for the derivation of the $SSTL_{HH}$ is as follows:

- A toddler aged 6 months to 4 years ingests and comes into dermal contact with surface soil contaminated with cadmium, lead, and zinc;
- A toddler aged 6 months to 4 years ingests wild game from hunting in the area. The wild game may have ingested or come into contact with surface soil contaminated with cadmium, lead, and zinc; and
- A person lives in Nanisivik from birth to 70 years of age and is exposed to cadmium by inhalation of soil-derived dust throughout their lifetime.

The conceptual model is illustrated on Figure 5.

Figure 5 Conceptual Site Model for Human Health



6.2 Receptor Characteristics

As discussed in Section 6.1.1, it is important that the most protective assumptions are made about the potential receptors. For the derivation of the $SSTL_{HH}$ for lead, zinc, and cadmium (by ingestion and dermal contact), the most sensitive receptor is a toddler aged 6 months to 4 years old. In addition, a reasonable maximum exposure approach is adopted in which it is assumed that the toddler will be present in Nanisivik 24 hours per day, 365 days per year. Receptor characteristics for the toddler are presented in Table 6.4 below:

Table 6.4 Summary of Receptor Characteristics – Toddler (6 months – 4 years)

Characteristic		Value	Source
Averaging Times and Constant Values			
ATn	Averaging time, non-cancer effects	1,643 days	Equal to the exposure duration
ED	Exposure duration	4.5 years	CCME (2001)
EFr	Exposure frequency, residential	365 days/year	Maximum value
EFh	Exposure frequency, hunting	60 days/summer [1]	Based on community survey
ET	Exposure Time	24 hours/day	Maximum value
BW	Body Weight	16.5 kg	CCME (2001)
Ingestion of Surface Soil			
IRr	Incidental ingestion rate – residential	41 mg/day	Refer to Section 6.5.1.1
IRh	Incidental ingestion rate – hunting	80 mg/day	CCME (2001)
Dermal Contact with Surface Soil			
SA	Exposed surface area	3010 cm^2	CCME (2001)
AF	Soil adherence factor	0.1	CCME (2001)
Inhalation of Dust			
IRair	Inhalation rate	9.3 m^3/day	CCME (2001)
Wild Game Ingestion			
IRwg	Ingestion rate	0.018 kg/day	Richardson (1997)

[1] Based on the limited community consultation, there would be a maximum of 60 days during the summer period that an individual would be hunting in the vicinity of Nanisivik Mine. This is likely to be an over-estimate of the number of hunting days in the summer.

For non-threshold chemicals (carcinogens), in which any level of exposure is considered to have a potential for health effects, exposures are not calculated within specific age groups (*e.g.*, toddler) but are averaged over a lifetime. In accordance with the reasonable maximum exposure approach, it is assumed that the individual grows up in Nanisivik from birth to 70 years old. For the purposes of the risk characterization calculations, exposures are averaged over five age groups: (0 – 0.5 years) + (0.5 - 4 years) + (5 – 11 years) + (12 – 19 years) + (20 – 70 years). Receptor characteristics for each age group are presented in Table 6.5:

Table 6.5 Summary of Receptor Characteristics for Each Age Group

Characteristic	Value						Source
	0-6 mths	0.5-4 yrs	5-11 yrs	12-19 yrs	20-70 yrs	Units	
Averaging Times and Constant Values							
ATc	25,550	25,550	25,550	25,550	25,550	days	70 year lifetime
ED	0.5	4.5	7	8	50	years	CCME (2001)
EFr	365	365	365	365	365	days	Maximum value
EFh	60	60	60	60	60	days	Community survey
ET	24	24	24	24	24	hours	Maximum value
BW	7	16.5	33	57	70.7	kg	CCME (2001)
Inhalation of Dust							
IRair	2.1	9.3	14.5	15.8	16.2	m^3/day	CCME (2001)

6.3 Toxicity Assessment

The potential hazards associated with exposures to non-carcinogenic (threshold) substances are assessed differently than the potential risks associates with exposures to carcinogenic (non-threshold) substances. For threshold substances, it is assumed that there is a dose (or concentration) of the chemical of concern that does not produce any adverse effect. A Tolerable Daily Intake (TDI) is an estimate of a chemical intake that is unlikely to cause an increased incidence of deleterious health effects during a lifetime of exposure. TDIs are specifically developed to be protective for chronic exposure to a chemical. For the purposes of deriving site-specific threshold levels, a chronic daily intake (CDI) is calculated for the exposed individual and compared to the TDI. If CDI/TDI >1, then there is the potential for adverse health effects and further assessment would be required.

For contaminants for which the critical effect is assumed to have no threshold (*i.e.*, carcinogens), it is assumed that there is some probability of harm to human health at any level of exposure (CCME 1996a,b). There is a linear dose-response relationship that converts estimated daily intakes averaged over a lifetime of exposure directly to an incremental risk of an individual developing cancer. For the purposes of deriving site-specific soil quality guidelines, CCME considers that a single increased case of cancer in an exposed population of 1,000,000 merits action. As such, a target risk (TR) of one in one million or 10^{-6} is used in the present analysis for carcinogenic effects.

6.3.1 Toxicity Benchmarks

An essential part of the risk assessment is the identification of appropriate toxicity values. This is typically done by a literature review of published toxicological assessments. Toxicity values have been established by several agencies including Health Canada, the United States Environmental Protection Agency (US EPA), and the World Health Organization (WHO). Preference has been given to the most recent values as these include the most recent scientific information and provide the best basis upon which to evaluate health risks.

Summaries of the toxicity values selected for inclusion in the risk assessment are provided in Table 6.6. Detailed rationales supporting the selection of each of the toxicity values recommended for use in this study are provided in **Appendix B**.

Table 6.6 Selected Toxicity Values

Metal	Route of Exposure	Exposure Limit	Toxicological Basis	Source Agency
Non-Cancer Effects				
Cadmium	Ingestion	1 μg/kg-day	Kidney damage in humans	US EPA (1998)
	Inhalation	NA		
Lead	Ingestion	3.57 μg/kg-day	Blood lead level in young children	Health Canada (1996)
	Inhalation	3.57 μg/kg-day	Blood lead level in young children	Health Canada (1996)
Zinc	Ingestion	300 μg/kg-day	Decreased erythrocyte SOD[1]	US EPA (1992)
	Inhalation	300 μg/kg-day	Decreased erythrocyte SOD[1]	US EPA (1992)
Cancer Effects				
Cadmium	Ingestion	NA		
Cadmium	Inhalation	9.8×10^{-3} $(\mu g/m^3)^{-1}$	Lung cancer in cadmium workers	Health Canada (1996)

[1] Based on the limited community consultation, there would be a maximum of 60 days during the summer period that an individual would be hunting in the vicinity of Nanisivik Mine. This is likely to be an over-estimate of the number of hunting days in the summer.

6.3.2 Bioavailability

Bioavailability refers to "the fraction of the total amount of material in contact with a body portal-of-entry (lung, gut, skin) that enters the blood". Absolute bioavailability is the amount of a substance entering the blood via a particular route of exposure (*e.g.*, gastrointestinal) divided by the total amount administered (*e.g.*, soil lead ingested). Bioavailability factors for cadmium, lead, and zinc following oral ingestion or dermal contact were estimated from the published literature. These factors were then applied in the risk assessment to more realistically represent the portion of contaminants held in soil that are available. Bioavailability via inhalation exposure was conservatively assumed to be factor of 1.0.

Table 6.7 provides the bioavailability factors used in this assessment. Detailed rationale supporting the selection of each of the values recommended for use in this study is provided in **Appendix B**.

Table 6.7 Selected Bioavailability Factors

Bioavailability Factor		Cadmium	Lead	Zinc
Oral	Gut	0.1	0.5	0.8
	Soil	0.1	0.3	0.8
Dermal		0.01	0.01	0.01

6.4 Estimating Total Daily Intakes

CCME define a TDI as an estimate of a chemical intake that is unlikely to cause an increased incidence of deleterious health effects during a lifetime of exposure. In addition, CCME incorporate an assumption that everyone is exposed to a "background" level of chemicals that cannot be avoided. This background exposure arises from ambient air, food, drinking water, and soil/dust. In setting soil quality guidelines, CCME subtracted this Estimated Daily Intake (EDI) from the TDI to account for this background exposure and based the derivation of the soil quality guidelines on the Residual TDI (RTDI).

Where possible, the same approach is adopted in this report to derive the $SSTL_{HH}$. Appropriate values for background exposures comprising the EDI are discussed in the following sections.

6.4.1 Lead

6.4.1.1 Ambient Air

Ambient Air	
Concentration	0.0117 $\mu g/m^3$
Daily Intake	0.1088 µg/day
EDI	0.0066 µg/kg-day

Concentrations of lead in Canadian air have been reported to have declined significantly since the introduction of unleaded gasoline in 1975. Furmanczyk (1994) reported that the average of the annual mean lead concentrations in total suspended particulate (TSP) matter, measured under National Air Pollution Surveillance (NAPS) network, decreased from 0.35 $\mu g/m^3$ in 1981 to 0.02 $\mu g/m^3$ in 1990. Health Canada (1996) adopted a value of 0.0117 $\mu g/m^3$, based on the 1993 average of the urban site means for lead concentrations in inhalable particulate matter <10µm (PM_{10}), sampled under NAPS. Because of a lack of adequate data, indoor air concentrations are assumed to be the same as outdoor air as demonstrated in limited studies in Windsor, Ontario (Bell *et al.* 1994) and Riverside, California (Clayton *et al.* 1993) where mean lead levels in indoor and corresponding outdoor air samples were similar. It should be noted that urban lead levels are generally higher than rural levels.

6.4.1.2 Supermarket Foods

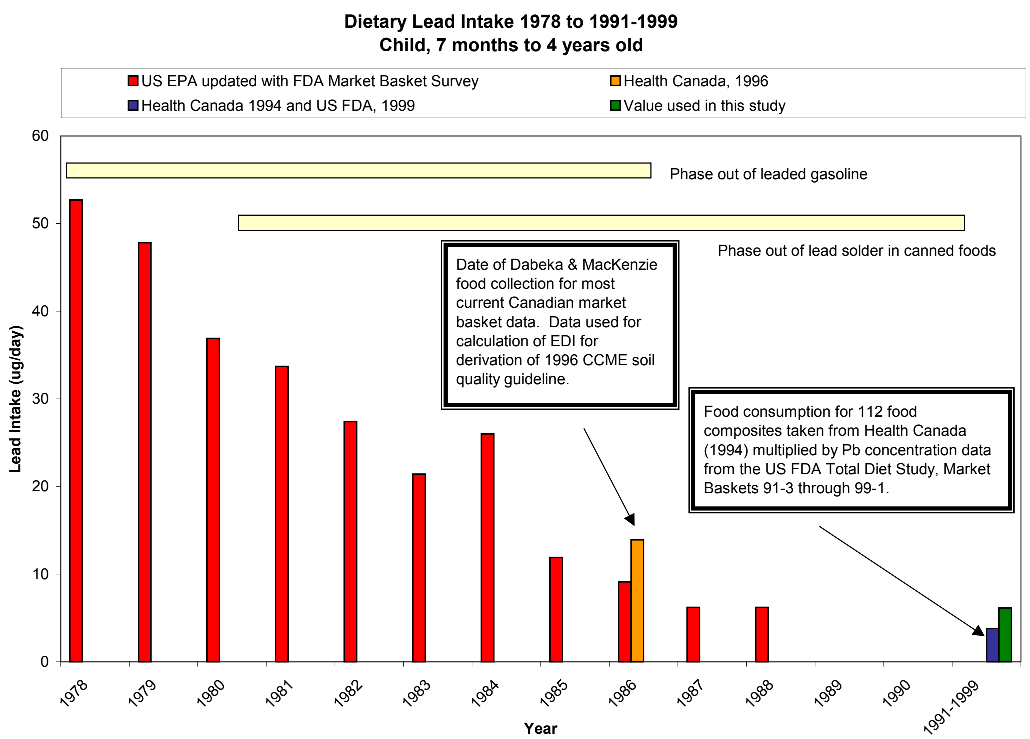
The most current lead levels in Canadian supermarket foods were determined by Dabeka and McKenzie (1995). Foods purchased in Vancouver, Winnipeg, Toronto, Montreal, and Halifax between 1986 and 1988 were combined into 112 food composites as detailed by Health Canada (1994) and prepared for consumption. Lead concentrations in individual food composites ranged from <0.4 ng/g for skim milk to 523.4 ng/g for canned luncheon meat.

Similarly to ambient air, lead concentrations in supermarket foods have been continually declining since the phase out of leaded gasoline and leaded solder in canned foods. Therefore, food data from the mid-1980s is likely to overestimate the lead concentrations. The US Food and Drug Administration (US FDA) conduct an on-going Total Diet Study (TDS) and have market basket data available from 1991 to 1999. Lead concentrations are reported for 267 different food items for 26 market baskets completed from 1991-1999.

As illustrated below, for this risk assessment, JWEL have combined the US FDA TDS information on lead concentrations with the Health Canada information on food consumption rates for toddlers to calculate an updated dietary intake of lead from supermarket foods.

Supermarket Food	
Concentrations	variable
Daily Intake	6.2 μg/day
EDI	0.3758 μg/kg-day

As indicated, the comparison of US FDA TDS lead concentration data and Health Canada food consumption rates results in a calculated lead intake of 3.8 μg/day for a toddler. Due to potential uncertainties in cross-referencing US and Canadian data and in order to maintain a conservative analysis, the lead intake rate used in this study has been set to the 1988 value from the US data (6.2 μg/day). It is probable that current Canadian exposures via supermarket foods are less than this value.



6.4.1.3 Drinking Water

For the development of their 1999 soil quality guidelines, CCME adopted a background drinking water lead concentration of 4.8 µg/L. This estimate was based on the median concentration obtained in a one week survey of composite samples taken at the point of use from 40 households at 7 Ontario locations. Drinking water consumption rates were lowered in the calculation of daily intake since the supermarket food data include water-based food items.

Drinking Water	
Concentration	4.8 µg/L
Daily Intake	0.96 µg/day
EDI	0.058 µg/kg-day

6.4.1.4 Background Soil/Household Dust

As discussed in Section 2, a geochemistry study of surface soil lead concentrations was completed at Nanisivik in 1985, prior to any potential influence from wind blown tailings. This sampling represents the most comprehensive assessment of surface soil quality completed in the area and can be used to set local background soil concentrations. Separate background concentrations were computed for both exposure areas: the town area and the general mine area.

For the purposes of assessing potentially contaminated sites, the standard protocol is typically to calculate the upper 95% confidence limit on the mean of the data and use this value as the background soil concentration (OMEE, 1996a). In this way, remedial action is unlikely to be required for metals concentrations that are simply within the naturally occurring background range for the region. A statistical analysis was completed on the 1985 geochemistry data set and background soil lead concentrations were calculated as 204 µg/g and 67.9 µg/g in the town area and general mine area, respectively. It is noted that the value used in the CCME generic soil quality guidelines development was 98 µg/g, based on old urban parkland sites in Ontario.

Background Soil – town area	
Concentration	204 µg/g
Daily Intake	2.72 µg/day[1]
EDI	0.165 µg/kg-day

1. Daily intake based on 4 hours per day of outdoor exposure as per Health Canada, 1996a.

Background Soil – mine area	
Concentration	67.9 µg/g
Daily Intake	5.432 µg/day[1]
EDI	0.329 µg/kg-day

1. Daily intake based on 24 hours per day of outdoor exposure.

There is little published data on the lead content of household dust in Canadian homes. For the derivation of the soil quality guidelines, Health Canada (1996) employed data collected by Kean (1995). Kean determined non-matrix lead concentrations in house dust samples collected in 1994 from 51 Ottawa homes. However, data from an urban center is unlikely to be applicable to remote sites. For this risk assessment, we have assumed that the lead concentration in household dust is equivalent to the soil lead concentration outdoors.

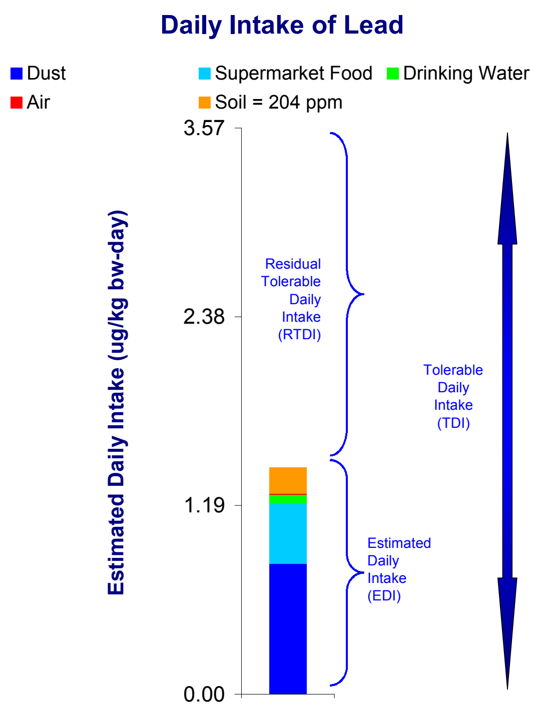
Household Dust – town area	
Concentration	204 µg/g
Daily Intake	13.6 µg/day[1]
EDI	0.824 µg/kg-day

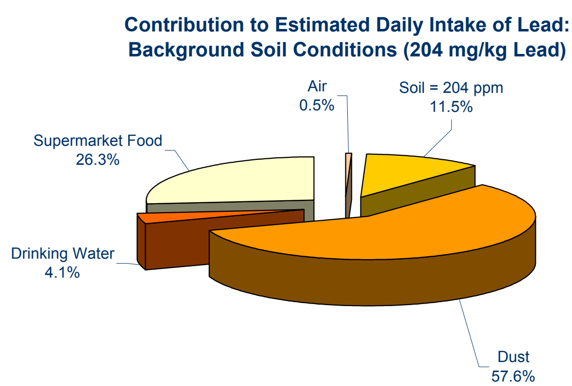
1. Daily intake based on 20 hours per day of indoor exposure as per Health Canada, 1996a.

6.4.1.5 Summary of Estimated Daily Intake

Based on the above discussion, the estimated total daily intake of lead for a 16.5 kg toddler, by all routes of exposure, is 1.4294 μg/kg-day and 0.7694 μg/kg-day for the town area and the general mine area, respectively. This intake for the town area is graphically represented below in two forms, illustrating the relative contribution of each route of exposure and comparing the background EDI to the TDI of 3.57μg/kg-day.

Total Daily Intake (μg/kg-day)		
	Town area	General mine area
Ambient Air	0.0066	0.0066
Supermarket Food	0.3758	0.3758
Drinking Water	0.058	0.058
Background Soil	0.165	0.329
Household Dust	0.824	na
TOTAL EDI	1.4294	0.7694





As indicated, the largest contributors to background exposure to lead are through household dust and supermarket food. Soil lead concentrations at background levels represent only a minor portion of the total EDI and drinking water and ambient air intakes are negligible. This finding is important when considering risk management strategies to reduce overall lead exposure.

6.4.2 Cadmium

6.4.2.1 Ambient Air

Ambient Air	
Concentration	0.0045 μg/m^3
Daily Intake	0.04185 μg/day
EDI	0.0025 μg/kg-day

Concentrations of particulate cadmium in Canadian air are comparable to values recorded in other parts of the world (Health Canada, 1994). Recent long term studies undertaken by Environment Canada indicate low cadmium concentrations in PM_{10} (inhalable particulates <10μm in diameter) in ambient air at 20 sites in 12 urban and 4 rural areas. Between 1990 and 1993, 84% of ambient air samples from across Canada contained cadmium in concentrations below the detection limit on 3.3 ng/m^3. Substituting half the detection limit for values below detection, average particulate cadmium levels ranged from 4 to 6 ng/m^3 and the average of the means was calculated to be 4.5 ng/m^3.

CCME (1996a) adopted the value of 4.5 ng/m^3, in the derivation of the generic soil quality guideline. Very limited data (Bell *et al.*, 1994) indicate that mean levels of cadmium in indoor air are similar to those measured in corresponding ambient air.

6.4.2.2 Supermarket Foods

The most current cadmium levels in Canadian supermarket foods were determined by Dabeka and McKenzie (1995). Foods purchased in Vancouver, Winnipeg, Toronto, Montreal, and Halifax between 1986 and 1988 were combined into 112 food composites as detailed by Health Canada (1994) and prepared for consumption. The highest cadmium concentrations in individual food composites were found in organ meats and potato chips which consistently contained greater than 90 ng/g fresh weight.

Supermarket Food	
Concentrations	variable
Daily Intake	7.54 μg/day
EDI	0.457 μg/kg-day

CCME (1996a) based their EDI for supermarket food on intakes estimated from the above data, assuming that foods were consumed in the amounts determined in the Nutrition Canada survey (Health Canada, 1994).

6.4.2.3 Drinking Water

For the development of their 1999 soil quality guidelines, CCME adopted a background drinking water cadmium concentration of 0.03 µg/L. This estimate was based on the median concentration determined in a 1977 national survey of tap water samples from 71 drinking water supplies across Canada (Méranger *et al.*, 1981). The results of more recent monitoring from various regions of Canada have been similar (Environment Canada, 1989; Lachmaniuk, 1993).

Drinking Water	
Concentration	0.03 µg/L
Daily Intake	0.006 µg/day
EDI	0.0004 µg/kg-day

6.4.2.4 Background Soil/Household Dust

The geochemistry study of surface soil metal concentrations that was completed at Nanisivik in 1985, prior to any potential influence from wind blown tailings, did not include any data from cadmium. Therefore, no site-specific soil background concentrations are available.

Background Soil	
Concentration	0.71 µg/g
Daily Intake	0.0568 µg/day[1]
EDI	0.0034 µg/kg-day

1. Daily intake based on 24 hours per day combined indoor/outdoor exposure.

In the absence of site-specific information, we have employed the Ontario Typical Range (OTR) values which were developed by the Ontario Ministry of the Environment and Energy (MOEE, 1993) to assist them in the interpretation of analytical data and in the evaluation of source related impacts. The OTRs essentially represent the expected range of concentrations of contaminants in surface soil from areas of Ontario not impacted by a point source of emissions.

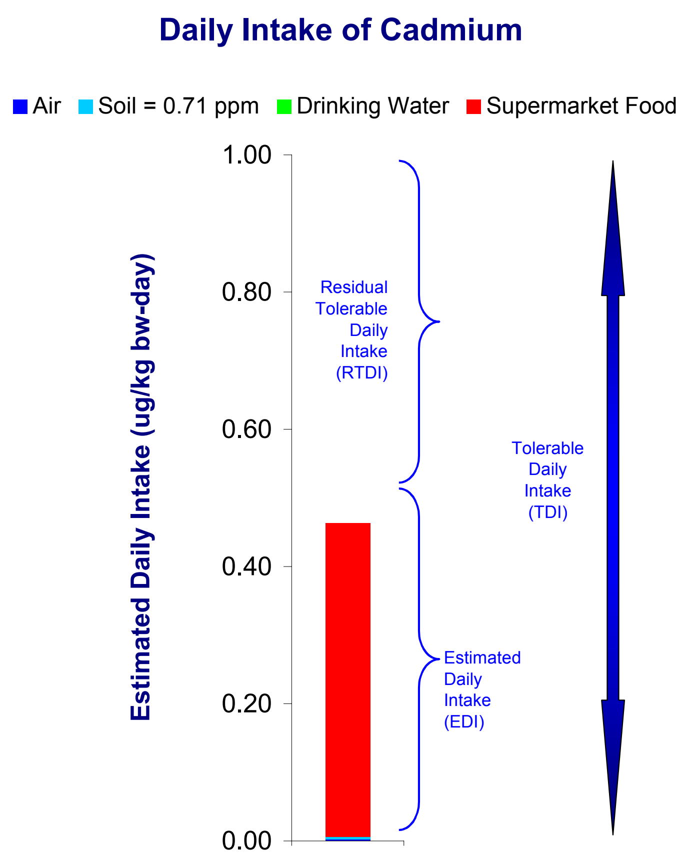
An upper limit was developed, referred to as the OTR_{98}, that represents the 98^{th} percentile of the distribution (roughly equivalent to the mean plus two standard deviations of a normally distributed population). An exceedance of the OTR_{98} for a soil sample from a given land use category would indicate a potential point source of contamination or potential mineralization.

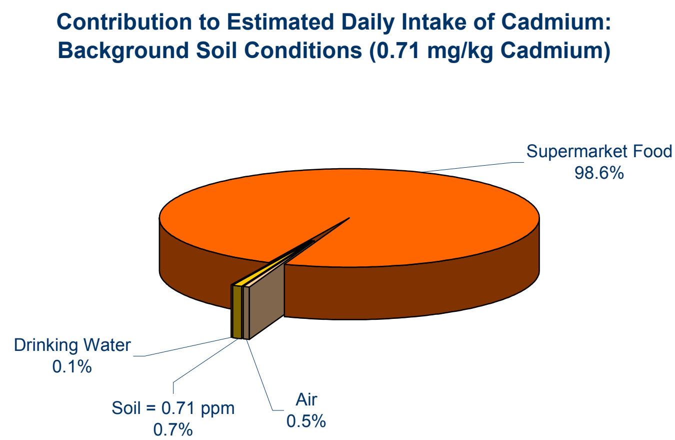
There is little published data on the cadmium content of household dust in Canadian homes. For this risk assessment, we have assumed that the cadmium concentration in household dust is equivalent to the soil cadmium concentration outdoors.

6.4.2.5 Summary of Estimated Daily Intake

Based on the above discussion, the estimated total daily intake of cadmium for a 16.5 kg toddler, by all routes of exposure, is 0.4633 µg/kg-day. This intake is graphically represented below in two forms, illustrating the relative contribution of each route of exposure and comparing the background EDI to the TDI of 1 µg/kg-day.

Total Daily Intake (µg/kg-day)	
Ambient Air	0.0025
Supermarket Food	0.4570
Drinking Water	0.0004
Background Soil/Dust	0.0034
TOTAL EDI	0.4633





As indicated, the largest contributor to background exposure to cadmium is through supermarket food. Soil cadmium concentrations at background levels represent only a minor portion of the total EDI and drinking water and ambient air intakes less significant.

6.4.3 Zinc

6.4.3.1 Ambient Air

Published data on Canadian ambient air concentrations of zinc is not available.

6.4.3.2 Supermarket Foods

Published data on zinc concentrations in Canadian supermarket food is not available. Zinc is known to be an essential nutrient.

6.4.3.3 Drinking Water

Published data on zinc concentrations in Canadian drinking water supplies is not available.

6.4.3.4 Background Soil/Household Dust

As discussed in Section 2, a geochemistry study of surface soil zinc concentrations was completed at Nanisivik in 1985, prior to any potential influence from wind blown tailings. This sampling represents the most comprehensive assessment of surface soil quality completed in the area and can be used to set local background soil concentrations. Separate background concentrations were computed for both exposure areas: the town area and the general mine area.

For the purposes of assessing potentially contaminated sites, the standard protocol is typically to calculate the upper 95% confidence limit on the mean of the data and use this value as the background soil concentration (OMEE, 1996a). In this way, remedial action is unlikely to be required for metals concentrations that are simply within the naturally occurring background range for the region.

A statistical analysis was completed on the 1985 geochemistry data set and background soil zinc concentrations were calculated as 323 μg/g and 89.7 μg/g in the town area and general mine area, respectively.

There no published data on the zinc content of household dust in Canadian homes. We have assumed that the zinc concentration in household dust is equivalent to the soil zinc concentration outdoors.

Background Soil – town area	
Concentration	323 μg/g
Daily Intake	4.31 μg/day[1]
EDI	0.261 μg/kg-day

1. Daily intake based on 4 hours per day of outdoor exposure as per Health Canada, 1996.

Background Soil – mine area	
Concentration	89.7 μg/g
Daily Intake	7.176 μg/day[1]
EDI	0.435 μg/kg-day

1. Daily intake based on 24 hours per day of outdoor exposure.

Household Dust – town area	
Concentration	323 μg/g
Daily Intake	21.53 μg/day[1]
EDI	1.305 μg/kg-day

1. Daily intake based on 20 hours per day of indoor exposure as per Health Canada, 1996.

6.4.3.5 Summary of Estimated Daily Intake

Based on the above discussion, there is insufficient data to calculate an estimated total daily intake of zinc by all routes of exposure. The absence of an EDI and the potential for background exposure to zinc for other sources is accounted for in the risk characterization as explain in Table 6.8.

Table 6.8 Comparison of CCME Guidelines Development to Nanisivik SSTLHH

Factor	CCME	This Study	Discussion
Soil/Dust Ingestion Rate	80 mg/day	80 mg/day – hunting 41 mg/day - residential	This study uses the CCME default ingestion rate as a starting point and then incorporates OMOE methods to account for indoor versus outdoor exposure in winter and summer months (refer to Appendix C). For the residential setting it is assumed that there is only indoor exposure to household dust in the winter months but increased exposure to soil and dust for the summer months (June – September). For the hunting scenario, it is assumed that there is exposure to soil outdoors during the summer months.
Exposure Term	1	0.164 – hunting 1 – residential	It is assumed that a local resident would hunt on the land on a regular basis throughout the summer (total of 60 days). Hunting may continue in the winter but there would be no exposure to surface soil due to snow cover. For the residential setting, the resident would live in Nanisivik year-round.
Exposure Pathways	Soil ingestion only	Soil ingestion, dermal contact, and dust inhalation	CCME employ a simplified equation that only addresses soil ingestion. This study also incorporates dermal contact with affected soil and dust inhalation to provide a more complete assessment of potential exposures.
Dietary Lead Intakes	1986-1988 data	1991-1999 data	Dietary lead intakes from supermarket food used in the CCME estimation of EDI date from the mid-1980s and are substantially higher than current levels. This study has researched up to date US FDA data on lead concentrations in supermarket food to derive a better estimate of current dietary lead intake.
Target Hazard Quotient (THQ)	0.2	1 – lead, cadmium 0.2 – zinc	CCME guidelines subtract our normal background intake (EDI) and also assume that guidelines may have to be established for other contaminated media at a site (*e.g.* air, drinking water, food) and therefore employ a THQ to apportion 20% of the allowable daily intake to soil exposure. For lead and cadmium, all potential routes of exposure have been accounted for, either in the EDI (*i.e.*, food, water, air, background soil/dust) or in the pathways assessed (ingestion, inhalation, dermal contact). Therefore, the target hazard quotient recognizes that 100% of the exposure has been accounted for. For zinc, no EDI was available to account for background exposures, hence the THQ remains at 20% to account for potential exposures from other sources.

6.5 Risk Characterization

6.5.1 Non-carcinogens - Lead, Zinc, and Cadmium (oral/dermal)

The potential health effects associated with non-carcinogenic chemicals are assessed differently than those for carcinogenic chemicals. Non-carcinogenic chemicals are generally considered to act through a threshold mechanism where it is assumed that there is a dose (or concentration) that does not produce any adverse effect. As the dose or concentration increases to the point where the body can no longer process or excrete the chemical, an adverse effect may occur. This point is termed the *threshold* and is different for every chemical.

6.5.1.1 Approach and Methodology

Risk characterization compares the estimated exposures with the identified toxicity values for each substance to determine the potential for an adverse effect. Based on the published toxicity value (TDI), the background estimated daily intake (EDI), and calculation of chronic daily intake associated with the contaminated site (CDI), a safe concentration in soil ($SSTL_{HH}$) can be calculated such that the total intake does not exceed the Residual TDI (TDI – EDI). A simplified version of the risk characterization equation is presented below:

$$SSTL_{HH} = \frac{(TDI-EDI) \times THQ \times Body\ Weight}{CDI \times Exposure\ Term} + Background\ Soil\ Concentration$$

This approach is based on methods presented by US EPA (1989), CCME (1996b), and the Ontario Ministry of the Environment (OMOE, 1996b). Details of the equations and parameter values used in the analysis are provided in **Appendix C**. Results of the risk characterization and the resulting site-specific threshold levels for the protection of human health are presented in Section 6.5.1.3.

6.5.1.2 Comparison to CCME

CCME have published generic soil quality guidelines for cadmium, lead, and zinc. It may reasonably be asked why these values are not adopted for use in Nanisivik. Generic or Tier I surface soil guidelines are conservative benchmarks for screening purposes because if soil concentrations are less than these guidelines then the potential for human health effects is negligible. However, if soil concentrations exceed these guidelines it does not necessarily mean that unacceptable risks exist. The generic guidelines do not take into account regional or site-specific information (*e.g.* artic climate conditions) and may not be appropriate for every site or region of the country.

In fact, the protocol for CCME guideline development acknowledges that these guidelines are not set in stone but may be modified in some instances if supported by sound reasoning and/or by the provision of site-specific data. To do otherwise could result in disruptive remedial action that brings little or no health benefit. Deriving surface soil SSTL specifically for Nanisivik is a more accurate way of assessing the human health significance of soil concentrations in the community.

When comparing the SSTL derived in this report with the generic CCME guidelines, it must be remembered that both numbers are based on the same Tolerable Daily Intake and therefore offer the same level of health protection. More current information has been used in this report to estimate total daily intakes of lead and in several respects the risk characterization methods used herein are more comprehensive than the simplified approach adopted by CCME. A summary of key differences in the development of the CCME soil guidelines and the SSTL established in this study are outlined below:

Working within the CCME framework, this study seeks to develop a more accurate and up to date assessment of potential exposures in Nanisivik than can be gained by adoption of the CCME generic guidelines. In doing so, there is no reduction in health protection offered to the community. In addition, potentially unnecessary and disruptive remedial actions may be avoided.

6.5.1.3 Non-Carcinogenic Effects

Estimated exposures for the human receptors, based on the calculated EPCs, were compared to the toxicity benchmarks (TDIs) presented in Section 6.3. Figures 6 and 7 indicate that exposures to potential human receptors in the town area and general mine area, for the scenarios outlined in this risk assessment, are not expected to result in adverse effects, as the predicted intakes by all routes of exposure are below the tolerable intakes.

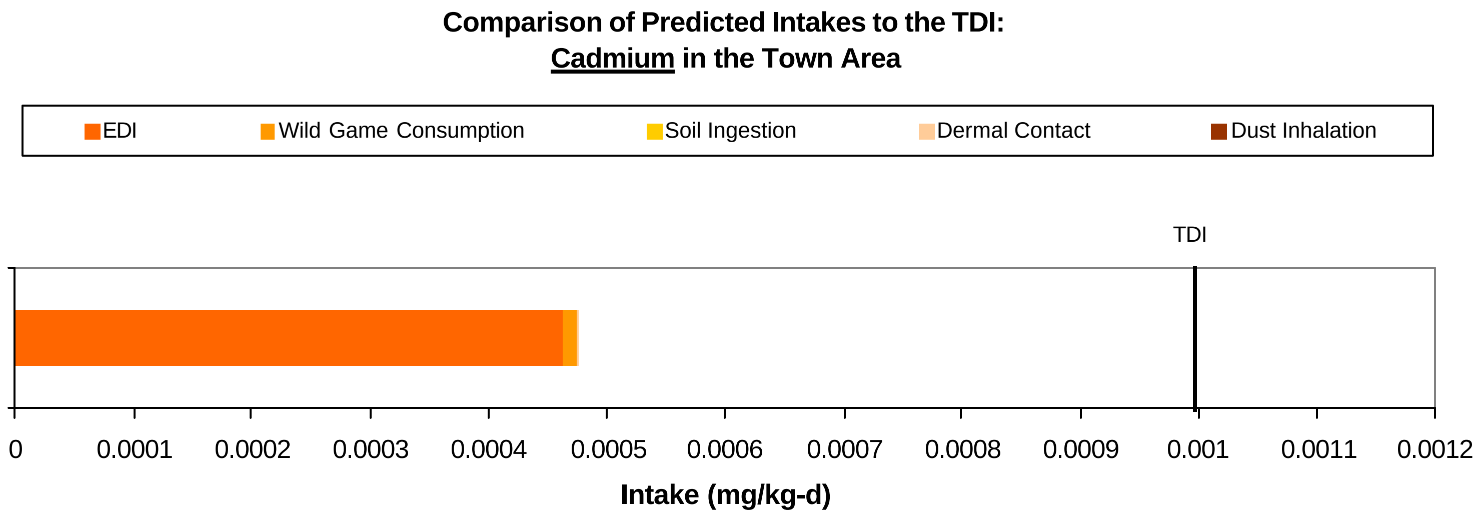
6.5.1.4 $SSTL_{HH}$

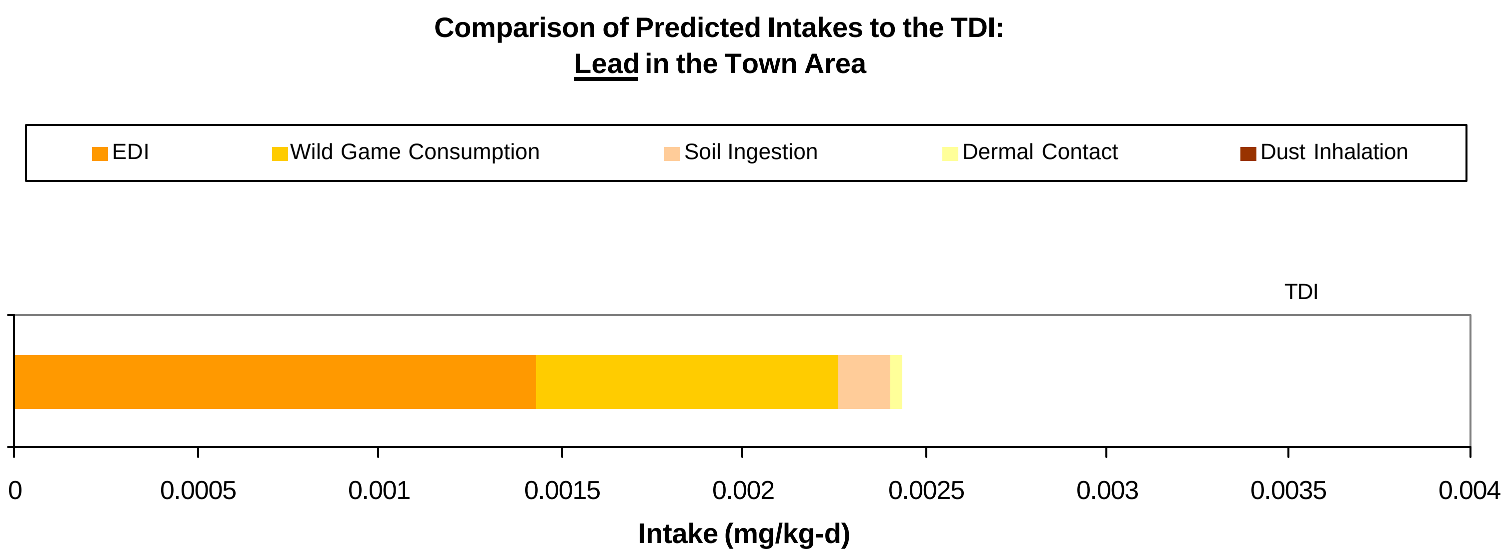
SSTL that have been derived for cadmium, lead, and zinc for Nanisivik are presented in Table 6.9.

Table 6.9 Surface Soil SSTLHH (mg/kg) – Non-Carcinogenic Effects

Metal	Site Exposure Category	
	Residential	Hunting/Recreational
Cadmium	1,100	3,900
Lead	990	3,500
Zinc	12,300	39,000

Figure 6 Comparison of Predicted Intakes to the Total Daily Intake: Town Area





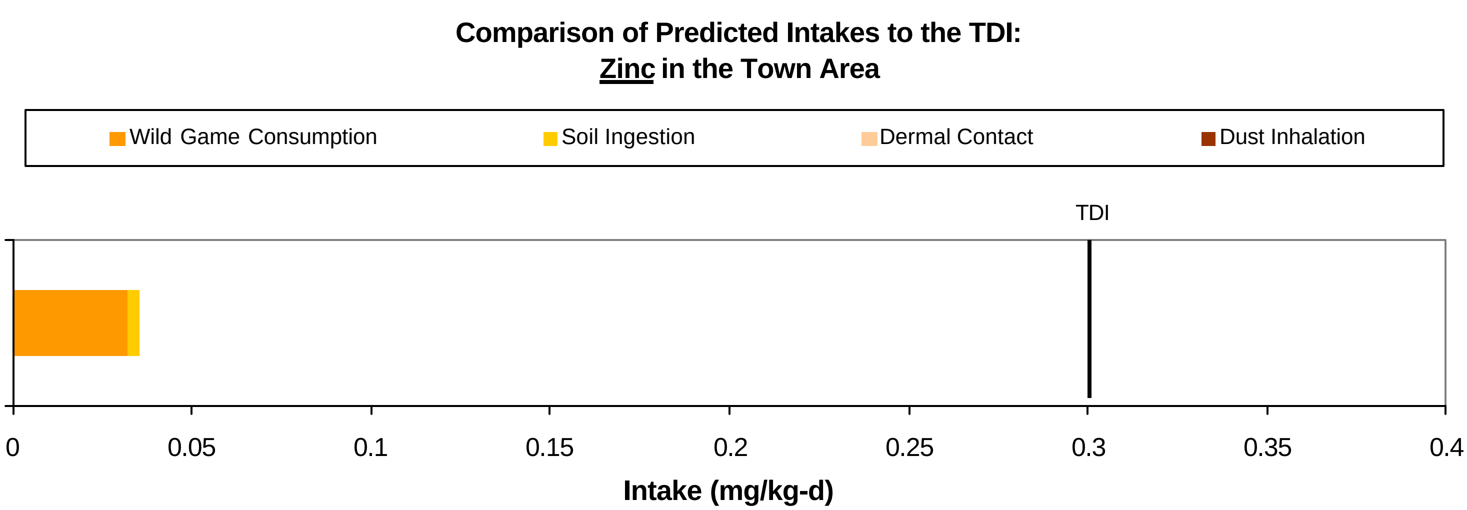
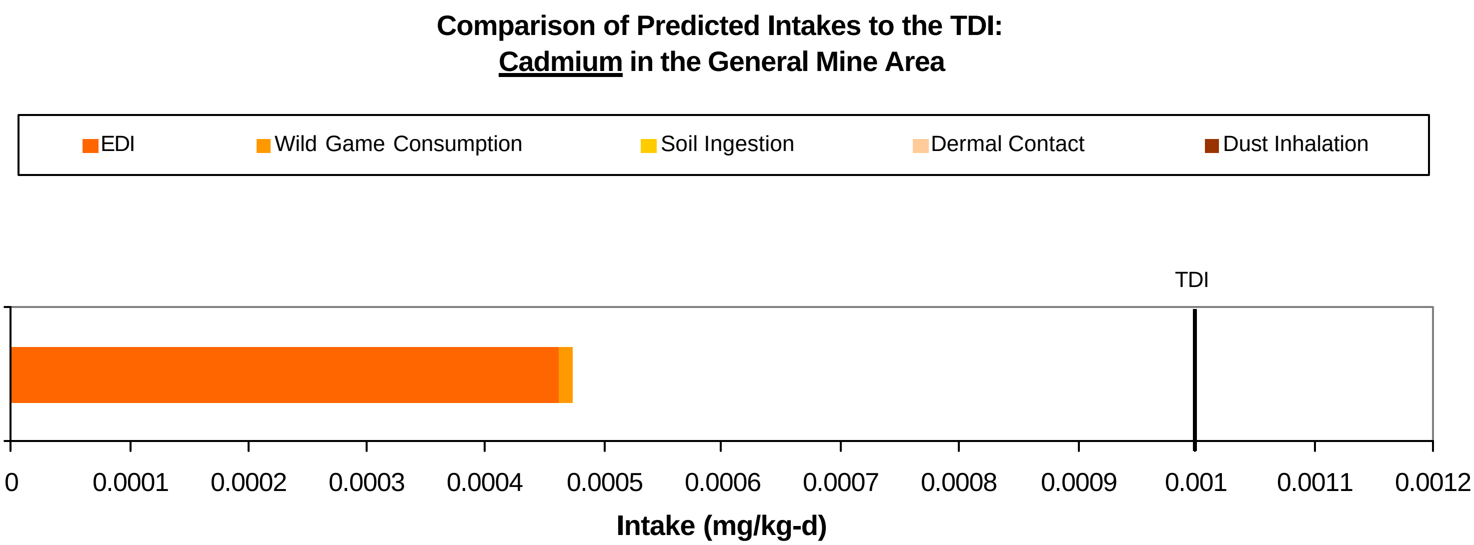
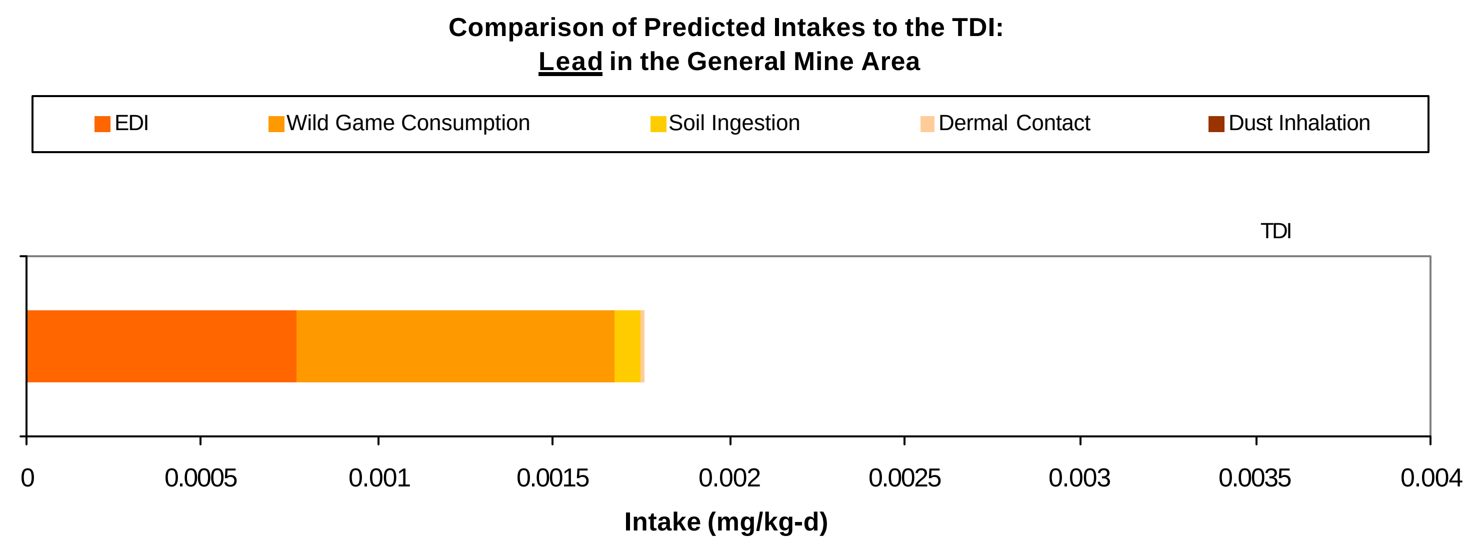
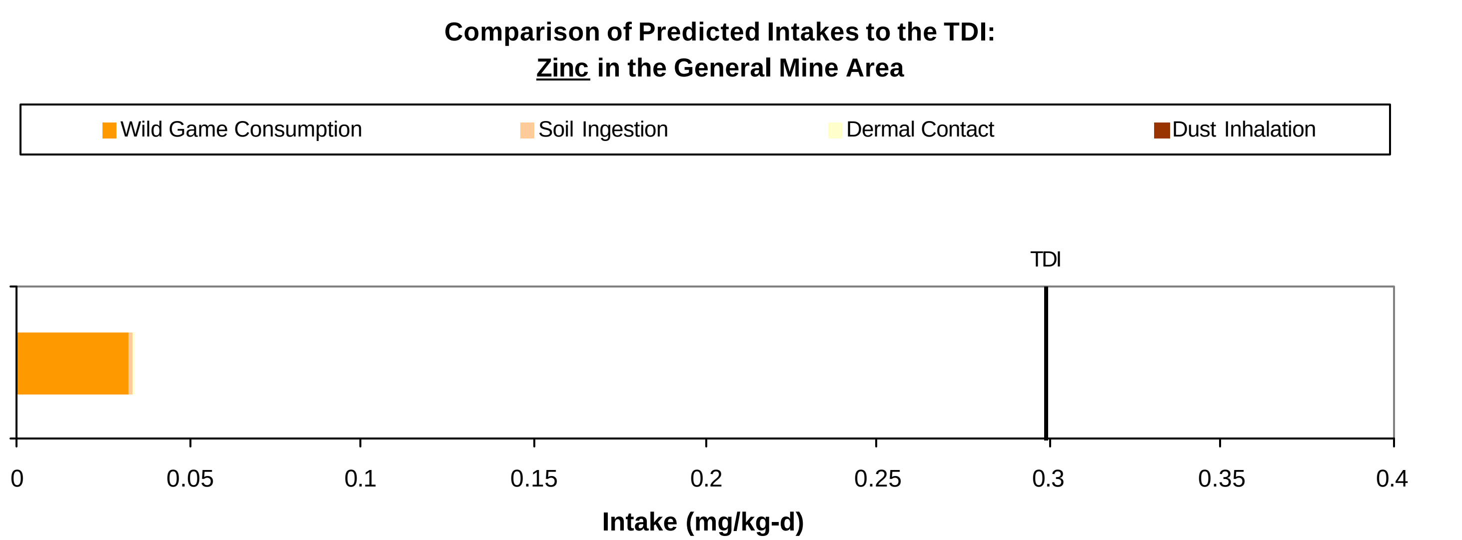


Figure 7 Comparison of Predicted Intakes to the Total Daily Intake of Metals: General Mine Area







Lead $SSTL_{HH}$ – Comparison to US EPA Approach

Although greater than the generic CCME criterion for residential soil, it is noted that the lead $SSTL_{HH}$ value for the residential setting is in the same range as the 2001 US EPA Federal Register standards.

EPA differentiated between children's play areas and the remainder of a residential property. It is important to note that EPA based their hazard standards on "the lowest levels at which its technical analysis showed that across the board *abatement* on a national level could be justified". EPA considered all options from 400 ppm to 5,000 ppm and selected the most protective option that could be supported by their analysis. For the final regulation, EPA selected an average of 1,200 ppm as the bare soil lead hazard standard for a residential property, outside of obvious play areas such as swing sets and sand boxes. A value of 400 ppm was chosen to apply specifically to designated play areas.

With respect to not choosing 400 ppm as a yard wide standard, EPA did not believe that, as a uniform national soil-lead standard, a value as low as 400 ppm yard-wide represented a reasonable public policy choice. The options proposed for the yard-wide abatement standard were 5,000 ppm, 2,000 ppm, and 1,200 ppm. Cost-benefit analyses were the primary reasons for not choosing either of the first two options as it was felt that significant risk reduction was possible below these levels. Ultimately, EPA chose 1,200 ppm as the yard-wide standard for the final rule because "it is the most protective level at which EPA has confidence that the risks warrant abatement".

This comparison lends support to the lead SSTL developed for Nanisivik, especially considering the more extreme climate and reduced exposure in Nanisivik compared to that envisaged by the US EPA for a typical home in the United States.

6.5.2 Carcinogens – Cadmium (Inhalation)

As previously discussed, the characterization of potential hazards associated with carcinogenic and non-carcinogenic exposures is assessed separately, based on the differences in the way these two types of chemicals may produce effects in the body. Although exposure to cadmium by ingestion and dermal contact is considered non-carcinogenic, inhalation of cadmium in particulate matter is considered carcinogenic.

6.5.2.1 Approach and Methodology

In determining the incremental increase in lifetime cancer risk associated with inhalation exposures to cadmium the estimated dose is compared to the established cancer slope factors as shown below:

$$IILCR = LADD*CSF$$

where:

IILCR = Incremental Increase in Lifetime Cancer Risk
LADD = Lifetime Averaged Daily Dose (μg/kg-day)
CSF = Cancer Slope Factor ($[\mu g/kg\text{-}day]^{-1}$)

The characterization of potential IILCR was undertaken using a target risk benchmark established by CCME of 1 in 1,000,000 (theoretically one additional cancer per 1,000,000 population). Calculation of the LADD is based on methods presented by US EPA (1989), CCME (1996b), and OMOE (1996b). Details of the equations and parameter values used in the analysis are provided in Appendix C. In general, exposure pathways and intake values were consistent with those used for the development of the non-carcinogenic $SSTL_{HH}$ but were averaged over a lifetime of exposure rather than being specific to one age group.

Results of the risk characterization and the resulting $SSTL_{HH}$ are presented in Section 6.5.2.3.

6.5.2.2 Comparison to CCME

CCME have published soil quality guidelines for cadmium and again it may reasonably be asked why these values are not adopted for use in Nanisivik. With respect to inhalation exposure to cadmium, this pathway is not incorporated into the CCME guideline. CCME based their 1999 soil quality guidelines only on soil ingestion and did not include either dermal contact or particulate inhalation as exposure pathways. Therefore, CCME gave no consideration to potential carcinogenic exposure to cadmium in the derivation of the generic guidelines. $SSTL_{HH}$ developed for cadmium in Nanisivik recognize the difference between ingestion/dermal exposure and inhalation exposure to cadmium and incorporate all three potential exposures with their appropriate health effect end-points.

6.5.2.3 Carcinogenic Effects

Calculated carcinogenic risks associated with potential inhalation of particulate matter containing cadmium are presented in Table 6.10.

Table 6.10 Calculated IILCR by Inhalation of Particulate

Cadmium	Town Area	General Mine Area
	1.29×10^{-8}	7.69×10^{-9}

As indicated the calculated IILCR in both the town area and the general mine area are less than the regulatory approved benchmark of 10^{-6}. Therefore, no unacceptable carcinogenic risks are predicted for the exposure scenarios modeled in this risk assessment.

6.5.2.4 $SSTL_{HH}$

$SSTL_{HH}$ which have been derived for cadmium by inhalation exposure are presented in Table 6.11.

Table 6.11 Surface Soil SSTLHH (mg/kg) – Carcinogenic Effects

Metal	Site Exposure Category	
	Residential	Hunting/Recreational
Cadmium	370	750

6.6 Uncertainty Analysis

Risk estimates normally include an element of uncertainty, and generally these uncertainties are addressed by incorporating conservative assumptions in the analysis. As a result, risk assessments tend to overstate the actual risk. Although many factors are considered in preparation of a risk analysis, analysis results are generally only sensitive to very few of these factors. The uncertainty analysis is included to demonstrate that assumptions used are conservative, or that the analysis result is not sensitive to the key assumptions.

A risk assessment containing a high degree of confidence will be based on:

- conditions where the problem is defined with a high level of certainty based on data and physical observations;
- an acceptable and reasonable level of conservatism in assumptions which will ensure that risks are overstated; or
- an appreciation of the bounds and limitations of the final solution.

The exposure assessment performed as part of this study was based on:

- available data to describe existing surface soil conditions and lead and arsenic distributions;
- sound conservative assumptions for certain parameters, as required; and
- well-understood and generally accepted methods for risk prediction.

6.6.1 Uncertainties in Toxicological Information

There is a very limited amount of toxicological information on the effects associated with human exposures to low levels of chemicals in the environment. What human information is available is generally based on epidemiological studies of occupationally exposed workers. These studies are generally limited in scope and provide results that may not be applicable to chronic or continuous exposures to low levels of chemicals. Because human toxicological information is limited, reference doses and cancer potency estimates for many compounds are based on the results of dose-response assessment studies using animals.

The use of experimental animal data to estimate potential biological effects in humans introduces uncertainties into the evaluation of potential human health effects. These estimations require that a number of assumptions be made:

- The toxicological effect reported in animals is relevant and could occur in humans.
- The assumption that extrapolation from high-dose studies to low-dose environmental exposures adequately represents the shape of the dose-response curve in the low-dose exposure range.
- Short-term exposures used in animal studies can be extrapolated to chronic or long-term exposures in humans.
- The uptake of a compound from a test vehicle (drinking water, food, etc) in animals will be the same as the uptake of the chemical from environmental media (soil, sediment, air-borne particulate matter) in humans.
- The pharmacokinetic processes that occur in the test animals also occur in humans.

There are clearly a number of uncertainties associated with extrapolating from experimental animal data to humans. In order to address these weaknesses, regulatory agencies, such as the Health Canada and the US EPA incorporate a large number of conservative assumptions to try and account for the uncertainties associated with this process. The uncertainties are accounted for by the use of *Uncertainty Factors* that are used to lower the reference dose well below the level at which adverse health effects have been reported in the test species. Uncertainty factors are generally applied by factors of 10 and are used to account for the following types of uncertainties:

- Variation within the population (protection of sensitive members of the population).
- Differences between humans and the test species.
- Differences in using short or medium-term studies to estimate the health effects associated with long-term or chronic exposures.
- Limitations in the available toxicological information.

The magnitude of the uncertainty factors applied by the various regulatory agencies provides an indication of the level of confidence that should be placed in the reference value. Uncertainty factors typically range between 100 and 10,000, although some can be lower than 10. The latter values are found for a few chemicals where sound and substantial human toxicological information is available to enable the setting of toxicological end-point solely on the basis of human epidemiological information.

The application of uncertainty factors is intended to introduce a high degree of conservatism into the risk assessment process and to ensure, as far as possible, that limited exposures that exceed the reference concentrations will not result in adverse human health effects. Because risk assessments that use these regulatory limits incorporate the conservatism used in the development of the toxicological information, the results can generally be viewed as being extremely conservative.

6.6.1.1 Summation of Hazards for a Single Compound

For cadmium, the toxicity values for inhalation and oral exposures are based on different biological end-points. In this case, the summation of exposures or hazard indices is not a sound toxicological practice and will not provide adequate assessments of either the inhalation or ingestion hazard. Therefore, it is necessary to assess the biological end-points separately. The estimate of overall risk would be based on the greater of the two risks. Inhalation and ingestion exposure hazard have been assessed independently and the greater of the two hazards selected as the representative hazard.

For lead and zinc, where the biological end-point is the same for both routes of exposure, estimates of hazard were based on estimates of total exposure.

6.6.1.2 Summation of Hazards Between Compounds

The summation of hazards between compounds that do not have the same biological end-point or mechanism of action has little practical meaning. Summation of hazard indices across compounds is only supportable when the individual compounds affect the same target organ and have similar mechanisms of action. In these cases, the summation of hazard indices may provide a better estimate of total risk than evaluations based on exposures to single chemicals. For this risk assessment, the toxicity values for cadmium, lead, and zinc are based on different biological end-points, hence, hazard indices have not been summed to provide an estimate of the overall hazard associated with these exposures.

6.6.2 Modeling Assumptions

Table 6.12 contains a summary of the assumptions used in this risk analysis, provides an evaluation for each assumption and an opinion as to whether the assumption is acceptable.

Table 6.12 Evaluation of Assumptions in the Risk Analysis

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Hazard Identification			
1. Screening of potential chemicals of concern against human-health based generic CCME, OMOE, or US EPA guidelines.	Generic guidelines by nature are very conservative in order that they can be reliably applied to any situation, potentially with little site-specific information available. Substances present at concentrations less than generic guidelines are unlikely to be of concern.	Neutral	Yes
2. Screening of metals against naturally occurring background conditions.	Metals are naturally occurring elements and in the Nanisivik area are known to be present in high concentrations due to mineralization, especially lead and zinc. To ignore natural background conditions may result in misleading conclusions that risk management could be recommended for naturally mineralized areas.	Neutral	Yes
3. Lead, cadmium, and zinc exposure point concentrations (EPCs) based on the upper 95% confidence limit on the data.	This methodology is in accordance with standard practice for evaluating large datasets. Decisions are not driven by outliers or a few high concentrations or hot spots but represent a reasonable estimate of exposure over the subject area.	Neutral. May ignore local hot spots. Maximum sample concentrations exceeding the $SSTL_{HH}$ should be targeted for risk management.	Yes
Receptor Characteristics			
1. For analysis of non-carcinogenic exposure, a toddler (0.5 – 4 years old) was chosen as the receptor.	Young children are the most sensitive age group for assessing non-carcinogenic effects. Resulting $SSTL_{HH}$ are over protective for an adult population. This approach is in accordance with accepted practice from Health Canada and the US EPA.	Neutral for young children but will over-estimate risks to adults.	Yes

Table 6.12 Evaluation of Assumptions in the Risk Analysis

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
2. For analysis of potential carcinogenic effects, a lifetime average was used representing exposure living in Nanisivik from birth to 70 years old.	For carcinogenic chemicals this is the most protective approach. In contrast, CCME only model adult exposure (20-70 years old) and US EPA only model exposure for 25 years (0-25 years old) averaged over a lifetime, both of which are less protective approaches. For cadmium, CCME did not account for carcinogenic effects of inhalation.	Approach likely to over-estimate the risk.	Yes
3. For the residential setting, both potential receptors (toddler and lifetime) assumed to be present on the property 24 hours per day, 365 days per year. For the hunting scenario, the receptor is assumed to be on the land hunting in the Nanisivik area for 60 days each summer.	These are maximum values providing a reasonable maximum exposure estimate for a toddler but likely overestimating lifetime exposure.	Neutral to over-estimate.	Yes
Toxicity Information			
1. Most current toxicity information available from Health Canada, US EPA Integrated Risk Information (IRIS) database, and World Health Organization (WHO) was employed.	This approach is in accordance with standard practice and provides the most recent scientific basis for toxicity values. Both values are extensively peer reviewed and accepted by Health Canada.	Neutral	Yes
2. Cancer slope factor for cadmium based on Health Canada TC_{05}.	Extrapolation of the TC_{05} to a low dose slope factor results in a slope factor 7 times more protective than that published by the US EPA on the IRIS.	Cadmium slope factor likely overestimates the risk to Canadian populations.	Yes
Risk Characterization			
1. Exposure was modelled for three potential exposure pathways: soil ingestion, dermal contact, and dust inhalation.	CCME base the generic guidelines on only soil ingestion. Therefore, this multi-pathway approach is more protective.	Neutral	Yes

Table 6.12 Evaluation of Assumptions in the Risk Analysis

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
2. Default CCME soil ingestion rate of 80 mg/day adopted and adjusted for the residential setting to account for indoor and outdoor exposure in winter and summer according to OMOE methods, resulting in daily average ingestion rate of 41 mg/day for a toddler. For the hunting scenario, the default CCME soil ingestion rate of 80 mg/day is adopted.	CCME employed a soil ingestion rate of 80 mg/day for toddlers when they developed the 1999 soil quality guidelines. In Nanisivik, climate considerations mean that outdoor exposure to soil likely only occurs over a limited period of time each year. During the winter months, residents may still be exposed to soil-derived household dust. For hunting exposure, no soil exposure is expected during winter months.	Neutral	Yes
3. Target risk for IICLR set at 1 in 1,000,000 (10^{-6}).	This is the value adopted by CCME for "acceptable" target risk. Health Canada uses target risks in the range of 10^{-5} to 10^{-6}. The CCME soil quality guidelines correspond to IILCRs of approximately 10^{-5} to 10^{-6}.	Neutral	Yes
4. Target Hazard Quotient for evaluating lead and cadmium exposure = 1.	This approach recognizes the contributions from all sources and provides the best estimate of total daily exposure. CCME guidelines assume that guidelines may also have to be established for other contaminated media at a site (*e.g.*, water) and therefore only apportion 20% of the allowable daily intake to soil exposure. In this instance, all potential routes of exposure have been accounted for, either in the EDI (*e.g.*, food, water) or in the pathways assessed (ingestion, inhalation, dermal contact). Therefore, the target hazard quotient recognizes that 100% of the exposure has been accounted for.	Neutral	Yes

7.0 ECOLOGICAL RISK ASSESSMENT

An ecological risk assessment (ERA) was conducted to assess the potential risks to ecological receptors associated with exposure to soils within the Nanisivik Mine area. The goal of the ERA is to develop a set of site-specific threshold limits (SSTLs) for elements in soils that would be protective of indigenous biota. The SSTLs for ecological health are used in conjunction with SSTLs for human health (see Section 6) to develop overall soil quality remedial objectives (SQROs) (see Section 8) for the Mine site. The ERA follows guidance of the Canadian Council of Ministers of the Environment (CCME 1996a,b).

This section provides an overview of the process used in conducting the ERA along with the corresponding results. The process used in conducting this ERA is as follows:

- hazard identification: the method used to identify which elements will be carried forward as contaminants of potential concern (COPC) into the quantitative risk assessment;
- receptor identification: selection process used to identify the ecological receptors that will be used in the ERA to represent indigenous wildlife;
- exposure assessment: process used to estimate exposure of receptors to COPCs by various pathways;
- conceptual model: a site-specific model that forms the foundation of the ERA by identifying the contaminant source, exposure media and pathways, and the potential ecological receptors.
- hazard assessment: process used to determine if the estimated exposure has the potential to result in adverse effects to ecological receptors; and
- site-specific threshold limits: process used to determine SSTLs, based on the hazard assessment, that will be protective of indigenous wildlife at the Mine site.

7.1 Hazard Identification

Table 7.1 illustrates the screening of COPCs in accordance with the flowchart outlined in Section 5. Elements included for consideration were all elements identified in the review of the GLL (2002c) and EBA (2002a) data at concentrations in soils exceeding the generic CCME soil quality guidelines for the protection of ecological health (CCME 1991, 1999). For those metals for which CCME guidelines have not been developed, concentrations were screened using guidelines from the Ontario Ministry of Environment (OMOE, 1996a). Hazard screening was done for each study area at the site: town area, dock area, and general mine area (see Section 2.2 for description of study areas).

7.1.1 Town Area

As indicated in Table 7.1, the maximum silver concentration in soils is less than the corresponding ecological health-based guideline. Boron was not analysed in soil samples collected from the town area. As a result, silver and boron are not considered further for the town area risk assessment. Maximum concentrations of arsenic, cadmium, cobalt, copper, nickel, lead, thallium and zinc in soils exceed their ecological health based generic guidelines. Based on these results, these elements are carried forward for comparison with typical background concentrations.

The exposure point concentrations (EPCs) for arsenic, cobalt, nickel and thallium are less than typical background values (OTR_{98} data for rural parkland) and are not considered further for the town area. The EPC for copper is not significantly different (ANOVA $p>0.005$) from the 1985 site-specific background data, and is less than the OTR_{98} for rural parkland as well as being lower than the 1985 site-specific background data for the general mine area. Therefore, copper is not considered further for the town area. The EPC for cadmium is greater than OTR_{98} data for rural parkland and the EPC for zinc significantly exceed 1985 site-specific background data (ANOVA $p<0.05$). Therefore, these metals are carried forward as hazards for the quantitative ERA for the town area.

The EPC for lead in the town area (192.3 mg/kg) is not significantly different (ANOVA $p>0.005$) from the 1985 site-specific background data (204.2 mg/kg), but it is greater than OTR_{98} for rural parkland (45 mg/kg) and greater than 1985 background for the mine area (67.9 mg/kg). As it cannot be conclusively shown that the town area in 1985 was free of any influence from the mine operations, lead is also carried forward as a hazard for the quantitative ERA for the town area.

7.1.2 Dock Area

As indicated in Table 7.1, the maximum silver, arsenic, cobalt, nickel and thallium concentrations in soils are less than the corresponding ecological health-based guidelines. As a result, these elements are not considered further for the dock area risk assessment. In addition, boron is not considered further because there is only one data point and therefore insufficient data to consider this metal further. Maximum concentrations of cadmium, copper, lead and zinc in soils exceed their ecological health based generic guidelines. Based on these results, these elements are carried forward for comparison with natural background concentrations.

The exposure point concentrations (EPCs) for cadmium, copper, lead and zinc exceed 1985 site-specific background data for the dock area and/or OTR_{98} data for rural parkland. Therefore, these metals are carried forward as hazards for the quantitative ecological risk assessment for the dock area.

Table 7.1 Hazard Screening Procedure for Ecological Risk Assessment.

Soil Concentration			Generic Ecological Health Guidelines						Background Soil Concentrations					
Metal	**Minimum Observed Soil Concentration**	**Maximum Observed Soil Concentration**	**Appicable Guideline**	**Exceeds? Y/N**	**Number of Samples**	**Number Exceeding Guideline**	**% Exceeding Guideline**	**Carried Forward**	**Exposure Point Concentration (EPC)**	**1985 Site Specific Background (SSB) 95% UCL**	**EPC/SSB Statistically Different? Y/N**	**OTR 1 Rural Parkland**	**EPC > BSC Y/N**	**Carried Forward Y/N**
TOWN AREA														
Ag	nd	8	20 [b]	N	109	0	0.00%	N	-	-		-	N	N
As	nd	50	17 [a]	Y	109	17	15.60%	Y	7.69	-		***11***	N	N
B	-	-	1.5 [b]	-	0	0	0.00%	N[IN]	-	-		-	N	N
Cd	nd	50.2	10 [a]	Y	116	25	21.55%	Y	4.74	-		***0.71***	Y	Y
Co	1	112	40 [b]	Y	109	2	1.83%	Y	9.68	-		***16***	N	N
Cu	8	166	63 [a]	Y	109	12	11.01%	Y	38	***42.7***	N	41	N	N
Ni	2	87	50 [a]	Y	109	2	1.83%	Y	22.2	-		***38***	N	N
Pb	15	2,720	300 [a]	Y	116	25	21.55%	Y	192.3	***204.2***	N	45	Y	Y**
Tl	nd	2	1.4 [a]	Y	109	2	1.83%	Y	0.57	-		***0.81***	N	N
Zn	90	38,500	200 [a]	Y	116	111	95.69%	Y	1,706	***322.8***	Y	120	Y	Y
DOCK AREA														
Ag	1	11	20 [b]	N	3	0	0.00%	N	-	-		-	-	N
As	3.7	5.4	17 [a]	N	13	0	0.00%	N	-	-		-	-	N
B	2.2	2.2	1.5 [b]	Y	1	1	100.00%	N[IN]	-	-		-	-	N [IN]
Cd	5.1	156	10 [a]	Y	29	24	82.76%	Y	33	-		***0.71***	Y	Y
Co	6	11	40 [b]	N	3	0	0.00%	N	-	-		-	Y	N
Cu	56	835	63 [a]	Y	3	2	66.67%	Y	835	123.3	*	***41***	14.3	Y
Ni	14	24	50 [a]	N	3	0	0.00%	N	-	-		-	N	N
Pb	67	4,330	300 [a]	Y	29	23	79.31%	Y	916.2	287	*	***45***	Y	Y
Tl	nd	1	1.4 [a]	N	3	0	0.00%	N	1	-		-	N	N
Zn	2,020	41,000	200 [a]	Y	29	29	100.00%	Y	11,246	690.2	*	***120***	Y	Y
GENERAL MINE AREA														
Ag	nd	32	20 [b]	Y	11	1	9.09%	Y	4.05	-		***0.27***	Y	Y
As	nd	9.7	17 [a]	N	11	0	0.00%	N	-	-		-	-	N
B	nd	2.3	1.5 [b]	Y	5	1	20.00%	N[IN]	-	-		-	-	N [IN]
Cd	nd	230	10 [a]	Y	51	14	27.45%	Y	5.75	-		***0.71***	0.102	Y
Co	6	35	40 [b]	N	11	0	0.00%	N	-	-		-	-	N
Cu	10	108	63 [a]	Y	11	4	36.36%	Y	66.7	***45.4***	N	41	N	N
Ni	10	29	50 [a]	N	11	0	0.00%	N	-	-		-	-	N
Pb	8	9,350	300 [a]	Y	51	19	37.25%	Y	297.2	***67.9***	Y	45	Y	Y
Tl	nd	nd	1.4 [a]	N	11	0	0.00%	N	-	-		-	-	N
Zn	51	131,000	200 [a]	Y	51	39	76.47%	Y	2,138	***89.7***	Y	120	Y	Y

[a] = CCME
[b] = MOEE
[1] = Ontario Typical Range
"-" = Analysis not conducted
[IN] = insufficient data
Bold indicates value used as background comparison

Note: With the exception of the dock*, the Exposure Point Concentration was compared to the 1985 Background 95% UCL (where available) in determining whether or not to carry the metal forward in the Risk Assessment. Where the 1985 Background 95% UCL was not available, the OTR value for Rural Parkland was used.

** It could not be determined with certainty that the 1985 Background 95% UCL concentrations were unaffected by anthropogenic (i.e., Mining) activities, therefore the OTR values were used for comparison instead.

7.1.3 General Mine Area

As indicated in Table 7.1, the maximum arsenic, cobalt, nickel and thallium concentrations in soils are less than the corresponding ecological health-based guidelines. As a result, these elements are not considered further for the general mine area risk assessment. In addition, boron is not considered further because there are only five (5) data points and therefore insufficient data to consider this metal further. Furthermore, the OMOE guideline (1.5 mg/kg) was exceeded in only one sample (2.3 mg/kg); the other samples were below the detection limit (<0.5 mg/kg). Maximum concentrations of silver, cadmium, copper, lead and zinc in soils exceed their ecological health based generic guidelines. Based on these results, these elements are carried forward for comparison with natural background concentrations.

The EPC for copper in the general mine area is not significantly different (ANOVA $p>0.05$) from the 1985 site-specific background data, and copper is therefore not carried forward as a hazard into the risk assessment. The exposure point concentrations (EPCs) for silver, cadmium, lead and zinc exceed 1985 site-specific background data for the general mine area and/or OTR_{98} data for rural parkland. Therefore, silver, cadmium, lead and zinc are carried forward as hazards for the quantitative ecological risk assessment for the general mine area.

7.1.4 Summary of Hazards in Soils

Table 7.2 provides a summary of the hazards and EPCs identified in soils for each study area and the elements carried forward into the ERA.

Table 7.2 Summary of Soil Hazards and Exposure Point Concentrations Used in the Ecological Risk Assessment

	Soil Exposure Point Concentration[a]		
	Town Area (mg/kg)	**Dock Area (mg/kg)**	**General Mine Area (mg/kg)**
Silver	na	na	na
Cadmium	4.74	33	5.75
Copper	na	835	66.7
Lead	192.3	916.2	297.2
Zinc	1706	11246	2138

Notes: a The selection of hazards and exposure point concentrations (a) are illustrated in Table 7.1.
na EPC not applicable because metal was screened out as a potential hazard; see text.

7.1.5 Surface Water

To assess metal uptake as part of the drinking water pathway for ecological receptors (see the conceptual model in Section 7.2), concentrations of metals in surface water were assessed for each study area. Data were obtained from monitoring stations established as part of the Surveillance Network Program being conducted by Nanisivik Mine (Carreau, pers. comm.). Data from sampling stations within each study area were available for cadmium, lead and zinc from 1996 to 2001. EPCs for each metal were calculated as arithmetic mean total metal concentrations (mg/L), based on 2001 data, as shown in Table 7.3.

Table 7.3 Exposure Point Concentrations for Metals in Surface Waters within Study Areas at the Nanisivik Mine Site.

	Surface Water Exposure Point Concentration[a]		
	Town Area[b] (mg/L)	Dock Area[c] (mg/L)	General Mine Area[d] (mg/L)
Cadmium	0.00175	0.00958	0.11032
Lead	0.0635	0.04842	0.08178
Zinc	0.021333	3.30573	0.17167

Notes:

a Surface water exposure point concentrations (EPCs) based on mean concentrations using 2001 data for total metals.

b Town area EPC based on Surveillance Network Program (SNP) Sampling Station 159-9 (Twin Creek, near town).

c Dock area EPC based on SNP Station 159-6 (Twin Creek, near dock).

d General mine area EPC based on highest mean from Stations 159-4 (West Twin Lake), NML 23 (East Twin Lake), 159-13 (Chris Creek) and 159-17 (Chris Creek at Strathcona Sound).

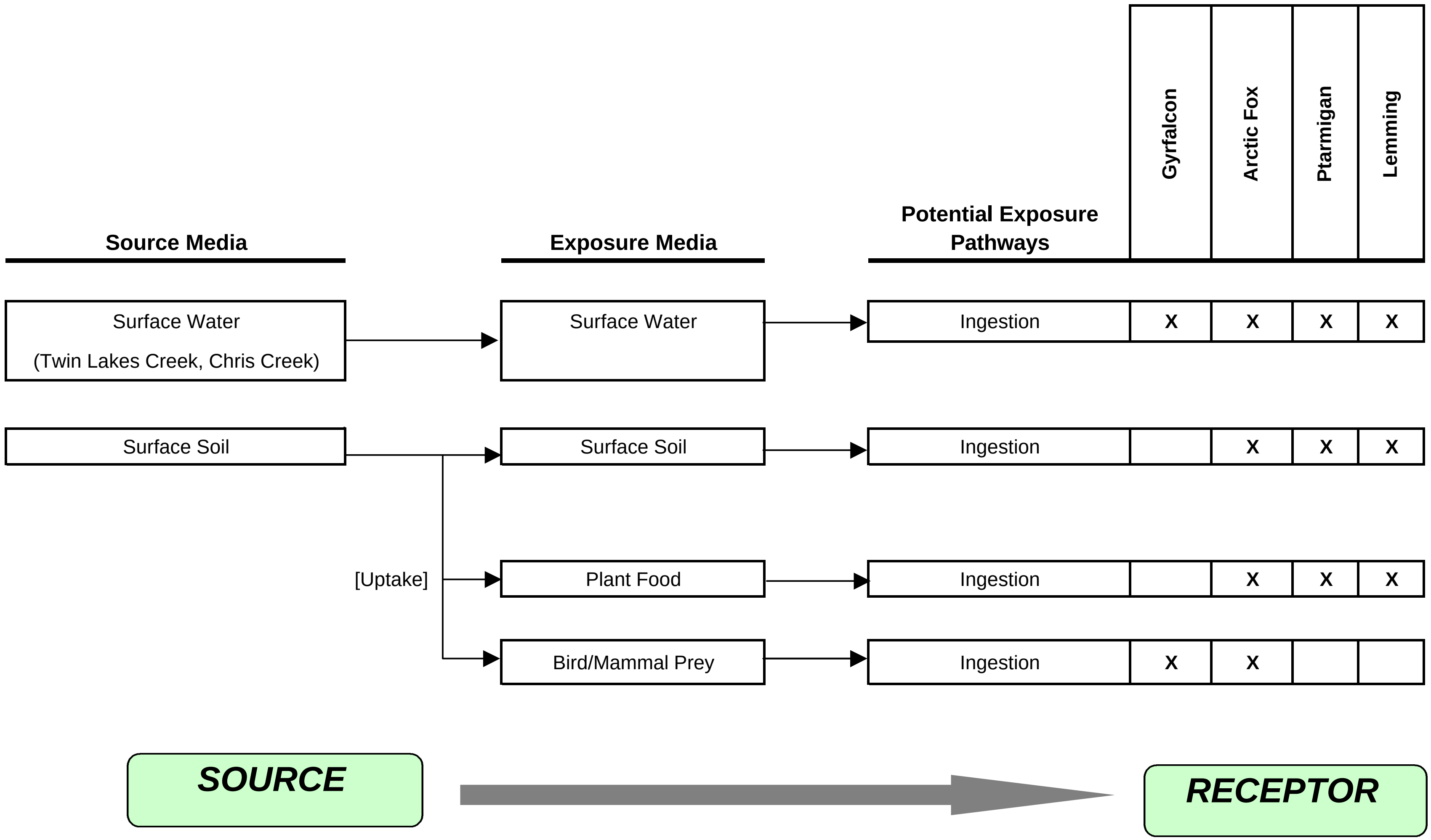
7.2 Conceptual Model

The conceptual model developed for the Nanisivik Mine site is illustrated in Figure 8. This model forms the foundation on which the ERA is based. Potential sources of metals to indigenous wildlife include surface soil and surface water. Although risks of exposure to contaminated soils are the focus of this ERA, wildlife on the site may also take in metals when they drink surface water from the site. Twin Lakes, Twin Creek and Chris Creek were assumed to be the main sources of drinking water for wildlife.

The potential exposure media for intake of metals include direct ingestion of surface water and soils, as well as uptake from eating plant material and animal (bird/mammal) prey at the mine site. The major exposure pathway considered was ingestion. Inhalation and dermal absorption are also possible exposure pathways, but these are considered to be relatively minor by comparison to ingestion, and are not included as direct pathways in this ERA. Soil that adheres to fur or feathers is, for the most part, ingested by preening/licking activity and is included in the estimate of direct soil ingestion. A similar ERA for the Polaris Mine site in Nunavut (Cantox 2001) considered the inhalation pathway, but determined that it did not contribute significantly to the exposure estimate of metals in soils for the four receptors: lemming, Arctic hare, caribou and Arctic fox.

The selected receptors in the model are lemming, Ptarmigan, Arctic fox and Gyrfalcon. These receptors are considered to be representative of indigenous wildlife for the Nanisivik mine. The rationale for their selection is provided in Section 7.3.

Figure 8 Conceptual Site Model for Ecological Receptors



Note:
1) **X** - Indicates a potentially complete exposure pathway.

7.3 Receptor Identification

Receptor selection was based on fundamental ecological considerations, but was also guided by information solicited from members of the local community (see Section 4). The following criteria were considered in selecting receptors for use in this ERA:

- keystone species known to be central to ecosystem function;
- exposed to surface soils at the site;
- representative of lower and higher trophic feeding levels (*i.e.*, herbivorous and carnivorous animals);
- present on or near the Mine site for some or most of the year;
- of significant cultural and/or economic significance; and
- endangered or sensitive species (no such species were determined to be indigenous to the study areas).

Based on these criteria, the following ecological receptors were selected: collared lemming, Arctic fox, Ptarmigan and Gyrfalcon. These receptors are briefly described below.

The collared lemming (*Dicrostonyx groenlandicus*) is a mouse-like burrowing rodent, weighing approximately 71 g, and lives on the tundra throughout the High Arctic. It is the smallest of the mammals in the High Arctic and is a key species in Arctic ecosystems. The lemming is herbivorous, feeding on whatever vegetation exists within its habitat. In the winter, lemmings do not hibernate; rather, they forage in the space that forms between the snow and soil. Lemmings are important food for Arctic fox, Gyrfalcon and other predatory species.

The Arctic fox (*Alopex lagopus*) is a relatively small canid mammal, weighing approximately 5.75 kg, and is widely distributed throughout the Arctic. It is predominately carnivorous, preying mostly on lemmings, but also on Ptarmigan and any other available meat (*e.g.*, small birds and mammals, Inuit meat caches, wolf kills). During the summer, the Arctic fox will also forage on any berries that might be available. Breeding dens are built in the surface soil and may be used for many generations. The Arctic fox is highly valued for its fur.

The Willow Ptarmigan (*Lagopus lagopus*) or Rock Ptarmigan (*L. mutus*) are small grouse-like birds, weighing approximately 0.5 kg, living year-round throughout alpine and Arctic tundra. These birds are herbivorous, feeding on willow buds and twigs throughout the year, and any other vegetation that might be available. Ptarmigan nest on the ground soon after the snow melts. They are valued for their meat and hunted by local residents.

The Gyrfalcon (*Falco rusticolus obsoletus*) is the world's largest falcon, weighing approximately 1.45 kg, and lives north of 60E latitude year-round. They prey on Ptarmigan, Arctic hare, lemming, and other small mammals and birds. Foraging areas may include coastal areas and beaches used by waterfowl. Gyrfalcon nest on the tundra, usually among tall cliffs. Feathers of the Gyrfalcon are valued by Inuit for ceremonial use. The Gyrfalcon is highly desired within the sport of falconry and is also much sought after by birdwatchers.

Receptors were selected to be representative of all potential wildlife receptors at the site. This approach is based on the premise that if highly exposed components of the ecosystem are protected, then populations of other exposed biota will also be adequately protected. Although this approach is considered reasonable, protection of selected ecological receptors for particular endpoints (*e.g.*, reproduction) may not always adequately protect all endpoints for all ecological receptors at site. The choice of receptors VECs was made, in part, on a trophic level approach in that they were chosen to represent lower and higher trophic levels. As a result, representative species were not chosen because of their sensitivity (information on sensitivity of arctic receptors is lacking), but because of their ecological significance and trophic level.

Lemming and Ptarmigan were chosen as representative of “highly exposed” biota for herbivore mammals and birds, as they remain in close contact with potentially contaminated soil year-round in a relatively restricted area. Arctic fox and Gyrfalcon were chosen to represent higher trophic levels that might be more likely to be exposed to contaminants via prey. Selection of receptors was made to ensure that risk estimates for the specific receptors could be representative of other wildlife receptors at the site.

Gulls and Ravens were not chosen as VECs because of uncertainty of their ongoing presence at the site post-closure when the landfill site has been reclaimed, and because they are not likely to be more exposed to contaminants than Ptarmigan. Gulls are noted by residents as being present seasonally and both Gulls and Raven are likely to have much larger home ranges and therefore lower exposure to metals than Ptarmigan. Gulls and ravens are considered to be scavenging omnivores and are often found in close association with people. After closure and reclamation of the mine site, these birds may spend substantially less time in the vicinity of the mine site.

Conceptually, a contaminant could cause an adverse effect at levels ranging from individuals to populations, and at intensities ranging from chronic to acute. For ecological receptors, adverse effects may be considered at the individual level where species of special conservation status are concerned. More commonly, however, (*i.e.*, where more common and widely distributed species are involved) emphasis is placed on protecting populations. In the context of this ERA, all of the selected receptors are common and widely distributed species. Even if there were significant risks to individuals, at point sources of contamination, these risks would be unlikely to translate into adverse effects at the population level.

7.3.1 Receptor Characterization

A number of ecological characteristics of the receptors are required in order to estimate their potential exposure to metals in surface soils from the site. These characteristics include body weight, feeding rate and food selection, water intake, length of time spent within the study area, and home-range size. Table 7.4 provides a summary of ecological characteristics and assumptions for each receptor. Where information on specific receptor species was lacking, data were either empirically derived, or estimated based on surrogate species with similar habits, as described below.

Body weight information for Gyrfalcon and lemming was obtained from the University of Michigan (2000). Information for the Arctic fox and Ptarmigan were obtained from the Canadian Wildlife Service (2002).

Home ranges for each receptor for drawn from a number of literature and web-based sources. The Gyrfalcon home range was estimated to be approximately 380,000 ha, based on satellite tracking data for Gyrfalcon in Greenland from The Peregrine Fund (2001). However, the home range size is conservatively estimated to be 100,000 ha, based on the assumption that Gyrfalcon will preferentially use selected habitat within its home range. The home range for Arctic Fox was estimated from Landa *et al.* (1998) and from information in a Government of NWT web-site (2001). The Ptarmigan home range was estimated using information for Northern Bobwhite (Quail) in US EPA (1993) and using Ptarmigan behaviour information from the Alaska Department of Fish and Game (1994). The home range for lemming was estimated as an average from data in Schmidt *et al.* (2002), Blackburn *et al.* (1998) and Predavec and Krebs (2000).

Occupancy factor was calculated as the study area size in hectares (ha) divided by the home range size (ha). If the home range size was less than the study area size, an occupancy factor of one (1) was used. Sizes of each study area were estimated to be as follows: Town 29 ha; Dock 24 ha, General Mine Area 4,350 ha. The fraction of food/water obtained from each study area is based on the occupancy factor.

Table 7.4 Ecological Receptor Characteristics and Assumptions Used in the Risk Assessment [a]

Parameter	Unit	Gyrfalcon	Arctic Fox	Ptarmigan	Lemming
Body weight	kg	1.45	5.75	0.5	0.071
Home range size	ha	100,000	1,875	10.3	0.475
Occupancy factor - per study area	Town	0.0003	0.0155	1	1
	dock	0.0002	0.0128	1	1
	general	0.0435	1	1	1
Fraction of food/water from on-site	town	0.0003	0.0155	1	1
	dock	0.0002	0.0128	1	1
	general	0.0435	1	1	1
Water intake rate	L/d	0.076	0.478	0.037	0.009
Food intake rate	kg-wet/d	0.223	0.933	0.124	0.023
Fraction of food from:	bird	0.3	0.20	0	0
	mammal	0.7	0.75	0	0
	plant/berry	0	0.05	1	1
Soil ingestion	fraction	--	0.03	0.02	0.02
Fraction of diet that is dry solid	fraction	--	0.31	0.30	0.30

[a] See Section 1.3 for sources of information and an explanation for how these ecological characteristics were derived.

Equations for food intake rate (IR_{food}) are taken from U.S. EPA (1993), as follows:

Lemming $$IR_{food} = 0.000621*(BW - g)^{0.564} / F_{dry\ solid}$$

Arctic Fox $$IR_{food} = 0.0687*(BW - kg)^{0.822} / F_{dry\ solid}$$

Ptarmigan $$IR_{food} = 0.0582*(BW - kg)^{0.651} / F_{dry\ solid}$$

Gyrfalcon $$IR_{food} = 0.000301*(BW - g)^{0.751} / 1000/ F_{dry\ solid}$$

where: IR_{food} = food intake rate in kg-wet/day
BW = body weight in kg (“BW – kg”) or g (“BW – g”)
$F_{dry\ solid}$ = Fraction of diet that is dry solid (see Table 7.4)

Equations for water intake rate (IR_{water}) are taken from U.S. EPA (1993), as follows:

Lemming and Arctic Fox $$IR_{water} = 0.099*(BW - kg)^{0.9}$$

Ptarmigan and Gyrfalcon $$IR_{water} = 0.059*(BW - kg)^{0.67}$$

where: IR_{water} = water intake rate in L/day
BW = body weight in kg (“BW – kg”)

Soil ingestion is from Beyer *et al.* (1994) and is expressed as a fraction of diet based on estimated soil in the diet of wildlife species. Surrogate species were selected based on food types eaten:

- white footed mouse was the surrogate for lemming;
- red fox was the surrogate for Arctic fox; and
- Blue-winged teal was the surrogate for Ptarmigan.

The Gyrfalcon was considered unlikely to ingest significant amounts of site soil due to their large home range and predatory behaviour.

The dry solids fraction in food is based on food items and corresponding water contents reported in US EPA (1993).

7.4 Exposure Assessment

Exposure of ecological receptors to metals in surface soils was estimated using the pathways of ingestion (surface water, surface soil, plant material, bird/mammal prey), receptor characteristics, soil and surface water data, and predicted metal concentrations in plant and animal tissue. The method used to predict metal concentrations in plant and animal tissues is presented in Section 7.4.1. Methods used to calculate exposure are presented in Section 7.4.2. Exposure estimates are presented in Section 7.4.3.

7.4.1 Metal Uptake in Plants and Animals

Metal concentrations in plant and animal tissues were derived using Exposure Point Concentrations (EPCs) in soils for each study area and applying an uptake factor to obtain dry weight tissue concentrations, then applying a conversion factor to obtain wet weight tissue concentrations. Calculation methods are provided in the following two sections (7.4.1.1 and 7.4.1.2). The predicted soil and animal tissue metal concentrations are presented in Table 7.5.

7.4.1.1 Soil to Plant Uptake

The concentration of metals in plants was predicted using two steps as follows. First, the metal concentration in dry weight plant tissue was derived from the soil EPCs by multiplying the EPC by an uptake factor to obtain a predicted concentration based on dry-weight plant tissue. For most metals, this uptake factor is based on empirical data using regression models in Efroymson *et al.* (2001), and is specific to the EPC being used. For silver, a regression model was unavailable, and therefore uptake from soil-to-plant was based on a factor from Frissel and Bergeijk (1989) in IAEA (1994).

To obtain the wet-weight tissue concentration, the predicted dry weight tissue concentration was multiplied by a conversion factor of 0.19, representing the average dry solids fraction (= 1- average water content) of dicot leaves and fruit pulp (US EPA, 1993).

7.4.1.2 Soil-to-Animal Uptake

The concentration of metals in animal (mammal or bird) was predicted using two steps as follows. First, the metal concentration in dry-weight animal tissue was derived from the soil EPCs by multiplying by an uptake factor. For most metals, this uptake factor is based on empirical data using regression models in Sample *et al.* (1998) and is specific to the EPC being used. For silver, uptake from soil-to-animal was based on the geometric mean of uptake factors for silver from Table B-1 in Sample *et al.* (1998).

Table 7.5 Uptake Factors for Metals of Concern in Surface Soil: Soil-to-Plant and Soil-to-Animal

Metal	Soil EPC (mg/kg)	Soil to Plant Uptake Factor (mg/kg-dry plant/ mg/kg-dry soil) [(a)]	Reference for Uptake Factor	Conversion Factor [(b)]	UP_{SP} (mg/kg-wet plant/ mg/kg-dry soil)	Soil to Animal Uptake Factor (mg/kg-dry animal/ mg/kg-dry soil) [(c)]	Reference for Uptake Factor	Conversion Factor [(d)]	UP_{SA} (mg/kg-wet animal/ mg/kg-dry soil) [(d)]
Town Area									
Cadmium	4.74	0.357	Efroymson et al. (2001)	0.19	0.068	0.125	Sample et al. (1998)	0.32	0.040
Lead	192.3	0.059	Efroymson et al. (2001)	0.19	0.011	0.043	Sample et al. (1998)	0.32	0.014
Zinc	1706	0.160	Efroymson et al. (2001)	0.19	0.030	0.078	Sample et al. (1998)	0.32	0.025
Dock Area									
Cadmium	33	0.143	Efroymson et al. (2001)	0.19	0.027	0.045	Sample et al. (1998)	0.32	0.014
Copper	835	0.050	Efroymson et al. (2001)	0.19	0.010	0.015	Sample et al. (1998)	0.32	0.005
Lead	916.2	0.035	Efroymson et al. (2001)	0.19	0.007	0.020	Sample et al. (1998)	0.32	0.006
Zinc	11246	0.062	Efroymson et al. (2001)	0.19	0.012	0.013	Sample et al. (1998)	0.32	0.004
General Mine Area									
Cadmium	5.75	0.326	Efroymson et al. (2001)	0.19	0.062	0.113	Sample et al. (1998)	0.32	0.036
Copper	66.7	0.191	Efroymson et al. (2001)	0.19	0.036	0.153	Sample et al. (1998)	0.32	0.049
Lead	297.2	0.051	Efroymson et al. (2001)	0.19	0.010	0.035	Sample et al. (1998)	0.32	0.011
Silver	4.05	0.0008	Frissel and Bergeijk (1989) in IAEA (1994)	0.19	0.0002	0.021	Sample et al. (1998)[(e)]	0.32	0.007
Zinc	2138	0.143	Efroymson et al. (2001)	0.19	0.027	0.063	Sample et al. (1998)	0.32	0.020

Notes:

(a) Equations used to solve for metal uptake factor (UP_{sp} mg/kg-dry plant/mg/kg soil) from soil to plant:

Cadmium UP_{sp} = EXP(- 0.30+0.53*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Copper UP_{sp} = EXP(0.57+0.47*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Lead UP_{sp} = EXP(-1.09+0.67*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Silver UP_{sp} = 0.0008
Zinc UP_{sp} = EXP(1.89+0.50*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)

(b) Conversion factor from mg/kg-dry to mg/kg-wet: multiply by 0.19. This conversion factor is based on the average dry solids fraction (= 1 - average water content) of dicot leaves and fruit pulp from Table 4-2 in U.S. EPA (1993).

(c) Equations used to solve for metal uptake factor (UP_{sa} mg/kg-dry herbivore/mg/kg soil) in herbivore (mg/kg-dry tissue):

Cadmium UP_{sa} = EXP(-1.2571 + 0.4723*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Copper UP_{sa} = EXP(2.0423 + 0.0675*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Lead UP_{sa} = EXP(-0.6114 + 0.5181*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)
Silver UP_{sa} = 0.021
Zinc UP_{sa} = EXP(4.3632 + 0.0706*(ln(Soil EPC mg/kg)))/(Soil EPC mg/kg)

(d) Conversion factor from mg/kg-dry to mg/kg-wet: multiply by 0.32. This conversion factor is based on the dry solids fraction (= 1 - water content) for small mammals from Table 4-1 in U.S. EPA 1993).

(e) Geometric mean of uptake factors for silver from Table B-1 in Sample et al. (1998)

To obtain wet-weight tissue concentrations of metals, the dry-weight tissue concentrations were multiplied by a conversion factor of 0.32, representing the average dry solids fraction (= 1- average water content) for small mammals (US EPA, 1993).

7.5 Exposure Estimates

The exposure to metals in soils for ecological receptors was calculated using the following equations, based on the receptor characteristics in Table 7.4.

For water ingestion:

$$ADD_{water} = \frac{EPC_{water} \times IR_{water} \times F_{area}}{BW}$$

where: ADD_{water} = average daily dose via surface water pathway (mg/kg-day)
EPC_{water} = exposure point concentration for surface water from area (mg/L)
IR_{water} = ingestion rate of water (L/day)
F_{area} = fraction of water obtained from area (unitless)
BW = body weight (kg)

For soil ingestion:

$$ADD_{soil} = \frac{EPC_{soil} \times IR_{food} \times F_{solid} \times F_{soil} \times F_{area}}{BW}$$

where: ADD_{soil} = average daily dose via soil pathway (mg/kg-day)
EPC_{soil} = exposure point concentration for soil from area (mg/kg)
IR_{food} = ingestion rate of food (kg/day)
F_{solid} = fraction of diet represented by dry solids (unitless)
F_{soil} = fraction of diet represented by soil (unitless)
F_{area} = fraction of food obtained from area (unitless)
BW = body weight (kg)

For plant/animal ingestion:

$$ADD_{food} = \frac{EPC_{soil} \times UP_{sp/sa} \times IR_{food} \times F_{food} \times F_{area}}{BW}$$

where: ADD_{food} = average daily dose via plant/animal pathway (mg/kg-day)
EPC_{soil} = exposure point concentration for soil from area (mg/L)

$UP_{sp/sa}$ = uptake factor for soil-to-plant OR soil-to-animal (unitless)
IR_{food} = ingestion rate of food (kg/day)
F_{food} = fraction of diet represented by food type (unitless)
F_{area} = fraction of food obtained from area (unitless)
BW = body weight (kg)

7.6 Hazard Assessment

The potential hazards associated with exposure of ecological receptors was evaluated by comparing the estimated average daily dose (ADD) with a reference toxicity dose (RTD). The RTD is a toxicity benchmark obtained from the literature that is conservative, in that it is considered to be the concentration below which the potential for adverse effects to the ecological receptor is low. Calculation of the hazard quotient (HQ) provides a mathematical comparison of exposure and RTD:

$$HQ = \frac{ADD_{receptor}}{RTD_{receptor}}$$

where: HQ = hazard quotient (unitless)
ADDreceptor = average daily dose calculated for the receptor (mg/kg-day)
RTDreceptor = reference toxicity dose established for the receptor (mg/kg-day)

The HQ is greater than one if the estimated ADD for a receptor is greater than the RTD; this result indicates that there is potential for an adverse ecological effect to occur. The HQ is less than one if the ADDs are below RTDs; this result indicates a low potential for the occurrence of an adverse ecological effect.

This section provides a description for how RTDs were established for the ecological receptors, and then provides the results of the hazard assessment for receptors at the Mine site.

7.6.1 Determination of Reference Toxicity Doses

Reference toxicity doses were used to evaluate the estimated exposures to determine the potential of adverse effects to the ecological receptors. The RTDs were based on “lowest observed adverse effects levels”, or LOAELs, for laboratory animals from the literature, and focussed on sublethal effects from chronic (long-term) exposures. As a result, the RTDs are considered to be protective of receptors for longer-term exposures at the population level.

In the absence of toxicity data for the specific ecological receptors, data for laboratory animals were obtained, for the most part, from the Oak Ridge National Laboratory toxicity database (Sample *et al.* 1996). The RTD for silver was obtained from Wahlberg (1965) in ATSDR (1990).

RTDs for bird receptors are presented in Table 7.6. RTDs that were based on laboratory studies conducted on bird species were not scaled for body weight (Sample *et al.* 1996). The RTD for silver was based on the guinea pig, and therefore an uncertainty factor of five was applied to derive a conservative RTD for Ptarmigan and Gyrfalcon.

RTDs for mammalian receptors are presented in Table 7.7 and were scaled for body weight using the following equation:

$$RTD_{receptor} = RTD_{test} \times \left[\frac{BW_{test}}{BW_{receptor}} \right]^{0.25}$$

where:

$RTD_{receptor}$	=	Reference toxicity dose derived for the receptor species (mg/kg-day)
RTD_{test}	=	Reference toxicity dose measured for the test species (mg/kg-day)
BW_{test}	=	Body weight for the test species (kg)
$BW_{receptor}$	=	Body weight for the receptor species (kg)

7.6.2 Hazard Estimate Results

Ecological hazard quotients (HQs) for lemming, Arctic fox, Ptarmigan and Gyrfalcon are presented in Tables 7.8, 7.9, 7.10 and 7.11, respectively, and include all three study areas. For each receptor and study area, the "total HQ" is expressed as the sum of the average daily doses for exposure media and pathway divided by the reference toxicity dose for that metal. For the Arctic fox (Table 7.9), total HQs for the Town Area and Dock Area were first considered in isolation from the Mine site, and then adjusted to include weighted HQs from the General Mine Area. This was done to reflect that the General Mine Area represents more than 98% of the fox home range. For the Gyrfalcon (Table 7.11), total HQs were summed across all study areas to generate an overall HQ for each metal based on exposure to the entire Mine site. This was done to reflect that the Mine site represents only a small fraction of the Gyrfalcon home range.

Table 7.6 Reference Toxicity Doses for Ptarmigan and Gyrfalcon.

Metal	Bird Species	Effect	Toxicity Reference	Chronic LOAEL Test Species (mg/kg-day)	Total Uncertainty Factor [a]	Chronic LOAEL- Bird Species [b] (mg/kg-day)
Cadmium	Mallard duck	reproduction	White & Finley (1978), Sample et al. (1996)	20	1	20
Copper	Chicken (chicks)	growth, mortality	Mehring et al. (1960), Sample et al. (1996)	61.7	1	61.7
Lead	Japanese quail	reproduction	Edens et al. (1976), Sample et al. (1996)	11.3	1	11.3
Silver	Guinea Pig	reduced grouth	Wahlberg (1965), ATSDR (1990)	137.13	5	27.4
Zinc	Leghorn chicken	reproduction	Stahl et al. (1990), Sample et al. (1996)	131	1	131

Notes:

[a] The following uncertainty factor is used: 5 for mammal to bird.

[b] The chronic LOAEL is calculated as the Daily Dose divided by the Total Uncertainty Factor.

Table 7.7 Reference Toxicity Doses for Lemming and Arctic Fox.

Metal	Test Species	Effect	Toxicity Reference	Chronic LOAEL Test Species (mg/kg-day)	Body Weight Test Species [a] (kg)	Receptor Species	Body Weight Receptor [b] (kg)	Body Weight Scaling Factor [c]	Reference Toxicity Dose [d] (mg/kg-day)
Cadmium	Rat	reproduction	Sutou et al. (1980), Sample et al. (1996)	10	0.35	Lemming	0.071	1.49	14.9
						Arctic Fox	5.75	0.497	4.97
Copper	Mink	reproduction	Aulerich et al. (1982), Sample et al. (1996)	15.1	1	Lemming	0.071	1.94	29.2
						Arctic Fox	5.75	0.646	9.78
Lead	Rat	reproduction	Azar et al. (1973), Sample et al. (1996)	80	0.35	Lemming	0.071	1.49	119
						Arctic Fox	5.75	0.497	39.8
Silver	Guinea Pig	reduced growth	Wahlberg (1965), ATSDR (1990)	137.13	0.86	Lemming	0.071	1.87	256
						Arctic Fox	5.75	0.62	85.3
Zinc	Rat	reproduction	Schlicker & Cox (1968), Sample et al. (1996)	320	0.35	Lemming	0.071	1.49	477
						Arctic Fox	5.75	0.497	159

Notes:

a Body weight for rat was taken from U.S. EPA (1985); for guinea pig from (U.S. EPA 1988) and for mink from (U.S. EPA 1993).

b Body weight for the test species is taken from Table 6.4.

c Body weight scaling factor is calculated using the following equation: *Scaling Factor*

$$= \left[\frac{BW_{test}}{BW_{receptor}} \right]^{0.25}$$

d Reference Toxicity Dose (RTD) for the receptor is calculated using the following equation:

$$RTD_{receptor} = RTD_{test} \times Scaling\ Factor$$

Table 7.8 Ecological Hazard Quotients for the Lemming Exposed to Metals in Soils and Surface Water at the Nanisivik Mine Site

Town Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	4.74	0.00175	14.9	0.0092	0.104	0.000222	0.00761
Lead	192.3	0.0635	119	0.373	0.702	0.00806	0.00908
Zinc	1706	0.021333	477	3.31	16.8	0.00271	0.0422

Dock Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	33	0.00958	14.9	0.064	0.291	0.00122	0.0239
Copper	835	--	29.1	1.62	2.57	-	0.143
Lead	916.2	0.04842	119	1.78	2.00	0.00615	0.0317
Zinc	11246	3.30573	477	21.8	43.2	0.42	0.137

General Mine Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	5.75	0.11032	14.9	0.0112	0.115	0.014	0.00942
Lead	297.2	0.08178	119	0.577	0.939	0.0104	0.0128
Silver	4.05	--	256	0.00786	0.000199	-	0.0000315
Zinc	2138	0.17167	477	4.15	18.8	0.0218	0.0483

Notes:

[a] *Total Hazard Quotient =* $\frac{\sum_{ADD} (mg/kg-day)}{RTD\ (mg/kg-day)}$

Table 7.9 Ecological Hazard Quotients for Arctic Fox Exposed to Metals in Soils and Surface Water at the Nanisivik Mine Site

Town Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
Town Area (1.55% of fox habitat) in isolation from remainder of mine site.								
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	4.74	0.00175	4.97	0.000111	0.0000405	0.000454	0.00000226	0.000122
Lead	192.3	0.0635	39.8	0.0045	0.000273	0.00633	0.0000819	0.000281
Zinc	1706	0.021333	159	0.0399	0.00655	0.102	0.0000275	0.000931
Town Area (1.55% of fox habitat) plus General Mine Area (98.45% of fox habitat)								
Cadmium	5.75	0.11032	4.97	Results at the right show the sum of Town Area in isolation (1.55% of fox habitat) plus occupancy in the General Mine Area (98.45% of the fox habitat)				0.0105577
Lead	297.2	0.08178	39.8					0.02479505
Zinc	2138	0.17167	159					0.0651204

Dock Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
Dock Area (1.28% of fox habitat) in isolation from remainder of mine site.								
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	33	0.00958	4.97	0.000637	0.0000934	0.000935	0.0000102	0.000337
Copper	835	--	9.75	0.0161	0.000825	0.00765	-	0.00251
Lead	916.2	0.04842	39.8	0.0177	0.000641	0.0117	0.0000513	0.000757
Zinc	11246	3.30573	159	0.217	0.0139	0.0956	0.0035	0.00208
Dock Area (1.28% of fox habitat) plus General Mine Area (98.72% of fox habitat).								
Cadmium	5.75	0.11032	4.97	Results at the right show the sum of Dock Area in isolation (1.28% of fox habitat) plus occupancy in the General Mine Area (98.72% of the fox habitat), using a total hazard quotient of 0.064 for copper in the General Mine Area.				0.01080132
Copper	297.2	0.08178	39.8					0.0656908
Lead	4.05	--	0.412					0.02533828
Zinc	2138	0.17167	159					0.06644544

General Mine Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	5.75	0.11032	4.97	0.00868	0.00289	0.032	0.00917	0.0106
Lead	297.2	0.08178	39.8	0.449	0.0235	0.511	0.0068	0.0249
Silver	4.05	--	0.412	0.00612	0.000005	0.00419	-	0.000121
Zinc	2138	0.17167	159	3.23	0.472	6.65	0.0143	0.0652

Notes:

[a] *Total Hazard Quotient =*

$$\frac{\sum_{ADD} (mg / kg - day)}{RTD \; (mg / kg - day)}$$

Table 7.10

Ecological Hazard Quotients for Ptarmigan Exposed to Metals in Soils and Surface Water at the Nanisivik Mine Site

Town Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	4.74	0.00175	20	0.00706	0.0796	0.00013	0.00434
Lead	192.3	0.0635	11.3	0.287	0.537	0.0047	0.0733
Zinc	1706	0.021333	131	2.54	12.9	0.00158	0.118

Dock Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	33	0.00958	20	0.0492	0.223	0.000709	0.0136
Copper	835	--	61.7	1.24	1.97	-	0.0521
Lead	916.2	0.04842	11.3	1.37	1.53	0.00358	0.256
Zinc	11246	3.30573	131	16.8	33.1	0.245	0.382

General Mine Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Surface Soil Ingestion	Terrestrial Plant Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	5.75	0.11032	20	0.00857	0.0882	0.00816	0.00525
Lead	297.2	0.08178	11.3	0.443	0.719	0.00605	0.103
Silver	4.05	--	27.4	0.00603	0.000153	-	0.000226
Zinc	2138	0.17167	131	3.19	14.4	0.0127	0.135

Notes:

[a] *Total Hazard Quotient =* $\dfrac{\sum_{ADD} (mg / kg - day)}{RTD\ (mg / kg - day)}$

Table 7.11 Ecological Hazard Quotients for Gyrfalcon Exposed to Metals in Soils and Surface Water at the Nanisivik Mine Site

Town Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	33	0.00958	20	0.00000875	0.0000000275	0.000000439
Lead	916.2	0.04842	11.3	0.000122	0.000000997	0.0000109
Zinc	11246	3.30573	131	0.00196	0.000000335	0.000015

Dock Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	4.74	0.00175	20	0.0000145	0.000000101	0.000000736
Copper	38	--	61.7	0.00012	-	0.00000194
Lead	192.3	0.0635	11.3	0.000184	0.000000508	0.0000163
Zinc	1706	0.021333	131	0.00149	0.0000347	0.0000117

General Mine Area

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	5.75	0.11032	20	0.00139	0.000252	0.0000821
Lead	297.2	0.08178	11.3	0.0222	0.000186	0.00198
Silver	4.05	--	27.4	0.000182	-	0.00000664
Zinc	2138	0.17167	131	0.289	0.000391	0.00221

Total Exposure: Town Area plus Dock Area plus General Mine Area.

Metal	Soil EPC (mg/kg)	Surface Water EPC (mg/L)	Reference Toxicity Dose (mg/kg-day)	Terrestrial Mammal/Bird Ingestion	Surface Water	Total Ecological Hazard Quotient [a]
				Average Daily Dose (mg/kg-day)	Average Daily Dose (mg/kg-day)	
Cadmium	5.75	0.11032	20	Results at the right show the sum of hazard quotients Town Area, Dock Area and General Mine Area. The total hazard quotient (HQ) for copper reflects the HQ shown for the Dock Area, plus the HQ in the Town Area (0.00000236) and the HQ in the General Mine Area (0.000355). This reflects the overall hazard presented to the Gyrfalcon from the entire mine site.		0.000083275
Copper	66.7	--	61.7			0.0003593
Lead	297.2	0.08178	11.3			0.0020072
Silver	4.05	--	27.4			0.00000664
Zinc	2138	0.17167	131			0.0022367

Notes:

[a] *Total Hazard Quotient =* $$\frac{\sum_{ADD} (mg / kg - day)}{RTD (mg / kg - day)}$$

The total HQs for all metals and all receptors are all much less than 1.0, indicating that the present levels of metals in surface soils at the Nanisivik Mine site are not expected to cause adverse ecological effects at the population level. Drinking water did not contribute significantly to any of the exposures. Exposure to metals for Gyrfalcon was very low, reflecting the fact that the overall Mine site represents a very small portion of its home range. There is no significant potential for adverse effects to Gyrfalcon associated with metals in surface soils at the Mine site.

The two receptors with the smallest home ranges (lemming and Ptarmigan) were predicted to have the highest overall daily doses of metals, and these doses are generally highest for the dock area, where surface metal concentrations are highest. This finding is not surprising since lemming and Ptarmigan may be expected to reside completely within the dock area or town area, whereas for Arctic fox, these areas represent only a small fraction of its home range (and therefore exposure is spread out over a larger area). Soil and plant ingestion contributed the most to the total daily dose for lemming and Ptarmigan.

The total hazard quotient for Arctic fox was very low (*i.e.*, much less than 1) for all metals in all study areas. The highest exposure for Arctic fox was to zinc in the general mine area, based on the conservative assumption that the fox would be exposed to the surface soil EPC throughout the general mine area where it resides 100% of the time. Although EPCs for metals were generally higher in the Town Area and Dock Area, this did not translate into higher HQs because these study areas represent less than 2% of the fox home range.

7.7 Site-Specific Threshold Limits

$SSTL_{ECO}$ were calculated for each ecological receptor to determine the concentration of metal that would result in a total hazard quotient (HQ) of 1. The $SSTL_{ECO}$ represents the concentration below which there is a low potential for adverse ecological effects to the ecological receptor.

Since the total HQ for all metals and all receptors was less than 1, the $SSTL_{ECO}$ were calculated by setting the HQ at 1, and determining the corresponding EPC for that HQ, using a forward calculation. The $SSTL_{ECO}$ established for each receptor are provided in Table 7.12. Given the very low total HQs for the Gyrfalcon, $SSTL_{ECO}$ were not calculated because the Mine site represents such a small part of its home range that metal concentrations in surface soil, no matter how high, will not present a risk at the population level.

$SSTL_{ECO}$ for the lemming, Ptarmigan and Arctic fox are applicable across all study areas for the Mine site. $SSTL_{ECO}$ for cadmium, copper and silver are much higher than the maximum surface soil concentrations across the Mine site, indicating that there is no potential for adverse ecological effects at the population level associated with exposure.

Table 7.12 Site-Specific Threshold Limits for Metals in Surface Soils for Ecological Receptors at the Nanisivik Mine Site

Metal	Maximum Soil Concentration (mg/kg)	Surface Soil SSTL (mg/kg)		
		Lemming	Ptarmigan	Arctic Fox
Cadmium	230	5,431	10,283	2,837
Copper	835	10,673	33,882	5,918
Lead	9,350	47,030	4,569	22,832
Silver	32	128,604	17,953	33,494
Zinc	131,000	161,382	44,001	97,439

$SSTL_{ECO}$ for lemming and fox are well above the maximum lead concentration in surface soils, indicating low potential for adverse effects to these receptors. However, the $SSTL_{ECO}$ for lead for Ptarmigan is lower than the highest measured concentration at the Mine site. $SSTL_{ECO}$ for Ptarmigan and Arctic fox for zinc are below the highest measured concentration in surface soils at the Mine site, although much higher than the highest exposure point concentration (11,246 mg/kg for the Dock Area).

The overall $SSTL_{ECO}$ for the site are presented in Table 7.13. These were selected based on the lowest $SSTL_{ECO}$ across the receptors. These results indicate that there may be some benefit to ecological receptors if remedial activities are undertaken at areas where the soil metals concentrations (lead and zinc) exceed the $SSTL_{ECO}$. However, the overall ERA results indicate that the existing conditions at Nanisivik are not likely to result in adverse effects to exposed biota at the population level.

Table 7.13 Overall Ecological Site-Specific Threshold Limits Derived for the Nanisivik Mine Site[a]

Metal	Maximum Soil Concentration (mg/kg)	Surface Soil SSTL (mg/kg)
Cadmium	230	2,837
Copper	835	5,918
Lead	9,350	4,569
Silver	32	17,953
Zinc	131,000	44,001

[a] The overall ecological site-specific threshold limit (SSTL) for each metal is based on the lowest SSTL across all receptors in Table 7.12.

7.8 Modeling Assumptions and Uncertainties

Table 7.14 contains a summary of the assumptions used in this risk analysis, provides an evaluation for each assumption and an opinion as to whether the assumption is acceptable.

Table 7.14 Evaluation of Assumptions and Uncertainties in the Ecological Risk Assessment

Risk Assessment Study Factor/Assumptions	Justification	Analysis Likely to Over/Under Estimate Risk?	Acceptable Assumption?
Hazard Identification			
1. Screening of potential chemicals of concern against ecological based guidelines	Generic guidelines are generally considered to be conservative in nature, in that they err on the side of protection of ecological resources. Chemicals present at concentrations less than generic guidelines are unlikely to be of concern.	Neutral	Yes
2. Screening of metals against naturally occurring background concentrations	Metals are naturally occurring elements and in the Nanisivik area are known to be present in high concentrations due to mineralization, especially lead and zinc. Background concentrations are taken into account as it would be inappropriate and futile to recommend remediation for naturally mineralized areas.	Neutral	Yes
3. Exposure point concentrations (EPCs) based on the upper 95% confidence limit on the data.	Using EPCs is a standard practice for evaluating large data sets. The use of EPCs in risk assessment means that decisions are not driven by outliers or a few high concentrations, but are instead based on concentrations that represent a reasonable estimate of average exposure over the study area.	Neutral. May ignore local hotspots. Unlikely to affect risk outcome since SSTLs were all well above EPCs, and maximum measured concentrations.	Yes
4. Metal concentrations in plant and animal tissues were estimated.	Empirical data for metals in plant and animal tissues from the mine site were unavailable. It is standard practice to estimate chemical concentrations in tissues if empirical data are lacking. Metal concentrations were estimated using regression models based on empirical data from a number of studies. These models represent the best available method to estimate tissue concentrations. It is possible that the metal concentrations are under- or over-estimated, based on the regression models.	Neutral. Risk estimates were very low (hazard quotients <<1). If there was a significant potential for risk (*i.e.*, hazard quotient $1), then obtaining tissue samples from plants and small mammals might be considered to refine the risk estimate.	Yes

Table 7.14 Evaluation of Assumptions and Uncertainties in the Ecological Risk Assessment

Risk Assessment Study Factor/Assumptions	Justification	Analysis Likely to Over/Under Estimate Risk?	Acceptable Assumption?
Receptor Characteristics			
1. Receptors were selected to be representative of all potential wildlife receptors at the site.	This is standard practice and is based on the premise that if key components of the ecosystem are protected, then other biota are also likely to be adequately protected. However, this approach may not always adequately protect all endpoints for all receptors at site. See Section 7.3 (Receptor Identification) for further discussion on the rationale for receptor selection.	Neutral	Yes
2. Ecological characteristics were based on the "average" receptor.	It is standard practice to use "average" receptor characteristics in estimating exposure. Generally, the assumptions made in selecting the characteristics tend to provide conservative, yet realistic, estimates of chemical exposure in receptors. The characteristics selected were based on best available data. It is possible that exposure is over-or under-estimated at the individual level for some component of a receptor population as the result of using "average" characteristics in the risk model. However, given the conservative assumptions used in selecting characteristics, it is likely that the resulting exposure estimates would be protective at the population level.	Neutral	Yes
Toxicity Information			
1. Reference toxicity doses (RTDs) were based on surrogate species and single chemical exposures.	RTDs were based on laboratory studies for similar species and were taken from reputable sources. The use of surrogate species is standard practice in risk assessments, particularly for sites such as this where toxicity information on the particular wildlife species is lacking. RTDs may be over- or under-protective for receptor species for a number of reasons, including that the RTDs will not represent all species, life stages, endpoints, exposure durations, and exposure routes.	Neutral. Risk estimates were very low (hazard quotients <<1). If there was a significant potential for risk (*i.e.*, hazard quotient $1), then obtaining species- and endpoint-specific RTDs might be considered to refine the risk estimate.	Yes

Table 7.14 Evaluation of Assumptions and Uncertainties in the Ecological Risk Assessment

Risk Assessment Study Factor/Assumptions	Justification	Analysis Likely to Over/Under Estimate Risk?	Acceptable Assumption?
2. Reference toxicity doses (RTDs) were based on single chemical exposures.	Toxicity data is almost exclusively based on single-chemicals, whereas natural exposure is almost always to a mixture of chemicals. The toxicology of chemical mixtures is very much a developing science. There is a currently a great deal of uncertainty regarding chemical interactions in mixtures and the effects of mixtures on receptors. RTDs based on single chemical exposures may over or under-estimate the potential toxicity of chemicals in mixtures on receptors. See Section 7.9 (Chemical Interactions) for further discussion.	Neutral	Yes
3. Bioavailability of metals in exposure media was assumed to be 100%	This is a conservative approach that represents a "worst-case" exposure scenario. It is likely to over-estimate the potential toxicity of chemicals present at the site.	Over-estimate. If significant risks were identified (*i.e.*, hazard quotient $1), then the bioavailability of metals may be reconsidered to refine the risk estimates. However, risk estimates were very low (*i.e.*, hazard quotients <<1), therefore bioavailability is not a concern at the population level.	YES

7.9 Chemical Interactions

The risk assessment of contaminants is complicated by the reality that most toxicological studies are conducted on single chemicals, but exposures are rarely limited to single chemicals. Exposures generally involve more than one contaminant. Although chemicals in the environment are most often present in some sort of mixture, guidelines for protection of ecological health are almost exclusively based on exposure to single chemicals.

Chemicals in a mixture may interact in four general ways to elicit a response:

- Non-interacting – chemicals have no effect in combination with each other; the toxicity of the mixture is the same as the toxicity of the most toxic component of the mixture;
- Additive – chemicals have similar targets and modes of action but do not interact, the hazard for exposure to the mixture is simply the sum of hazards for the individual chemicals;
- Synergistic – there is a positive interaction among the chemicals such that the response is greater than would be expected if the chemicals acted independently; and

- Antagonistic – there is a negative interaction among the chemicals such that the response is less than would be expected if the chemicals acted independently.

To derive a best estimate of risk associated with exposure to a number of chemicals at one time, the U.S. EPA suggests using information on the toxicology of the specific mixture (U.S. EPA 1986). The type of interaction (see bullets above) between metals in mixtures is dependent on the biological response measured, because mixtures can have additive effects on one biological endpoint, while having antagonistic or synergistic effects on other endpoints (ATSDR 2002). In addition, environmental factors may also influence the toxicity of metal mixtures, not just the toxicity of the individual metals (Franklin *et al.* 2002).

For environmental exposures, and particularly for wildlife, information on interactions among metals in mixtures is rarely available. In the absence of information on the mixture, risk is sometimes based on the addition of the risks of the individual mixture components, unless there is information indicating that the interaction is other than additive in nature. This is considered to be most reasonable if the individual components are structurally similar and have similar toxicity characteristics. However, there is considerable uncertainty associated with the additive approach in that risk may be greatly overestimated or underestimated. Given this uncertainty, this ERA focused on the individual and independent risks of hazardous elements to wildlife, and does not consider chemical interactions.

8.0 SOIL QUALITY REMEDIAL OBJECTIVES

CanZinco Ltd. is committed to closing and decommissioning the Nanisivik Mine site in an environmentally responsible manner that ensures that no unacceptable environmental or human health risks are present as a result of mine operations. This HHERA has been conducted to develop site specific soil quality remedial objectives (SQROs) for this purpose. JWEL has worked within the framework established by the CCME and in general accordance with the methods outlined in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME 1996b).

Generic surface soil guidelines were developed by the CCME as conservative benchmarks for screening purposes, applicable to any site in Canada without consideration for site-specific circumstances. However, these generic guidelines do not take into account regional or site-specific information and may not be appropriate for every site or region of the country. In fact, the protocol for CCME guideline development acknowledges that these guidelines are not set in stone but may be modified in some instances if supported by sound reasoning and/or by the provision of site-specific data. To do otherwise could result in disruptive remedial action that brings little or no health benefit.

The physical characteristics of the Nanisivik Mine site (*e.g.*, high arctic climate, natural mineralization, barren terrain) are not representative of a "typical" site envisaged by the CCME. Deriving SQROs specifically for the Nanisivik Mine site is a more accurate way of assessing the environmental and human health significance of soil concentrations in the area.

8.1 Selection of SQROs

Risk assessment has been conducted for ecological and human receptors in accordance with the conceptual models illustrated in Figures 5 and 8. Resulting SQROs are based on the lower of the human health based and ecologically based SSTLs to ensure that the most sensitive receptor is protected. For instance, a soil lead concentration of 4,560 mg/kg is protective of ecological receptors in the general mine area, whereas the human health based guideline for the same area is 3,500 mg/kg. Therefore, the selected SQRO for lead in the general mine area is 3,500 mg/kg. Tables 8.1 to 8.3 present the selection of final SQROs for the Nanisivik Mine site, expressed to two significant digits.

Table 8.1 SQROs (mg/kg) for Surface Soils: Town Area

	Metal				
	Cadmium	**Copper**	**Lead**	**Silver**	**Zinc**
Human Health SSTL	370	NA	990	NA	12,000
Ecological SSTL	2,800	5,900	4,600	NA	44,000
Final SQRO	**370**	**5,900**	**990**	**NA**	**12,000**

Table 8.2 SQROs (mg/kg) for Surface Soils: Dock Area

	Metal				
	Cadmium	**Copper**	**Lead**	**Silver**	**Zinc**
Human Health SSTL	NA	NA	NA	NA	NA
Ecological SSTL	2,800	5,900	4,600	NA	44,000
Final SQRO	**2,800**	**5,900**	**4,500**	**NA**	**44,000**

Table 8.3 SQROs (mg/kg) for Surface Soils: General Mine Area

	Metal				
	Cadmium	**Copper**	**Lead**	**Silver**	**Zinc**
Human Health SSTL	750	NA	3,500	NA	39,000
Ecological SSTL	2,800	5,900	4,600	18,000	44,000
Final SQRO	**750**	**5,900**	**3,500**	**18,000**	**39,000**

8.2 Sample Locations Exceeding SQROs

Table 8.4 provides a summary of the site data, based on the GLL and EBA data sets, and a comparison of the soil concentrations to the SQROs.

As indicated, all soil EPCs are less than the corresponding SQROs indicating that there are no area-wide unacceptable risks to either ecological or human receptors. A limited number of individual sample concentrations in the town area and general mine area exceed the SQROs, suggesting the presence of local hot spots that may require risk management. The locations of these samples are illustrated on Figure 9.

Table 8.4 Comparison of Sample Concentrations to SQROs

Constituent of Concern	Focus Area	Generic Soil Quality Guideline: Human Health (mg/kg)	Generic Soil Quality Guideline: Ecological (mg/kg)	Maximum Soil Concentration (mg/kg)	Exposure Point Concentration (mg/kg)	Soil Quality Remedial Objective [(a)] (mg/kg)	Number of Samples > SQRO (%)	Comment
Cadmium	Town Area	14[b]	10[b]	**50.2**	4.74	370	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	Dock Area	2,090[b]		156	33	2,800	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	General Mine Area	14[b]		**230**	5.75	750	0	SQRO > maximum soil concentration, therefore no site clean-up required.
Copper	Town Area	1,100[b]	63[b]	166	38	5,900	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	Dock Area	20,000[b]		835	835	5,900	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	General Mine Area	1,100[b]		108	66.7	5,900	0	SQRO > maximum soil concentration, therefore no site clean-up required.
Lead	Town Area	140[b]	300[b]	**2,720**	192.3	990	2 (1.7%)	EPC < SQRO < Max, risk management of localized "hot spots" may be required.
	Dock Area	8,200[b]		4,330	916.2	4,500	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	General Mine Area	140[b]		**9,350**	297.2	3,500	2 (3.9%)	EPC < SQRO < Max, risk management of localized "hot spots" may be required.
Silver	Town Area	98[b]	20[b]	8	--	--	--	Max < generic guidelines, no risk assessment required
	Dock Area	240[b]		11	--	--	--	Max < generic guidelines, no risk assessment required
	General Mine Area	98[b]		32	4.05	18,000	0	SQRO > maximum soil concentration, therefore no site clean-up required.
Zinc	Town Area	16,000[c]	200[b]	**38,500**	1,706	12,000	7 (6.0%)	EPC < SQRO < Max, risk management of localized "hot spots" may be required.
	Dock Area	100,000[c]		41,000	11,246	44,000	0	SQRO > maximum soil concentration, therefore no site clean-up required.
	General Mine Area	16,000[c]		**131,000**	2,138	39,000	2 (3.9%)	EPC < SQRO < Max, risk management of localized "hot spots" may be required.

Notes:

(a) The Soil Quality Remedial Objective (SQRO) is the lowest Site-Specific Threshold Limit established across ecological and human receptors.

(b) CCME

(c) OMOE

Bold = maximum soil concentration > human health and ecological generic guidelines

Underline = maximum soil concentration > ecological generic guidelines

-- indicates that maximum soil concentration < generic criteria and no risk assessment or clean up required

Figure 9 Sample Locations Exceeding SQROs

9.0 CONCLUSIONS

JWEL has completed a human health and ecological risk assessment for the Nanisivik Mine site on Baffin Island, Nunavut. The purpose of the risk assessment was to evaluate potential risks associated with metal concentrations in surface soil in the mine area. The following points summarize the major findings of this report:

- For the purposes of assessing potential exposures, the Mine site was subdivided into three areas: the Nanisivik town area, the dock area, and the general mine area.
- Data from previous reports completed by GLL and EBA were compiled and soil sample concentrations were compared to applicable generic guidelines. Maximum concentrations of cadmium, copper, lead, silver, and zinc were found to exceed their generic guidelines (ecological or human health) in one or more of the three identified areas.
- EPCs were calculated for each element in each exposure area as the 95% UCL on the combined GLL and EBA data sets.
- Potential environmental and human health risks were then calculated, based on the soil EPCs, for each potential receptor in each exposure area for all applicable elements (varied by exposure area and receptor type), with the following outcomes:
    - Surface soil EPCs of the identified metals are not anticipated to produce any adverse effects in the ecological receptors and exposure scenarios included in this risk assessment.
    - Surface soil EPCs of the identified metals are not anticipated to produce any adverse effects in the human receptors and exposure scenarios included in this risk assessment.
- SQROs were developed for each metal in each exposure area as the lowest of the ecological or human health guidelines developed in this risk assessment.
- Maximum cadmium, copper, and silver surface soil concentrations were less than their SQROs, indicating that no remedial action is required for these metals.
- Lead and zinc SQROs in the town area and general mine area are greater than their EPCs, indicating that there is no unacceptable area-wide impact. However, a limited number of sample concentrations exceeded the SQROs, indicating that localized hot spots may require risk management. No remedial action is required for the dock area.

10.0 CLOSURE

This report has been prepared for the sole benefit of CanZinco Ltd. The report may not be used by any other person or entity without the express written consent of Jacques Whitford Environment Limited and CanZinco Ltd.

Any use which a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. JWEL accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

JWEL makes no representation or warranty with respect to this report other than the work was undertaken by trained professional and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. Any information or facts provided by others and referred to or utilized in the preparation of this report was assumed by JWEL to be accurate. Conclusions presented in this report should not be construed as legal advice.

This risk assessment was undertaken exclusively for the purpose outlined herein and was limited to those contaminants, exposure pathways, receptors, and related uncertainties specifically referenced in this report. This work was specific to the site conditions and land use considerations described herein. The report cannot be used or applied under any circumstances to another location or situation or for any other purpose without further evaluation of the data and related limitations.

If any conditions become apparent that differ significantly from our understanding of conditions as presented in this report, we request that we be notified immediately to reassess the conclusions provided herein.

This report was prepared by Erin Smith, EIT and Mary Murdoch, M.Sc. and reviewed by David A. Rae, Ph.D., P.Geo. and Malcolm Stephenson, Ph.D.

Respectfully submitted,

JACQUES WHITFORD ENVIRONMENT LIMITED

Peter Pheeney, P.Eng.
Project Manager

p:\14xxx\143xx\14333\final report\final report - jan 30-03.doc

11.0 REFERENCES

Alaska Department of Fish and Game. 1994. Ptarmigan. URL: www.state.ak.us/local/akpages/FISH.GAME/notebook/bird/ptarmiga.htm.

ATSDR (Agency for Toxic Substances and Disease Registry). 1990. Toxicological Profile for Silver. U.S. Public Health Service. 145 pp.

ATSDR (Agency for Toxic Substances and Disease Registry). 2002. Draft Interaction Profile for: Arsenic, cadmium, chromium and lead. Division of Toxicology, ATSDR, Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.

Bell, R.W., Chapman, R.E., Kruschel, M.J., and Spencer, M.J. 1994. Windsor Air Quality Study: Personal Exposure Survey Results. Atmospheric Studies Section, Science and Technology Branch, Ontario Ministry of the Environment and Energy. ISBN 0-7778-3492-8.

Beyer, W.N., E.E. Connor and S. Gerould. 1994. Estimates of soil ingestion by wildlife. J. Wildl. Manage. 58: 375-382.

Blackburn, G.S., D.J. Wilson and C.J. Krebs. 1998. Dispersal of juvenile collared lemmings (*Dicrostonyx groenlandicus*) in a high-density population. Can. J. Zool. 76: 2255-2261.

British Columbia Research Incorporated (BCRI). 1975. Terrestrial Environmental Studies at Strathcona Sound, Northwest Territories, Progress Report Nos. 1, 2, & 3. Prepared for Strathcona Mineral Services, Project 1552.

CCME (Canadian Council of Ministers of the Environment). 2001. Canadian Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale. Supporting Technical Document, December 2000.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian soil quality guidelines for the protection of environmental and human health. *In:* Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 1996a. Guidance Manual for Developing Site-Specific Soil Quality Objectives for Contaminated Sites in Canada, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 1996b. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 1991. Interim Canadian environmental quality criteria for contaminated sites, Winnipeg.

Canadian Wildlife Service. 2002. Hinterland Who's Who. URL: http://www.cws-scf.ec.gc.ca/hww-fap/hww-fap.cfm

Cantox Environmental Incorporated (Cantox). 2001. Human health and ecological risk assessment of Cominco's Polaris Mine on Little Cornwallis Island: Derivation of soil quality remediation objectives. Prepared for Cominco Ltd. – Polaris Mine.

Clayton, C.A., Perritt, R.L., Pellizzari, E.D., Thomas, K.W., and Whitmore, R.W. 1993. Particle Total Exposure Assessment Methodology (PTEAM) Study: distributions of aerosol and elemental concentrations in personal, indoor, and outdoor air samples in a southern California community. J. Expos. Analysis Environ. Epidem. 3(2): 227-250.

Dabeka, R.W., and McKenzie, A.D. 1995. Survey of Lead, Cadmium, Fluoride, Nickel, and Cobalt in Food Composites and Estimation of Dietary Intakes of These Elements by Canadians in 1986-1988. J. Assoc. Off. Anal. Chem. Int. 78(4): 897-909.

EBA Engineering Consultants Limited (EBA). 2002a. Soil Sampling Program. Nanisivik Town Site. Nanisivik, Nunavut. Final Report. Prepared for the Department of Sustainable Development, Nunavut. August 2002.

EBA Engineering Consultants Limited (EBA). 2002b. Letter to Paul Smith (Manager), Water Management, Government of Nunavut. Subject: July-02 Water Board Hearings, Nanisivik Mine Closure. July 30, 2002.

Efroymson, R.A., B.E. Sample and G.W. Suter. 2001. Uptake of inorganic chemicals from soil by plant leaves: Regressions of field data. Environ. Toxicol. Chem. 20: 2561-2571.

Environment Canada. 1989. Atlantic-Region-Federal-Provincial Toxic Chemical Survey of Municipal Drinking Water Sources 1985-1988. Interpretive Report. Water Quality Branch, Inland Waters Directorate, Conservation and Protection, Environment Canada, Moncton, New Brunswick.

Franklin, N.M., J.L. Stauber, R.P. Lim and P. Petocz. 2002. Toxicity of metal mixtures to a tropical freshwater alga (*Chlorella* sp.): The effect of interactions between copper, cadmium, and zinc on metal cell binding and uptake. Environ. Toxicol. Chem. 2412-2422.

Furmanczyk, T. 1994. Lead. *In:* National Urban Air Quality Trends 1981-1990. Report EPS 7/UP/4. October 1994 pp.40-43.

GLL (Gartner Lee Ltd.) 2002a. Nanisivik Mine Closure and Reclamation Plan, GLL 21-957. Prepared for CanZinco Limited.

GLL (Gartner Lee Ltd.) 2002b. Nanisivik Mine 2001 Environmental Site Assessment and Proposal for Phase II Environmental Site Assessment. (Appendix to the Closure and Reclamation Plan). Prepared for CanZinco Limited.

GLL (Gartner Lee Ltd.) 2002c. 2002 Phase II Environmental Site Assessment, Nanisivik Mine, Nunavut, Site Characterization. Prepared for CanZinco Limited.

Government of Northwest Territories (NWT). 2001. Arctic fox. Wildlife and Economic Development, Northwest Territories Resources, Government of NWT. URL: www.nwtwildlife.rwed.gov.nt.ca/NWTwildlife.

Government of Nunavut (GN). 2002. Follow-up Submission to the Nunavut Water Board on the Application by CanZinco Ltd. for a Water License, and for Approval of their Closure and Reclamation Plan. August 14, 2002.

Health Canada. 1994. Canadian Environmental Protection Act. Human Health Risk Assessment for Priority Substances. Ottawa. Cat. No. En40-215/41E. 36pp.

Health Canada. 1996. Canadian Soil Quality Guidelines for Contaminated Sites, Human Health Effects: Inorganic Lead. Final Report. March 1996.

IAEA (International Atomic Energy Agency). 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. Technical Report Series No. 264. IAEA, Vienna, Italy. 74pp.

Kean, R. 1995. Unpublished Data on Pb Levels in Ottawa House Dust, Street Dust, and Soil. Research and Productivity Council, Fredericton, New Brunswick. (*cited in Health Canada, 1996a*).

Lachmaniuk, P. 1993. Personal communication with Patricia Lachmaniuk. Drinking Water Assessment Specialist, Drinking Water Surveillance Program, Ontario Ministry of the Environment, Toronto, Ontario. (*cited in Health Canada, 1996b)*

Landa, A, O. Strand, J.D.C. Linnell and T. Skogland. 1998. Home-range sizes and altitude selection for arctic foxes and wolverines in an alpine environment. Can. J. Zool. 76: 448-457.

Méranger, J. C., K. S. Subramanian, and C. Chalifoux. 1981. Metals and Other Elements: Survey for Cadmium, Cobalt, Chromium, Copper, Nickel, Lead, Zinc, Calcium, and Magnesium in Canadian Drinking Water Supplies. J. Assoc. Off. Anal. Chem. 64:1: 44-53.

NWTWB (Northwest Territories Water Board and Department of Indian Affairs and Nothern Development). 1990. Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories.

Ontario Ministry of the Environment (OMOE). 1996a. Guidelines for use at Contaminated Sites in Ontario.

Ontario Ministry of the Environment (OMOE). 1996b. Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria for use at Contaminated Sites in Ontario.

Ontario Ministry of Environment and Energy (MOEE). 1993. Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow, Version 1.0a, April, 1994.

Predavec, M. and C.J. Krebs. 2000. Microhabitat utilisation, home ranges, and movement patterns of the collared lemming (*Dicrostonyx groenlandicus*) in the central Canadian Arctic. Can. J. Zool. 78: 1885-2890.

Richardson, G.M. 1997. Compendium of Canadian Human Exposure Factors for Risk Assessment. O'Connor Associates Environmental Inc., Ottawa, ON.

Sample, B.E., D.M. Opresko and G.W. Suter. 1996. Toxicological benchmarks for wildlife: 1996 revision. Prepared by Oak Ridge National Laboratory for U.S. Department of Energy, Office of Environmental Management. ES/ER/TM-86/R3. 43pp. + app.

Sample, B.E., J.J. Beauchamp, R.A. Efroymson and G.W. Suter. 1998. Development and validation of bioaccumulation models for small mammals. Prepared by Oak Ridge National Laboratory for the U.S. Department of Energy, Office of Environmental Management. ES/ER/TM-219. 40 pp + app.

Schmidt, N.M., T.B. Berg and T.S. Jensen. 2002. The influence of body mass on daily movement patterns and home ranges of the collared lemming (*Dicrostonyx groenlandicus*). Can. J. Zool. 80: 64-69.

The Peregrine Fund. 2001. First falcon study in Northern Greenland using satellite tracking. URL: www.peregrinefund.org.

United States Environmental Protection Agency (US EPA). 2002. Region 3: Mid-Atlantic Region Hazardous Site Cleanup Division Risk Based Concentration Tables. http://www.epa.gov/reg3hwmd/risk/rbc1002.pdf October 9, 2002.

United States Environmental Protection Agency (US EPA). 1993. Wildlife Exposure Factors Handbook. EPA/600/R-93/187.

United States Environmental Protection Agency (US EPA). 1989. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A) Interim Final. EPA/540/1-89/002.

U.S. EPA (U.S. Environmental Protection Agency). 1986. Guidelines for the health risk assessment of chemical mixtures. Fed. Reg. 51: 34014-34025.

University of Michigan. 2000. The Animal Diversity Web. Museum of Zoology. URL: http://animaldiversity.ummz.umich.edu/.

APPENDIX A

LIMITED COMMUNITY CONSULTATION

APPENDIX B

TOXICITY PROFILES

APPENDIX C

RISK ASSESSMENT TECHNICAL INFORMATION